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OPTIMUM FORMING PROCESSES AND EQUIPMENT NECESSARY TO PRODUCE HIGH QUALITY, CLOSE TOLERANCE TITANIUM ALLOY PARTS

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GRUMMAN AIRCRAFT ENGINEERING CORPORATION

FINAL TECHNICAL REPORT AFML-TR-68-259

September 1968

Project No. 9-770

ADVANCED FABRICATION TECHNIQUES BRANCH
MANUFACTURING TECHNOLOGY DIVISION
AIR FORCE MATERIALS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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Joseph S. Newman

John S. Caramanica

Project 9-770

FOREWORD

This Final Technical Report covers all work performed under Contract AF33(615)-5083 from 1 June 1966 through 30 May 1968. The manuscript was released by the author in September 1968 for publication as an AFML Technical Report.

This contract with Grumman Aircraft Engineering Corporation, Bethpage, New York, was initiated under Manufacturing Methods Project No. 9-770, "Optimum Forming Processes and Equipment Necessary to Produce High Quality, Close Tolerance Titanium Alloy Parts". This work was administered under the technical direction of Mr. Max A. Guenther and Capt. G. F. Hollobaugh of the Advanced Fabrication Techniques Branch (MATF), Manufacturing Technology Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

This program was directed by Mr. Joseph S. Newman, Project Manager. Others assisting on the project were J. Caramanica, Group Leader, Manufacturing Engineering; Mr. G. Gagnon, Principal Tool Engineer; Mr. J. Fogarty, Group Leader, Chemical Processes, Advanced Manufacturing Development; Mr. S. Trink, Group Leader, Advanced Manufacturing Development; Mr. C. Shaver, Vehicle Technology Staff (Project Metallurgist); Mr. M. Meyer, Metallurgist; Mr. A. Wolynski, Tool and Die Maker; Mr. E. Leszak and Mr. J. Kavanaugh, Advanced Development Engineers; and Mr. L. Spinner, Advanced Manufacturing Development.

This project has been accomplished as a part of the Air Force Manufacturing Methods Program, the primary objective of which is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components.

This technical report has been reviewed and is approved.

JACK R. MARSH, Chief
Advanced Fabrication Techniques Branch
Manufacturing Technology Division
Air Force Materials Laboratory

ABSTRACT

This Final Report summarizes the accomplishments of Grumman Aircraft Engineering Corporation under Contract AF 33(615)-5083 during the two-year period from 1 June 1966 to 30 May 1968.

This Air Force Contract required Grumman to develop and establish optimum forming processes and equipment for the production of high quality, close tolerance titanium alloy parts of varied and complex configurations. Six parts representative of present and future structural titanium requirements (tail cone frame, door channel, annular ring, zee, frame and channel) were selected for study. These six parts are typical of varied configurations which impose complex forming problems.

Since forming difficulties vary with material thicknesses, Grumman used .025" and .070" material for each of the three alloys selected. Tooling for the one-step and two-step forming methods was made to handle both material thicknesses. All parts produced by the one-step forming process, after determining the optimized forming parameters for each, were within ±.005 conformity to contour and ± 1/4° angular tolerance. Similar dimensioned tolerances were also achieved with the two-step process, however, there was poorer definition in joggled areas as well as other areas of sharp changing contours.

For this program, Grumman's two USI hot draw forming and sizing presses were used to evaluate the one-step form method as well as the two-step cold preform hot sizing method. When utilized in accordance with various tooling concepts, the unique features of these two presses resulted in lower manufacturing costs, better quality, reduced flow time, and production of more intricately shaped parts.

Grumman's one-step hot forming of the complex-compound shaped parts were major achievements in titanium forming. This vertical draw forming operation is described in detail in Section IX. Grumman also developed a horizontal draw forming technique that makes it possible to form curved "hat" and channel sections with deep chordal heights. This technique eliminates costly preform operations such as brake forming, stretching, drop hammering, and rubber forming.

Based on generally lower tool fabrication costs, time-savings, and opportunities for greater latitude in the design of aircraft parts, Grumman believes that the one-step forming process is preferable for all six parts.

This Final Report also documents: 1) The metallurgical tests performed on all three alloys--8 Al-1Mo-1V, 6Al-6V-2Sn, and 6 Al-4V; 2) Grumman's method of determining the time-temperature parameters and minimum bend radii values of the three alloys tested; and 3) The feasibility of simultaneous forming and aging of production parts from solution-treated 6Al-4V alloy using short-time aging cycles.

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SECTION I

INTRODUCTION

1. OBJECTIVES

a. Prime Objective

The prime objective of this project was to develop and establish optimum forming processes and equipment for the production of high quality, close tolerance titanium alloy parts of varied and complex configurations. To determine this, six parts truly representative of present and future structural titanium requirements were selected for study (Figure 1-1). These six parts were also typical of the varied configurations that impose the most serious forming problems. Since forming difficulties vary with material thickness, two different thicknesses of material (.025" and .070") were used for each of the three alloys selected. Tooling for the one-step and two-step forming methods for the selected parts was made to handle these two material thicknesses.

The target tolerances for all parts were: angular $\pm$ 1/4°; conformity to contour $\pm$.005".

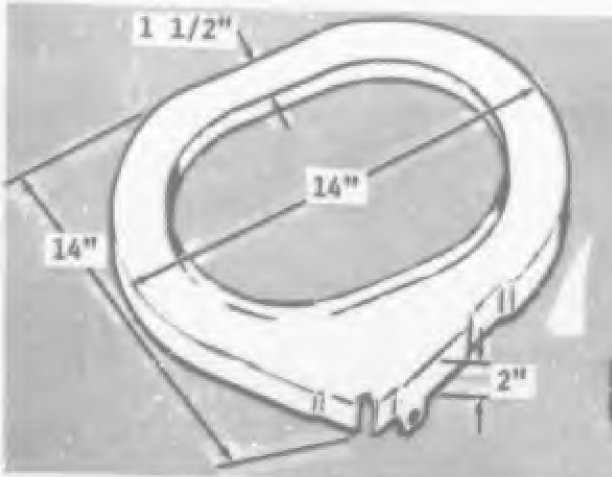
b. Ultimate Objective

An ultimate objective of this project was to evaluate the developed one-step hot forming method (which provides greater design latitude in the configuration of titanium details) with an optimized two-step process of preforming and hot sizing.

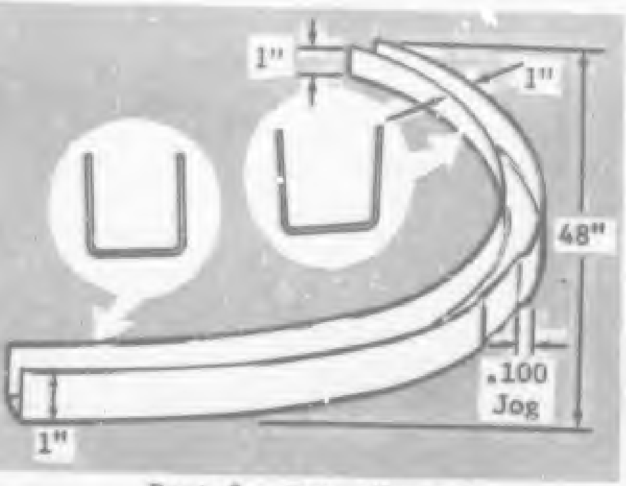
The Grumman-developed hot draw forming and sizing presses were used to evaluate both the one-step hot forming method and the cold form hot sizing method to determine the advantages and disadvantages of each approach.

Table 1-1 indicates the parts evaluated, the forming method, tooling material, and forming sequence utilized.

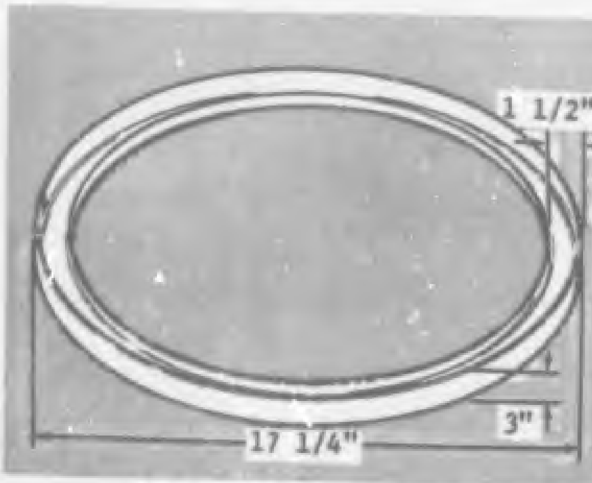
Some of the parts completed on this project are shown in the 8-foot-high caged area (approximately 15' x 15') set up near the presses for part and tool storage and inspection purposes (Figure 1-2). Figure 1-3 shows a close-up of the actual parts arranged in the same order as in Figure 1-1 for comparison purposes.



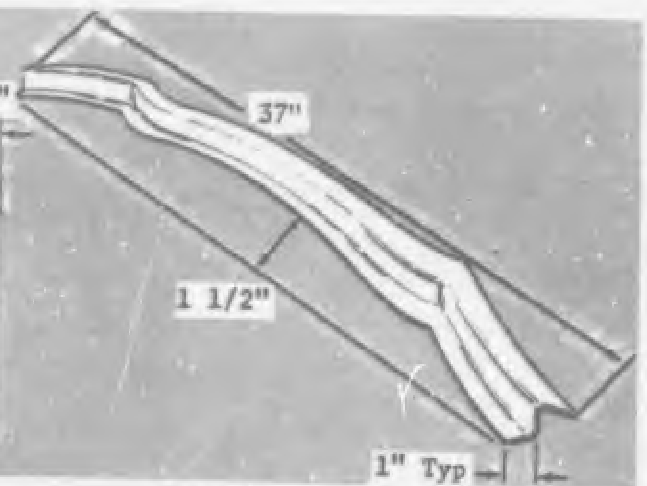
Part 1 - Tail Cone Frame



Part 2 - Door Channel

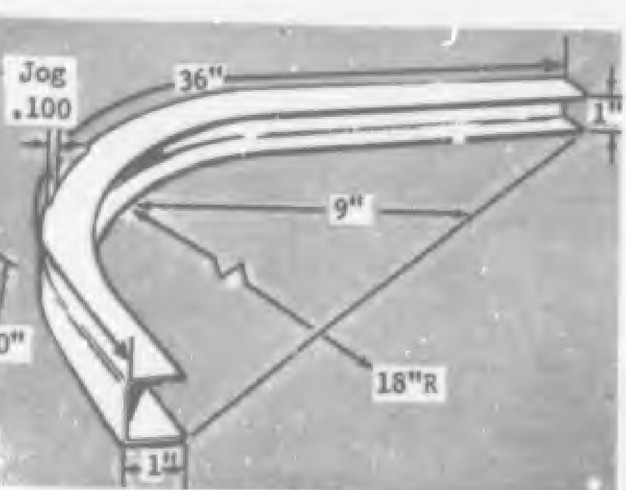


Part 3 - Annular Ring



Part 4 - Zee

Part 5 - Frame



Part 6 - Channel

Figure 1-1 Part Configurations Evaluated

TABLE 1-1 FORMING METHOD - TOOLING MATERIAL

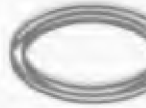
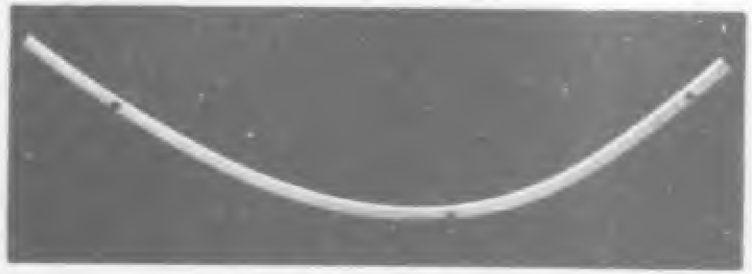
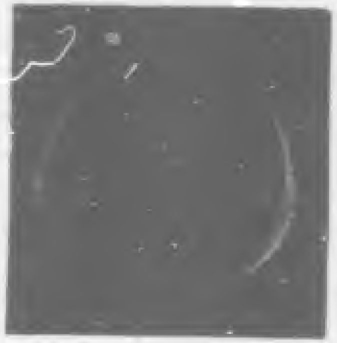
Part No.	Forming Method (Steps)	Tooling Material	Forming Sequence	Schematic
1 1 (Tail Cone Frame)	One Two	Incoloy 802 HRS (Preform Tool)	Form Die (Only tool required) 1. Preform blanks by two operations: drop hammer/rubber (2-stage block) 2. Hot-size parts on (1) one-step form die.	
2 2 (Door Channel)	One Two	HSV(Meehanite) HSV(Meehanite)	Form Die (only tool required) 1. Use male punch of (2) two-step form die to preform blanks by drop hammer/rubber. 2. Replace male on two-step form die and hot-size parts on two-step form die.	
3 (Annular Ring)	One	HSV(Meehanite)	Form Die (only tool required)	
4 4 (Zee)	One Two	HSV(Meehanite) Nicrosil	Form Die (only tool required) 1. Utilize one-half of hot-sizing die to preform blanks by drop hammer. 2. Reassemble sizing die and hot-size preformed parts.	
5 5 (Frame)	One Two	Incoloy 802 Incoloy 802	Form Die (only tool required) 1. Utilize male punch of one-step form die to preform blanks by drop hammer/rubber. 2. Replace male on one-step form die and hot-size parts on one-step form die	
6 6 (Channel)	One Two	HSV(Meehanite) Nicrosil	Form Die (only tool required) 1. Utilize sizing die to drop hammer preform parts. 2. Hot-size on same tool.	

Figure 1-2 Some of the Parts Completed on This Project

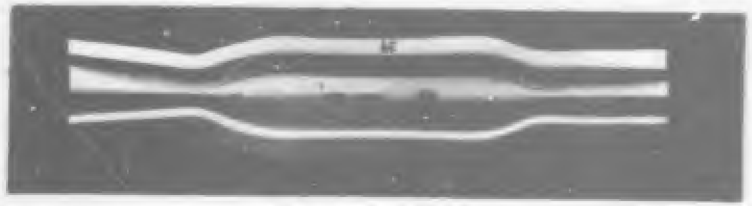
Part 1,
Tail Cone Frame RDM 1500



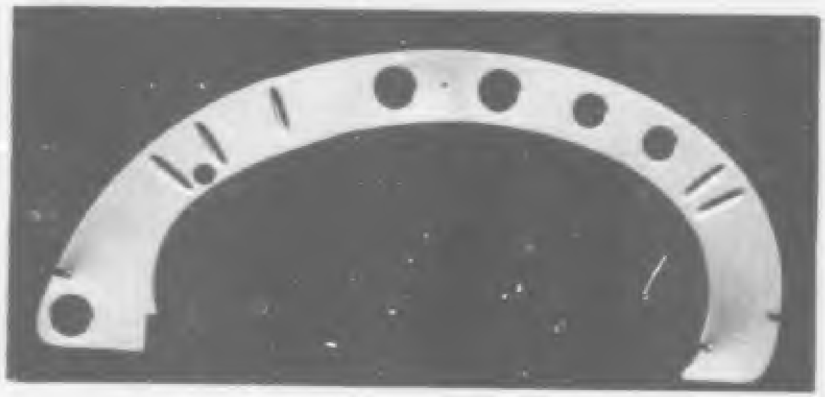
Part 2, Door Channel
RDM 1502, 1509



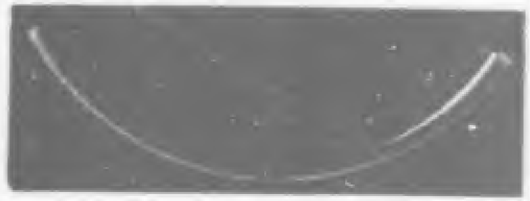
Part 3,
Annular Ring RDM 1497



Part 4, Zee
RDM 1435, 1516



Part 5, Frame RDM 1498



Part 6, Channel
RDM 1510, 1496

Figure 1-3 Close-up of Actual Parts for Comparison

2. PHASES

a. Phase I

Phase I was devoted to the study and investigation of process variables to determine design criteria for optimized tooling systems for the one- and two-step forming process, perform lubricant and cleaning studies, and to study time-temperature and pressure variables. This phase was initially described and illustrated in Interim Reports I and II.

b. Phase II

Phase II included the design and fabrication of tools incorporating the information acquired during the earlier phase. Equipment modifications necessary to optimize the forming operations were also accomplished during this period. Interim Reports III and IV initially recorded the achievements of this phase.

c. Phase III

Phase III was the time allocated for testing of tools, forming of parts, testing of parts, economic analysis of tooling concepts, and evaluation of the entire forming systems. These results are included in this Final Report along with all pertinent information from all previous Interim Engineering Progress Reports.

3. STUDY AREAS

Studies were made to improve and optimize the following conditions in conjunction with the development of new forming processes:

- Forming cycle time
- Part removal time
- Tool handling and wear
- Closer tolerance control of complex parts

4. TECHNICAL APPROACH

a. The Problem

At present, the most widely used technique of forming titanium sheet is an operation consisting of two steps--cold (or warm) preforming and hot-sizing. This method is not wholly satisfactory because it is characterized by formability limitations and by excessive floor-to-floor (cycle) time.

Formability limitations stem from preforming:

- At temperatures considerably below optimum
- In a hydraulic or impact type press with insufficient rubber pressures
- With inadequate metal restraint to effect a balance between draw and stretch movement on more complex shapes

Excessive cycle time stems from:

- Inability to satisfactorily preform complex parts in a single press-stroke.
- The need for reheating during multi-stroke preforming operations
- Longer hot-sizing "dwell times," caused by insufficiently preformed parts
- Lack of automatic part ejection devices
- Manual retraction of side and top die components

In general, relatively simple shapes can be preformed in a single stroke of either the hydraulic rubber press or the drop hammer. As part shapes become more complex, however, preforming in a single stroke becomes difficult. In such cases it is usually necessary to apply heat to the material and the die. This is a poor expedient at best, since the temperatures at which forming occurs are invariably lower than the optimum uniform forming temperatures that would be achieved in a heated platen press. There are definite limitations in rubber press preforming, since the high pressures (above 5000 psi) needed to preform complex shapes are usually not available. Drop-hammer preforming of complex shapes is also limited because the presses used are not double-acting, which would permit proper restraint of the peripheral areas of the blank to allow optimum stretch-draw movement of the metal. The use of peripheral beads as a restraining device is helpful, but does not permit the forming of deep contours in a single stroke. Deep contours are usually formed by filling the die cavity with rubber pads and then progressively removing the pads a few at a time, at certain forming stages. The extent and frequency of these operations are contingent upon operator skill. During these operations, the material must be frequently preheated.

The forming techniques presently used impose severe limitations on the designers of today's high-performance aircraft. Parts with severe contour complexity must be designed either with flange notches, or they must be designed in smaller pieces to avoid wrinkles that cannot be "pressed out" during hot-sizing operations. Moreover, the forming of tight bend radii is impossible at the low preforming temperatures.

Many of the difficulties in forming titanium parts can probably be overcome by a one-step forming operation in which preforming and sizing are done simultaneously by a single stroke of the press. Further, the entire operation can benefit significantly from automatic tool retraction and part ejection devices. One-step forming is not a panacea--there are undoubtedly some types of titanium parts that would, for reasons of economics, be best formed in two steps. Only a thorough evaluation of both methods as pursued in this contract could reveal the proper application and the respective advantages of each one.

Although it is evident that the two-step method demands closer tolerance control in the preforms, the Grumman approach was to emphasize the elimination of the cold preforming operation wherever possible, rather than make an intensive effort to improve the preforming technique. It is acknowledged that, for some parts, a two-step operation will always be more economical (or required) to make a specific configuration, therefore, an analysis was made to determine which part configuration should be done by each process.

5. SELECTION OF MATERIALS

The three titanium alloys which were selected for use in this program were:

ALLOY	MATERIAL CONDITION	DENSITY (lb/cu.in.)
Ti-6Al-4V	Annealed and Solution Treated	.160
Ti-8Al-1Mo-1V	Duplex Annealed	.158
Ti-6Al-6V-2Sn	Annealed	.164

The selection of these materials was based on the expressed purpose of this contract, that is, to establish optimum processes and equipment for the production of close tolerance sheet metal parts made from the titanium alloys which are most likely to be used by designers. Two thicknesses of each alloy, .025" and .070", were also used for this investigation. The use of test specimens of different thicknesses allowed a more complete evaluation of the effectiveness of each of the two approaches involved in the forming of selected shapes. The forming of light gauge materials presents different problems from those encountered in heavier gauge materials. Generally, forming difficulties increase as thickness decreases.

a. Ti-6Al-4V Alloy

The 6-4 alloy has been extensively used in the design of aerospace structures for the past several years. The alloy has numerous characteristics which make it desirable for varied applications. They are:

- Excellent fatigue properties--with no degradation of these properties in salt water
- High usable strength at temperatures up through 600°F--even in the presence of hot salts
- Excellent corrosion resistance at high temperatures

In general, the 6-4 alloy is an excellent structural material for use in or near sea water where high strength, toughness, light weight and low maintenance are required.

b. Ti-8Al-1Mo-1V Alloy

The 8-1-1 alloy has many qualities which have made it attractive to the design engineer. Some of these properties are:

- Excellent creep resistance
- Superior high tensile strength at temperatures ranging from 750°F to 950°F
- Good welding capabilities

- Relative weight advantage (.158 lb/cu.in.)

c. Ti-6Al-6V-2Sn Alloy

The 6-6-2 alloy in the annealed condition has mechanical properties considerably higher than those exhibited by other titanium alloys in the same material state. These properties are:

- High strength without the manufacturing difficulties associated with heat treating

- Greater strength/weight ratio

This alloy is expected to find many applications in future aircraft since a considerable amount of structure will be exposed to temperatures below 550°F. and above the temperature range of available aluminum alloys.

Its application within normal temperature ranges of aluminum alloys is advantageous when high loading requires the use of thick aluminum parts. The greater strength/weight ratio of the annealed 6-6-2 alloy permits the design of lighter assemblies.

6. PRELIMINARY STUDIES

The development of an optimized forming process necessitates the investigation of the process variables to determine the tooling concepts, fabrication techniques, and forming parameters to guide the manufacture of titanium shapes.

The study performed under this contract, therefore, emphasized the following manufacturing aspects:

- Design of an optimum tooling system for the two approaches as applicable to each of the six selected shapes, emphasis being placed on minimizing floor-to-floor time

- Selection of tooling materials to be used for each approach taking into consideration tool life, cost, and pressures to be applied

- Choice of lubricants and coatings to minimize or eliminate oxidation of titanium parts and to extend tool life

- Evaluation of cleaning and descaling processes

- Selective laboratory tests of titanium alloys (8-1-1, 6-6-2, and 6-4) with regard to mechanical properties at room temperatures and elevated temperature to establish optimum forming parameters.

- Simultaneous forming and heat treating (age-hardening) of the 6-4 titanium alloy

- Preheating and handling of tools

7. ACHIEVEMENTS

As a result of the work performed under this contract, the following significant accomplishments have been effected:

- An optimized forming press capable of either hot draw forming or improved hot sizing has been developed and is now being utilized on a production basis to produce titanium details for the F-111
- Development of a unique feature within the press - Horizontal draw forming and associated tooling, capable of making curved hat or channel sections of deep chordal dimensions in one operation
- Development of a simultaneous age-forming technique for the 6Al-4V alloy
- Optimization of one-step hot forming tooling and techniques
- Production of more intricately shaped details in one piece (heretofore considered impossible in titanium)
- Produced parts repeatedly within the following targeted tolerances, conformity to contour ±.005 and angular conformity ± 1/4°
- Reduced the floor-to-floor time for production of titanium details 40 to 50 percent
- Established optimum lubrication and cleaning procedures
- Established optimum time-temperature forming parameters

In addition, the above accomplishments will result in the following:

- Lower manufacturing costs to produce titanium details and assemblies
- A better quality product, lighter in weight, but with increased structural integrity by the elimination of splice plates and fasteners

8. PART QUALITY OF ONE-STEP FORMED DETAILS

It has been established as part of this program that the quality of these details are superior to those formed by the multi-step operations. One of the areas of concern was the effect, if any, on material thin-out.

A detailed check of the thickness variation of each part blank was made prior to forming tests. This check showed variations up to .002". An additional detailed check of each one-step formed part (where draw forming was utilized) was also made. This check indicated no thin-out problems, that is, the variation in the wall thickness or flange thickness did not vary more than that of the thickness of the original blank. This, in addition to the capability of producing parts within ±.005" conformity to contour and ± 1/4° angular conformity, is indicative of the quality which can be attained.

SECTION II

EQUIPMENT

1. USI PRESSES

Grumman purchased two hot draw forming and sizing presses from U. S. Industries and installed them in Plant 2, Bethpage, N.Y.,in February, 1967 (Figures 2-1 and 2-2).

These presses were used to evaluate the new one-step hot form method and the two-step cold preform/hot sizing method. The advantages and disadvantages for both were studied and analyzed and the preferred process was determined for a given set of conditions.

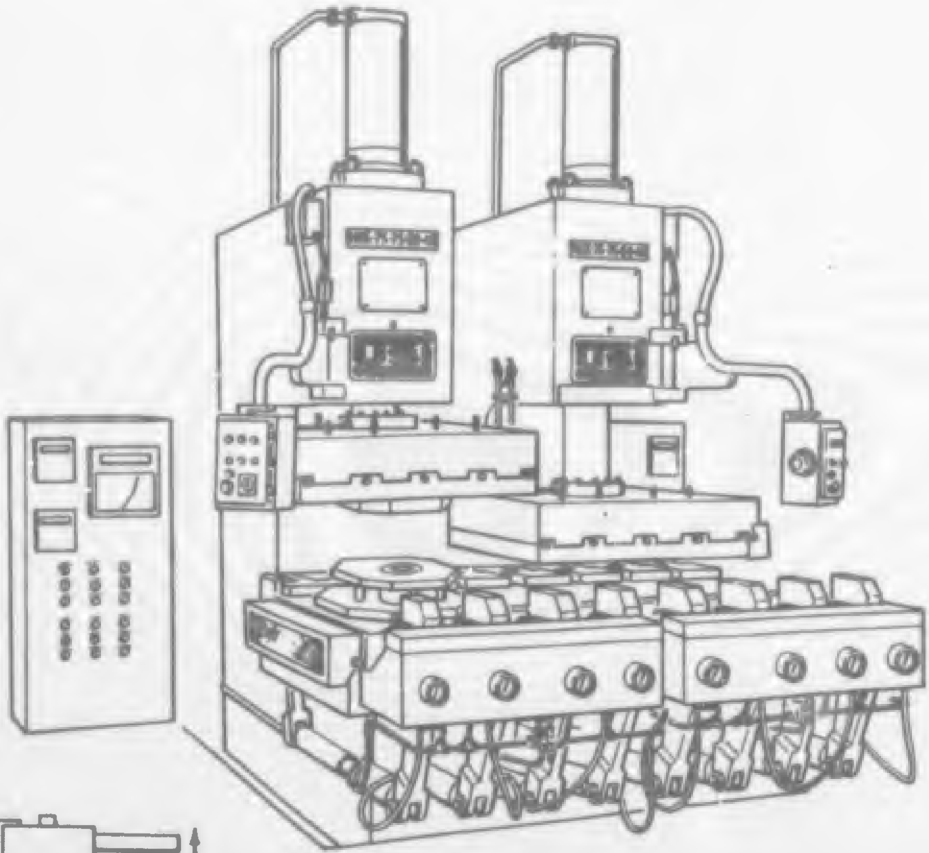
Used in conjunction with various tooling concepts, the presses' unique features result in:

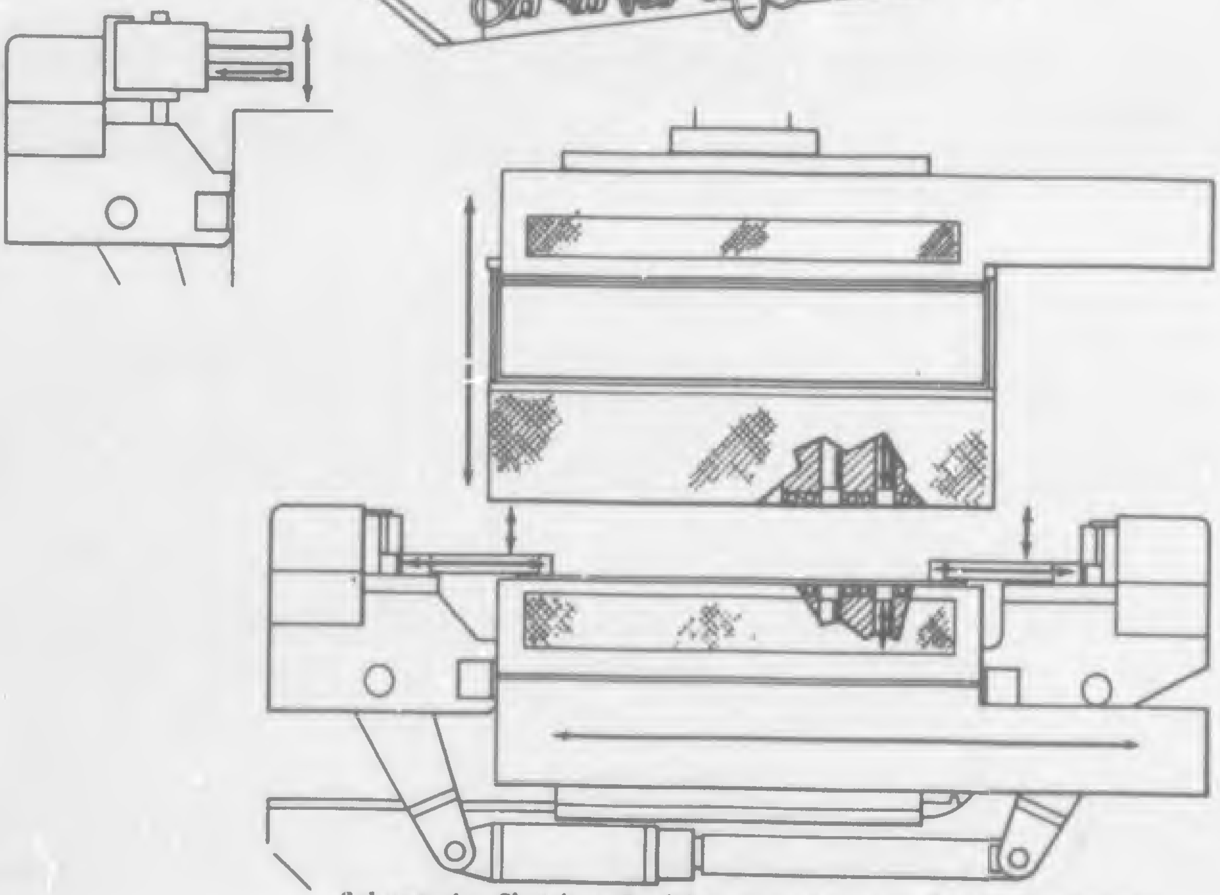
- Lower manufacturing costs
- Better quality
- Reduced flow time
- Production of more intricately shaped parts

2. PRESS PROBLEMS

Acceptance tests indicated that certain modifications were necessary if the presses were to attain the program objective. The press problems encountered, and since solved, were:

- Shifting of heated platens - After a few repeated heatings of test tools to temperatures up to 1650°F., a shifting of both the upper and lower platens on both presses was observed. To solve this problem, the platen area was re-machined. Four keyways were machined in the platens and new keys installed.
- Breaking of ceramic pressure pins - As a result of the shifting of the platens, some of the ceramic pins were broken. These pins were replaced by stainless steel pins topped by ceramic. The ceramic-topped pins proved to be unsatisfactory,necessitating their replacement with solid RA330 stainless steel pins. These pins have been trouble-free since their installation.
- Excessive heat at heater terminals - During the high temperature checkout tests, softening of the soldered connections at the heater terminals resulted. Fans were installed and appropriate openings made to circulate air through the upper terminal compartments.





Schematic Showing Cushion Concept and Basic Movements

Figure 2-1 Schematic of Hot Forming Presses

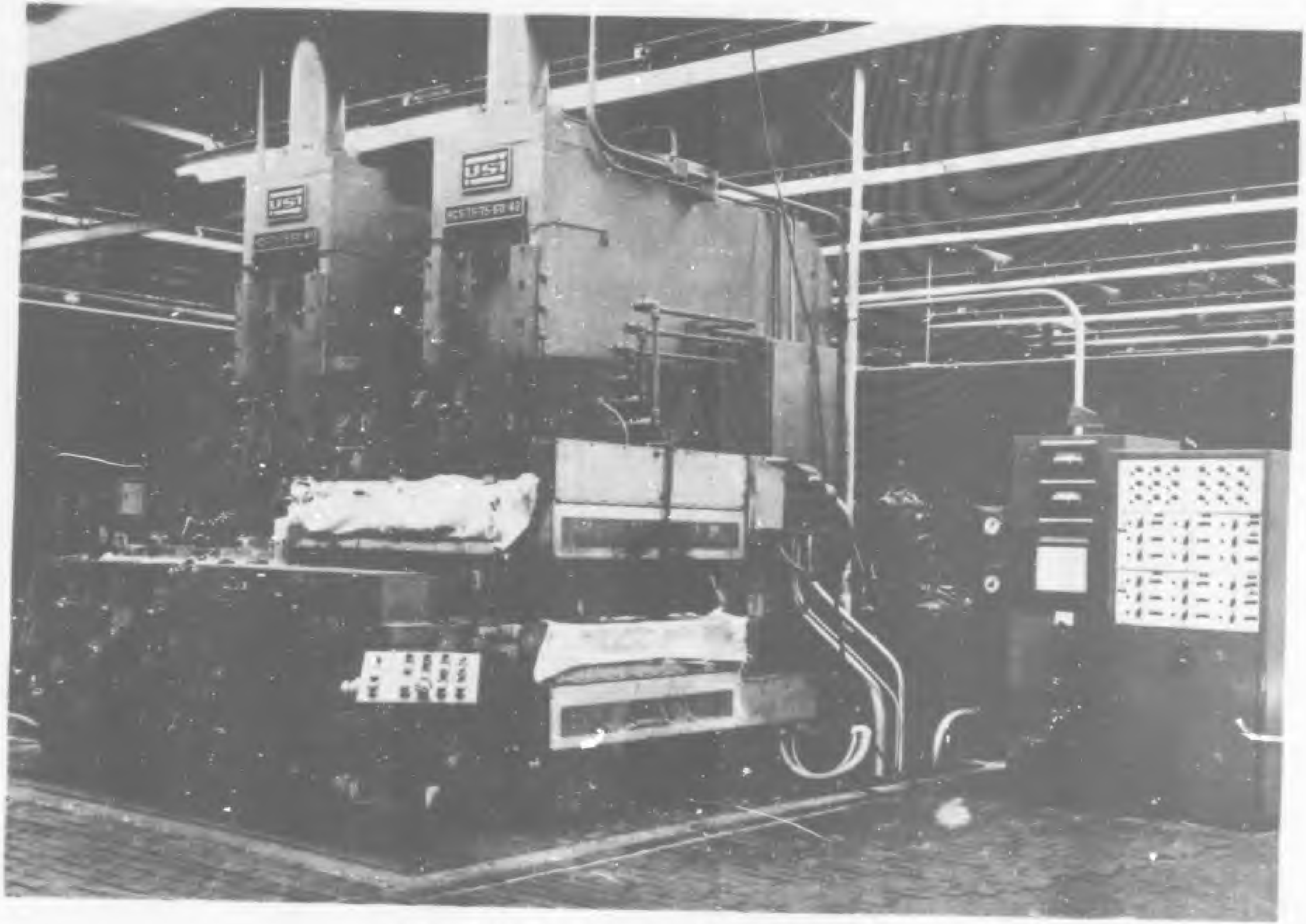


Figure 2-2 Grumman Hot Forming Presses

- Booster pumps - The original booster pumps were Racine 5:1 ratio boosters, a pulsating type. When operating at the special slow speeds, an intermittent jogging was detected which could have hindered draw forming operations. These pumps have been replaced by Dennison fixed volume hydraulic motors, which now provide a very smooth forming stroke when operated at slow speeds. A service representative of U.S. Industries worked with Grumman mechanics to complete this replacement.

- Calibration of controllers - Recalibration of all controllers (18 for each press) still indicates need for improvement. A revised system of 18 individually controlled potentiometers as well as a new single unit control for all 18 zones is currently being investigated.

- Electrical harnesses - The electrical harnesses on each press were relocated to prevent them from being scorched.

- Temperature indicator - A damaged temperature indicator was repaired.

- Hydraulic system - The entire hydraulic system was purged after the oil resevoir was found to contain many metal chips from drilling operations performed prior to shipping and assembly of the presses.

- Gibs - Gibs under tables were replaced.

- Drifting - Downward drifting of the ram was corrected.

Many other minor problems were also corrected.

No Air Force funds were expended in the repair or installation of these presses. However, considerable time was spent in proving out press functions to meet Air Force contract commitments.

3. IMPROVED PLATEN POSITIONING SYSTEM

The original design for maintaining position of the platens on the presses incorporated three positioners and two keys for each platen. Each of the positioners was embedded in the ceramic insulating block as seen in Figure 2-3. Two floating keys (.006 clearance) set into the anti-rotational keyed positioners engaged milled slots in the platens for positioning (Section A-A).

It was evident upon examination of the positioning components that:

- The key and mating slots were of insufficient area to prevent a brinelling effect.

- The castable ceramic in which the positioners were embedded was not of sufficient strength to prevent them from shifting.

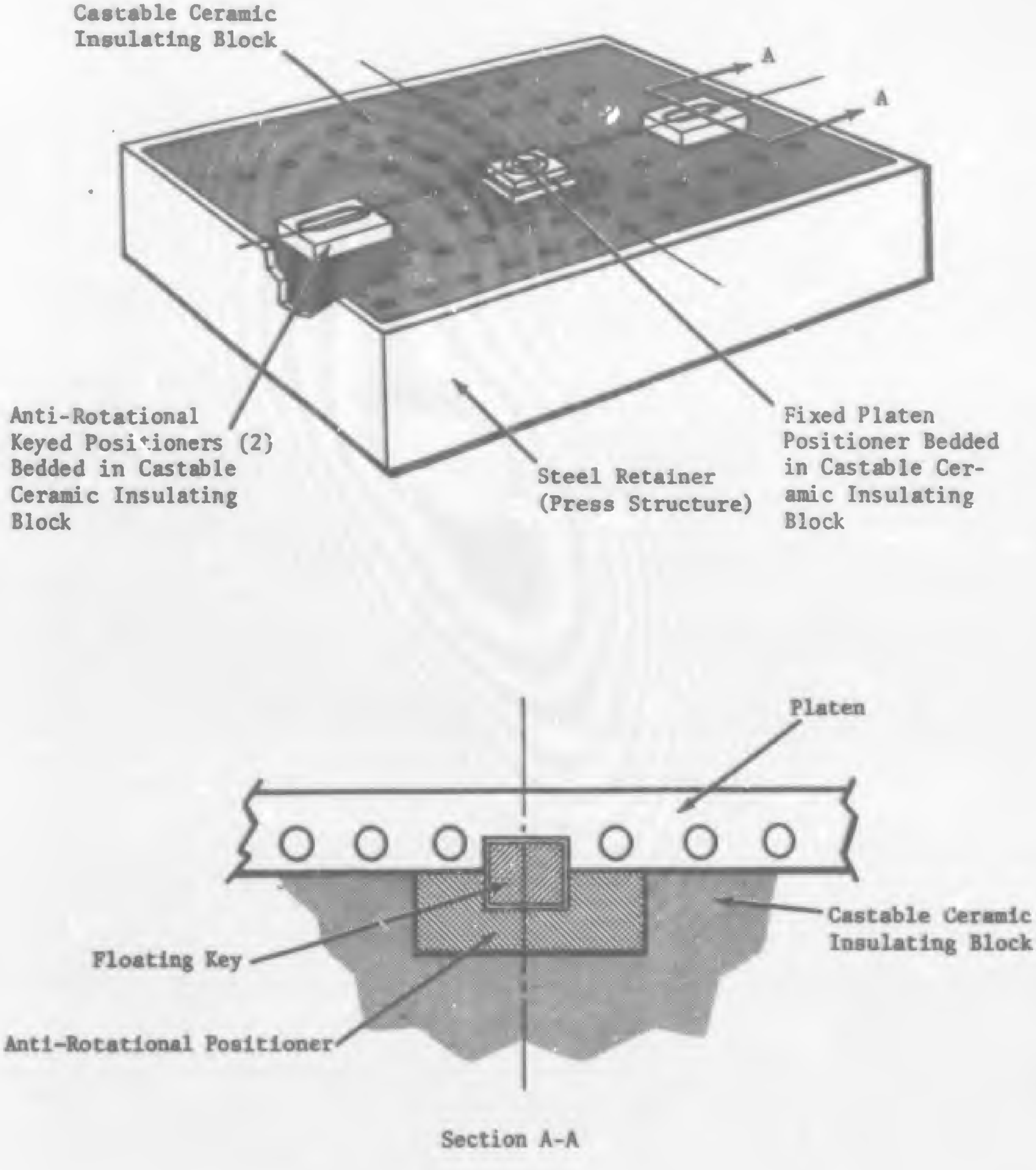


Figure 2-3 Original Platen Positioning Design Shown with Platen Removed

- An improved system of positioning was necessary

The improved platen positioning system consisted of the following modifications:

- Complete elimination of original positioning components (Figure 2-4)
- Four slots cut into the steel retainer to accept four keys welded in place
- Four coordinated slots milled into the platen (all slots and keys on L-R and F-B C_L)

These changes were incorporated and proved satisfactory. The two presses were modified to include both the upper and lower platens of each press.

4. DESIGN FEATURES

The following hot forming press features contributed towards optimizing forming procedures:

- Titanium parts can be drawn in one step from sheet stock with dies, die pins, material, and press platens at temperatures up to 1600°F.
- Cushion pressure holds the flange through the draw cycle, preventing wrinkles in formed parts.
- Upper and lower cushions offer the option of drawing against one of the cushions, using the other as a third action pressing force at any desired time, or as an automatic ejector.
- All heat is generated in the platens, hence no intricately heated sections in the die are required.
- The unit is a "C" frame, vertical, down-acting press incorporating upper and lower cushions.
- The unit has a 75-ton horizontal clamping arrangement including an interchangeable 75-ton horizontal forming action with a side cushion.
- Adjoining presses may be interlocked through electrical, hydraulic and mechanical systems controlled from one station.
- The structures are made of welded steel, fully stress-relieved.

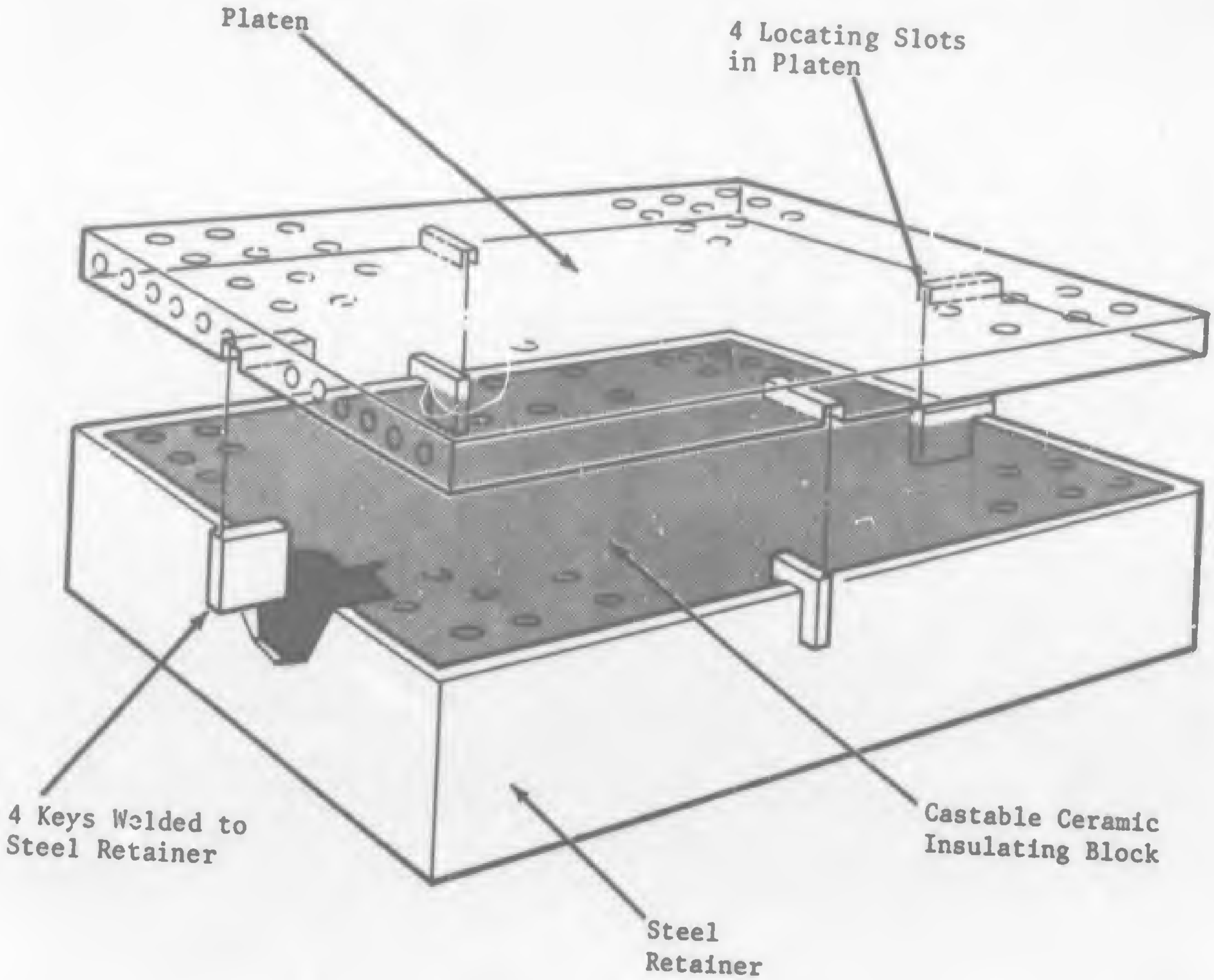


Figure 2-4 Improved Platen Positioning System

- The platens (Figure 2-5) are one piece RA330 2 1/2" thick, gun-drilled through the 60" length. They are secured by spring-loaded, high-temperature steel bolts. Each platen has eighty 5/8" tapped holes for tool mounting and eighty cushion-pin holes.
- The shuttle table is hydraulically operated. It will register accurately when traversed from the "out" position (Figure 2-6) to the "in" position (Figure 2-7) and will repeat the "in" position within .004".
- Manually operated Trabon System lubricates all ways simultaneously (Figure 2-8).

a. Heating Elements

The upper and lower platens are each heated with twenty-seven 60" long slip-in electric heating elements. All elements are readily removable and replaceable while the platens remain at operating temperature. Removal of elements is easily accomplished through the incorporation

Figure 2-5 Lower Heated Platen

of the following features: 1) Loose fit of heating elements into holes in the platens (heating element diameter .687", hole diameter .750"); 2) Quick disconnect plugs at terminal ends of heating elements (Figure 2-9).

Each heating element is zoned into three separate and controllable cells and is rated at 3000 watts operating at 480 volts when heater zones are connected in series wye.

All heating elements are sheathed in Inconel X material. Insulation material is magnesium oxide.

Figure 2-6 Tandem Mounted Hot Forming Presses (Tables Out)

Figure 2-7 Tandem Mounted Hot Forming Presses (Tables In)

Figure 2-8 Trabon Manual Grease System

The terminal ends of the heaters are air-cooled by a fan mounted on the terminal box. The inside of the terminal box is baffled to assure cooling of all heater terminal ends and connectors.

Service life of the heating elements is of a very satisfactory degree. Average heater life is better than one year with presses operating intermittently at approximately 65% of maximum time available. The heating elements are manufactured by Arc-O-Vec, Inc., of Stanton, California.

Eighteen controllers provide independent control for nine zones in each platen (Figure 2-10).

b. Cushion Die Pins for Upper, Lower, and Side Cushions

The cushion pins are designed to be 2 3/8" below the face of heated upper and lower platens and 1/2" below the face of the resistance head for the side cushion (Figure 2-11). Sufficient length permits a 6" draw stroke with the pin fully guided. Upper cushion pins are shouldered to be a permanent part of the upper assembly. There are eighty pins in the upper cushion, eighty pins in the lower cushion, and ten pins in the side cushion (Figure 2-12).

Figure 2-9 Slip-out, Plug-in Heater Tubes

c. Insulation

Platens are mounted in a castable refractory capable of withstanding high-compressive loads at elevated temperatures. Insulation is fully contained within a steel enclosure designed so that all "heat sink" points are eliminated.

d. Guiding

The press slide is guided by a square gibbing (Figure 2-13) identical to that used on metal draw presses throughout the industry. A running clearance of .003" is held through easy adjustments in the bronze ways. The depth of the guide permits off-center loading without stops or shim blocks. Water cooling maintains ambient temperatures.

5. PRESS TONNAGE

A force sufficient to counter balance the weights of all moving parts is maintained as a back pressure on the main ram. Vertical forming tonnage may be adjusted from absolute zero to maximum. Cushion tonnage is also adjustable with a maximum theoretical bed or slide cushion tonnage of 60 tons, if all pins are used.

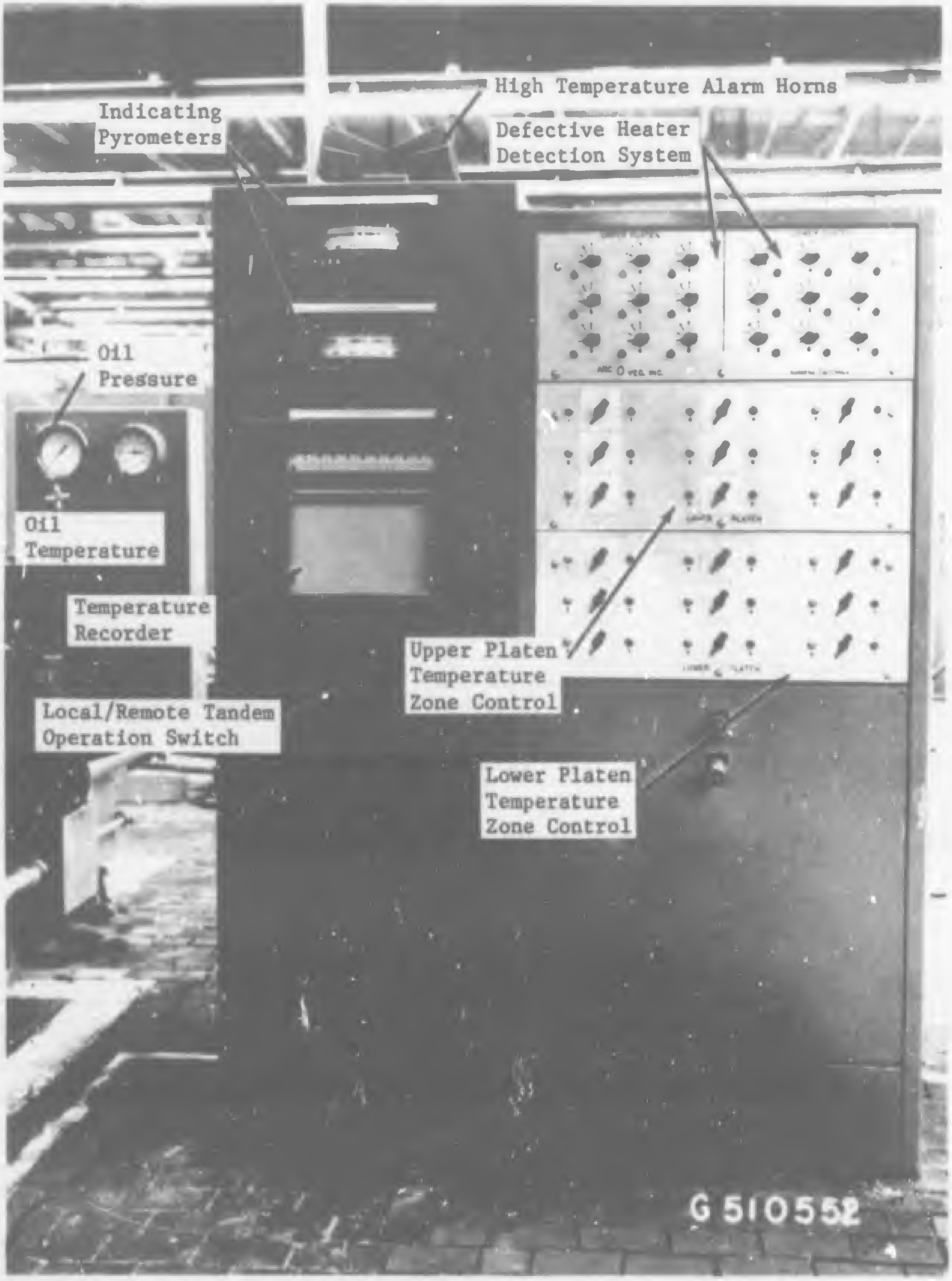


Figure 2-10 Temperature Control Console

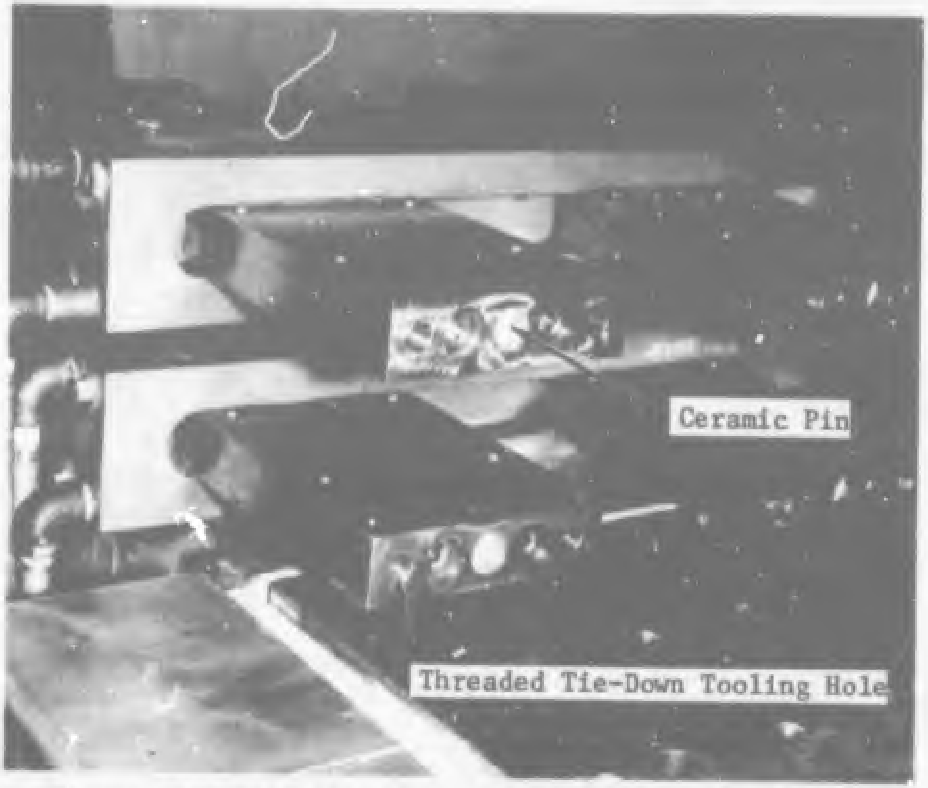


Figure 2-11 Water-cooled, Horizontal Cushion System

Figure 2-12 Special Test Device - Cushion Check in Ram and Bed

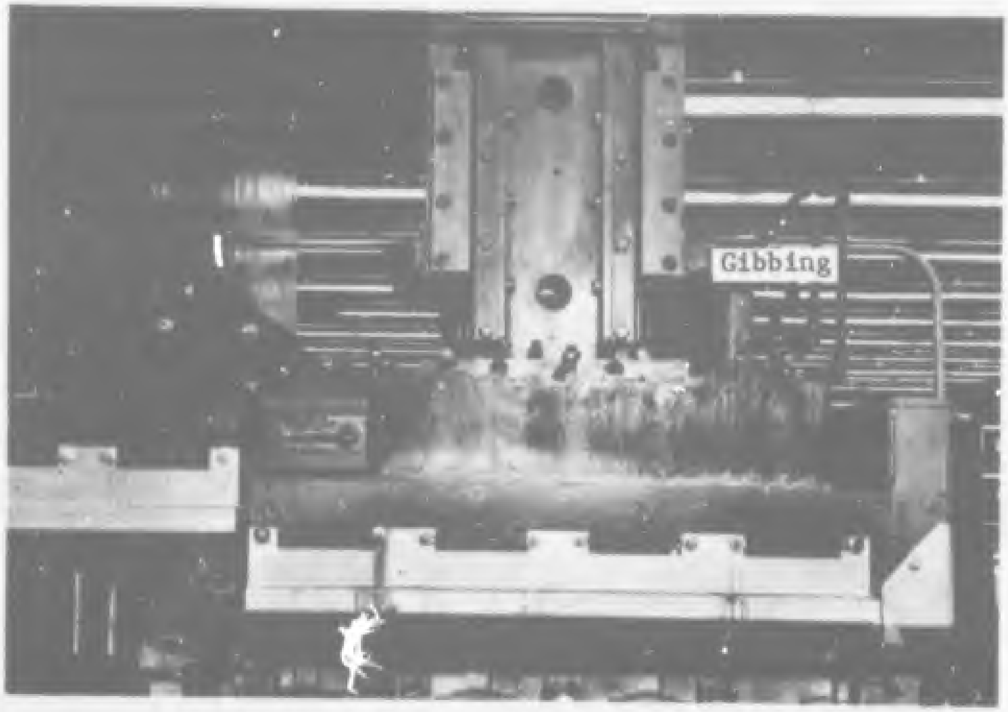


Figure 2-13 Press Slide - Square Gibbing Guide

Vertical force	0 to 75 tons (adj.)
Cushion capacity (top & lower)	3/4 ton per pin
Horizontal clamping & force (total)	75 tons
Individual force on each clamp	18 3/4 ton (adj. down to 2 ton)
Horizontal forming force (total)	75 tons (total)
Horizontal cushion capacity	3/4 ton per pin

Adjustable theoretical side cushion tonnage is maximized at 7 1/2 tons for each press if all pins are used.

6. WORK SPACE CAPACITY

A press has the following work space capacity:

Vertical forming stroke	18"
Vertical daylight(between platens)	20" max - 2" min
Cushion stroke (upper & lower)	6"
Platen area	48" F to B - 60" L to R

Horizontal forming stroke	Rigid bolster - 4" cushion (front)
Horizontal clamping stroke	8" total (4" front-4" rear)
Quantity of side clamps	4 front - 4 rear
Distance between horizontal clamps	40" max - 32" min
Vertical adjustment of side clamp	4"
Shuttle capacity (tooling)	3,000 lb
Top ram tooling capacity	3,000 lb

Forming speed per minute is as follows:

Vertical closing (rapid traverse)	135"
Vertical pressing	0" - 12"
Vertical opening	125"
Horizontal clamping	0" - 14"
Lower platen positioning (shuttle mechanism)	100" out - 100" in

7. VERTICAL FORMING

The following sequence is that of a typical cycle in vertical forming with this press:

- Lower action cushion is pressurized and top action is vented (by selector switch)
- Sheet stock is placed on die pressure pad
- Main slide is brought down at rapid advance speed
- Slide presses at present pressing speed, forming the part with cushion pressure holding the flanges
- With the dies closed, the lower cushion is depressurized at any desired time in the dwell; the upper cushion can be pressurized, providing a third action pressing force
- After the proper dwell period, the main slide is returned at rapid speed
- Pressurization of the lower action actuates the die pressure pad, ejecting the part

- Press is ready to receive sheet stock for forming the next part. Operation can be reversed, pressurizing upper action as a cushion and using lower action as a third action force.

8. SIDE FORMING

Side forming is accomplished through the following steps:

- Sheet stock is placed in die against pressure pad
- Main slide (top) is lowered, providing heat for tooling but maintaining minimum clearance to permit horizontal forming action
- Rear slide advances, forming part against cushion pressure. After desired dwell, slide returns. Cushion can be actuated as an ejector.

Die cushion is located at front of press (Figure 2-14). Forming action is from rear. The cushion and forming action are interchangeable with multiple horizontal clamps permitting conventional sizing operations (Figure 2-15).

9. PART EJECTION

a. Dual Process Evaluation

Part ejection was determined for both the one-step and the two-step process. The removal or ejection of formed parts at elevated temperatures presents problems, particularly in time consumption and the possibility of damage to the part. An optimized tooling system will reduce the number of actions in the sequence, and thus reduce costs.

b. One-Step Method

Utilization of the hydraulic pressure pins resulted in a one-step formed part ejection sequence as follows:

- Pressurize hydraulic pressure pins for clamping during the forming stroke.
- At the bottom of the stroke (closed die position) depressurize pressure pins during the dwell cycle.
- After the proper dwell period, return press to open.
- Pressurization of pressure pins will actuate die pressure pad from which the part will be ejected.

c. Two-Step Method

The two-step formed part ejection process may be tried with varying

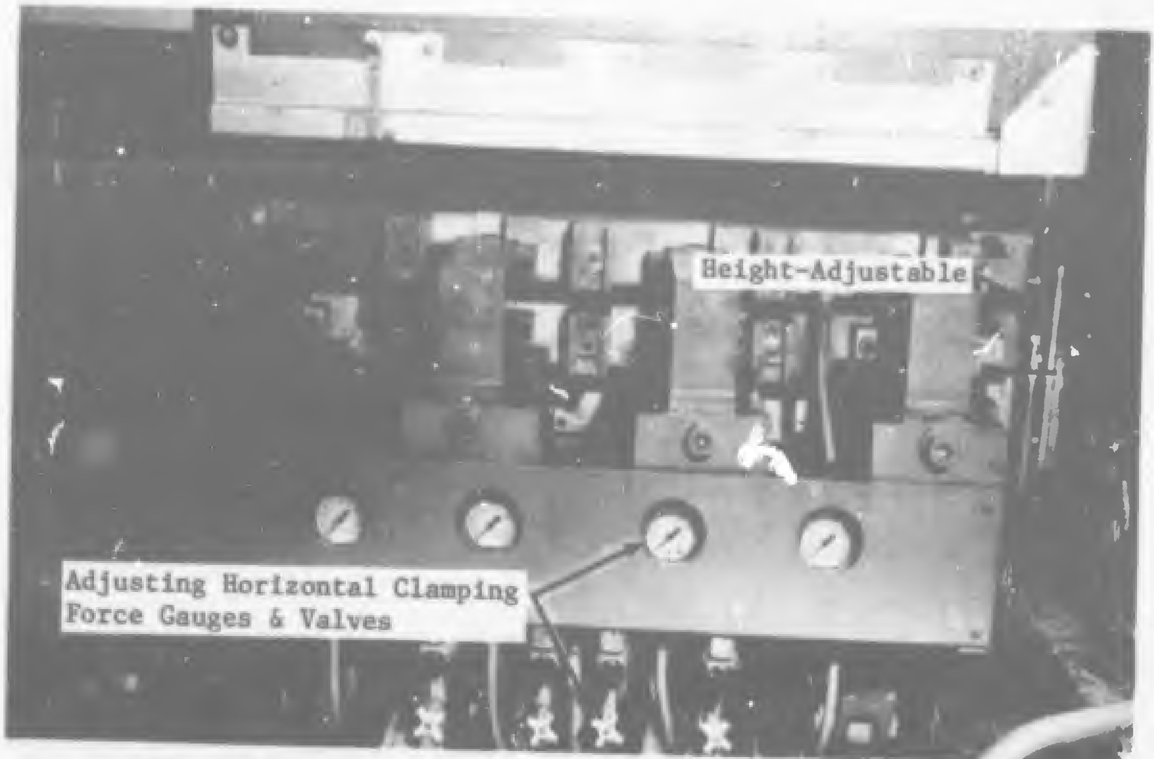


Figure 2-14 Front View, Horizontal Hydraulic Cushion

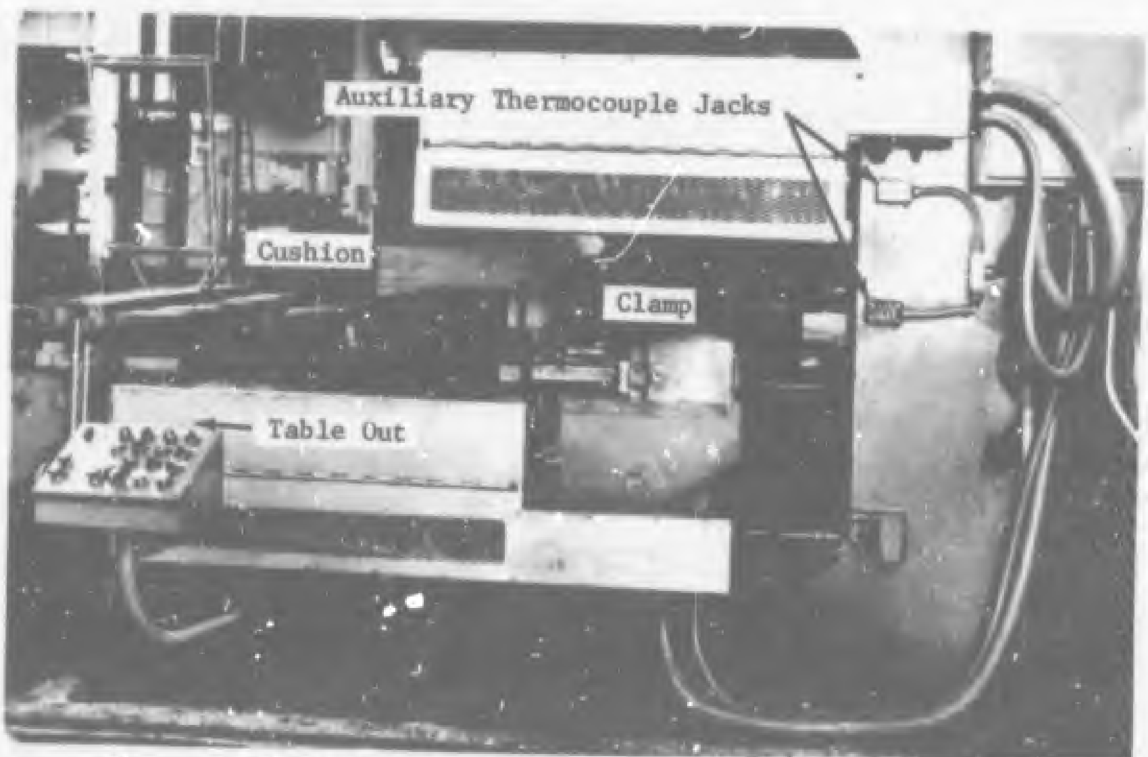


Figure 2-15 Horizontal Hydraulic Cushion, Horizontal Clamp

procedures. The current process uses the pressure pins of the press as follows:

- Depressurize the hydraulic pressure pins of the press to permit the die stripping pins to drop in flush with the top face of the male form die (Figure 2-16).
- Load workpiece on die
- Complete forming and dwell cycles
- Open press and eject formed part by pressurizing pressure pins

10. TOOLING ACCESSORIES

Since new techniques often create new problems to be overcome, the development of the optimized tooling system requires the development of new coordinated accessories. During the program, several new tooling accessories were designed and fabricated (Figure 2-17).

a. Tool Positioners and Keys

The upper and lower hydraulic die cushions on the new hot-forming presses incorporate independently acting pistons. Tool locations on the presses was a major consideration. A fixed center location positioner and key have been designed which should be used as a removable central pivot point locator on the press. Two steps are required:

- Rotate tool about the locator until correct orientation is obtained.
- Insert locating key into coordinated slots on the tool and the press.

The two-point positioning eliminates any movement of the tool during the forming operations (Figure 2-18).

b. Tool Holding Clamps

The dogging clamps secured to the high temperature platens must be manufactured of materials with high strength and resistance to oxidation at elevated temperatures. For this purpose, RA330 was used. Slotted clamps permitted compensatory adjustments for the various tool shapes and sizes.

c. Tool Mounting Bolts

Bolts for securing tools to the heated platens must withstand high heat effects. Investigation and physical testing for a qualified bolt material led to the selection of RA330 with NC-2A threads. The tapped holes in the platens have been made .015" oversize to provide

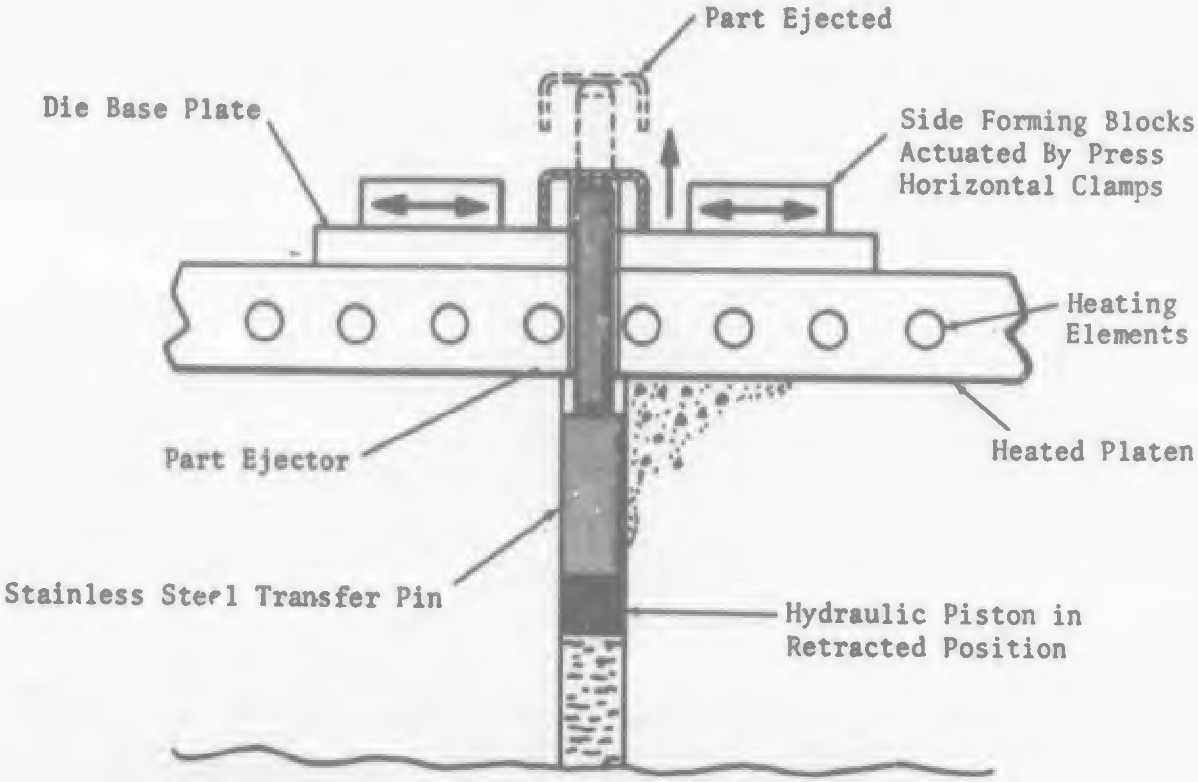


Figure 2-16 Part Ejection (Two-Step Forming)

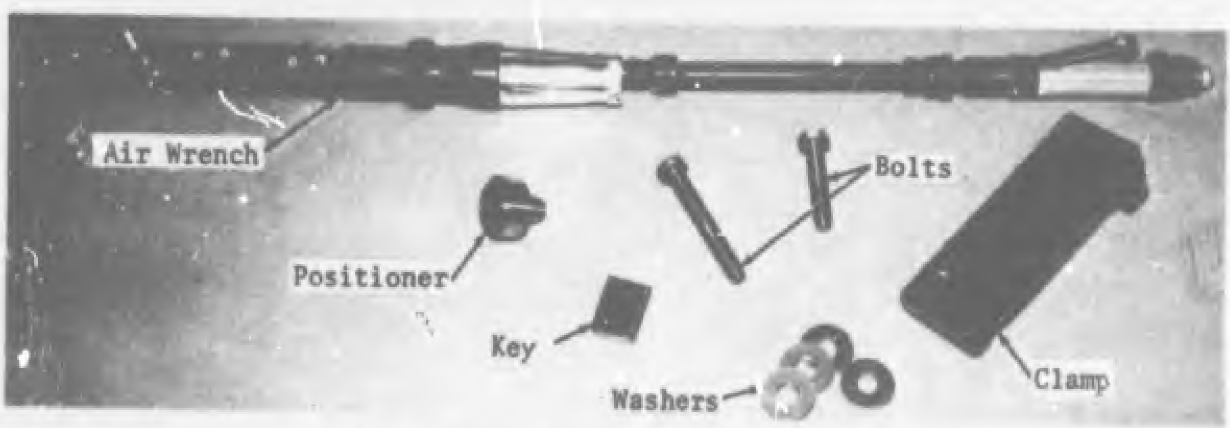


Figure 2-17 Hot Forming Tooling Accessories

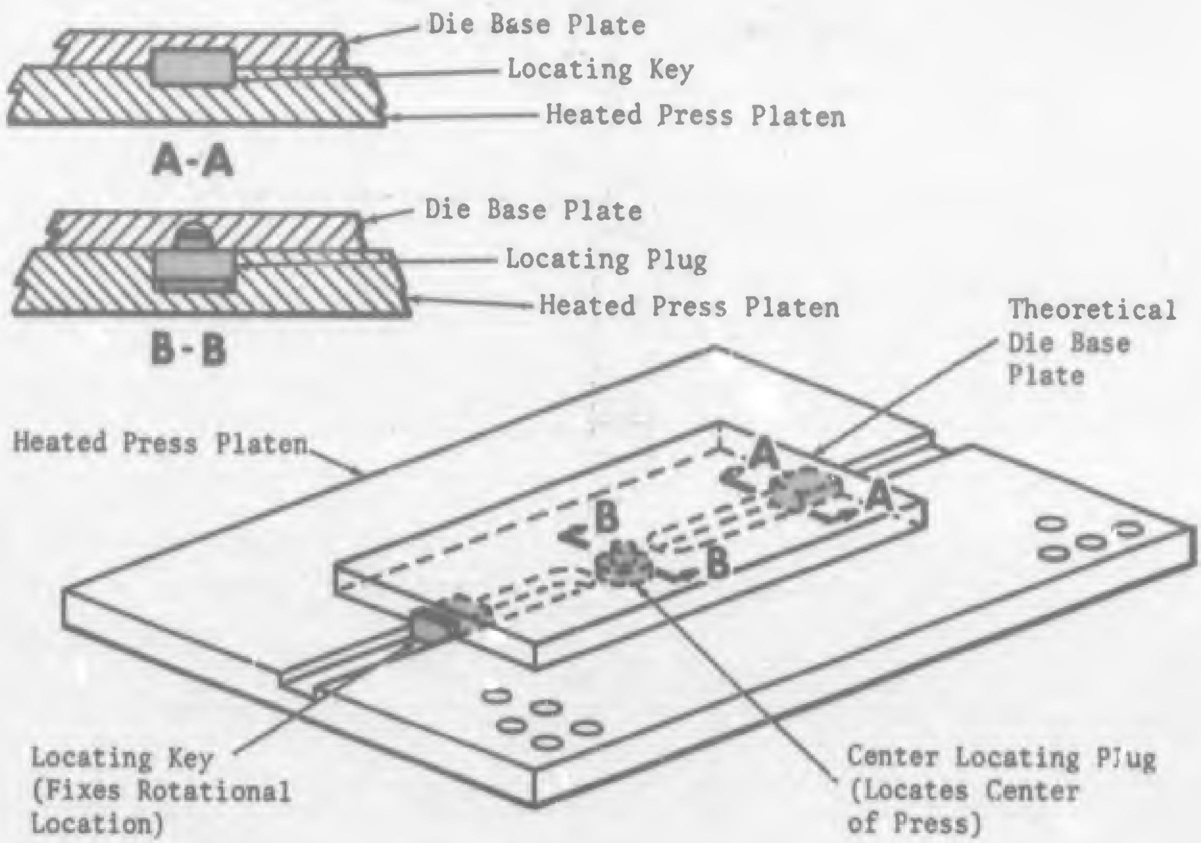


Figure 2-18 Die Alignment System (Common to Upper and Lower Press Platens)

for easy insertion and removal of the bolts, using the more viscous heat-resistant lubricants and automatic wrench.

d. Automatic Wrench

A special air-operated automatic wrench (Figure 2-19) was developed for this program. The wrench has the following advantages:

- Extended handle permits operation at a safe distance from the high heat units and for a shorter duration.
- Faster bolting of tooling, even at elevated temperatures, reduced floor-to-floor time.
- Bolts can be removed while the platens and tools are hot.

11. TOOL HANDLING

Tool location on the presses is a major consideration. Using the Grumman-developed center pivot point locator and key method of die positioning (see Tooling Accessories) required much flexibility of the tool handling equipment. Loading of tools by use of a fork lift meant much lost time due to limited maneuverability in attempting to accurately position the tools on the presses.

A greatly improved alternate to the fork lift method of tool loading and positioning has been incorporated into this total optimization project. Installation of an overhead three-ton bridge crane with electric hoist has been completed and fully utilized for all tool loading and positioning. The infinitely variable control of the hoist permits precise positioning of tooling over the tool locators as well as over the pressure pin holes for ease of alignment. Benefit derived from the availability of the overhead crane versus the fork lift for loading tooling has been a time saving of better than 60%.

In conjunction with the overhead crane, special lifting hooks have been fabricated of Hastelloy X (see Figure 2-20) to permit loading and unloading dies while hot. These hooks are slipped into holes bored into the tooling base plates and chain slung to the hoist hook to lift tooling. Figure 2-20 pictures one hook engaged in the base plate of the tool. A second hole can be seen at the opposite end of the base plate. Normally four holes per die are required for lifting; in some cases, however, two or three may be used, depending upon tool size and configuration.

As part of the tool handling program, it was initially planned to use a furnace as a tool pre-heat source to study tool loading at temperature. However, because of the remote position of the furnaces relative to the presses, this part of the study is based on handling, loading, and unloading of dies within a given press, simulating transporting from furnace to press. It has been determined through these simulated exercises that with

Figure 2-19 Automatic Air Wrench

Figure 2-20 Special Hastelloy X Lifting Hooks Showing One Inserted in Base Plate of RDM 1500 (Tail Cone Frame)

overhead bridge crane handling equipment, heat-resistant lifting hooks, and the tooling accessories described in this section, loading and unloading of heated tooling is readily feasible. This applies to cushion type tooling as well as hot sizing tooling.

SECTION III

TOOLING MATERIALS

1. MATERIAL STUDY AND SELECTION

Twenty-one alloys were originally considered for use as tooling materials. After comparing twelve characteristics of each of the materials, cost and chemistry were guiding factors. (See Table 3-1.) During the initial phase, Incoloy 802, Meehanite HSV, and Hastelloy X appeared to offer the most desirable qualities. However, Hastelloy X was subsequently eliminated because of uncertain availability and was replaced by Nicrosil.

The advantages of Nicrosil were made known through a previously established agreement to exchange non-proprietary information with Boeing Manufacturing Research and Development personnel. Nicrosil is a hot form die material newly developed for Boeing after a recently completed study by the Illinois Institute of Technology Research Institute in Chicago. It is believed to have superior characteristics to many other hot form die materials.

NOMINAL CHEMICAL COMPOSITION WT. %											
	C	Mn	Si	Cr	Ni	Co	Mo	W	Fe	Ti	Al
Nicrosil	2.8	.5	5.0	5.0	20.0	-	-	-	62.0	-	-
Incoloy 802	.35	-	.55	20.5	32.0	-	-	-	46.0	0.4	0.4
Meehanite HSV	"Cast" - a high silicon nodular iron with molybdenum or tungsten and vanadium.										

a. Nicrosil

Nicrosil is a readily castable high nickel cast iron alloy. It has been recommended for cast-to-shape dies. Surface finishes of 125 RMS in the "as cast" condition are attainable when cast by the Shaw process. The shrinkage factor for cast-to-shape tooling is quite predictable, thereby reducing subsequent machining requirements to a minimum. Nicrosil is readily machinable.

TABLE 3-1 BASIC COMPARISON OF STEELS FOR HIGH-TEMPERATURE FORMING

Material	Manufacturer or Supplier	Thermal Cond. B.T.U. @1500°F.	Maximum Operating Temp.	Maximum Oxidation Resist. Temp.	Tensile Strength PSI @1500°F. @2000°F.	Yield Strength PSI @1500°F. @2000°F.
Inconel 600	International Nickel, Inc.	193	2150°F.	2150°F.	25,000	14,000
Inconel 625	International Nickel, Inc.	151	2150°F.	2150°F.	52,000 10,000	52,000 10,000
Inconel 718	International Nickel, Inc.	167	1300°F.	1800°F.	75,000 8,000	75,000 8,000
Inconel X750	International Nickel, Inc.	159	1500°F.	1800°F.	77,300	76,800
Inconel 800	International Nickel, Inc	174	2050°F.	2050°F.	24,800	14,200
RA330	Rolled Alloys	142	1600°F.	2100°F.	30,000 6,500	16,600 5,000
RA333	Rolled Alloys	162	2100°F.	2100°F.	38,000 9.000	30,500 7.000
Rene' R41	Haynes	168	1800°F.	1800°F.	126,000	118,000
Alloy X	Haynes	174	2000°F.	2200°F.	43,000	24,000
M 252	Special Metals	135	1600°F.	1800°F.	110,000	90,000
Incoloy 802	International Nickel, Inc.	175	1800°F.	2100°F.	46,000	26,000
H.S. 1%V	Meehanite	145	1700°F.	1800°F.	10,000	7,000
S816 B	Allegheny	164	2000°F.	2000°F.	48,000	45,000
AISI H13	Allegheny	—	1200°F.	—	109,000	—
AISI H24	Allegheny	—	—	—	31,750	—
Almar 18	Allegheny	—	1300°F.	1000°F.	—	—
Alloy 25	Haynes	172	1500°F.	1500°F.	50,000	40,000
Alloy 31	Haynes	152	2000°F.	2000°F.	63,000	40,000
Alloy 150	Haynes	—	2200°F.	2200°F.	11,400	5,100
Alloy 713C	Haynes	190	1800°F.	2000°F.	124,000	105,000
Pyromet 860	Carpenter	—	1500°F.	—	103,000	106,000

*Based on Free Machinable Steel (B1112)
Condition Annealed 200 BHN 1.00

(Sheet 1 of 2)

TABLE 3-1 BASIC COMPARISON OF STEELS FOR HIGH-TEMPERATURE FORMING (CONT'D)

Coef. of Thermal Expan. @1500°F. @2000°F.	% of Elong. @1500°F	Machinability Index*	Average Listed Cost $/lb.	Cost Index H-13 @.70/lb.	Key Element	Material
$9.0x10^{-6}$ $9.5x10^{-6}$	46%	.23	$1.48	2.1	Nickel Chromium	Inconel 600
$8.65x10^{-6}$	84%	.09	$3.00	4.3	Nickel Chromium	Inconel 625
$9.3x10^{-6}$ $10.0x10^{-6}$	45%	.12	$3.37	4.3	Nickel Chromium	Inconel 718
$9.05x10^{-6}$	10%	.09	$2.60	3.7	Nickel Chromium	Inconel X750
$10.1x10^{-6}$	91%	.23	$0.95	1.4	Nickel	Inconel 800
$10.0x10^{-6}$ $10.3x10^{-6}$	—	.18	$1.25	1.8	Nickel Iron	RA330
$9.5x10^{-6}$ $10.1x10^{-6}$	—	.12	$2.26	3.2	Nickel	RA333
$8.45x10^{-6}$	5%	.09	$7.00	10.0	Nickel	Rene' R41
$8.9x10^{-6}$	34%	.23	$2.80	4.1	Nickel	Alloy X
$8.25x10^{-6}$	10%	.09	$3.85	5.5	Nickel	M 252
$9.95x10^{-6}$	13%	.23	$1.50	1.7	Nickel	Incoloy 802
$7.45x10^{-6}$	11%	.5	$0.40	0.6	Pearlite	H.S. 1%V
$8.83x10^{-6}$	22%	.12	$8.00	11.4	Cobalt	S816 B
$7.9x10^{-6}$	—	.49	$0.70	1.0	Chromium	AISI H13
—	23%	.40	$1.80	1.1	Tungsten	AISI H24
—	—	—	$1.80	1.1	Nickel Cobalt	Almar 18
$9.08x10^{-6}$	24%	.12	$5.30	7.5	Cobalt	Alloy 25
$9.2x10^{-6}$	15%	.06	—	—	Cobalt	Alloy 31
—	—	—	—	—	Cobalt	Alloy 150
$8.2x10^{-6}$	6%	.12	$6.80	9.7	Nickel	Alloy 713C
—	16%	.09	$2.75	3.9	Nickel	Pyromet 860

(Sheet 2 of 2)

b. Incoloy 802

Incoloy 802 is a nickel base alloy with a stable austenitic structure. The material remains ductile and does not form a brittle sigma phase even after extended use in the critical temperature range of 1200°F to 1600°F. The iron content resists sulphur attack and "green rot" (internal oxidation). Dispersion hardening gives this alloy superior mechanical properties at elevated temperature over the former Incoloy 800. It is judged as slightly difficult to machine when compared with H-13 steel. It is not castable.

c. Meehanite HSV

Mechanite HSV alloy is a pearlite base material. The self-lubricating properties in Meehanite dies are significant. The application of surface pressure on dies releases a surface smear of finely dispersed graphite which prevents searing and sizing. Meehanite accentuates the effect of various lubricants, thus enabling dies made of it to develop a high polish and a mirror-smooth wearing surface. Consistent uniformity of metal structure throughout variable thicknesses of cast sections insures dependability and freedom from structural failures.

The easy castability of Meehanite HSV permits economical casting of complex single-unit die components. Machining is reduced and in some cases may be completely eliminated,necessitating only mild hand grinding.

2. MATERIAL DIFFICULTIES

During a study project such as this, the most interesting and gainful knowledge is sometimes obtained when meeting the challenges of completely unexpected problems. This has been particularly true when working with the tooling materials.

a. Nicrosil

Of the three tooling materials used on this program, Nicrosil presented the least difficulty. Slight distortions were present in the as-cast condition of these tools. However, minimal time was expended on final fitting of the dies.

b. Incoloy 802

Machinability data on Incoloy 802 is minimal because of the relatively brief history of the material. Unexpected problems caused undue delays; efficient machining almost became a supplemental development program.

Incoloy 802 is an austenitic iron-nickel-chromium alloy that is supplied in an annealed hot-rolled condition. It becomes gummy and work hardened during machining. Heat and pressures develop between the workpiece and tool when heavy feeds and carbide tools are used. Thus, further machining is hindered by the presence of a deformed stressed surface layer.

Assistance was requested from the International Nickel Company, the manufacturer of Incoloy 802. Machining continued with their recommendations incorporated. However, the rate was slower than originally anticipated.

3. MEEHANITE TESTS

a. Study

While machining Meehanite, the Tool Shop encountered numerous large, hard, metallic inclusions that delayed grinding, sawing, and planing. Experts from the Meehanite Metal Corporation, New Rochelle, N. Y., and the Barnett Foundry and Machine Company, Irvington, N. J., were invited to inspect and advise on the composition of the metal. Meanwhile, Grumman initiated its own metallurgical investigation.

Observations and conclusions from the separate investigations are summarized in the following paragraphs.

Macroscopic examination at low magnification (to 10X) revealed that irregularly shaped and sized particles were randomly dispersed over the bottom of the cast plate (Figure 3-1). A hardness survey taken on the matrix yielded a BHN_{3000} 217. Meehanite HSV that did not exhibit this condition had an average Brinell hardness of 218. The Rockwell hardness of the metallic particles ranged from 40 to 50 Rc.

The reported spectrographic analyses of the above samples were:

ELEMENTS, %							
Specimen	Si	Mn	V	Cr	Mo	Ni	Fe+C
Known HSV	7.0	0.57	0.99	<0.2	<0.2	<0.2	Bal
Subject Casting	7.0	0.46	0.73	<0.2	<0.2	<0.2	Bal
Particle	1.0	0.30	>20.0	-	<0.2	-	Bal

Metallographic samples were prepared from an acceptable sample of cast Meehanite HSV and from the top and bottom surfaces of the rejected subject cast plates.

As polished (Figures 3-2 and 3-3) the two castings showed strikingly dissimilar structures. The Meehanite HSV contained a blend of nodular graphite and carbides; the cast plate was composed of a heterogeneous mixture of flake and nodular graphite plus carbide. When etched (Figures 3-4, 3-5, and 3-6) further differences were revealed. The Meehanite showed carbide clusters within the grain boundaries (Figure 3-7). This chain-like carbide structure in the grain boundaries is missing in the subject die material; instead, common lamellar pearlite is evident (Figure 3-8).

When viewed under the microscope, the particles appear as large masses whose edges are gradually breaking away and being dissolved (Figures 3-9 and 3-10). The particles are not a precipitate from the melt; they are ferro-vanadium additives (introduced as pellets at the foundry) which sank to the bottom instead of dissolving. This is evident from the spectrographic analysis and the fact that vanadium, in addition to being a grain refiner and improving high temperature properties, is a very strong carbide former. Dissolved vanadium formed carbides of the type found in Figure 3-7; it was the lack of dissolved vanadium that resulted in the low number of carbides in the die material.

b. Conclusions

The hard metallic particles found in the cast plates were the ferro-vanadium pellets added to the ladle by the foundry to increase the vanadium content of the melt. Common foundry grade ferro-vanadium melts at 3700°F, but in this instance the ladle temperature never exceeded 2700°F. Time and temperature were inadequate to permit the particles to be completely dissolved; as a result, they settled to the bottom of the casting.

c. Recommendations

It is recommended that the following conditions be carefully maintained when casting in Meehanite HSV:

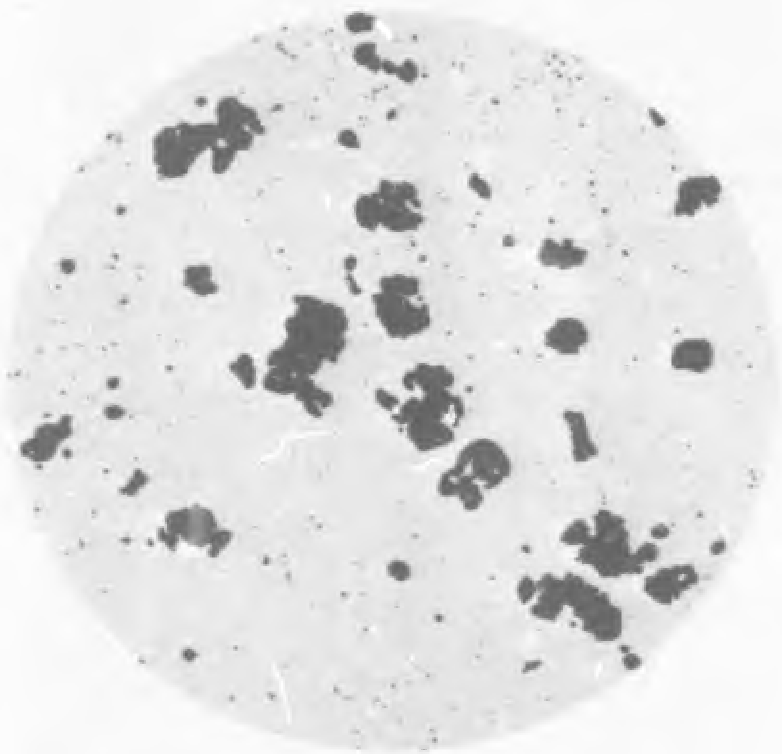
(1) Use a vanadium alloy, such as Union Carbide's Carvan, to ensure complete solubility prior to nodularization.

(2) Mix adequately to ensure an homogeneous blend during nodularization and solidification.

(3) Slag off all excessive vanadium additives.

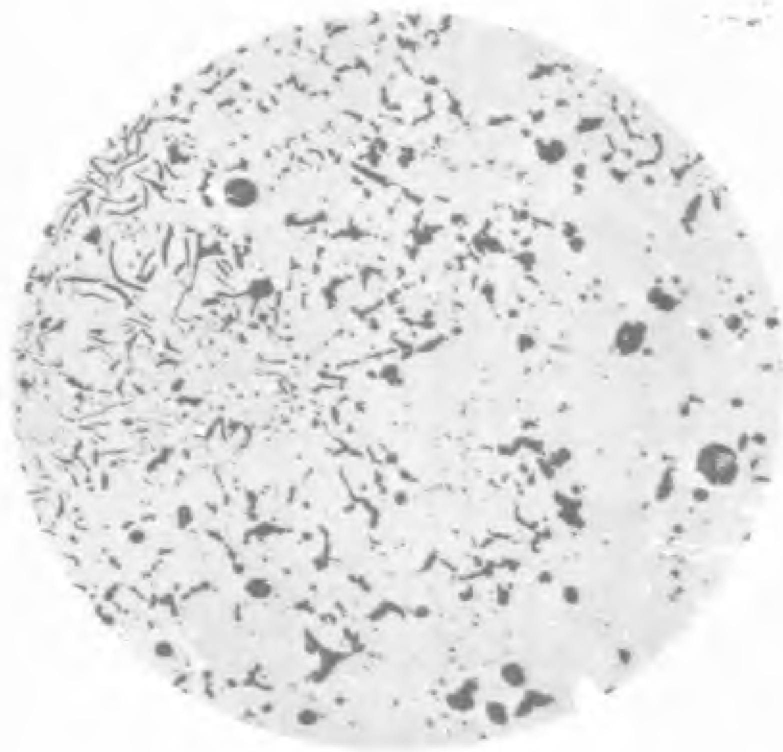
Magnification: 1X Etchant: 50% HCl at 150°F.

Figure 3-1 Ground Section of Subject Cast Plate Showing Particles on Bottom Surface



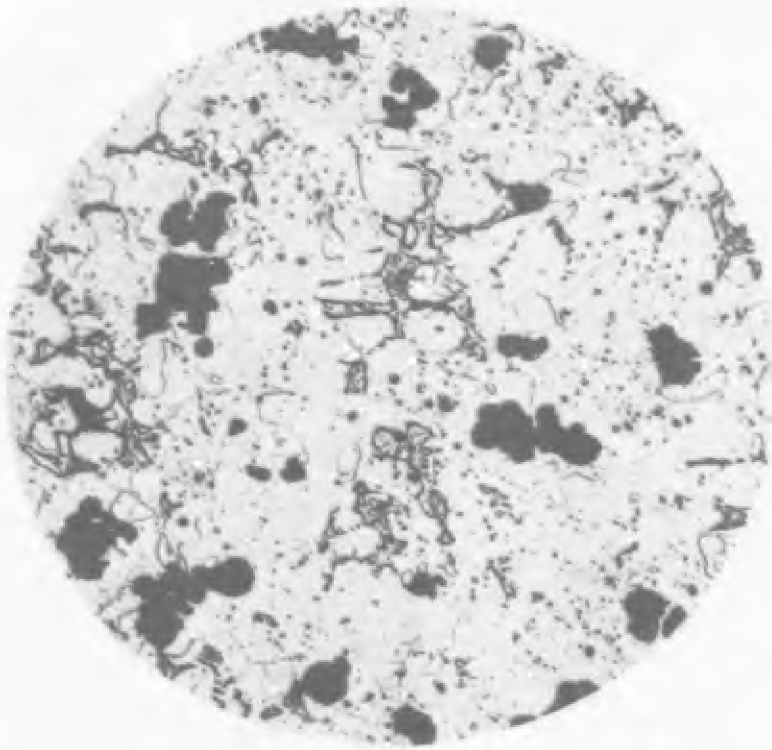
Magnification: 100X *As-Polished*

Figure 3-2 Standard Meehanite HSV Showing Nodular Graphite with a Dispersion of Particles



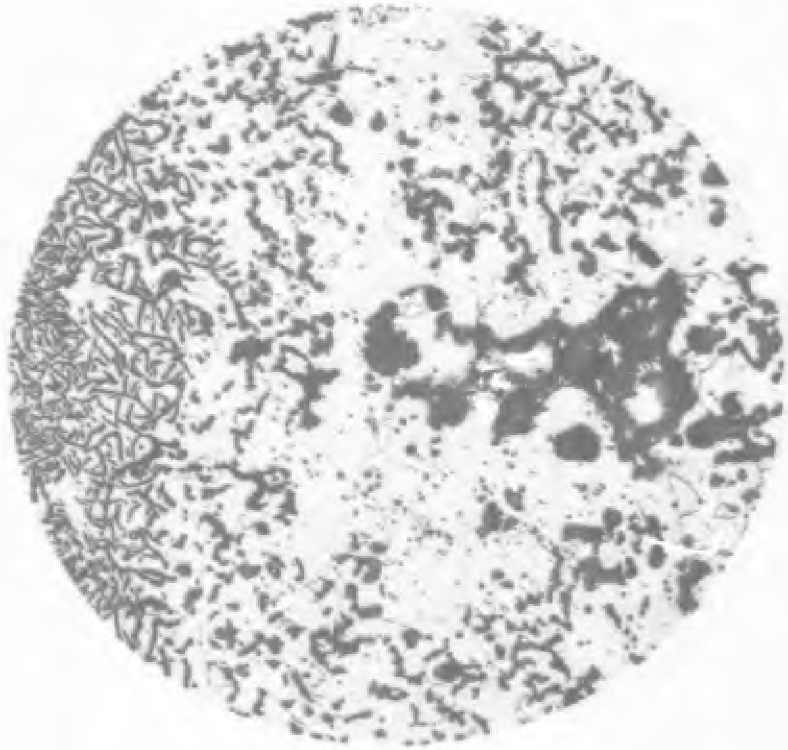
Magnification: 100X *As-Polished*

Figure 3-3 Subject Cast Material. Note Heterogeneous Mixture of Nodular and Flake Graphite



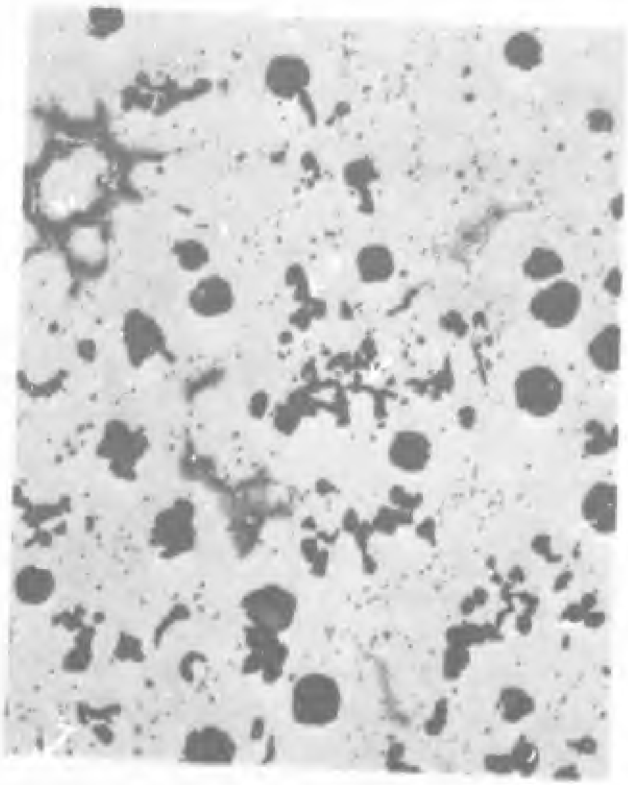
Magnification:100X Etchant:2% Nital

Figure 3-4 Typical Structure of Meehanite HSV, Nodular Craphite in a Ferritic Matrix with Grain Boundary Carbides



Magnification: 100X Etchant: 2% Nital

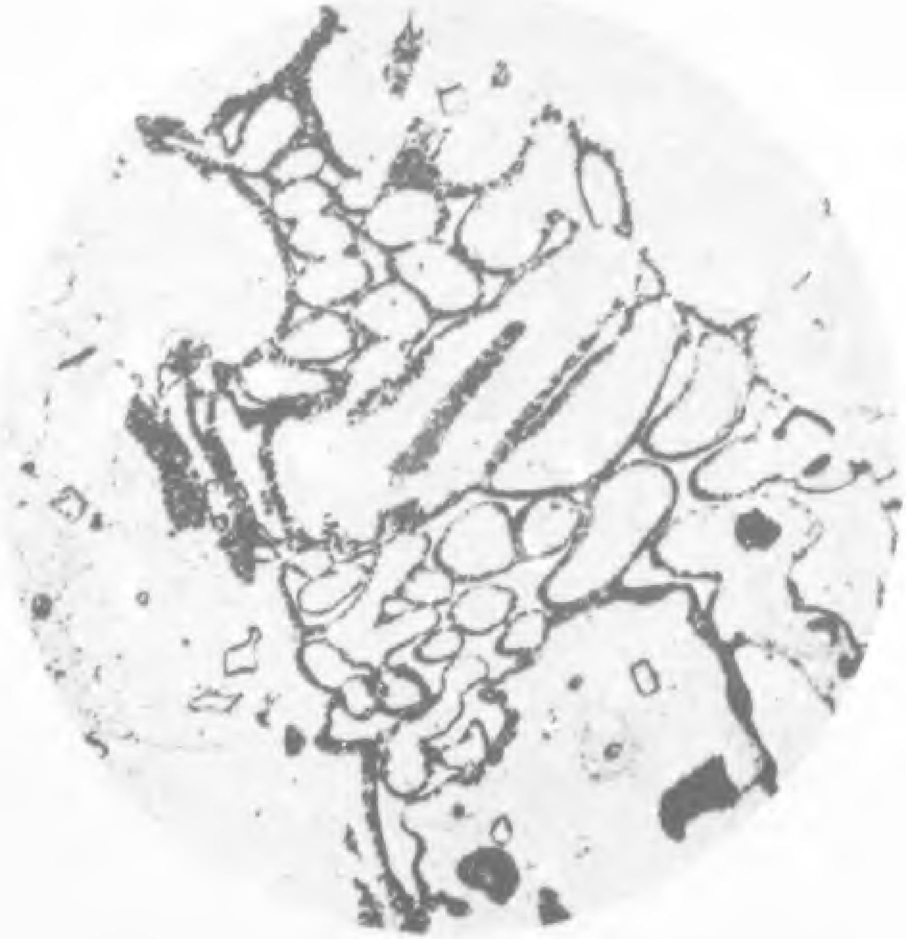
Figure 3-5 Structure of Subject Cast Material, Mixture of Nodular and Flaked Graphite with Pearlite at the Grain Boundaries



Magnification: 100X *Etchant: 2% Nital*

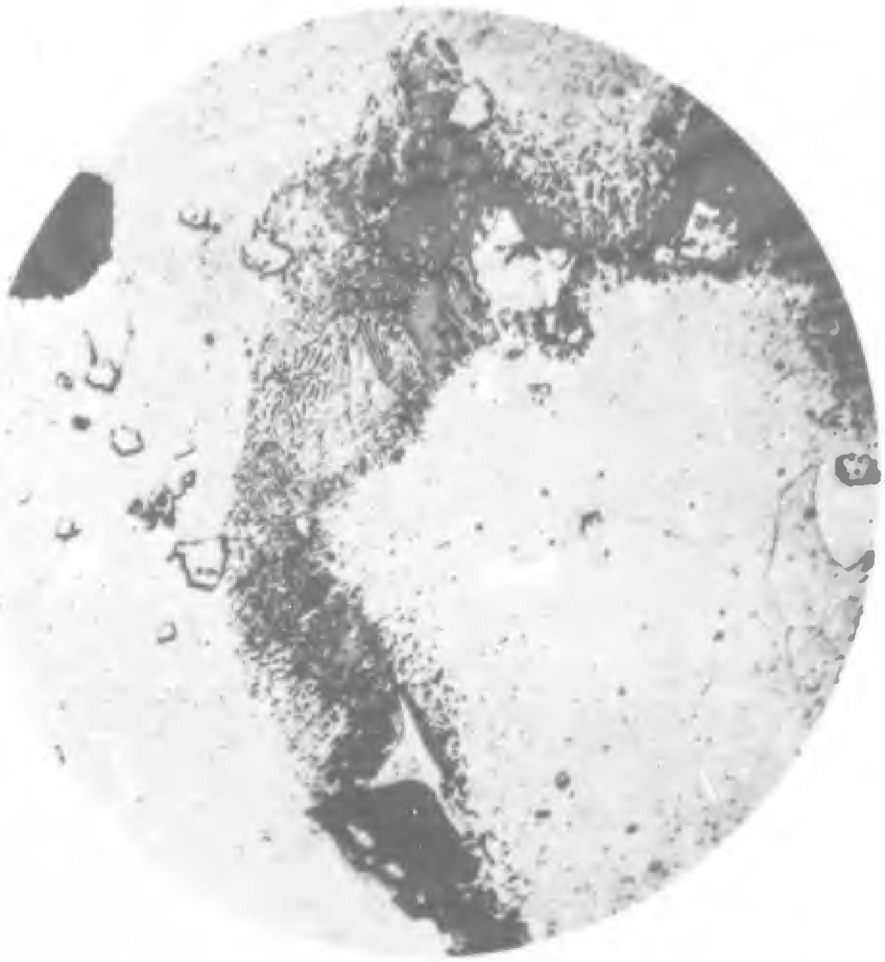
Photomicrograph Courtesy
Meehanite Metal Corporation

Figure 3-6 Section Away From an Inclusion Showing Nodular and Semi-Nodular Graphite in a Predominantly Ferritic Matrix



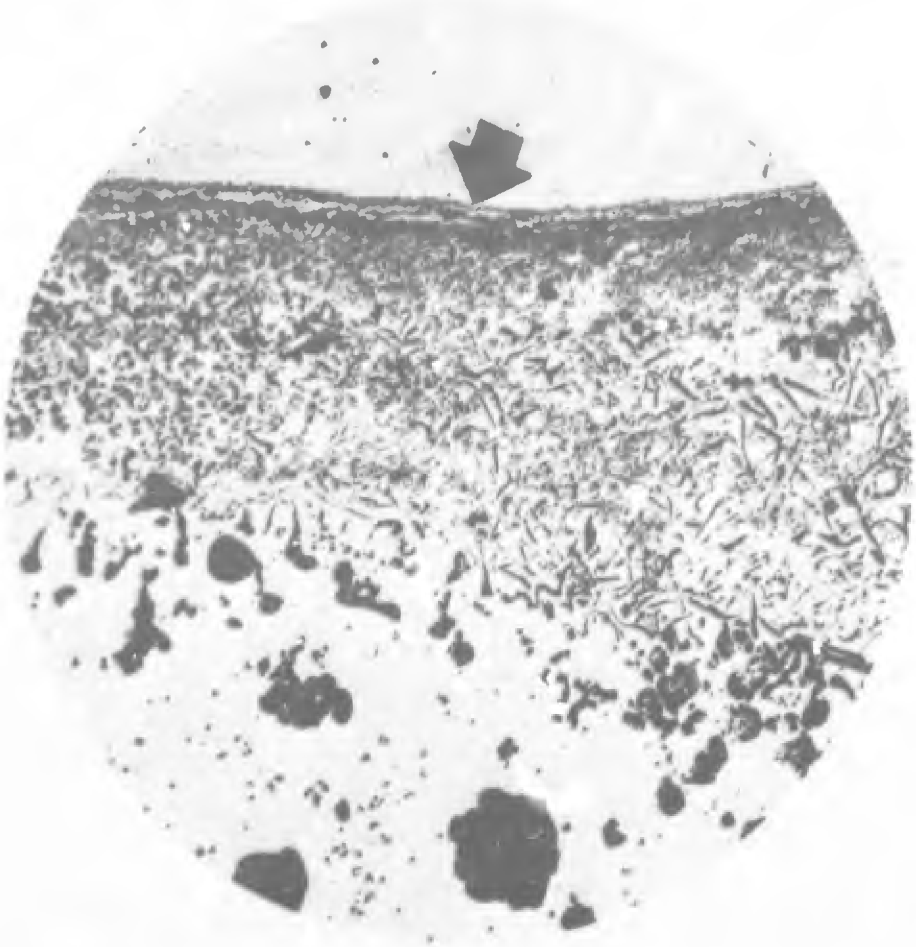
Magnification: 750X *Etchant: 2% Nital*

Figure 3-7 Grain Boundary Carbides as Found in Meehanite HSV



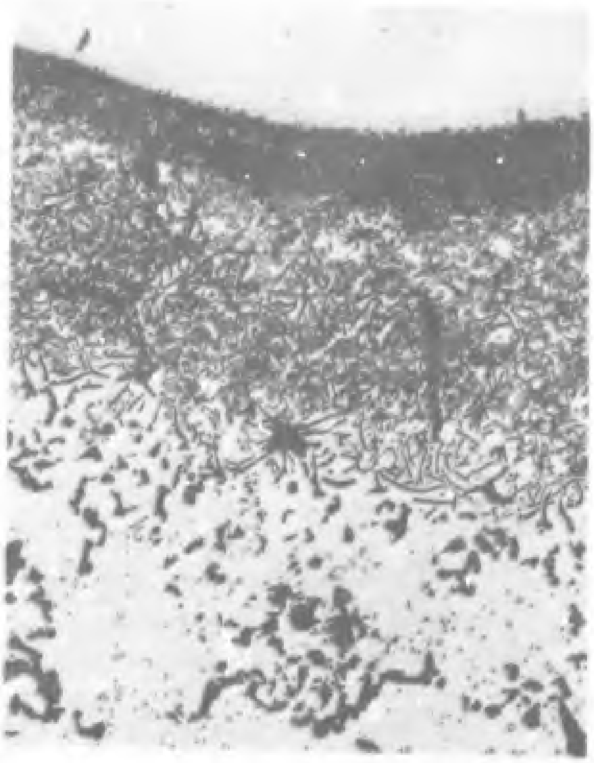
Magnification: 750X *Etchant: 2% Nital*

Figure 3-8 Lamellar Pearlite at the Grain Boundaries of the Subject Cast Material



Magnification: 100X *As-Polished*

Figure 3-9 Interface of Particle and Cast Matrix Material. Note Edge of Particle (Arrow) Being Slowly Dissolved



Magnification: 100X *Etchant: 2% Nital*

Photomicrograph Courtesy
Meehanite Metal Corporation

Figure 3-10 An Inclusion is Shown as the White Area at the Top of the Photograph. The Diffusion Zone is Between the Inclusion and the Base Metal (Bottom). Partial Solution is Noted with Vanadium Carbides Forming and Coming Away from the Ferro Vanadium Inclusion

SECTION IV

TOOL FABRICATION TECHNIQUES

1. TECHNIQUE DETERMINATION

Optimized forming must be accomplished with a saving of time and money and within the boundaries of economical production. The machining of tools is a phase of fabrication that must be constantly reviewed. Various methods must be compared and evaluated.

2. ELECTRICAL DISCHARGE MACHINING PROCESS

A study of tool fabrication by the electrical discharge machining process (EDM) has been completed. This study is based upon the manufacture of a second punch to be used with the one-step form die used to produce part 4(zee). The original punch (machined conventionally) is used to form all the .025" thick Ti material. The second punch is required to form the .070" thick titanium. The punches in both instances are rough cast from Meehanite HSV.

Comparative costs of machining are:

TABLE 4-1 TOOL MACHINING - COST COMPARISONS

Conventional Machining		Electrical Discharge Machining	
Operation	Hours	Operation	Hours
Hydrotel	62	Machine Electrode #1	100
Hand Fit (Die Spotting)	24	Machine Electrode #2	50
		EDM Surface #1	150
		EDM Surface #2	50
		Die Spotting	24
Total	86	Total	374

When totaling the EDM cost, a charge of $1,300 for additional electrode materials should be included.

Because the EDM method cost is so much greater than the conventional method, additional studies were not made.

3. ELECTROCHEMICAL MACHINING PROCESS

Electrochemical machining (ECM) was used to fabricate tooling when conventional machining techniques proved to be difficult or time-consuming.

a. Machining of Bead-Shaped Clearance Holes in Incoloy 802 (RDM 1495) Pressure Pad

Conventional hydrotel machining of one bead-shaped clearance hole in the two-inch-thick Incoloy 802 die pressure pad required eight hours and several cutters to produce. It was then decided to use electrochemical machining to produce the remaining four holes in this plate. Accordingly, the cathode tool shown (Figure 4-1) was fabricated from 1020 cold rolled steel. Test cuts were made without difficulty in scrap Incoloy 802 with a sodium chloride electrolyte at feed rates of 0.020 to 0.065-inch per minute. When an attempt was made to electrochemically machine the actual Incoloy 802 die plate, however, electrical shorting occurred almost immediately. It was found that the 3/8-inch-diameter holes, which had been pre-drilled at opposite ends of each clearance hole to facilitate conventional machining, interrupted the flow of electrolyte. Small passivated areas formed around these holes, causing material to flake off in those areas where stray machining was taking place in advance of the frontal gap. Attempts to correct this condition by varying the process parameters and by closing the holes with drill rod and stainless steel plugs proved to be unsuccessful. Because the plugs were being machined at a faster rate than the Incoloy 802 die material, the electrolyte flow condition eventually reverted to that observed previously with the unplugged holes.

Test cuts were next made on a scrap Incoloy 802 piece that had predrilled holes at each end of a bead-shaped hole, using sodium nitrate electrolyte instead of sodium chloride electrolyte. The cuts were made without difficulty. When an attempt was made to electrochemically machine the actual Incoloy 802 die plate, however, shutdowns due to electrical shorting again occurred. It was found that the pre-drilled holes in the test piece were centrally located while those in the part were off-center. Apparently, accurate location of the holes results in a more balanced electrolyte flow. The cathode tool was modified to distribute the electrolyte more evenly over the working face. A copper plate was also added to this tool. Using the modified tool, the bead-shaped clearance holes were electrochemically machined into the Incoloy 802 die pressure pad with a sodium nitrate electrolyte without difficulty. Machining conditions used include a voltage of 14 volts, a current of 1,200 amperes, a feed rate of 0.045 inch per minute, and an electrolyte temperature of 100°F.

Each bead-shaped clearance hole was electrochemically machined in the Incoloy 802 pressure pad in 45 minutes. Eight hours were required to

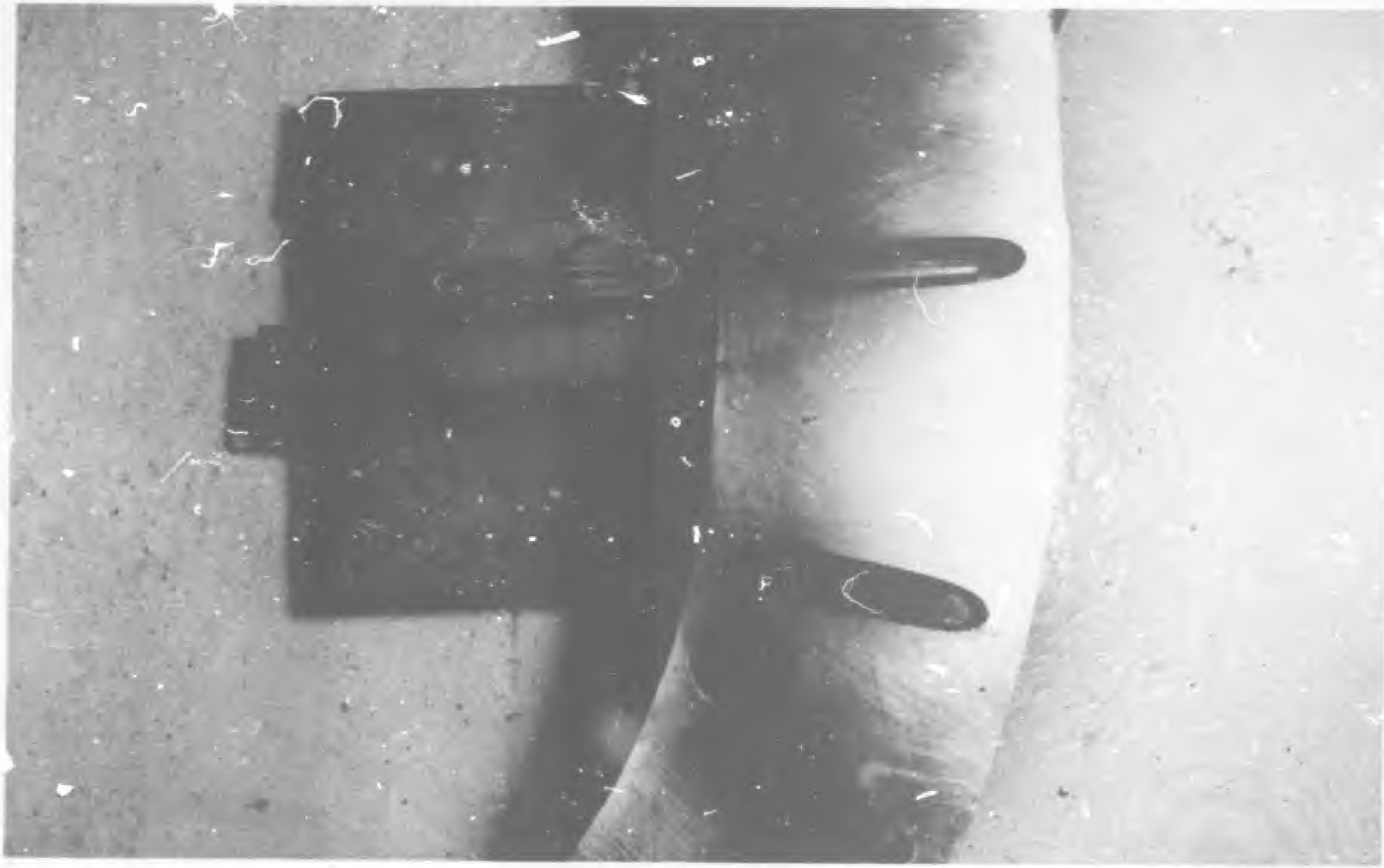


Figure 4-1 Arrow Indicates Cathode Tool Fabricated from 1020 Cold Rolled Steel

conventionally machine the first hole. Considering the 16 hours required to fabricate the tool, electrochemical machining of the remaining four clearance holes saved 29 hours and many cutters.

Use of the ECM process to produce intricate internal shapes in difficult-to-machine materials such as Incoloy 802 is highly recommended as a time and cutting tool saving process.

4. NUMERICAL CONTROL SYSTEM OF FABRICATION

An in-house study of tool fabrication by the numerical control (NC) system has been completed. Results of this study proved to be unfavorable for application to any of the tooling required for this project.

5. "CAST-TO-SHAPE" TOOLING

With the shortage of available machine time becoming more critical, newer techniques may present alternate means of producing dies with less need for heavy tracer-type machines. Production of dies by the "cast-to-shape" method is one of the recent developments indicating potential application to high-rate tooling programs.

The initial research program for the "cast-to-size" dies was sponsored by Boeing. The specific objectives of this program were: 1) to select a suitable cast alloy for use as a high-temperature ironing die for titanium alloy sheet shapes; 2) to evaluate the dimensional precision and surface qualities obtainable in "cast-to-shape" dies using different casting techniques; and 3) to combine material and processes to optimize economy. As a result of this program, a modified Shaw Process molding technique was used to cast test dies to net dimensions. Additional foundry test results also showed that a variety of part shapes could be successfully formed to net dimensions on the cast dies.

a. MODIFIED SHAW PROCESS

In the Shaw Process, an alcohol-based binder medium, a gelling agent, and a refractory mixture are mixed to produce a refractory slurry. When the slurry is poured over the pattern to form the 1/4-inch facing shell, the binder medium and the gelling agent undergo a chemical reaction and the slurry hardens after passing through a rubbery stage. While still in this rubbery stage, the pattern is withdrawn from the mold and the alcohol is burned off. Burning off the alcohol in the mixture causes a microcrazing on the mold surface which is characteristic of the Shaw Process. This aids in the venting of gases during casting and increases the resistance of the mold to thermal shock.

After all traces of free alcohol have been removed, the mold is fired at a high temperature to complete the dehydration of the gel. This is followed by a curing process at elevated temperature (about 1000°F.).

In view of the success which Boeing has achieved, and since the success of this technique could play an important role in the reduction of time-consuming machining of dies, it was decided to utilize this process as part of this contract. A visit was made to Boeing, where tooling samples produced by this process were viewed and additional data obtained which permitted Grumman to take advantage of Boeing's achievement.

b. DIE SELECTION

Two dies were selected to be manufactured by the "cast-to-shape" method. The dies are RDM 1510 and RDM 1516. It should be noted that these dies were to be the largest cast by this process, and the results would complement those of Boeing. (Grumman made an agreement with Avnet Shaw, similar to the one Avnet has with Boeing.)

In order to produce both male and female die members, models (male and female) were made from the checking fixtures originally used to make draw die RDM 1435. Models for RDM 1510 were made to dimensional layouts. In both instances the models were made without allowance for shrinkage. The models were shipped to Waukesha Foundry, Waukesha, Wisconsin (which also did work for Boeing) for casting. The material used in all the castings was Nicrosil.

Upon receipt of the castings from Waukesha Foundry, they were checked for fit and contour (both male and female). Figure 4-2 shows the male and female castings for RDM 1516 assembled in the spotting press. Note the warped condition as evidenced by the varying gap between male and female contoured die faces. Maximum gap measured at center is .125-inch (as received from the foundry).

c. AGING PROCESS

An aging process was recommended by the foundry to stress-relieve the castings. Furnace temperature requirements suggested were 1575 ± 25°F. for six hours, followed by slow cooling. In an effort to improve matching of the die contours, it was decided to perform the aging in the USI hot-forming press. In this way, two benefits could result: 1) stress-relieving of the castings; 2) improvement of the fit between the male and female die members.

Figure 4-3 shows the same castings set together in the press. The castings were heated to 1575°F. and a vertical 60-ton load applied to the castings for six hours. The castings were left in the press to cool slowly while still under a load. As soon as the castings could be handled, the load was removed and the gap rechecked. At this point the maximum gap had been reduced to .010-inch, as seen in Figure 4-4.

Figure 4-2 Male and Female Castings for RDM 1516 Assembled in the Spotting Press

Figure 4-3 The Same Castings Set Together in the Press. The Castings were Heated to 1575°F and a Vertical 60-Ton Load Applied for Six Hours

Figure 4-4 The Maximum Gap Reduced to .010-inch

d. FINAL FITTING

Final fitting of the die members was accomplished by hand-grinding, thus eliminating costly machining operations from the initial model-making step to the final matching of the male and female mating surfaces. Figures 4-5 and 4-6 show the completed die in the opened and closed positions.

The Nicrosil die (RDM 1510) is shown in Figure 4-7. The die is shown in the "as cast" condition. The maximum contour deviation between male and female is .025-inch at the center of the die. Although a deviation did exist, since it was relatively small it was decided not to attempt to improve the fit by heating under a load, as was done with die RDM 1516. Final fitting is being completed by hand. Aging of these casts will be performed during the first preheating prior to formed part production.

All the castings were produced by an identical casting technique (top heat risers). Contact has been made with Avnet Shaw and Boeing to determine possible solutions to the warp condition. Consensus and experience indicate that castings produced by end heat risers result in less warping during the cooling period.

One set of Nicrosil dies (RDM 1516) had a 1/8-inch gap between male and female in one area (Figure 4-8). This gap was the result of a difference in shrinkage between the male and female castings, or more likely, a warpage of the female casting due to the fact that this was top risered. The restraint on the casting shrinkage which this would tend to cause, combined with the relatively thin section (about two inches) at the center of the arch, would be expected to create the type of misfit shown. In this respect the side gating and rising recommended by IITRI* might have been a more suitable choice, since casting soundness is not a critical factor in this case. Styrofoam riser pads would also have helped.

The assistance and cooperation of Mr. Stewart Paterson, Jr., of the Boeing Company and Mr. Kenneth Brinsmead of Avnet Shaw is hereby acknowledged.

The state of the art indicates that further development of casting techniques are still required to produce better quality "cast-to-shape" dies. However, the process developed by Grumman to age and improve match of die contours as used on die RDM 1516 clearly indicates great potential as an aid in production of dies by the "cast-to-shape" technique.

6. INSULATION

Insulation of tools to prevent heat losses is not necessary for the forming of typical airframe structural parts when used on presses similar to the presses utilized in this project. The following equipment features

* Illinois Institute of Technology, Research Institute

Figure 4-5 Completed Die in the Open Position

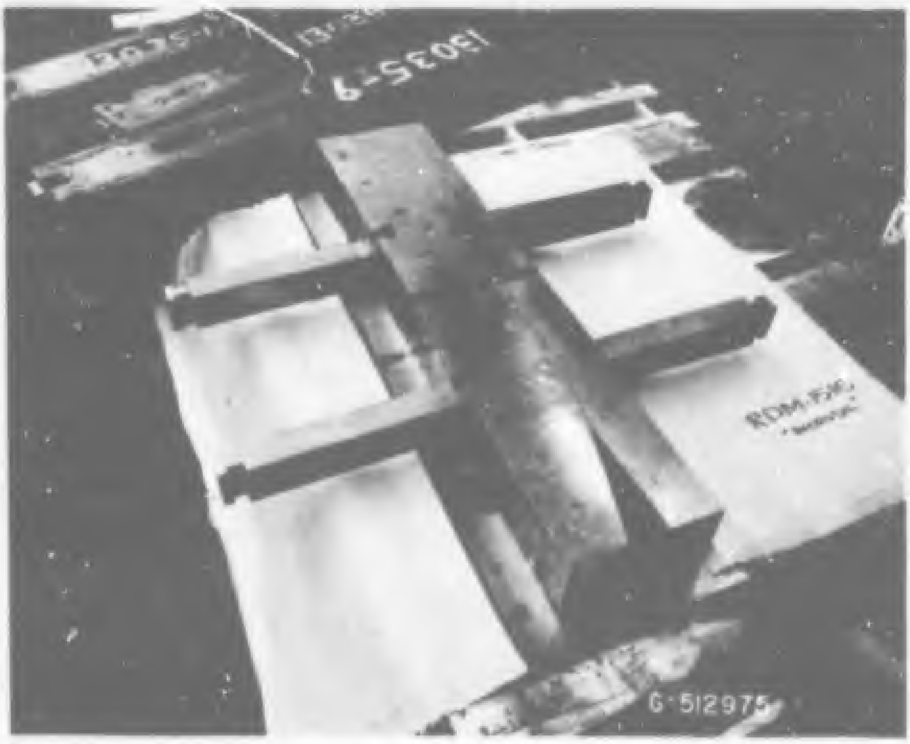
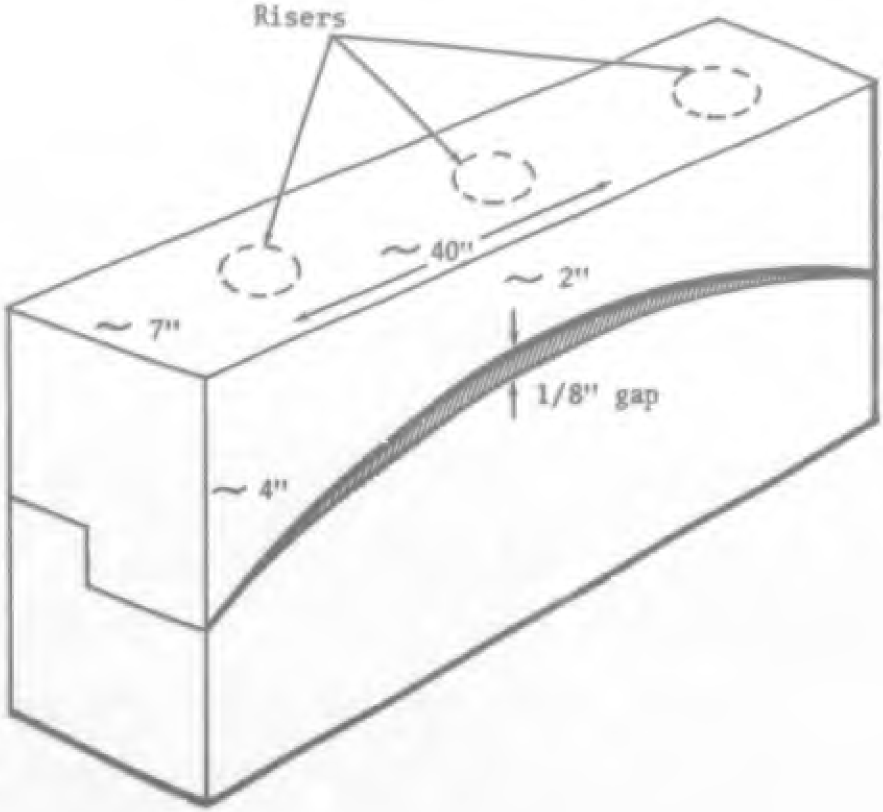
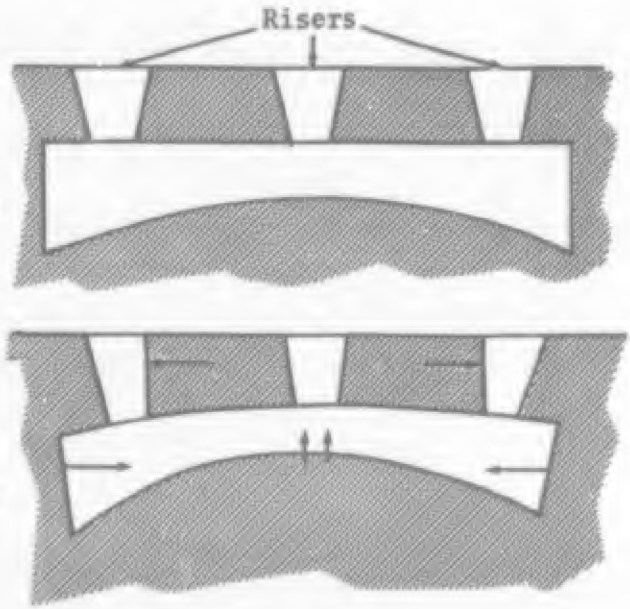


Figure 4-6 Completed Die in the Closed Position

Figure 4-7 Nicrosil Die RDM 1510; Maximum Contour Deviation .025-inch at the Center of the Die





Casting Immediately after Pouring

Casting after Cooling

Figure 4-8 Nicrosil Dies (RDM 1516) Showing 1/8" Gap between Male and Female Castings minimize normal heat losses:

- The zoned (9 zones upper and lower) platens automatically sense and supply added heat to the tooling in specific areas calling for heat.
- Heat shielding of the platen-die work area (on all sides) creates a furnace-type atmosphere, thereby accelerating recovery of any heat losses.
- Automatic part ejection through use of the cushion system considerably speeds up the time the press must be open for conventional part removal, thereby minimizing heat losses.

SECTION V

LUBRICANT COATING AND CLEANING

1. APPROACH

This study has been divided into two separate activities, as follows:

a. Lubricants

The objective is to find a substance that will provide the lowest coefficient of friction, while also serving to minimize oxidation.

b. Cleaning

The objective is to compare various cleaning methods for ability to remove various forming lubricants and scales with a minimal effect on the base material.

2. LUBRICANT EVALUATION

This phase of the study entailed the selection of candidate lubricants for use on titanium and the evaluation of each under simulated hot forming conditions. The objective was to determine the ease with which each lubricant system cleaned.

a. Test Facilities

Several laboratories were visited to observe facilities and equipment and to select an organization to conduct completed lubricant tests. These were:

- Mechanical Technology Incorporated
- General Electric Company
- International Nickel Corporation
- Titanium Metals Corporation of America
- Grumman Aircraft Engineering Corporation

Mechanical Technology Incorporated was selected as most qualified because of their:

- Specialization in metal processing
- Proprietary test equipment
- Ability to simulate related hot sizing and draw forming conditions.

b. MATERIAL

i Lubricant Materials

The fifteen lubricant and coating materials can be categorized as:

- Molybdenum disulfide and graphite compounds
- Metallic and glass compounds
- Oxide conversion coatings

A complete description of all fifteen lubricants can be found in Table 5-1.

ii Tooling Materials

The detailed description of the three tool materials selected can be found in Section III. The materials are:

- Hastelloy X
- Incoloy 802
- Meehanite HSV

c. Testing of the Lubricants

i Test Specimens

Test specimens consisted of a Hastelloy X anvil, which is non-functional, a 5/8-inch diameter by .080-inch thick titanium disk, and a flat piece of tooling material (Figure 5-1).

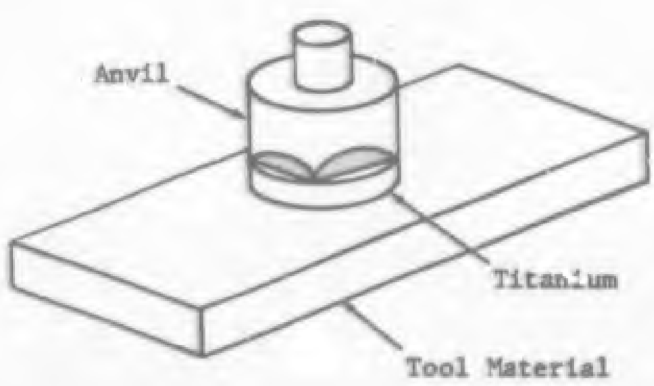


Figure 5-1 Schematic Diagram of Test Specimens

TABLE 5-1 LUBRICANT CHARACTERISTICS

Lubricant or Coating	Source	Temp. Limit	Approximate Physical Characteristics	Remarks
Form Kote T-50	Everlube Corp., N. Hollywood, California	1400°F.	MoS_2 + Graphite	Apply to Ti & Die
Everlube-1120-8	Everlube Corp., N. Hollywood, California	1800°F.	MoS_2 dispersed in binder with solvent carrier	For moving die and press components
Dag #41	Acheson Colloids Co., Port Huron, Michigan	1200°F.	Colloidal graphite in lacquer	Currently used at Grumman
*ED2453C	Acheson Colloids Co., Port Huron, Michigan	1200°F.+	Graphite & glass dispersed in isopropyl alcohol	New product - no data
Fel-Pro C-300	Felt Products Mfg. Co., Skokie Illinois	2400°F.+	MOS dispersed in a high temperature binder with a solvent carrier	
Lubri-cool	Lord Laboratories Detroit, Michigan	2000°F.	Powder	Can be used as additive to other lubricants or coatings
Electro Film	Electro Film, Inc. N. Hollywood, California	1400°F.	MoS_2 + Graphite	
Boron Nitride	Carborundum Electronics Div. of Latrobe, Latrobe, Pa.	2500°F.	White Powder	Dust on parts & die
Titanium Oxide (TiO_2)	Grumman Aircraft Engineering Corp. Bethpage, N.Y.	-	TiO_2	Heat Ti to 1000°F for 15 min., cool & apply lubricant
Conversion Coating	Grumman Aircraft Engineering Corp. Bethpage, N.Y.	1400°F.	Potassium Phosphate	Bath dip 3 minutes
Tungsten Disulfide Powder (WS_2)	Bemol, Inc. Newton, Mass.	1400°F.	Collodial suspension in water	Spray and let dry
Calcium Floride CaF_2	Meta-Therm, N.Y., New York	2000°F.	CaF_2	Dust on parts & die
#318WW	Ceramic Color & Chemical Mfg. Co., New Brighton, Pa.	2000°F.	Glass-water base	New product
Granadraw-L-785 +T50	Amchem Corp., Ambler, Pa.	1700°F.	Oxide conversion coating	Used by TMCA
Covington	Kolene Corp., Detroit, Michigan	1600°F.	Proprietary coating developed by TMCA	New product

ii Test Conditions

The following conditions and materials remained constant throughout the test period to permit precise evaluations:

- Sliding material - Ti 6Al-4V
- Temperature - 1400°F
- Pressure - 1000 psi
- Velocity - 54 inches/minute
- Sliding distance - 5 inches
- Tool materials - Hastelloy X, Incoloy 802, Meehanite HSV
- Anvil material - Hastelloy X

iii Test Equipment

Figure 5-2 shows the test apparatus. The equipment operates as follows:

- A rod with a hemispherical end slides back and forth against a flat plate
- The lower plate is held stationary while the upper rod, mounted on an arm, is driven back and forth
- One end of the moving arm is supported by ball bearings and can move in either a horizontal or vertical direction
- An air cylinder moves the opposite end of the arm back and forth
- Cartridge heaters mounted in the plate holders supply 1400°F to the upper and lower specimens
- An air cylinder directly above the specimens applies the 1000 psi load

iv Test Procedure

To perform the 45 tests, the following steps were taken:

- All titanium disks and alloy flats, except those previously coated, were cleaned in reagent grade alcohol.

Figure 5-2 Lubricant Test Apparatus

- Specimens and flats were air dried
- Lubricant was applied to both the disks and flats
- Test rig temperature was raised to 1400°F
- The titanium and tool specimens were placed in the rig, with a thermocouple touching both specimens
- The temperature was raised to 1400°F and 1000 psi pressure was applied
- The titanium specimen traveled five inches with a reciprocating motion while the friction force was constantly recorded
- The specimens were removed and allowed to cool to room temperature
- The flat was photographed. The lubricant was removed by a polishing wheel. Specimens were examined for damage

d. Test Results

Figure 5-3 through 5-17 contain the photographic and annotated results of the tests. The results are also indicated in Figure 5-18 and Table 5-2. Note that the lubricant was left on the specimen; therefore, these reports pertain to the lubricant film rather than the titanium material.

The deposited coatings used with the T-50 lubricant reduced the coefficient of friction but did not reduce the scratches on the tool material. The 22-T lubricant produced no damage on any of the tool materials. This lubricant was liquid at 1400°F with Incoloy 802 and Hastelloy X but appeared not to be with the Meehanite HSV. Apparently the oxide film on the Meehanite HSV had absorbed the liquid in the lubricant without impairing the lubricating properties of the 22-T.

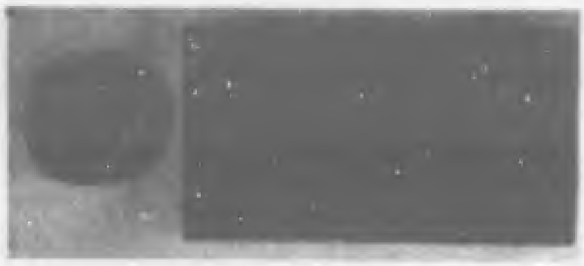
Incoloy 802 showed no damage when using T-50, Fel-Pro C-300, 22-T, GAEC conversion coat and T-50, and Am Chem GD-L-785+T-50. The Meehanite HSV which had a much thicker oxide film than Hastelloy X and Incoloy 802, showed damage with all three systems using T-50 but did not show damage with 22-T or Fel-Pro C-300. The Hastelloy X, which had a thin oxide film similar to Incoloy 802, showed evidence of damage using T-50.

The 318-WW lubricant was liquid at 1400°F. At room temperature, a glass-like coating remained which was very difficult to remove.

Coefficient of Friction
Start .12 End .12

Remarks: Lub Turned White
Flat - No Damage
Ti - No Damage

Incoloy 802



Meehanite HSV

Coefficient of Friction
Start .06 End .08

Remarks: Lub Still Black
Flat - Light Scratches
Ti - No Damage

Coefficient of Friction
Start .1 End .1

Remarks: Lub Turned White
Flat - No Damage
Ti - No Damage

Hastelloy X

Figure 5-3 Test Lubricant - GAEC Coat + T50

Coefficient of Friction
Start .14 End .14

Remarks: Lub-Wet at 1400°F
Flat - No Damage
Ti - Light Scratches

Incoloy 802

Meehanite HSV

Coefficient of Friction
Start .14 End .14

Remarks: Lub-Dry at 1400°F
Flat - No Damage
Ti - No Damage

Coefficient of Friction
Start .12 End .14

Remarks: Lub-Wet at 1400°F
Flat - No Damage
Ti - No Damage

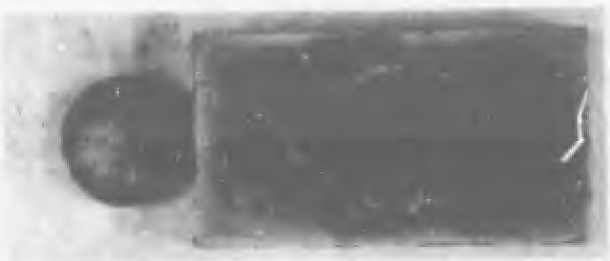
Hastelloy X

Figure 5-4 Test Lubricant - Electrofilm 22-T

Coefficient of Friction
Start .09 End .09

Remarks: Lub Turned White
Flat - No Damage
Ti - No Damage

Incoloy 802



Meehanite HSV

Coefficient of Friction
Start .08 End .08

Remarks: Lub Still Dark
Flat - Light Scratches
Ti - No Damage

Coefficient of Friction
Start .2 End .15

Remarks: Lub White
Flat - Light Scratches &
Pull Outs

Hastelloy X

Figure 5-5 Test Lubricant - Am. Chem. GD-L785 & T50

Coefficient of Friction
Start .2 End .2

Remarks:
Flat - No Damage
Ti - Light Scratches

Incoloy 802

Meehanite HSV

Coefficient of Friction
Start .14 End .13

Remarks:
Flat - Damaged Lightly
Ti - No Damage

Coefficient of Friction
Start .16 End .15

Remarks:
Flat - No Damage
Ti - No Damage

Hastelloy X

Figure 5-6 Test Lubricant - Form Kote T50

Coefficient of Friction
Start .12 End .12

Remarks: Lub Turns Yellow
Flat - No Damage
Ti - No Damage

Incoloy 802

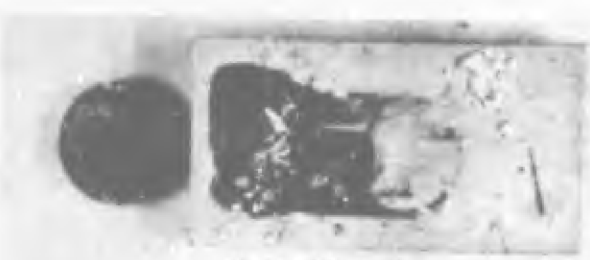
Meehanite HSV

Coefficient of Friction
Start .22 End. 23

Remarks: Lub Turns Yellow
Flat - No Damage
Ti - No Damage

Coefficient of Friction
Start .14 End .14

Remarks: Lub Turns Yellow
Flat - No Damage
Ti - No Damage



Hastelloy X

Figure 5-7 Test Lubricant - Fel-Pro C-300

Coefficient of Friction
Start .38 End .29

Remarks: Liquid at 1400°F
Lub Does Not Come
Off the Flat Readily
Flat - No Damage
Ti - No Damage

Incoloy 802

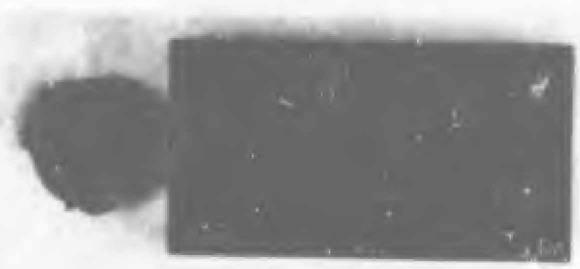
Meehanite HSV

Coefficient of Friction
Start .28 End .28

Remarks: Lab Liquid at 1400°F
Flat - Surfaces Heavily
Scratched & Pitted
Ti - No Damage

Coefficient of Friction
Start .19 End .19

Remarks: Lub Liquid at 1400°F
Lub Can Not Be Taken
Off the Surface Easily
Flat - Light Scratches
Ti - No Damage



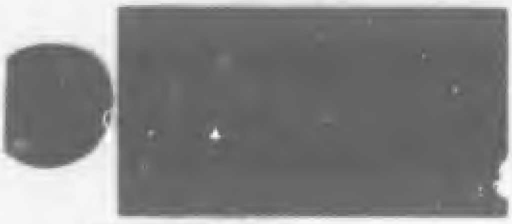
Hastelloy X

Figure 5-8 Test Lubricant - CC&C 318-WW

Coefficient of Friction
Start .24 End .27

Remarks:
Flat - One Heavy Scratch
Ti - No Damage

Incoloy 802



Meehanite HSV

Coefficient of Friction
Start .31 End .36

Remarks: Stick Slip Action
Flat - Damaged
Ti - No Damage

Coefficient of Friction
Start .4 End .42

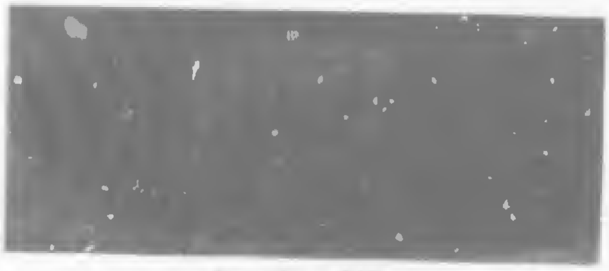
Remarks:
Flat - No Damage
Ti - No Damage

Hastelloy X

Figure 5-9 Test Lubricant - Everlube 1120B

Coefficient of Friction
Start .33 End .39

Remarks:
Flat - No Damage
Ti - No Damage



Incoloy 802

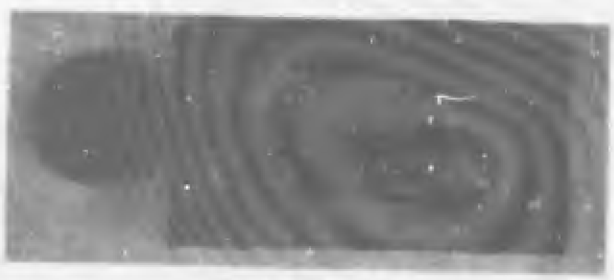
Meehanite HSV

Coefficient of Friction
Start .34 End .4

Remarks:
Flat - Light Scratches
Ti - No Damage

Coefficient of Friction
Start .33 End .43

Remarks:
Flat - Light Scratches
Ti - Light Scratches



Hastelloy X

Figure 5-10 Test Lubricant - Carborundum HTP-325

Coefficient of Friction
Start .15 End .21

Remarks: Lub Turned Yellow
Flat - Light Scratches
Ti - Light Scratches

Incoloy 802

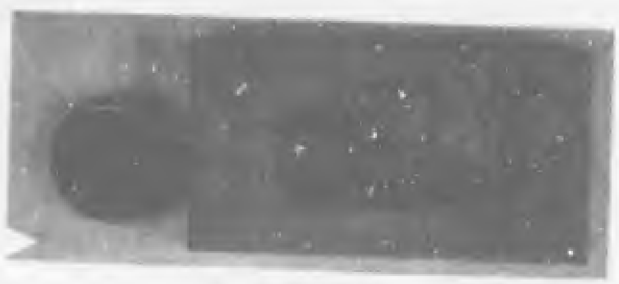
Meehanite HSV

Coefficient of Friction
Start .4 End .45

Remarks: Lub Turned Orange-Yellow
Flat - Light Scratches
Surface Pitted
Ti - Light Scratches

Coefficient of Friction
Start .25 End .28

Remarks: Lub Turned Yellow
Flat - No Damage
Ti - No Damage



Hastelloy X

Figure 5-11 Test Lubricant - Bemol Tung Spray

Coefficient of Friction
Start .24 End .24

Remarks:
Flat - Light Damage
Ti - Light Scratches

Incoloy 802

Meehanite HSV

Coefficient of Friction
Start .55 End .55

Remarks:
Flat - Scratched and Pitted
Ti - Light Scratches

Coefficient of Friction
Start .42 End .42

Remarks:
Flat - No Damage
Ti - Light Scratches

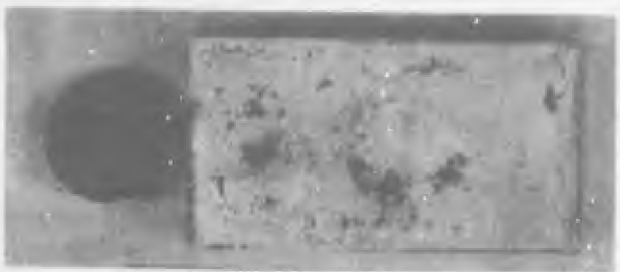
Hastelloy X

Figure 5-12 Test Lubricant - #EC2453C

Coefficient of Friction
Start .6 End .6

Remarks: Stick Slip Action
Lub Cannot Be Burnished Easily
Flat - Interupted Pull Outs
Ti - No Damage

Incoloy 802



Meehanite HSV

Coefficient of Friction
Start .46 End .46

Remarks: Stick Slip Action
Flat - No Damage
Ti - No Damage

Coefficient of Friction
Start .46 End .46

Remarks:
Flat - Surface - Pulled Out
Ti - Heavy Scratches

Hastelloy X

Figure 5-13 Test Lubricant - CaF_2 Bemol

Coefficient of Friction
Start .62 End .62

Remarks:
Flat - Heavy Scratches
Ti - Heavy Scratches

Incoloy 802

Meehanite HSV

Coefficient of Friction
Start .36 End .36

Remarks:
Flat - Heavy Scratches
Ti - No Damage

Coefficient of Friction
Start .6 End .6

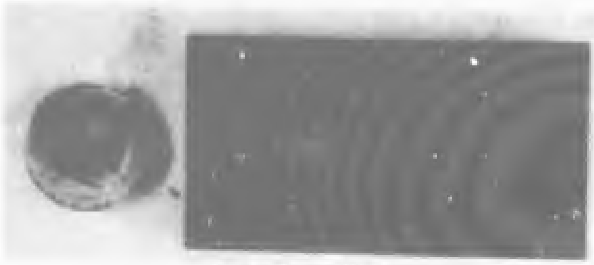
Remarks:
Flat - Heavy Scratches
Ti - Light Scratches

Hastelloy X

Figure 5-14 Test Lubricant - Acheson Dag 41

Coefficient of Friction
Start .85 End .85

Remarks: Specimens Seized
Flat - Surfaces Scratched & Large Pull Outs
Ti - No Damage



Incoloy 802

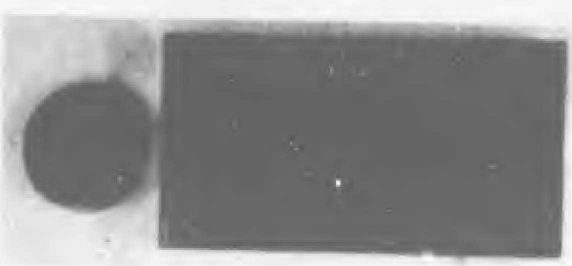
Meehanite HSV

Coefficient of Friction
Start .6 End .62

Remarks: Lub Melted
Flat - Surface Heavily Scratched
Ti - Heavy Scratches

Coefficient of Friction
Start .8 End .8

Remarks: Lub Melted - Specimens Siezed
Flat - Surface Lightly Pitted
Ti - Heavy Scratches



Hastelloy X

Figure 5-15 Test Lubricant - Kolene Kov-Kote

Coefficient of Friction
Start .8 End .8

Remarks: Specimens Cemented Together
Flat - No Damage

Incoloy 802

Meehanite HSV

Coefficient of Friction
Start .8 End .8

Remarks: Specimens Cemented Together
Flat - Surface Damaged
Ti - No Scratches

Coefficient of Friction
Start .8 End .8

Remarks: Specimens Cemented Together
Flat - No Damage
Ti - Heavy Scratches

Hastelloy X

Figure 5-16 Test Lubricant - Lords Lab Lubri. Cool

Coefficient of Friction
Start .8 End .85

Remarks:
Flat - Light Scratches Throughout the Running Track
Ti - Light Scratches

Incoloy 802

Meehanite HSV

Coefficient of Friction
Start .8 End .8

Remarks:
Flat - Heavily Scratched
Ti - Light Scratches

Coefficient of Friction
Start .8 End .8

Remarks:
Flat - Light Scratches Throughout the Running Track
Ti - Heavy Scratches

Hastelloy X

Figure 5-17 Test Lubricant - Titanium Oxide

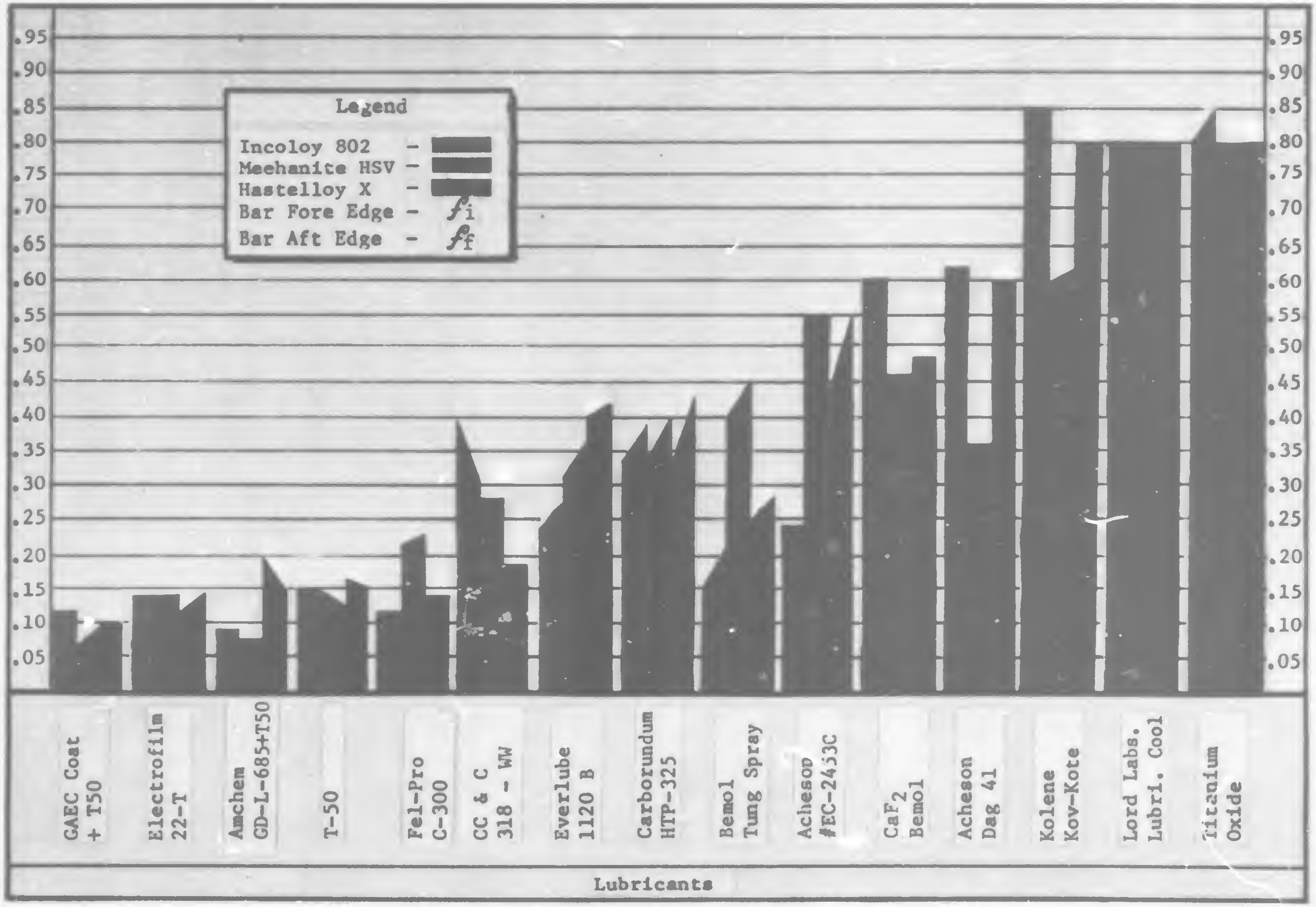
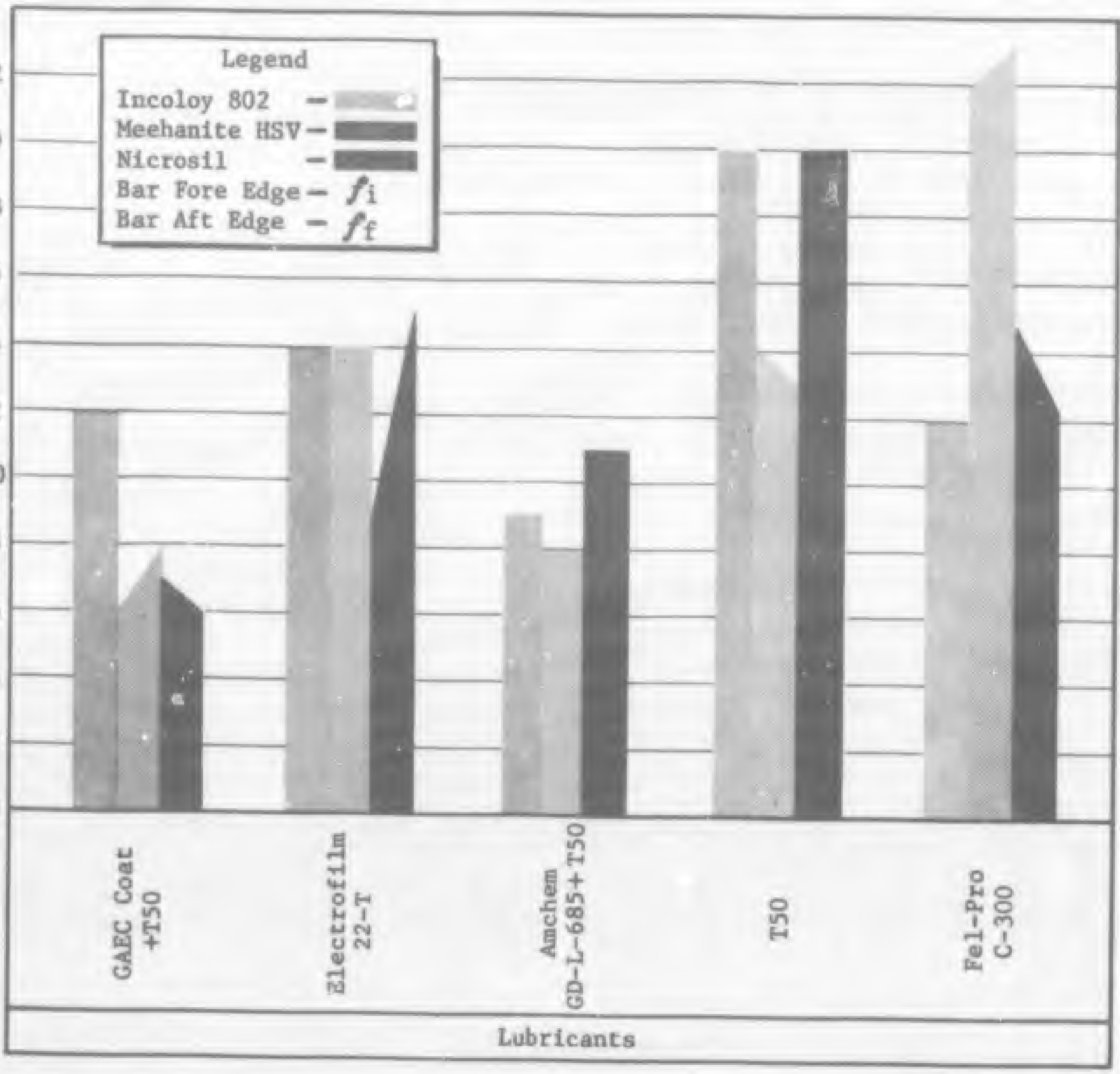


Figure 5-18 Coefficient of Friction - Lubricant Tests



Flat Material	Incoloy 802			Meehanite HSV			Nicrosil		
Lubricant	f_i	f_f	Result	f_i	f_f	Result	f_i	f_f	Result
GAEC Coat +T50	.12	.12	No Damage	.06	.08	Light Scratches	.07	.06	Very Light Scratches
Electrofilm 22-T	.14	.14	No Damage	.14	.14	No Damage	.09	.15	Light Scratches
Amchem GD-L-685 +T50	.09	.09	No Damage	.08	.08	Light Scratches	.11	.11	No Damage
T50	.20	.20	No Damage	.14	.13	Light Scratches	.20	.20	Light Scratches
Fel-Pro C-300	.12	.12	No Damage	.22	.23	No Damage	.15	.12	No Damage

Figure 5-19 Coefficient of Friction - Lubrication Test

Lub - GAEC Coat +50

Coefficient of Friction
Start .07 End .06

Remarks:
Flat - No Damage
Ti - Very Light Scratches

Lub - Electro-film 22-T

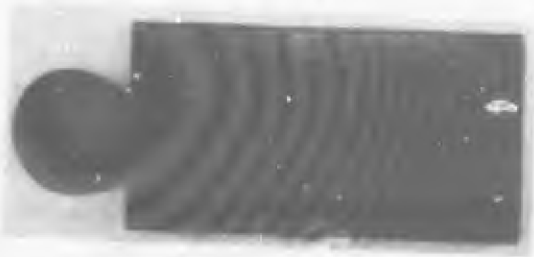
Coefficient of Friction
Start .09 End .15

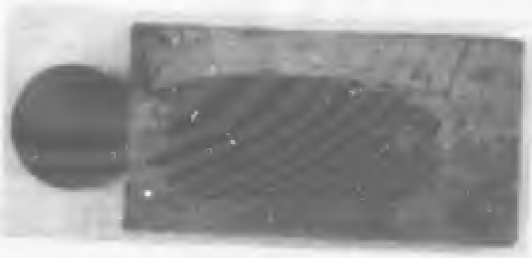
Remarks: Lub-Liquid at 1400°F.
Flat - Light Scratches
Ti - Light Scratches

Lub - Amchem GD-L-685+T50

Coefficient of Friction
Start .11 End .11

Remarks:
Flat - No Damage
Ti - No Damage





Lub - T-50

Coefficient of Friction
Start .20 End .20

Remarks: Lub-Pink in Color
Flat - No Damage
Ti - Light Scratches

Lub - Fel-Pro C-300

Coefficient of Friction
Start .15 End .12

Remarks: Lub-Yellow; Peels Off
Flat - No Damage
Ti - No Damage

Figure 5-20 Lubricant Tests with Nicrosil

TABLE 5-2 COEFFICIENT OF FRICTION - LUBRICANT TESTS

Flat Material	Incoloy 802			Meehanite HSV			Hastelloy X			
Lubricant	f_i	f_f	Result	f_i	f_f	Result	f_i	f_f	Result	Figure No.
GAEC Coat + T50	.12	.12	No Damage	.06	.08	Light Scratches	.1	.1	No Damage	5-3
Electrofilm 22-T	.14	.14	No Damage	.14	.14	No Damage	.12	.14	No Damage	5-4
Amchem GD-L-785	.09	.09	No Damage	.08	.08	Light Scratches	.2	.15	Light Scratches and Pull Out	5-5
T-50 Form Kote	.2	.2	No Damage	.14	.13	Light Scratches	.16	.15	No Damage	5-6
Fel-Pro C-300	.12	.12	No Damage	.22	.23	No Damage	.14	.14	No Damage	5-7
CC & C #318WW	.38	.29	No Damage	.28	.28	Heavy Scratches and Pitted	.19	.19	Lightly Scratched and Pitted	5-8
Everlube 1120 B	.24	.27	One Heavy Scratch	.31	.36	Light Scratches	.4	.42	No Damage	5-9
Carborundum HTP-325	.33	.39	No Damage	.34	.4	Light Scratches	.33	.43	Light Scratches	5-10
Bemol Tung Spray	.15	.21	Light Scratches	.4	.45	Light Scratches Surface Pitted	.25	.28	No Damage	5-11
Acheson #EC-2453C	.24	.24	Light Scratches	.55	.55	Scratched & Pitted	.42	.55	No Damage	5-12
CaF_2 Bemol	.6	.6	Interrupted Pull-Outs	.46	.46	No Damage	.48	.48	No Damage	5-13
Acheson Dag 41	.62	.62	Heavy Scratches	.36	.36	Heavy Scratches	.6	.6	Heavy Scratches	5-14
Kolene Kov-Kote	.85	.85	Scratches and Large Pull Out	.6	.62	Surface Heavily Scratched	.8	.8	Surface Lightly Pitted	5-15
Lord Labs. Lubri-cool	.8	.8	Specimens Stopped in Test	.8	.8	Specimens Stopped in Test	.8	.8	Specimens Stopped in Test	5-16
Titanium Oxide	.8	.85	Light Scratches	.8	.8	Heavy Scratches	.8	.8	Light Scratches	5-17

3. STUDY OF CLEANING SYSTEMS

Three descalents were tested for removal of the lubricants and scales remaining on the part material specimens used for the lubricant study. The processes were:

a. Solution Parameters

i Grumman Process (presently used)

- Soak 30 minutes in a 180°F solution of sodium hydroxide (8 ounces/gallon)
- Pickle up to 10 minutes in a room-temperature solution of 50% nitric acid and 50 grams/liter of Actane #70

ii Turco 4316 Process

- Soak for 30-45 minutes in a 280°F solution of Turco 4316 (8 pounds/gallon)
- Pickle up to 10 minutes in a room-temperature solution of 50% nitric acid and 50 grams/liter of Actane #70

iii Kolene Process

- Soak up to 30 minutes in a 425°F solution of Alko-N
- Pickle up to 10 minutes in a room-temperature solution of 50% nitric acid and 50 grams/liter of Actane #70

b. Test Results

i Results of the cleaning and descaling of test specimens are:

- Grumman Process

  T-50 - adequate, with moderate difficulty

  C-300 - adequate, with moderate difficulty and some resulting surface roughouts

  Remaining specimens - not adequate

- Turco 4316 Process

  T-50, Lubri-Cool, 22-T, and 318W - adequate with moderate difficulty

  HTP, GAEC Conversion Coat, Tung Spray, Amchem Conversion Coat, and Kov-Kote - adequate with moderate difficulty and surface roughness noted on all specimens

Remaining specimens - not adequate

- Kolene Process

  T-50, Lubri-Cool, 22-T, 318W, Tung Spray, and Kov-Kote - excellent

  Remaining specimens - excellent results with some remaining rough spots

ii In addition, 2" X 2" samples of Ti-8Al-Mo-1V with coatings of the five most effective lubricants were furnace-heated for 20 minutes at 1400°F. The following conditions were noted:

- Turco Process

  T-50 - excellent cleaning and no roughness due to preferential etching

  C-300 - tough black scale formed. Only 80% cleaned with much surface roughness

  22-T - cleaned well with no surface roughness

  GAEC Conversion Coat with T-50 - one side clean and the other side 80% clean with some roughness on both sides on the GAEC Conversion Coat

  Amchem Conversion Coat with T-50 - very rough both sides but clean on one side and 50% clean on the other

- Kolene Process

  T-50 - excellent cleaning and descaling with no roughness

  C-300 - light scale remaining but surface finish still below 60 RMS

  22-T - cleaned well with slight roughness in spots

  Amchem Conversion Coat with T-50 - complete scale removed with sporadic roughness

iii In addition, trim area from production parts processed by Kolene showed excellent cleaning capability and surface finish. Samples of Ti-6-4, Ti-6-6-2 and Ti-8-1-1, with representative forming scales (oven heat) were easily cleaned after processing through the following cycles:

- Alko-N at 425 °F for 1 to 5 minutes

- Rinse with cold water

- Dip in nitric-actane solution for 1 to 10 minutes

- Rinse with cold water

c. Pilot Line Study

The final phase of this study was the evaluation of three methods of descaling from an economic and ease-of-processing viewpoint on a pilot production basis. Twelve door channel parts, four of each alloy (Ti-6-6-2, Ti-6-4 and Ti-8-1-1) fabricated on RDM 1502 were Turco-coated 2.3 mils, T-50 coated, hot formed and descaled with each process.

The exact processing time and procedures required for complete scale removal are given in Tables 5-3 through 5-5. The results from hydrogen pick-up analysis, hardness, and surface finishes are listed in Table 5-6.

4. CONCLUSIONS

On the basis of this laboratory work, the following conclusions are made:

- Cycling of scaled parts between the Alko-N and subsequent acid solutions is the most effective scale removal procedure. It produces the most desirable finish in the shortest time with the least amount of handling.

- The cleaning of formed titanium parts is greatly eased by the use of protective coatings and/or lubricants during heat operations. The use of these coatings should be considered mandatory.

- Make-up control and replenishment of the Alko-N bath is quite simple due to the use of a eutectically combined single crystal salt. Bath life is indefinite at temperatures below 500°F. The Alko-N cycling, however, must be kept under close control to prevent preferential etching during pickling.

- The successful results of the lubrication cleaning and descaling tests appear to obviate the necessity for the more costly forming in an inert atmosphere.

- As can be seen from Tables 5-5 and 5-6, the Alko-N process reduced the descaling time considerably and eliminated any hand rubbing on hot formed parts. This offers definite advantages when considering high production runs and/or large surface area parts. The effect of all of these methods on the base metal in each case is minimal.

- Of the lubricants tested, five had coefficients of friction below 0.2. They are: Everlube T-50, Fel-Pro 300, Amchem GD-L-685 + T-50, GAEC Conversion Coating + T-50, and Electrofilm 22-T.

- It should be noted that the Everlube T-50 lubricant not only provided a low coefficient of friction and minimum tool wear, but also provided an excellent surface for the various methods of chemical descaling.

TABLE 5-3

GRUMMAN PROCESS

STEPS	ELAPSED TIME MINUTES (per part)			MAN MINUTES
	Titanium 6-6-2	Titanium 6-4	Titanium 8-1-1	LABOR
1. Alkaline Bath (Sodium Hydroxide)	20	20	20	1
2. Cold Water Rinse	2	2	2	1
3. Hand Rub S/S Wool	3 ea	3 ea	3 ea	3 ea
4. Nitric Actane #70	5	5	6	1
5. Cold Water Rinse	2	2	2	1
6. Hand Rub S/S Wool	3	3	3	3 ea
7. Nitric Actane #70	1	1	1	1
8. Cold Water Rinse	3	3	3	1
9. Air Dry				2
	39	39	40	14

NOTE: Grumman descaling performed using current production equipment, Plant 2.

TABLE 5-4

TURCO PROCESS

STEPS	ELAPSED TIME MINUTES (per part)			MAN MINUTES LABOR
	Titanium 6-6-2	Titanium 6-4	Titanium 8-1-1	
1. #1 Cleaner (as listed in McDonnell spec)	5	5	5	1
2. Alkaline Clean	10	10	10	1
3. Cold Water Rinse	2	2	2	1
4. 4316 Tank 250°F	20	20	20	1
5. Cold Water Rinse	3	3	3	1
6. 4316 Tank 250°F	15	15	15	1
7. Cold Water Rinse	3	3	3	1
8. Nitric Hydro-fluoric Bath R.T.	5	5	5	1
9. Cold Water Rinse	3	3	3	
10. Hand Scrub	3	3	3	3
11. Cold Water Rinse	3	3	3	1
12. Air Dry				
	72	72	72	14

NOTE: Turco descaling performed at Spectrum Finishing Co., Farmingdale, New York

TABLE 5-5

ALKO-N - KOLENE PROCESS

STEPS	ELAPSED TIME - MINUTES (per part)			MAN MINUTES
	Titanium 6-6-2	Titanium 6-4	Titanium 8-1-1	LABOR
1. Alko-N Salt Bath 400°F +25° - 0	1	1	3 → 3	1
2. Cold Water Rinse	2	2	2 2	1
3. Nitric Actane #70 Bath	4	4	5 5	1
4. Cold Water Rinse	3	3	3	1
5. Air Dry				2
	10	10	23	6

NOTE: The Alko-N Kolene descaling process was performed using pilot line set up in Plant 12A at Grumman.

TABLE 5-6

HYDROGEN ANALYSIS, HARDNESS, AND SURFACE FINISH

Process	Material	Hydrogen Analysis On Material Before Forming, ppm Total	Hydrogen Analysis On Material After Descaling, ppm Total	Rockwell Hardness Before Forming	Rockwell Hardness After Descaling	R.M.S Finish As Received	R.M.S Finish After Descaling
Grumman Process	Titanium 6-6-2	46.0	57.0	34.0	33.5	10-12	10-12
	6-4	45.0	49.0	29.5	30.5	8-10	8-10
	8-1-1	81.0	76.0	31.5	32.0	8-10	8-10
Turco Process	Titanium 6-6-2	↓	61.0	↓	29.0	↓	8-12
	6-4	↓	46.0	↓	25.0	↓	7-10
	8-1-1	↓	77.0	↓	27.5	↓	8-11
Alko-N Kolene Process	Titanium 6-6-2	↓	65.0	↓	34.5	↓	9-11
	6-4	↓	51.0	↓	31.5	↓	6-8
	8-1-1	↓	81.0	↓	33.0	↓	9-11

SECTION VI

FORMING PART 1, TAIL CONE FRAME

1. ONE-STEP FORMING, .025" MATERIAL

RDM 1500 is a one-step forming die made of Incoloy 802 alloy (Figures 6-1 and 6-2). The sequence for operating this die is similar to that of RDM 1435 (part 4, zee - see sequential operations depicted in section IX).

During tool try-out of RDM 1500 (one-step tail cone die) using .025" thick material, extreme difficulty was encountered. After trying a variety of techniques: varying pressures, time, flat patterns, etc., the best effort can be seen in Figure 6-3. Note the fold-over areas and wrinkles which could not be eliminated. After exhausting all possible approaches to the problem, it was concluded that acceptable parts from the .025" thickness could not be successfully produced on this tool. However, the consensus was that a complete modification of the die would produce good parts. Because of the short time remaining in the program, this modification could not be completed in time.

As a substitution an actual production tool which was made for a tail cone frame was used to replace the tool described above for the .025" thickness only (Figure 6-4). The cross-section of this part was changed from the original zee to a channel, at the suggestion of the Manufacturing Engineering Department. Therefore, the die for this part was used in place of the original die to form .025" thick material.

All parts produced on this die were checked and found to be totally acceptable and within the target tolerances of this program.

2. TWO-STEP FORMING, .025" AND .070" MATERIAL

The two-step method of forming this part actually consists of two cold preforming dies (Figures 6-5 and 6-6) followed by a final hot sizing operation. The inner flange was pre-formed first (Figure 6-7, left side). Although the flange formed well and without cracks, it was difficult to remove the part from the first stage preform block (Figure 6-8, right side). Once removed (note twist on left side of Figure 6-7), the part was placed in a second stage block and formed under high pressure rubber. This was not successful (see wrinkles and broken areas, right side of Figure 6-7). This was tried several times with and without dams, as shown in Figure 6-8, left side. It was then decided to preform the inner flange and form the outer flange hot (Figure 6-9, right side). This also proved unsuccessful. One can readily see the sharp folds, some of which have fractured.

The preforming techniques could not be made to produce acceptable parts using .025" and .070" thick materials.

3. ONE-STEP FORMING, .070" MATERIAL

In try out and running of the .070" gauge one-step forming, three problems were encountered: tightness of the punch for the thicker gauge materials, ejection of the part, and galling of die material (Incoloy 802). The die was reworked and additional clearance added, but it still galled at various spots. The knockout plate (shown in center of Figure 6-10) did not cover the part completely, and consequently trouble developed in ejecting the part. This was due to a tendency of the outer flange to "hang up."

Consideration was given to better lubrication of part material and the die to aid in ejecting the part. After many try-outs and experiments, a mixture of boron nitride and other ingredients was tried. The die problem areas and the parts were sprayed with this mixture. After a run of three parts, a decided improvement was noticed, galling was minimized, and part ejection was operating well. It is interesting to note from the dimensional check chart (Table A-10)that the parts checked-back to the cold die were within target tolerances. (Note parts 62 through 72.)

Figure 6-11 shows a side view of the .070" gauge part 1 tail cone frame. In Figure 6-12 the left side shows a flat pattern and the right side a formed part, .070" gauge. In Figure 6-13 the background shows a female section of the die on the left side and a male forming punch on the right side with a pressure pad. In the foreground at right is a flat pattern .070" gauge; in the center, a formed part; at left, a descaled part.

Although unsuccessful in forming the .025" gauge "zee" in the one-step die, the .070" gauge worked out well. The redesigned one-step production part (Figure 6-4) channel section is suggested for the lighter gauges.

4. CONCLUSION

The Part 1 speed bump frame produced by the one-step forming technique clearly indicates a greater part design latitude, i.e., part geometry considerations may now include design of single unit type parts versus the generally accepted design of multipart assemblies. This greater design latitude reduces or eliminates many detail part and assembly tools as well as the attendant time required to produce a multi-part assembly.

Tool fabrication costs are considerably less for one-step forming. Only one draw-die is required. Because of this part's geometry, the two-step technique did not produce satisfactory results. Though difficult to machine, Incoloy 802 is an excellent die material.

COST COMPARISON

	One-Step	Two-Step*	Time Saved	Preferred Technique
Tool Mfg. Time	325 hr	545 hr	220 hr	1-Step
Average Part Forming Time	12 min			

* Not suitable to produce acceptable parts of this configuration; however, tool manufacturing time shown here is for the two preform blocks and the hot sizing die used for this program.

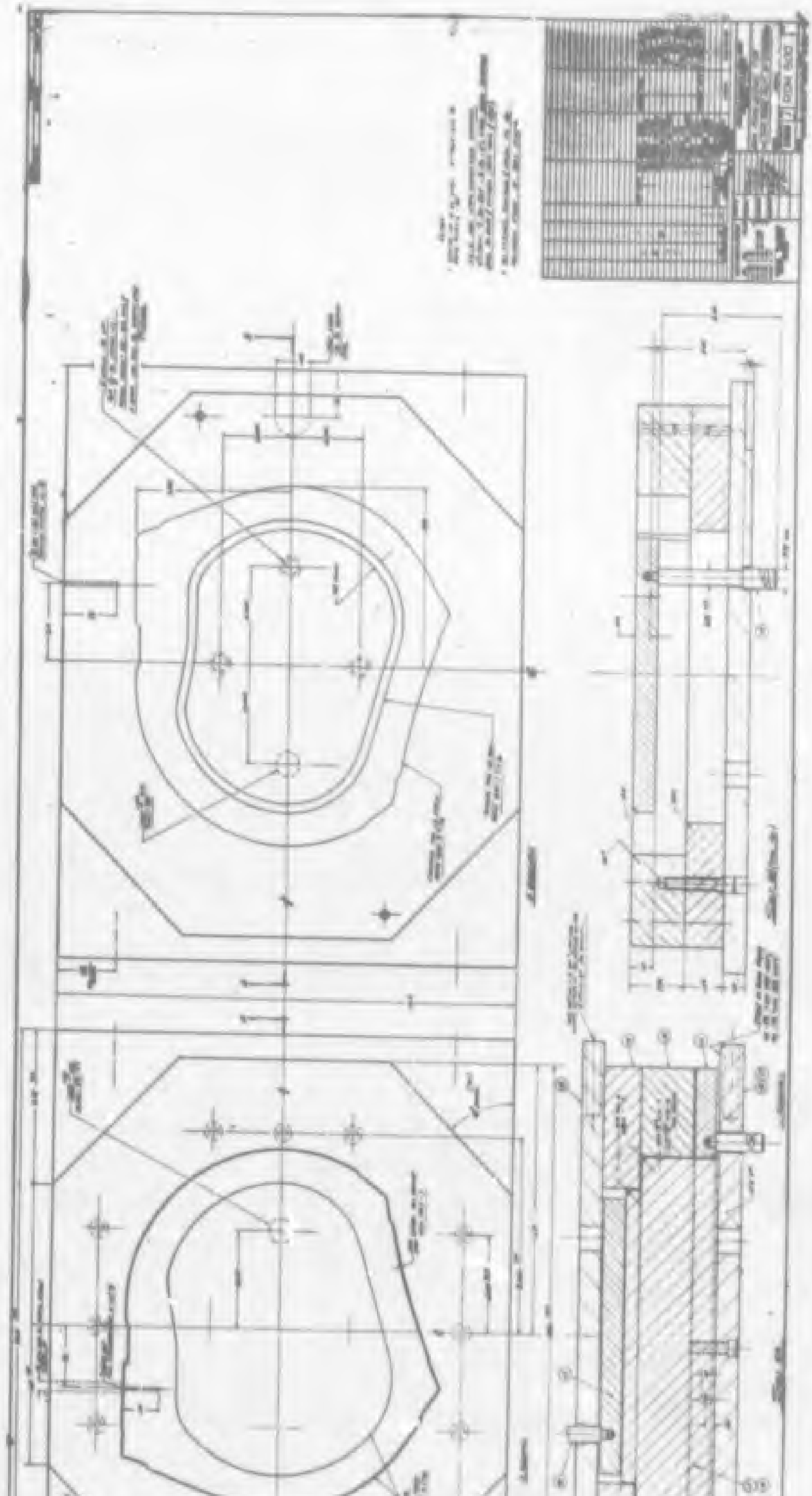


Figure 6-1 RDM 1500 - One-Step Hot Form Die for Part #1 - Tail Cone Frame

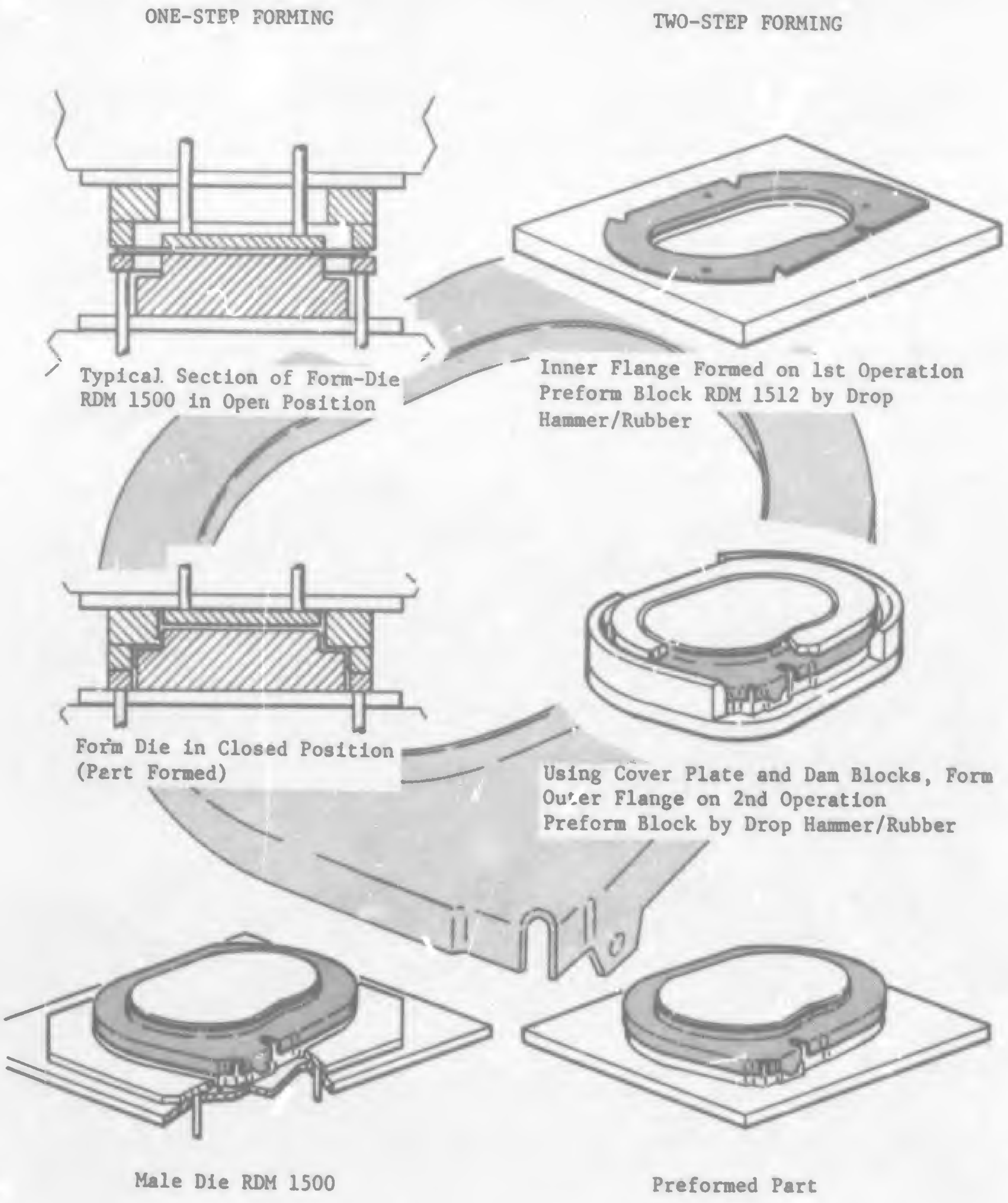


Figure 6-2 Forming Tools for Test Part #1 - Tail Cone Frame

Figure 6-3 Part 1, Tail Cone Frame, .025" Gauge Material; Note Fold-over Areas and Wrinkles Later Corrected (see Figure 6-12)

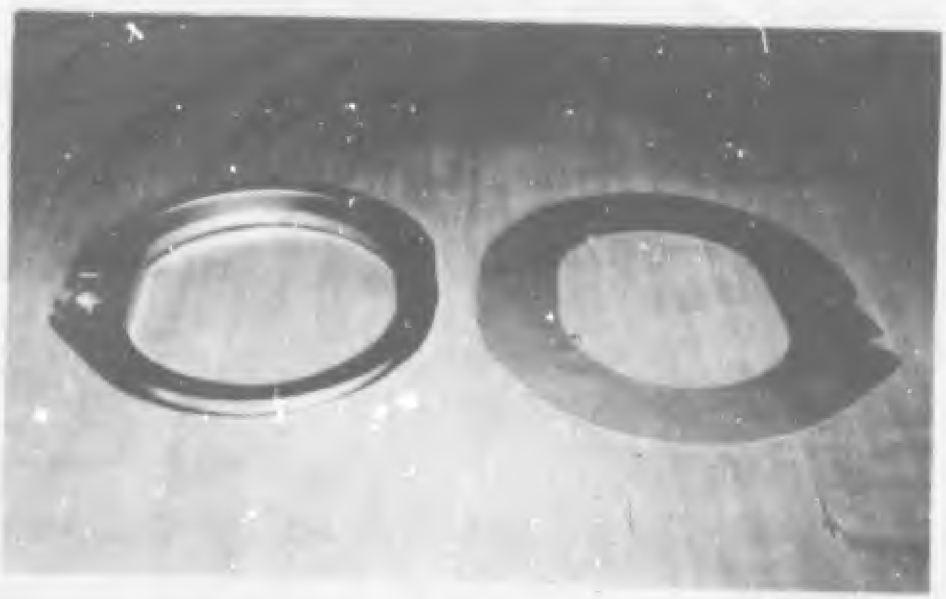


Figure 6-4 Left - Production Tail Cone Frame
Right - Flat Pattern for Same

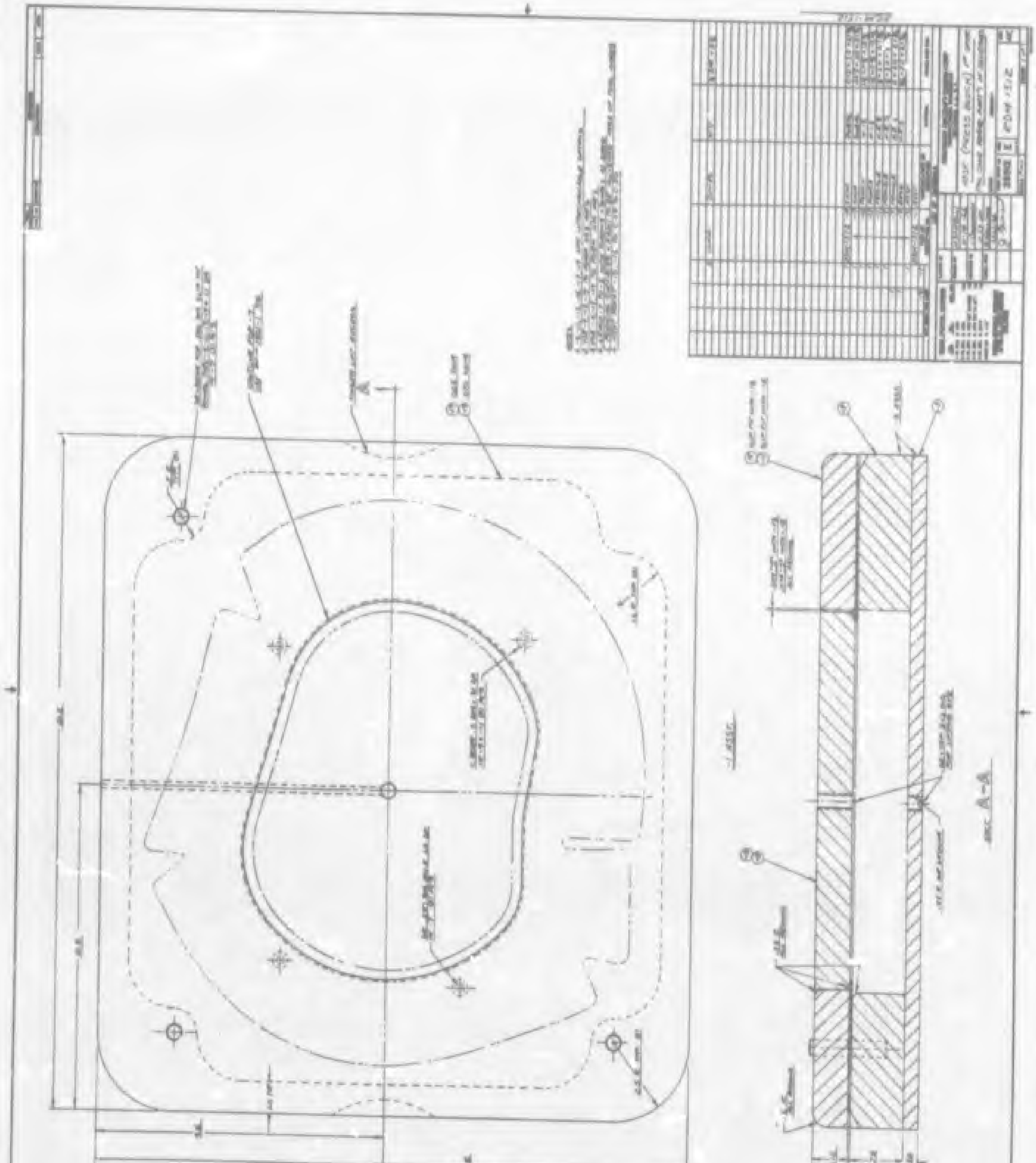


Figure 6-5 RDM 1513 - Preform Press Block (1st Operation) for Part #1 - Tail Cone Frame

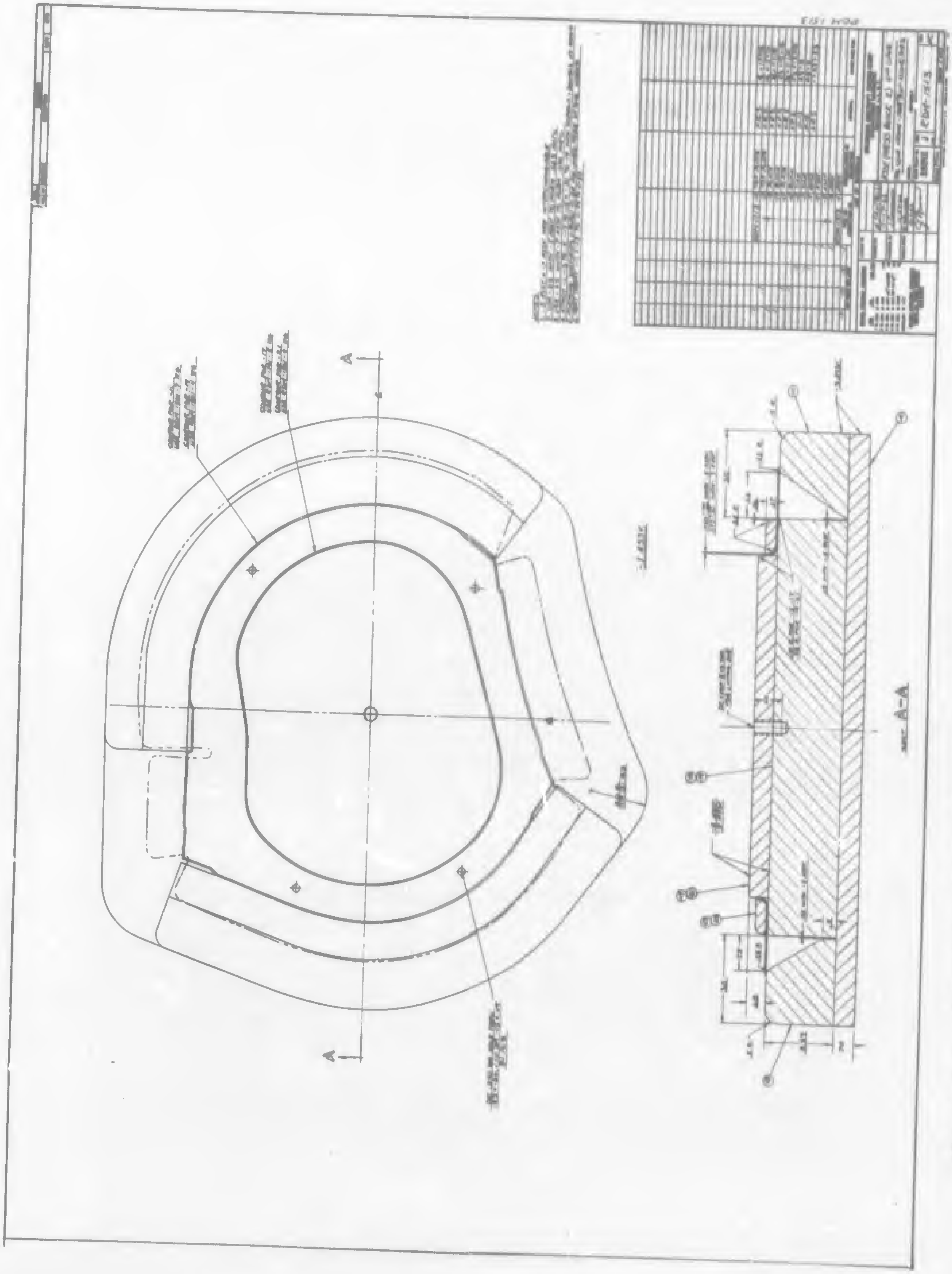


Figure 6-6 RDM 1513 - Preform Press Block (2nd Operation) for Part #1 - Tail Cone Frame

Figure 6-7 Part 1, Tail Cone Frame, .025" Gauge Material (Left), Showing Preformed Inner Flange Accomplished in Two-Step Verson Block. At Right, View Showing Second Operation, Formed Outer Flange Cold, Part not Feasible

Figure 6-8 Part 1, Tail Cone Frame, Preform Blocks. Right: First Operation Block for Forming Inner Flange; Left: Second Operation Block for Forming Outer Flange

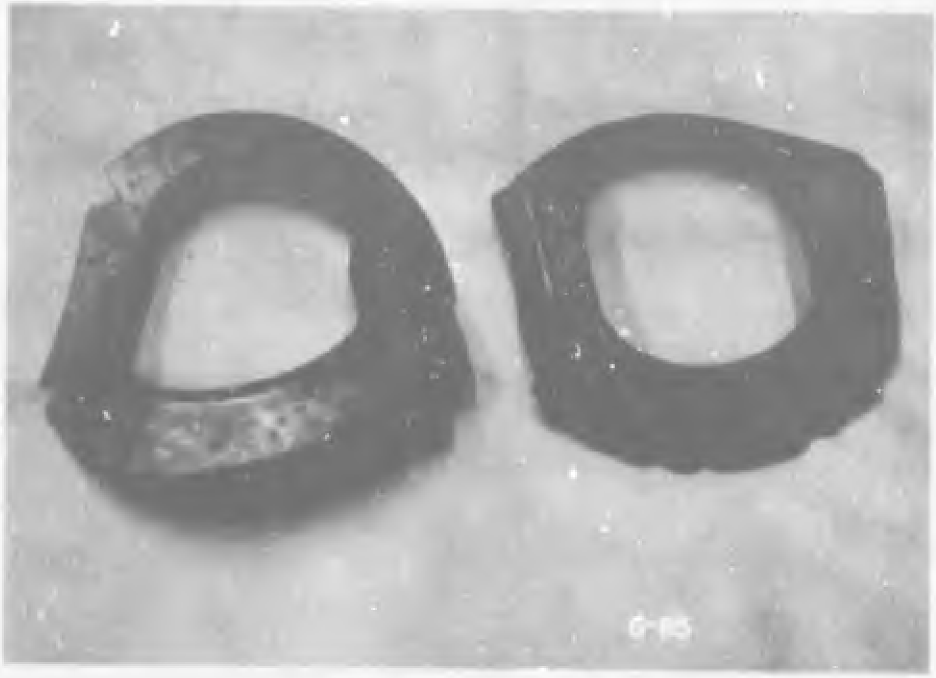


Figure 6-9 Part on Right was Preformed Hot at 1000°F
Drop Hammer/Rubber, not Feasible

Figure 6-10 View Showing RDM 1500
(Hot Form Die) Made of
Incoloy 802

Figure 6-11 Part 1, Tail Cone Frame, Showing Finished Formed Part (One-Step), .070" Gauge Material

Figure 6-12 Flat Pattern for Tail Cone Frame (.070" Gauge Material), is Shown at Left. Formed Part, One-Step Method, is Shown at Right

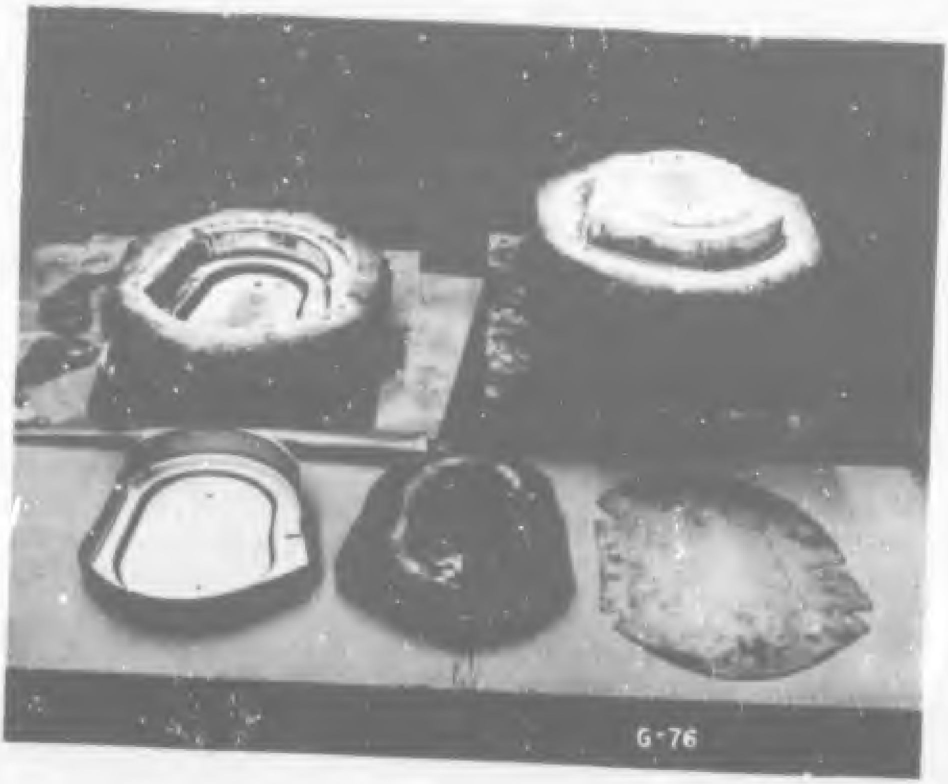


Figure 6-13 Part 1, Tail Cone Frame. Note Special Lifting Hooks and Female Section of Die in Background, at Left. Male Section of Die is Shown at Right. In Foreground, Flat Pattern is Shown at Right; Finished Part (One-Step Method) is at Left

SECTION VII

FORMING PART 2, DOOR CHANNEL

1. RDM 1502, ONE-STEP FORMING

RDM 1502 is a one-step forming die made of HSV Meehanite (Figures 7-1 and 7-2). Its operating procedure is similar to that of RDM 1498 (frame). The function of this die is to simultaneously form the two outer flanges, one at 90° and the other at varying angles from 90° to 5° open; also included is a joggle in one leg of the channel.

Figure 7-3, foreground, shows a view of the flat pattern. Note the center hole. This hole is used to locate the part on a pin in the male section of the die. The two elongated holes in the part on both ends are also picked up by locating pins in the die. As the part "soaks" (heats up to temperature of the die), the slots allow the part to expand and still maintain its central location on the die. A completely formed part is shown in the background. Figure 7-4 shows descaled parts.

Complete success was attained in forming all of the .025" and .070" gauge in the three different alloys (6Al-6V-2Sn, 6Al-4V, and 8Al-1Mo-1V) for a total run of seventy-two pieces. The only problem encountered with this die was heating. Because of its size, the base plate and female section extended to the extreme ends of the hot platen of the US1 press. This problem was overcome by providing additional insulation to minimize heat losses.

2. RDM 1509, TWO-STEP FORMING

RDM 1509 is a two-step hot sizing die for Part 2, door channel and is also made of HSV Meehanite. The male members were used for both preforming and hot sizing. (See Figures 7-5 and 7-2.)

Fabrication of parts is as follows. The male punch is set up in the trapped rubber drop hammer press and the flat pattern is located on it. Heat is applied by means of portable quartz lamps. When the part reaches 1000°F, the lamps are removed and the drop hammer press actuated. A preformed part can be seen in the foreground of Figure 7-6.

The preform operation is followed by hot sizing to refine the part shape. The complete die is mounted on the press utilizing the same male punch used during the preform operation. After the die has reached the desired temperature the preformed part is located on the male, where it is allowed to "soak". Upon reaching temperature, the front and rear rams are actuated, moving the two female halves of the die inward, conforming the part to the male. Tonnage is applied to the press rams and the part is held in the closed die for the desired time.

The first part did not fully conform at the bend radii. A clamping plate was then added on top of the part for the second try-out. The clamping plate assured flatness in the web of the part while the female halves refined the outstanding legs of the part. To remove the part from the die, the clamps were actuated to the out position, moving the female halves outward and away from the male. Bed cushion pressure was then applied, actuating four pressure pins fitting flush with the top of the male, lifting the part off the male.

A problem encountered with this part geometry was that after preforming, the part developed a twist. This caused some difficulty in locating the part on the male for hot sizing, at the expense of additional time. After hot sizing six pieces, the die developed a crack in one of the moving female blocks. The die was reworked and compensations were made in the die to overcome an uneven clamping problem of the press. After a total run of a dozen pieces, the die again cracked. As can be seen from the dimensional check chart (Table A-12), those parts that were hot sized checked out well within target tolerances. Parts 13 through 36 (.025" gauge) and parts 37 through 72 (.070" gauge) were the only preformed parts.

3. CONCLUSION

When comparing the one-step and two-step forming techniques for Part 2, door channel (see chart below), tool fabrication costs are higher for the one-step method, but a substantial savings can be realized in part forming time. One-step formed parts are wrinkle-free and are produced in one operation, thereby reducing handling time. The recommended tooling method for parts of this configuration is dependent upon production quantity requirements.

COST COMPARISON

	One-Step	Two-Step	Time Saved	Preferred Technique
Tool Mfg. Time	548 hrs	360 hrs	188 min	Two-Step*
Average Part Forming Time	10 min	18 min	8 min	

* For lower production rates

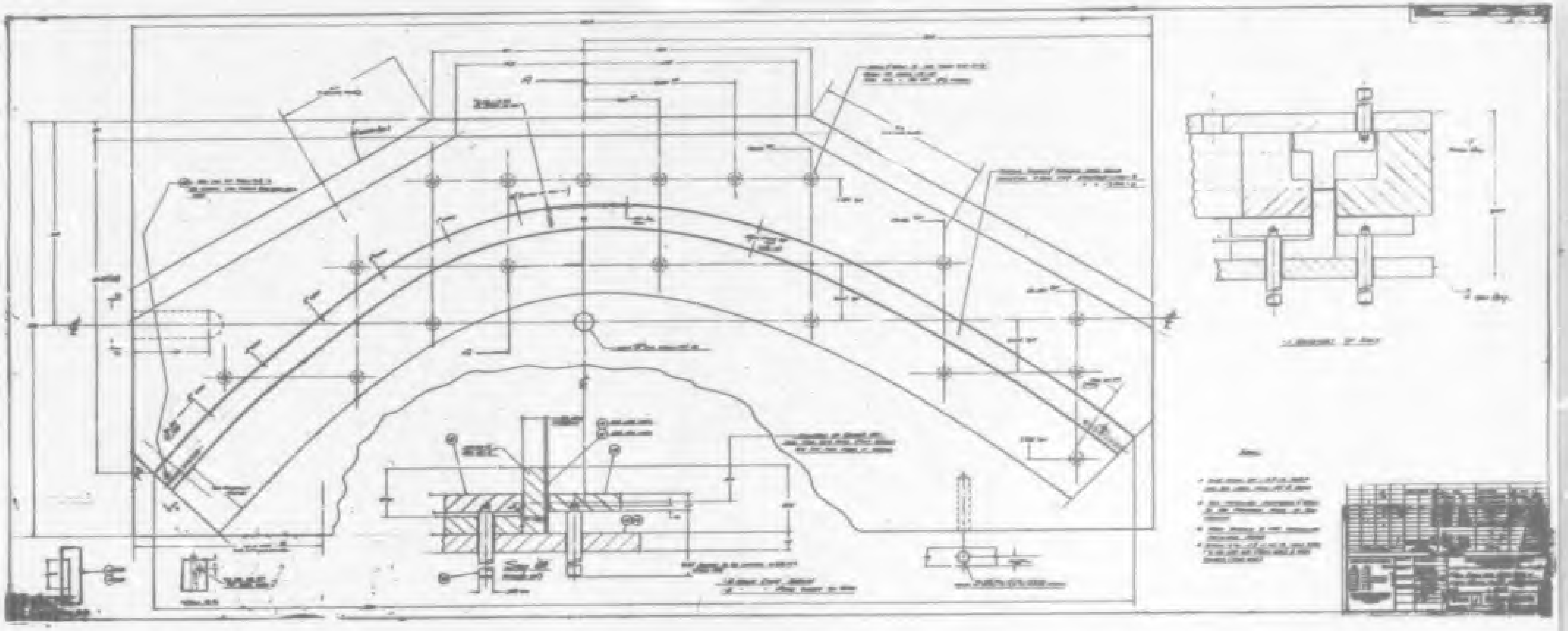


Figure 7-1 RDM 1502 - One-Step Hot Form Die for Part #2 - Door Channel

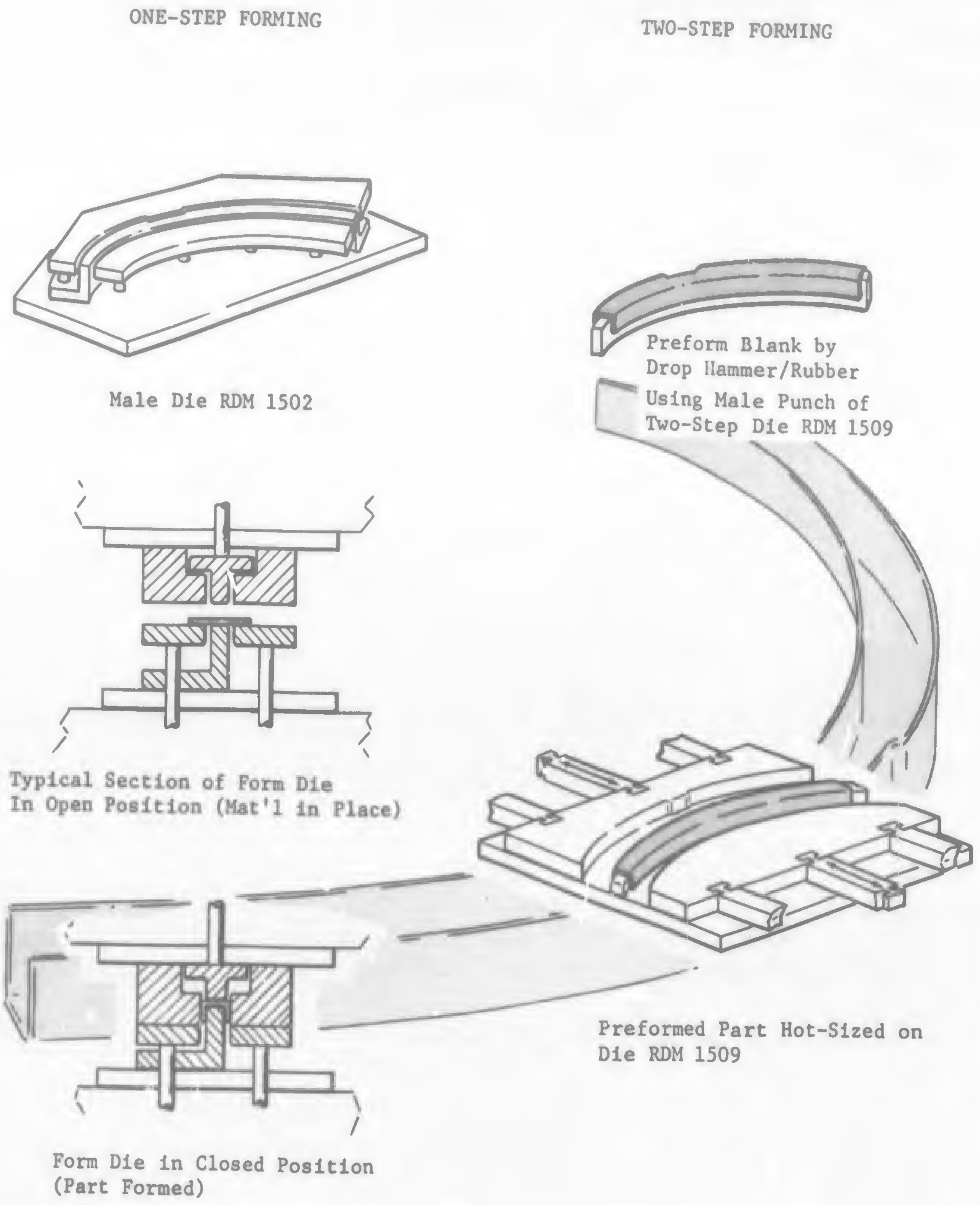


Figure 7-2 Forming Tools for Test Part #2 - Door Channel

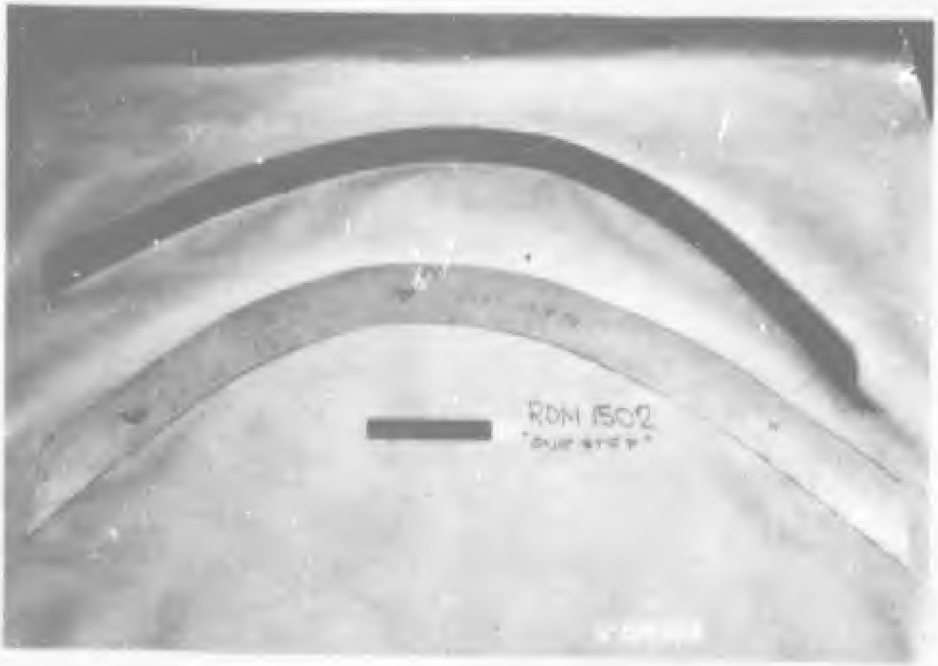


Figure 7-3 Foreground - A View of the Flat Pattern
Background - Finished Formed Part in One Operation

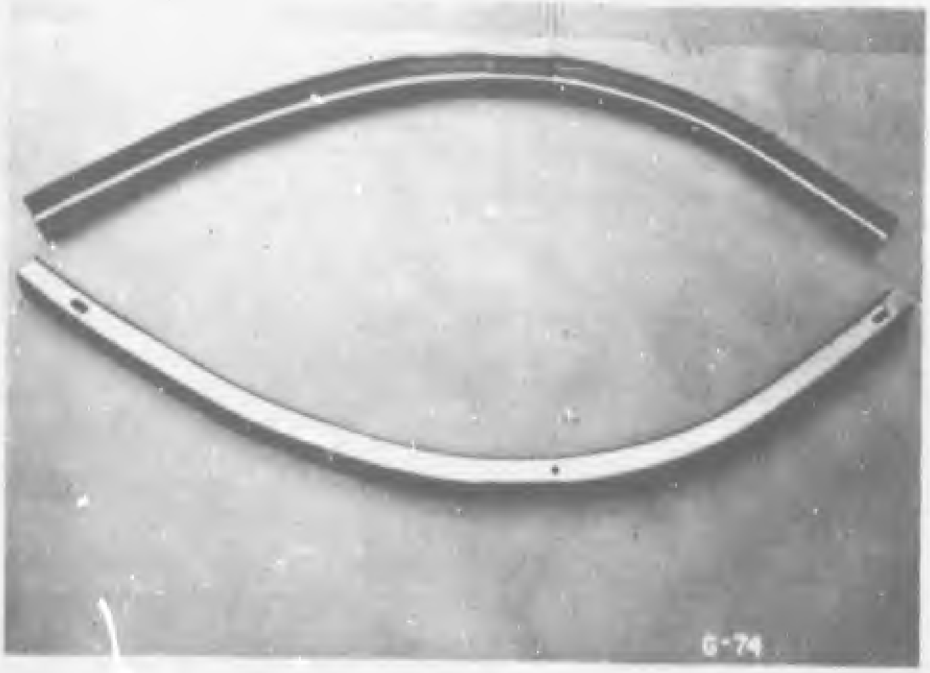


Figure 7-4 Part 2, Door Channel, One-Step Formed Part, .070" Gauge Material

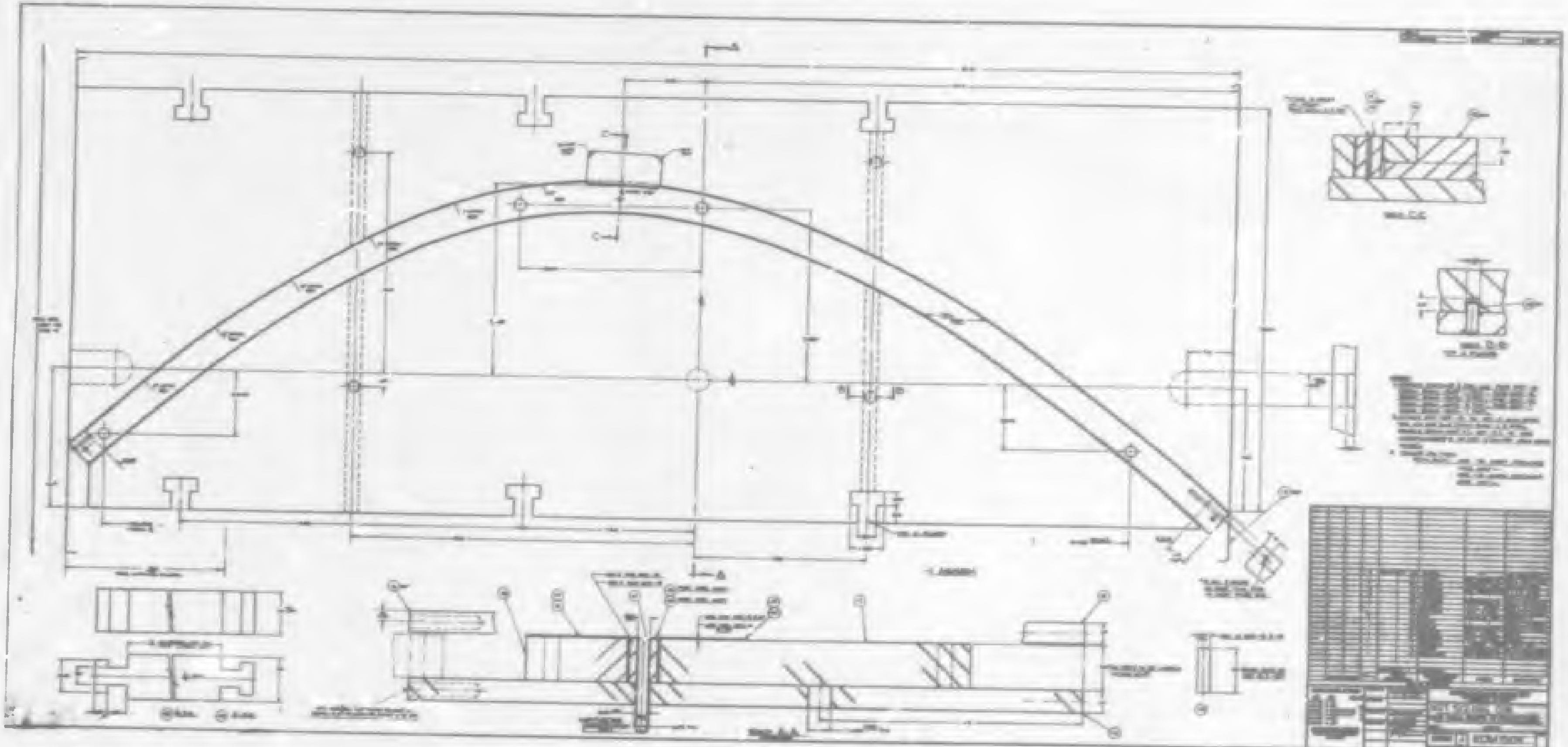


Figure 7-5 RDM 1509 - Two-Step Cold Preform and Hot Sizing Die for Part #2 - Door Channel

Figure 7-6 Foreground - Door Channel (Part #2) Preformed at Drop Hammer Rubber/Hot @ 1000°F, Utilizing Male from RDM 1509
Background - Shows Preformed Part After Hot Sizing

SECTION VIII

FORMING PART 3, ANNULAR RING

1. RDM 1497, ONE-STEP FORMING DIE

RDM 1497 is a one-step hot forming draw die for forming Part 3, an annular ring (Figures 8-1 and 8-2). The die was cast out of HSV Meehanite, using approximately 3/8" oversized patterns. It was designed at Grumman and fabricated by Ideal Engineering Company, Indianapolis, Indiana.

Development of a flat pattern and establishing proper cushion pressures produced a two-inch depth of draw for the .025" gauge on all the titanium alloys designed for this program. This is one inch deeper than originally planned. Continued development with the die also produced a four-inch, wrinkle-free depth of draw using the pure titanium alloy (Figure 8-3). This effort surpassed the Air Force Contract requirements. Operation of RDM 1497 is similar to that of RDM 1498 (frame die).

During tool proving and die try-out at elevated temperatures, the seizing together of the die halves with the part in the "home" position occurred. An examination of the die members (after they were removed from the press and separated) indicated that tool marks left by the turning operation had caused the problem. After grinding and polishing out the tool marks, the die was tried again and operated satisfactorily.

Another problem which occurred with this die was faulty part ejection utilizing the inner pressure pad or knockout. After a complete check was made of the cold die, it was found that the pressure pins were not to tool design dimensions. To solve this problem, new pins were installed and satisfactory part ejection was achieved.

Although scaling was not a major problem, some was visible on the HSV die material. To remove the scale, the draw die was dry-honed with 120 aluminum oxide grit. Figures 8-5 and 8-6 show the forming surface after dry-honing. This operation proved highly successful and saved much time, as compared to other means of descaling. It is recommended that tools periodically be lightly dry-honed and coated with T-50 lubricant to prevent a build-up of scale. This procedure also seems to retard further scaling to some degree. This practice, used on HSV Meehanite, makes this lower cost tooling material highly desirable for production usage.

Continuing with the project, twelve pieces each of 6Al-6V-2Sn, 6Al-4V, and 8Al-1Mo-1V out of .025" gauge, for a total of thirty-six pieces, were successfully formed. Initial checking of these .025" thick parts indicates that a slight change in shape had gradually taken place over a period of days in those of the 6Al-6V-2Sn alloy. This change was in the form of a "dishing" of the web. In view of this unexpected change, a detailed analysis was made to study and relate the specific forming criteria (time, temperature, pressure, rate of deformation, etc.) with the mechanical properties for each heat, for each individual part. It was concluded that the cause of this change in shape was due to insufficient time at temperature with the die in the closed position. This resulted in residual stresses in the inner flange in particular, and caused the "dishing."

It should be noted that while forming at the higher temperatures in 8Al-1Mo-1V alloy, there was a noted differential in temperature between the male and female die segments. The female segment is substantially more massive than the male segment and does not absorb the heat as readily. Solutions to this condition could be as follows:

- Provide better insulation around the platens (to give more of a furnace effect)
- Make the draw ring more massive (act as a heat sink)
- Operate upper and lower platens at different temperatures so that forming surfaces of the tool are uniform

Upon completion of the .025" parts, the die was converted for the heavier material and forming tests proceeded with the .070" gauge titanium (twelve pieces each of three alloys). A dimensional check of all formed .070" thick parts back to the cold male section of the die (see Figure 8-7 and Table A-13) showed the parts to be within or better than target tolerances.

2. CONCLUSION

The forming of annular titanium rings is virtually impossible by any other method. A heated draw die can be used very successfully for any thickness of material. Good die making practices should be adhered to. Tool marks in a die of this configuration cannot be tolerated. Die surfaces must be thoroughly polished, as in any draw die. Higher cushion pressures offer definite advantages for the control of wrinkle formation, particularly when forming the heavier gauge materials and when deeper draws are desired. Figure 8-4 shows the results of insufficient pressure when attempting to make deeper draws in the heavier materials.

3. COST COMPARISON

Only the one-step tool was programmed for this part since it could not be made by the preforming/hot sizing technique; therefore, a cost comparison cannot be made. Total tool fabrication cost for this die was 224 hours.

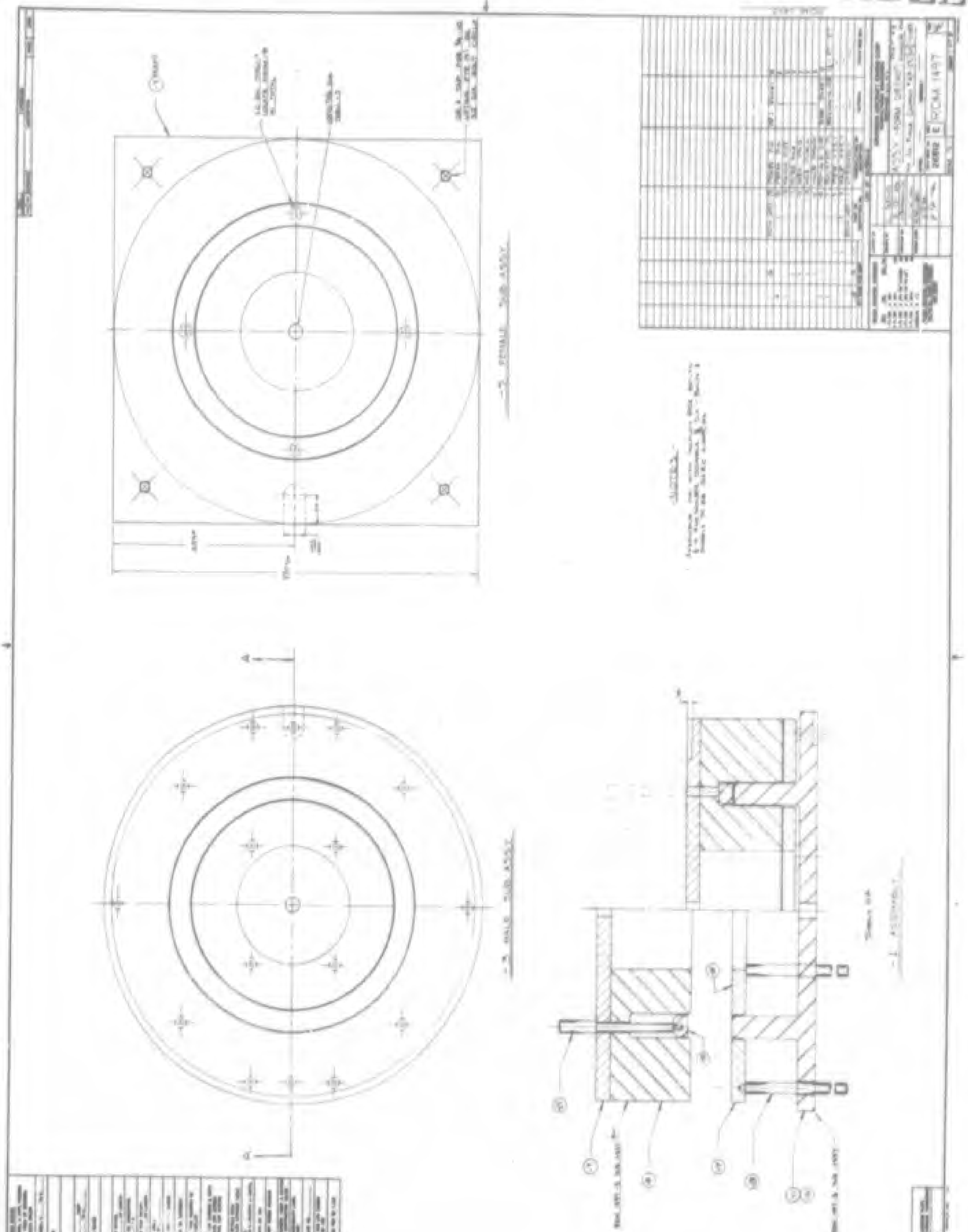
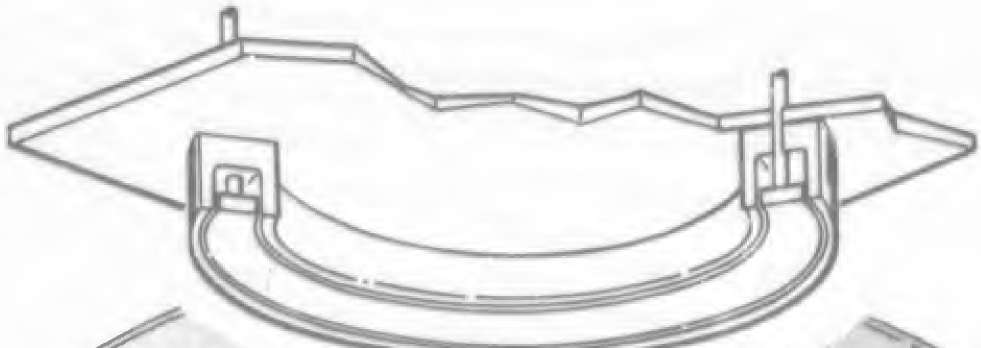
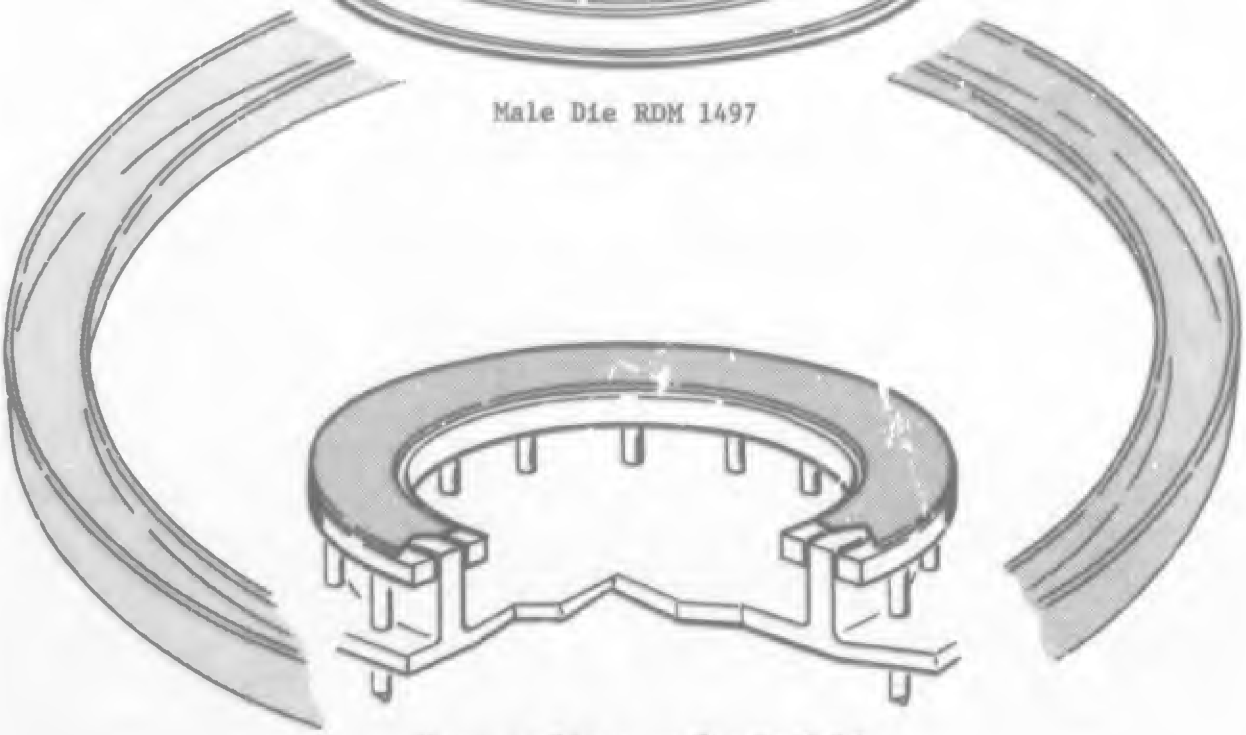


Figure 8-1 RDM 1497 - One-Step Hot Form Die for Part #3 - Annular Ring

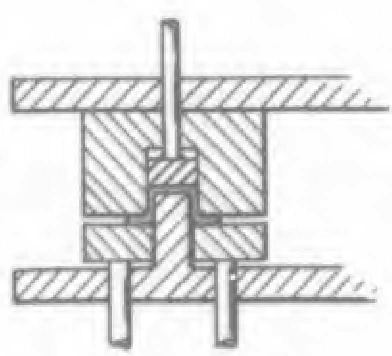
One-Step Forming Only



Male Die RDM 1497



Blank in Place on Female Half
Die in Open Position



Typical Section of Die
Partially Formed Part in Die

Figure 8-2 Forming Tool for Test Part #3 - Annular Ring

Figure 8-3 Commercially Pure .025" Gauge, Showing a 4" Depth of Draw

Figure 8-4 .070" Gauge Part Made From 24" Diameter Blank, Showing the Need for Additional Cushion Pressure

Figure 8-5 View of Annular Ring Die After Dry-Honing

Figure 8-6 Close-Up of Forming Surface After Dry-Honing

Figure 8-7 Checking Part Back to Cold Male

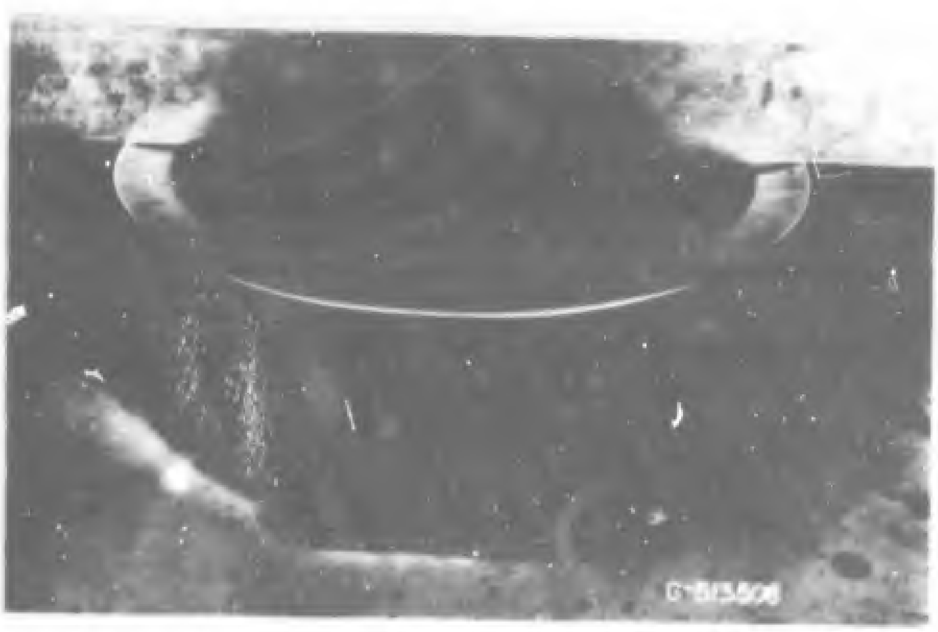


Figure 8-8 Checking Part Back to Cold Male, Note "Dishing" Effect Caused By Insufficient Time and Temperature

SECTION IX

FORMING PART 4, ZEE

1. RMD 1435, ONE-STEP FORMING

The design for the RDM 1435, a one-step hot form die for part 4, zee, is shown in Figure 9-1. The forming tools for part 4 are shown in Figure 9-2.

This one-step form die was cast from HSV Meehanite to oversized Grumman patterns by Parnett Foundry of New Jersey. The balance of the die fabrication was accomplished at Grumman.

From the first try-out and tool proving, all went well and no serious problems were encountered. Parts were formed from all three alloys: 6Al-6V-2Sn, 6Al-4V, 8Al-1Mo-1V. In addition, this die was also used to produce solution treated and aged parts by age forming 6Al-4V ST material in the .025" thickness. After all work was completed with the lighter gauge alloys, the die was converted for use for forming parts from the .070" gauge. This was accomplished by the use of a second punch which provided the additional required clearance. A total of seventy-two pieces were produced, twelve of each alloy. There was no cracking, wrinkling, or tearing of any of these parts.

The die was used for approximately 300 hours at temperatures up to 1600°F. No significant deterioration or distortion occurred, although a slight indentation of the draw ring and the female was now visible; however, this did not have any effect on the formed parts. It should be noted that the HSV Meehanite die material held up very well, and is well suited for production use.

2. VERTICAL DRAW FORMING OPERATION

The one-step hot forming of this complex-compound zee part on these unique presses marks a major break-through in titanium forming. The sequence of forming operations is described below.

Figure 9-3 shows the draw die in the open position. Note that the die mounting clamps are bolted directly into the heated platens. The flat blank was then placed on the heated die. Orientation of the part blank was accomplished by locating pins mounted on the male punch (Figure 9-4). At this point the upper and lower cushions were energized, raising the lower female draw ring (Figure 9-5). The upper die assembly was then brought down to make contact with the part blank between the upper and lower die assemblies (Figure 9-6). There was a soak period of one to two minutes in this position to allow the blank to pick up the heat from the die. A slow draw was effected by activating the "slow down" control on the press. During this "slow down" cycle the part blank was draw formed to its final configuration. The die was held in the closed position at the desired pressure for a dwell period of three to five minutes (Figure 9-7). Upon completion of the forming cycle, the press was opened, automatically ejecting the formed part for easy removal by the operator (Figure 9-8). (Note: Automatic ejection was accomplished by re-energizing the draw ring upon opening the press.) If at any time the blank remained in the upper portion of the die, energizing of the upper cushion would actuate the knockout and provide automatic part ejection.

The progression from flat blank to formed part and finally to separation of left-and right-hand details is shown from left to right in Figure 9-9. Figure 9-10 shows the separated left- and right-hand parts being checked on the 2700-pound Meehanite HSV draw die. Parts are formed free of wrinkles, springback, and galling.

Grumman believes that the one-step hot draw forming of a complex-compound contoured part of this configuration cannot be duplicated by any other forming method.

3. RDM 1516, TWO-STEP FORMING

The design for RDM 1516 is shown in Figure 9-11. RDM 1516 is a horizontal hot sizing die cast from Nicrosil steel. This is the two-step die used to make one zee member at a time. The forming tools for Part 4, zee, are shown in Figure 9-2.

Fabrication of parts was as follows. One-half of RDM 1516 was utilized at drop hammer/rubber (Figure 9-12). Here the die can be seen set up in the drop hammer press. The part was pre-heated on a portable platen and then placed on the die and heated to 1000°F by quartz lamps. Heat-resistant rubber was used; the part was "hit" once to obtain a preform configuration. Figure 9-13 shows the preformed part and flat pattern.

For hot sizing, the die was mounted horizontally (Figure 4-5) and four clamps were tied into the front and rear of the press. The preformed part was then located by means of a locating pin. The die was closed until it touched the part for the "soak" period. After the part was at temperature, the clamps were actuated and the die moved slowly to the closed position, "dwelling" in this position for the required amount of time to eliminate all springback. The clamps were then actuated, the die moved to the open position, and the completed hot-sized part was then removed. Figure 9-14, background, shows the preformed part; center, hot-sized part; foreground, a descaled and trimmed piece, all done on RDM 1516.

The .025" material formed very well, except in the sharp transition areas where a slight waviness appeared. Difficulty, however, was encountered in forming the .070" material. The die had a tendency to "over-ride" or lift during the closing cycle. This condition was corrected by adjusting the front clamps so that half the die remained stationary. Shims were then placed on this half of the die and the ram brought down on it. To close the die the rear set of clamps were engaged and successfully corrected the "override" condition. This operation of the .070" material did not produce satisfactory results. The severe contours of this part are beyond the limitations of the preform hot sizing operation.

4. CONCLUSION

After comparing the one-step die (RDM 1435) with the two-step die (RDM 1516), it may be said that the one-step die can produce two pieces for the price of one. It can be seen that much more time is required to produce the same parts by the two-step method(even if the latter produced acceptable results). Extra material is also needed for the forming of the two-step drop hammer operation, whereas a developed flat pattern with very little scrap area is used for the one-step draw.

One of the major factors to take into consideration is the handling time of the two-step method. Parts have to be pre-heated and the die must be set up in the drop hammer press. After preforming, the die has to be cooled down and moved to the hot sizing area for the second operation. Besides finish trimming, an additional trimming operation is required at this stage to remove excess material required by the drop hammer operation. Here set-up and more heat-up time is involved. It should also be noted that preformed parts are only partially formed and are difficult to nest, locate, or position in the hot sizing die. Extreme caution must also be used to ensure that the preformed mold lines are not "off" in the hot sizing operation.

Here again one-step formed parts are wrinkle-free and are produced in less time. For parts of this complexity, hot draw forming is the preferred method.

COST COMPARISON

	One-Step	Two-Step	Time Saved	Preferred Technique
Tool Manufacturing Time	520 hr	580 hr**	60 hrs	One-Step
Average Part Forming Time	9 min/2 parts or 4.5 min/1 part	16 min 1 part	13.5 min/ part*	

* Includes an additional 2 min for the added trimming operation.

** Includes tooling for hot sizing dies and drop hammer dies for left-& right-hand details.

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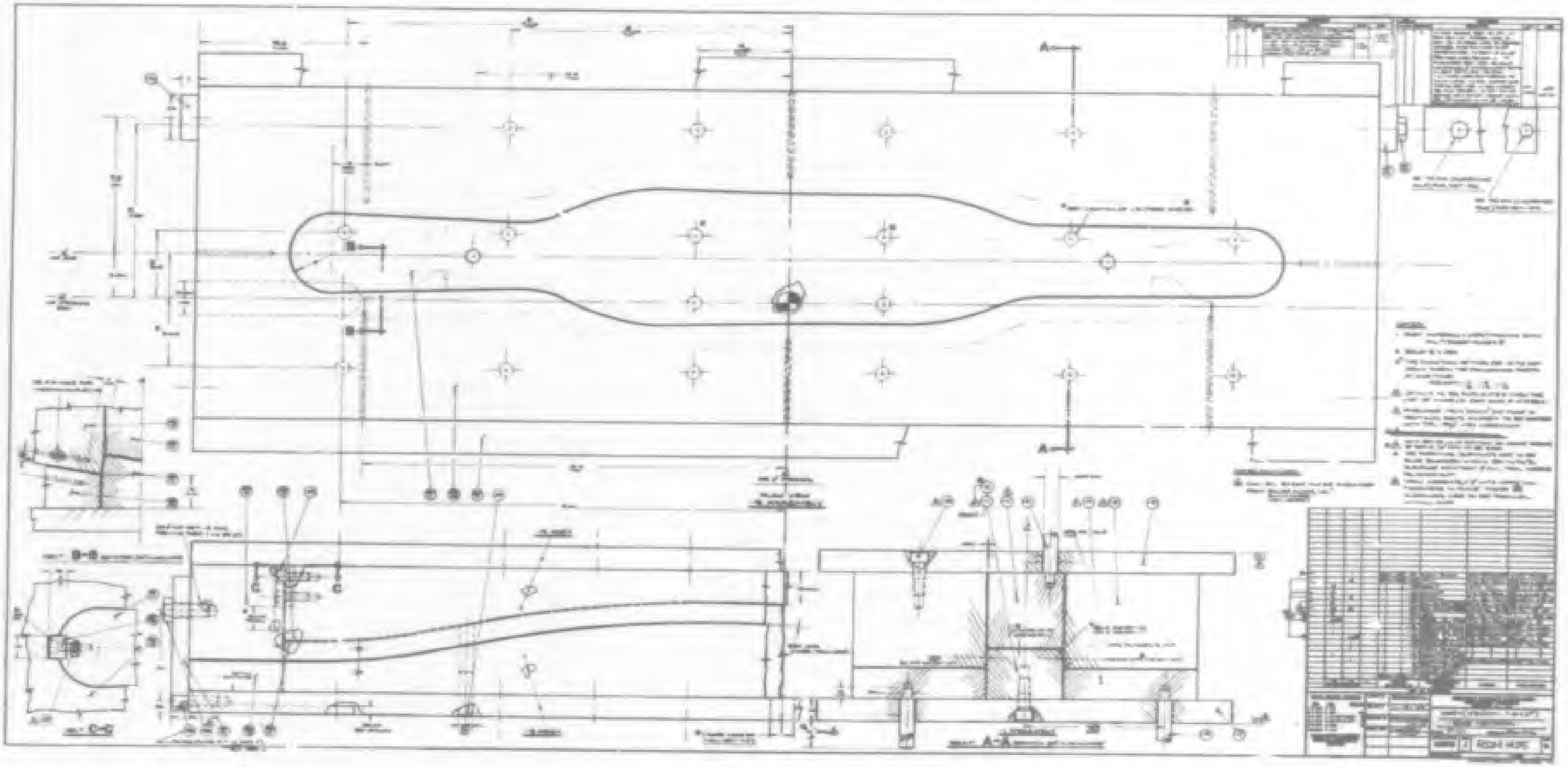

Figure 9-1 RDM 1435 - One-Step Hot Form Die for Part #4 - Zee

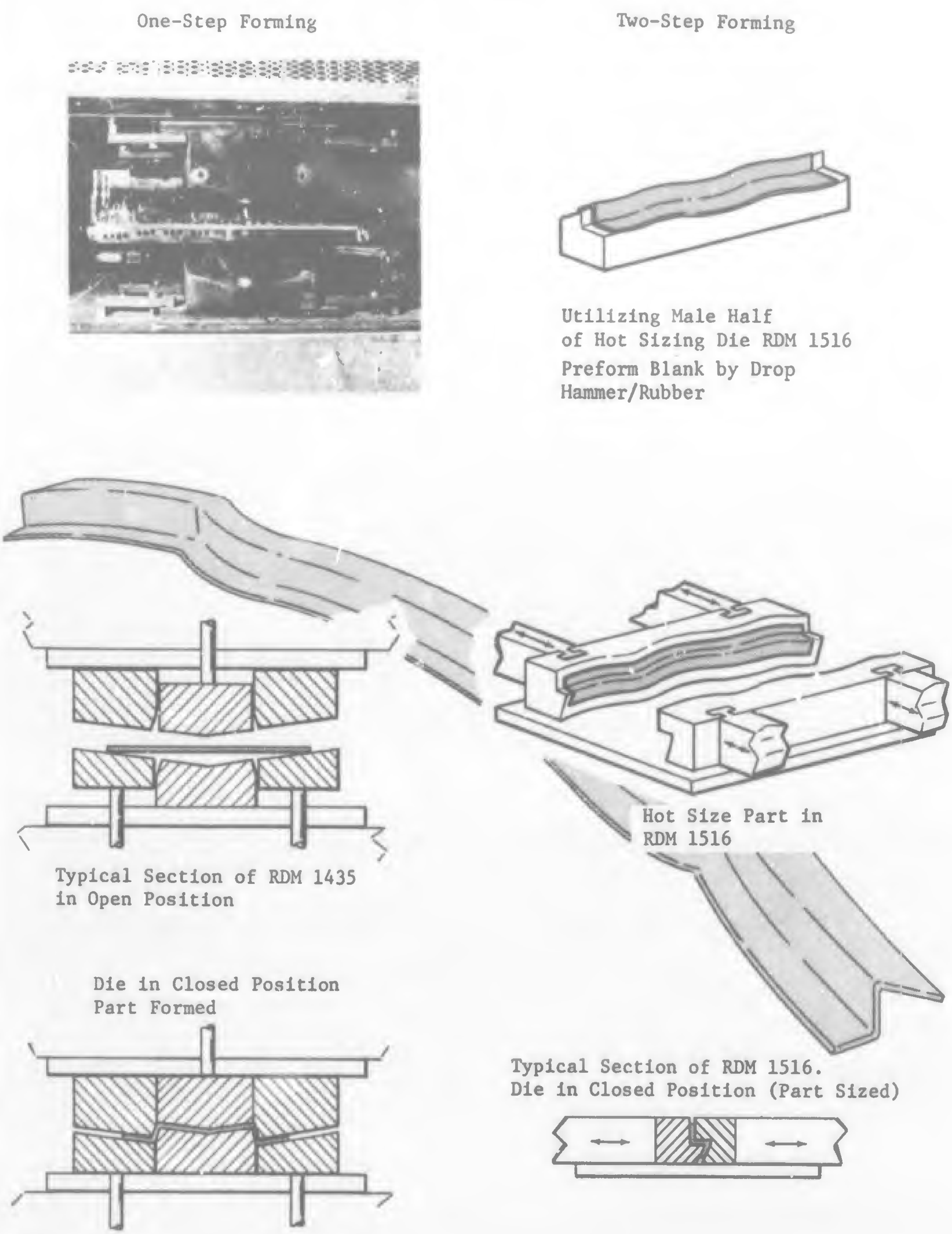

Figure 9-2 Forming Tools for Test Part #4 - Zee

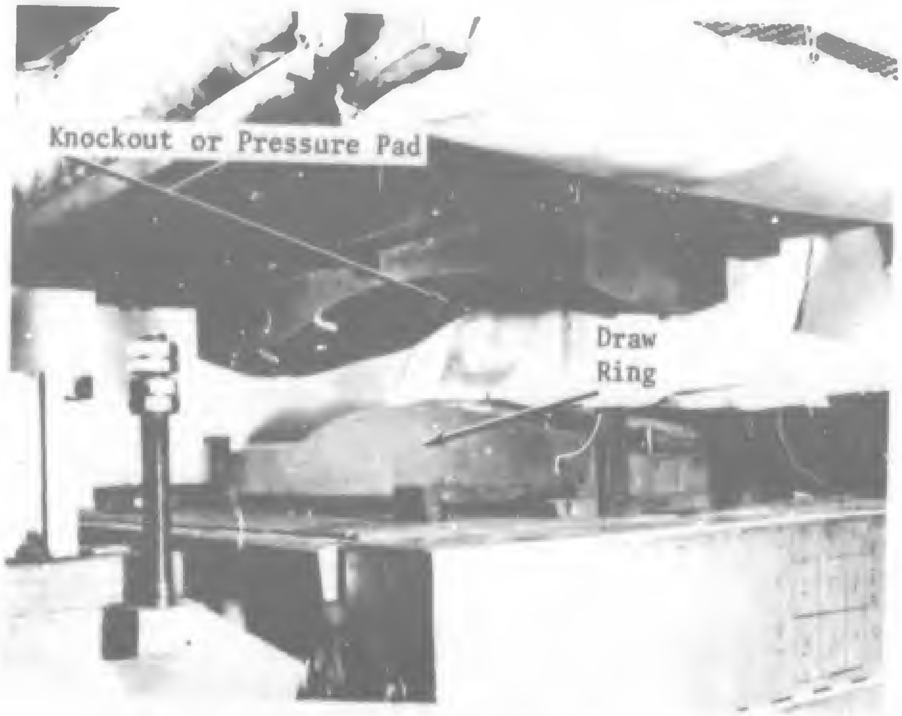

Figure 9-3 Draw Die in Open Position

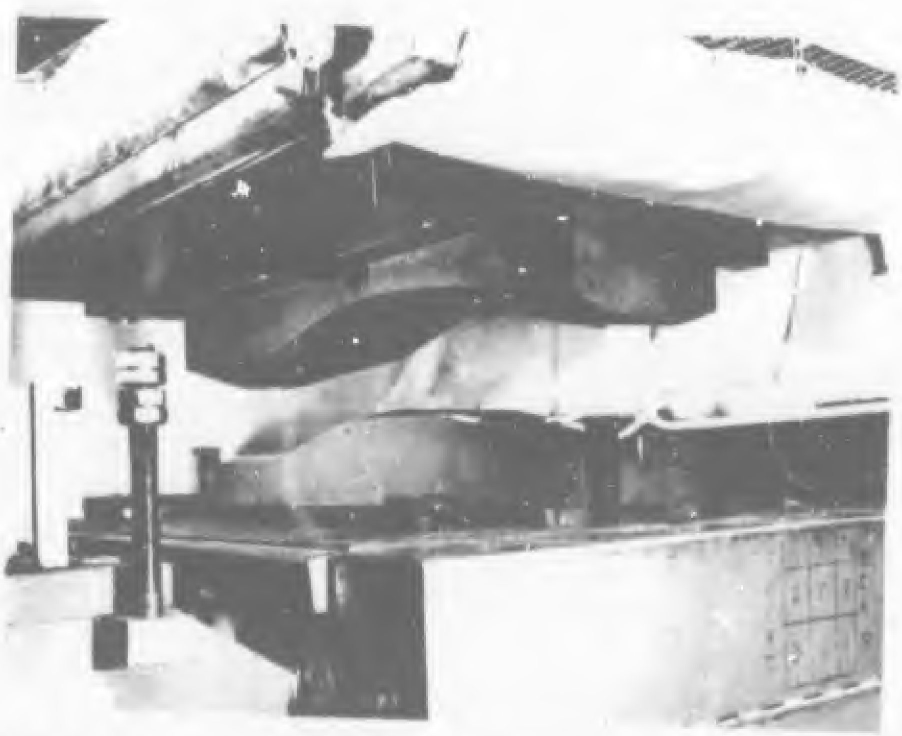

Figure 9-4 Flat Blank Being Placed on Heated Draw Die. Blank Could Also be Placed on Die After the Draw Ring is Raised.

Figure 9-5 Position of Blank Before Press is Closed

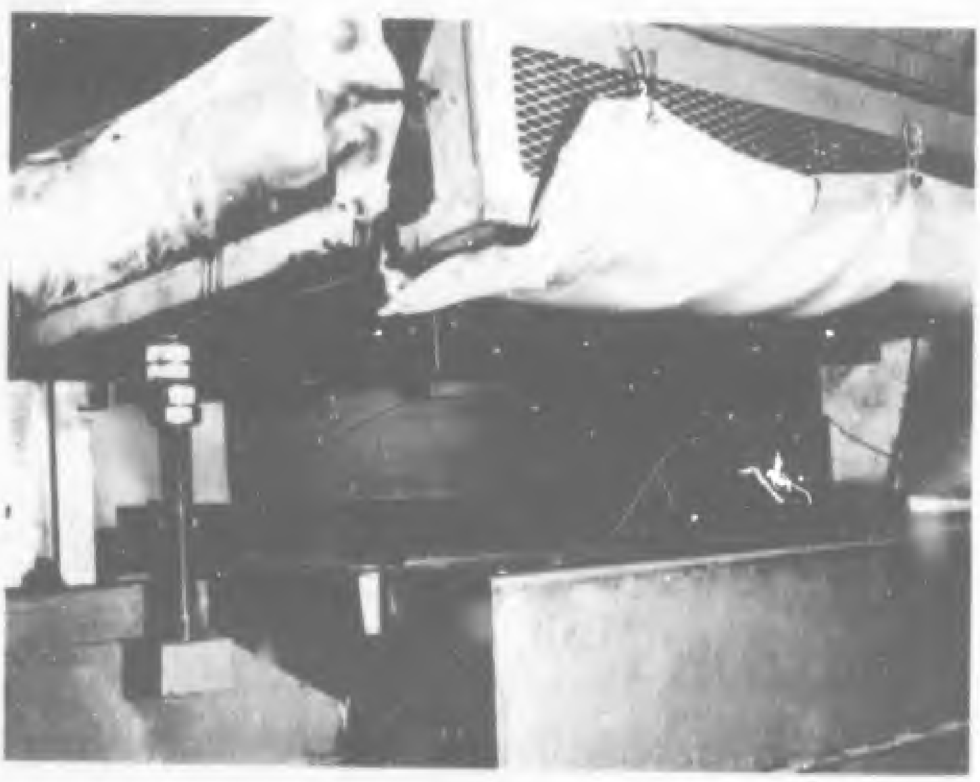

Figure 9-6 Upper Portion of Die is Brought Into Contact with Draw Ring

Figure 9-7 The Die is Held in the Closed Position for a Three-to-Five-Minute Dwell Period

Figure 9-8 The Formed Part is Raised off the Punch by the Draw Ring and is Easily Removed

Figure 9-9 Flat Blank to Formed Part; Left - Developed Flat Pattern; Center - Formed Part (One-Step Method); Right - Left- and Right-hand Details After Trimming

Figure 9-10 Left - and Right-Hand Parts Being Checked on the Draw Die

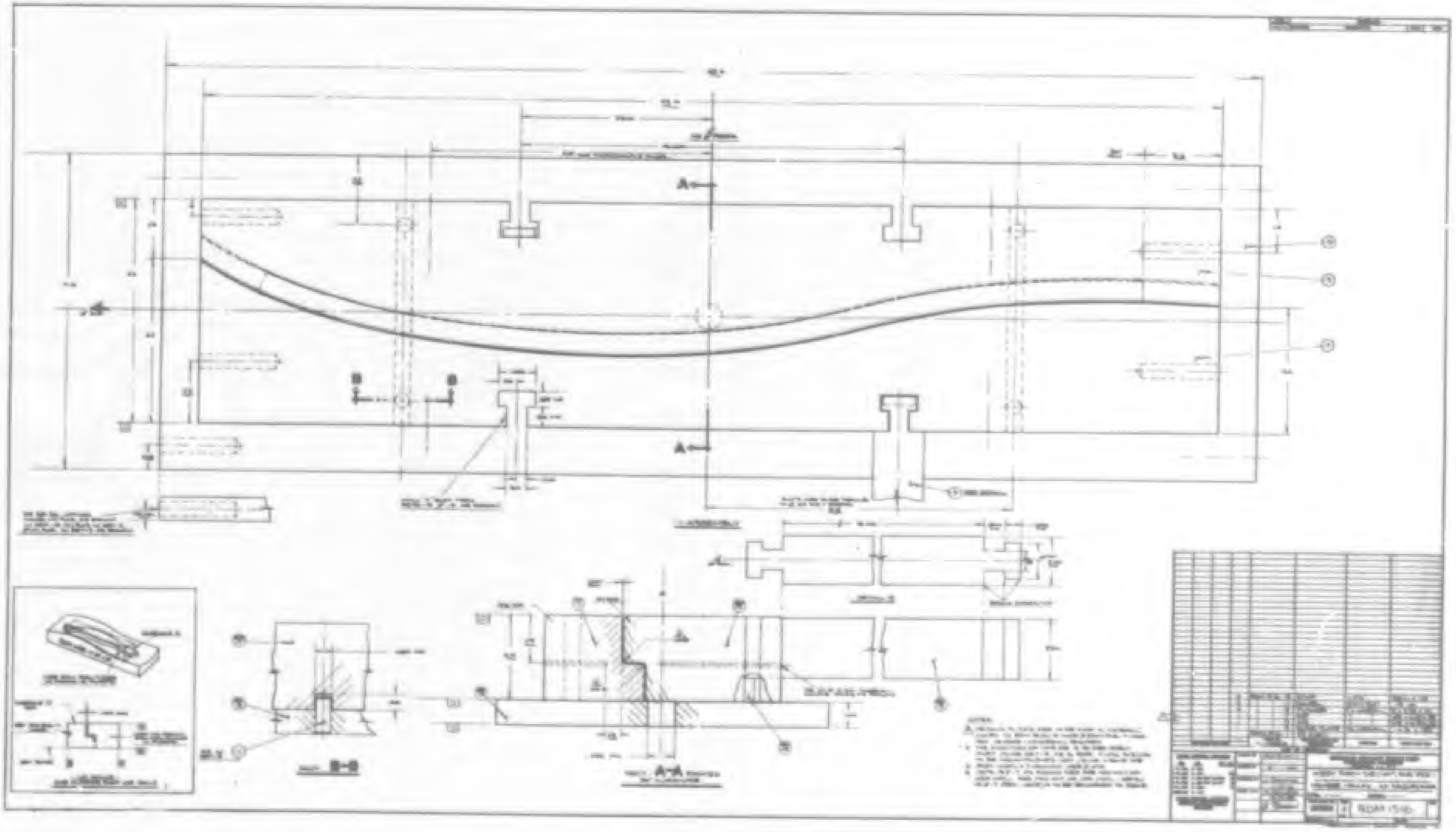

Figure 9-11 RDM 1516 - Two-Step Preform and Hot Sizing Form Die for Part #4 - Zee

Figure 9-12 Half-Die (Nicrosil) Set Up for Preforming Operation; Die at 700/800°F; Part Being Heated to 1000°F by Quartz Lamps (Upper Portion Not Shown)

Figure 9-13 Flat Pattern in Foreground, Preformed Part in Background; Material .025" 6Al-4V

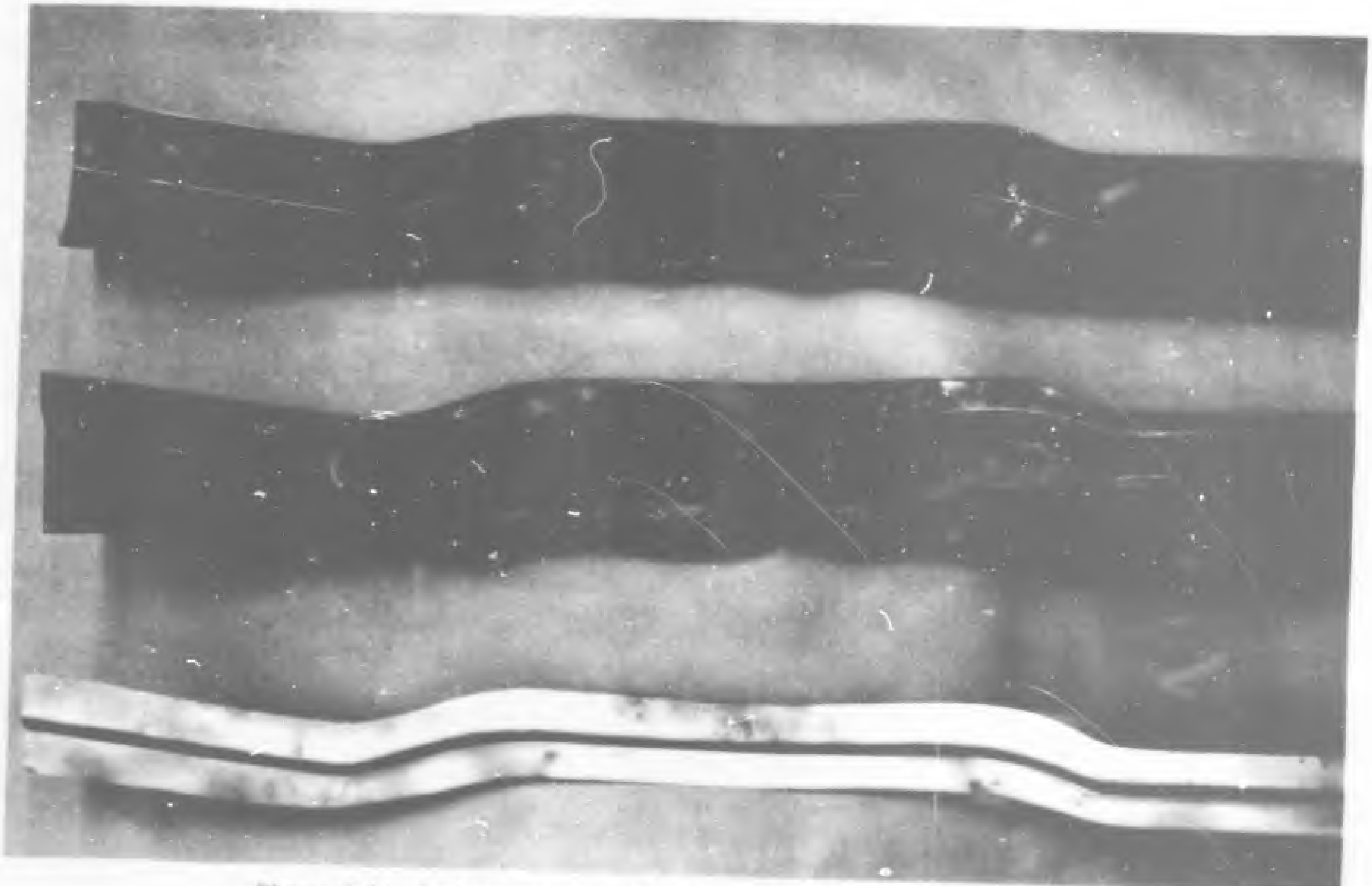

Figure 9-14 Background Shows Pre-Formed Part; Center, Hot Sized Part; Foreground, Descaled and Trimmed Part

SECTION X

FORMING PART 5, FRAME

1. RDM 1498 ONE-STEP FORMING DIE

RDM 1498 is a one-step forming die made of Incoloy 802 steel, utilizing a combination pressure pad and knockout fabricated into the female cavity. The designs are shown in Figures 10-1 and 10-2. The forming tools for Part 5, frame, are shown in Figure 10-3.

Figure 10-4 is the male assembly for forming .025" material; Figure 10-5 is the male assembly for forming .070" gauge material.

The pressure pad of the female assembly is shown in the "home" position in Figure 10-6. This would be the closed position of the die; the lightening hole flanges and beads would be completely formed at this stage.

Figure 10-7 and 10-8 are views of the male assembly mounted on the platen of the USI press. Figure 10-8 shows the male assembly mounted in the press with bed cushion pressure on the male pressure pad in the up position. It is in this starting position that the flat pattern is placed on the locating pins (see three pins in Figure 10-8). The female assembly is then brought down until it touches the part and held in this position until the part reaches the temperature of the die.

With bed cushion pressure on, the slow down action of the ram (slide) is actuated. The part is now sandwiched between the female and male pressure pad and is slowly drawn over the male in a downward action. The outer flanges of the part are now formed. As the bottom of the stroke is approached, the beads and flanged lightening holes are formed. After bottoming, the die dwells in the closed position for the time required to eliminate springback. The ram is then returned to the up or open position. The part is now "locked" in the female cavity. To remove the part the slide cushion is actuated, which, in turn, moves the female pressure pad or knockout, and automatically ejects the part.

Twelve pieces of each alloy (6-6-2, 6-4, and 8-1-1) and of each gauge (.025" and .070") were produced for a total of seventy-two pieces. The only trouble encountered was galling of the die; this was eliminated by using a special Grumman-developed lubricant - JGAW #1.

After checking the formed parts, they were all found to be consistent and well within the target tolerances (Table A-16).

2. TWO-STEP OPERATION

After attempting to form parts by the preform/hot size method in the .070" thickness, and getting unsatisfactory results, it was decided not to attempt to form the remaining details. Figure 10-9, lower right-hand corner, shows a tight corner radius. This 1 1/2" corner radius was successfully formed as shown by the one-step operation. (See enlarged views, Figure 10-10.) It is impossible, however, to accomplish this in a two-step operation. In order to preform this part, a cut-out must be added to prevent fracture of the flange. Parts with a cut-out in this area were successfully preformed.

3. CONCLUSION

It should be noted that a splice plate would have to be fastened to parts in the cut-out area in order to have the same structural integrity as the continuous flange produced by the one-step method. This, therefore, pemits greater design latitude, potential weight savings, and lower assembly costs.

COST COMPARISON

	One-Step	Two-Step	Time Saved	Preferred Technique
Tool Mfg. Time	560 hr	420 hr	140 hr	One-Step
Average Part Forming Time	10 min	15 min (with cut-out in corner flange only)	5 min	

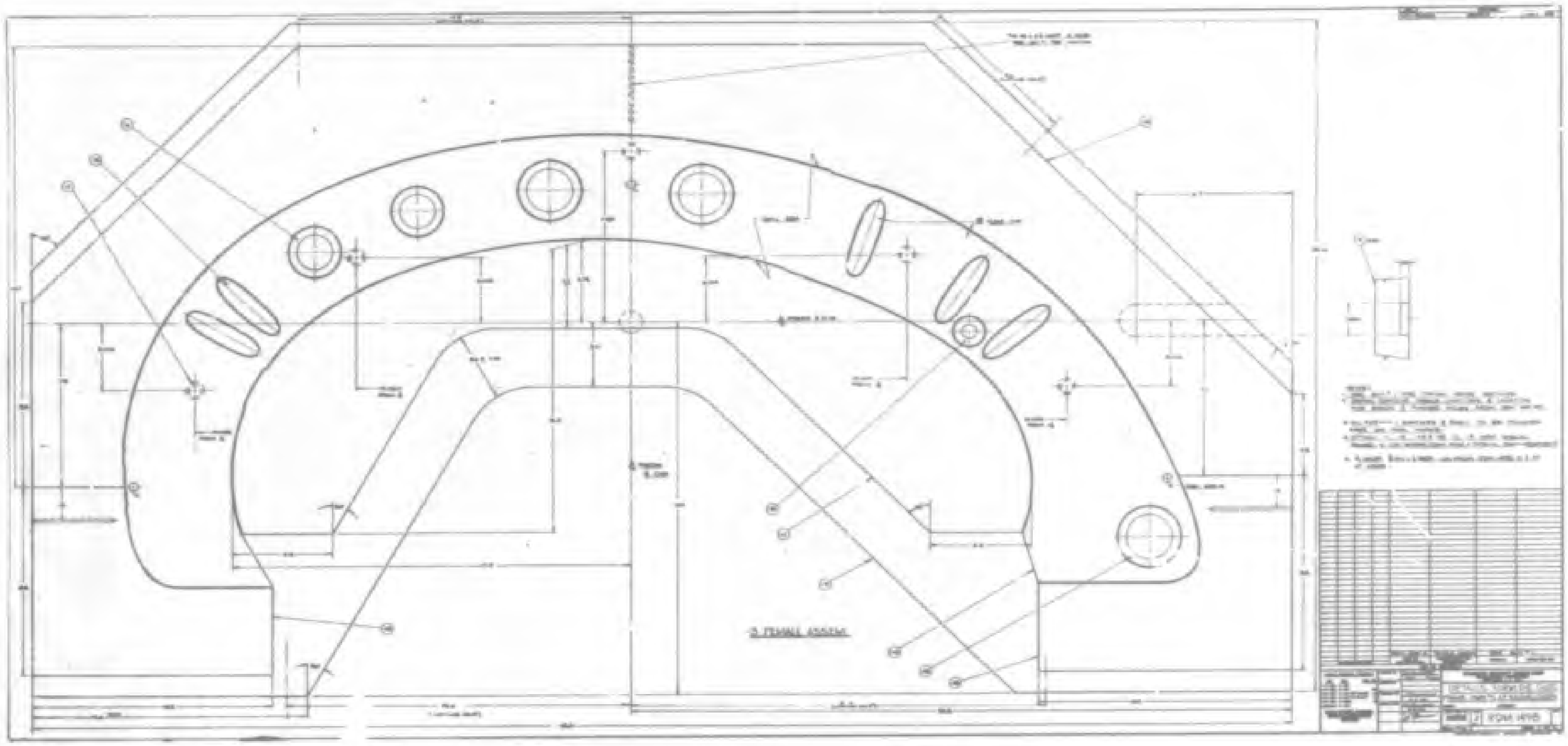

Figure 10-1 RDM 1498 - One-Step Hot Form Die for Part #5 (Female) - Frame

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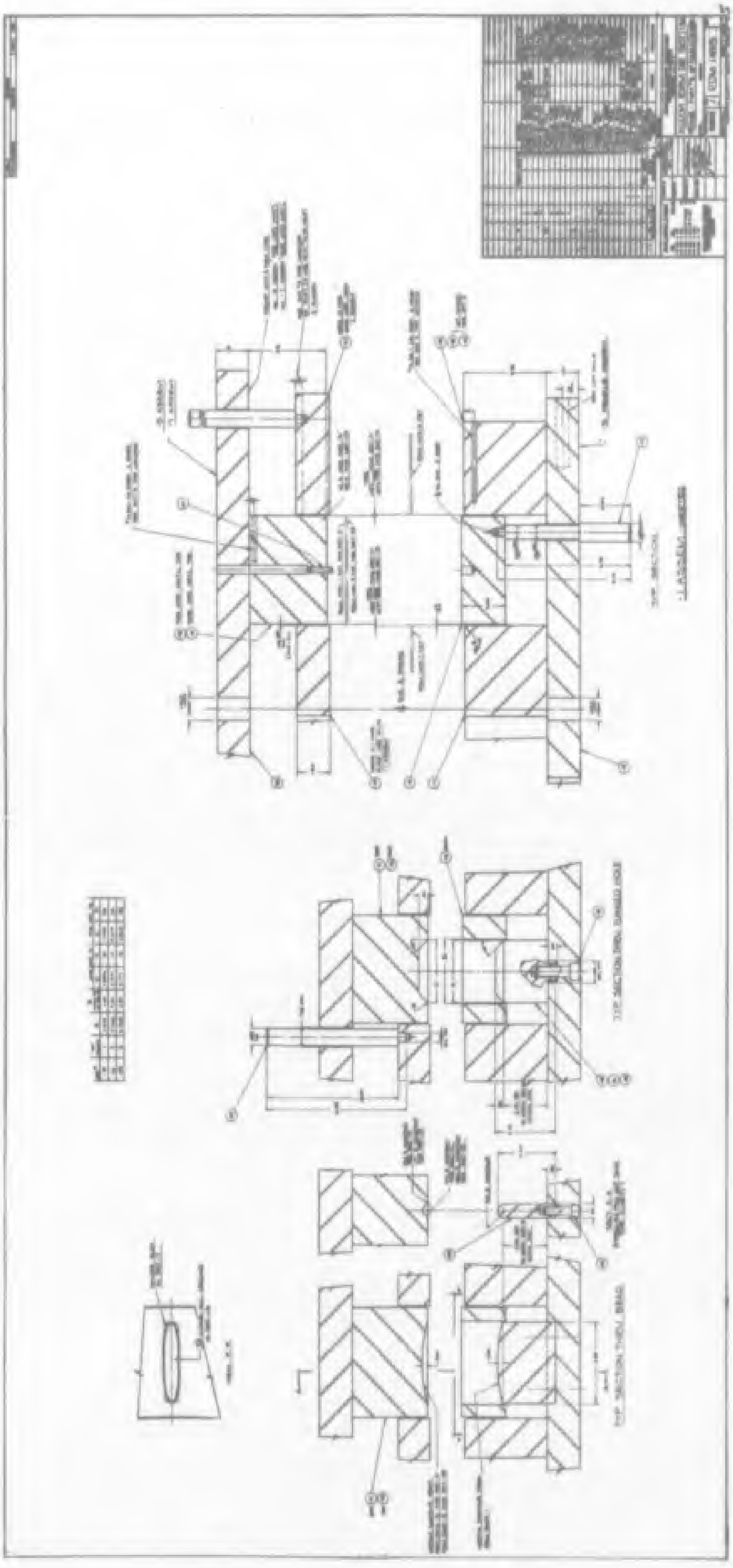


Figure 10-2 RDM 1498 - One-Step Hot Form Die for Part #5 - Frame

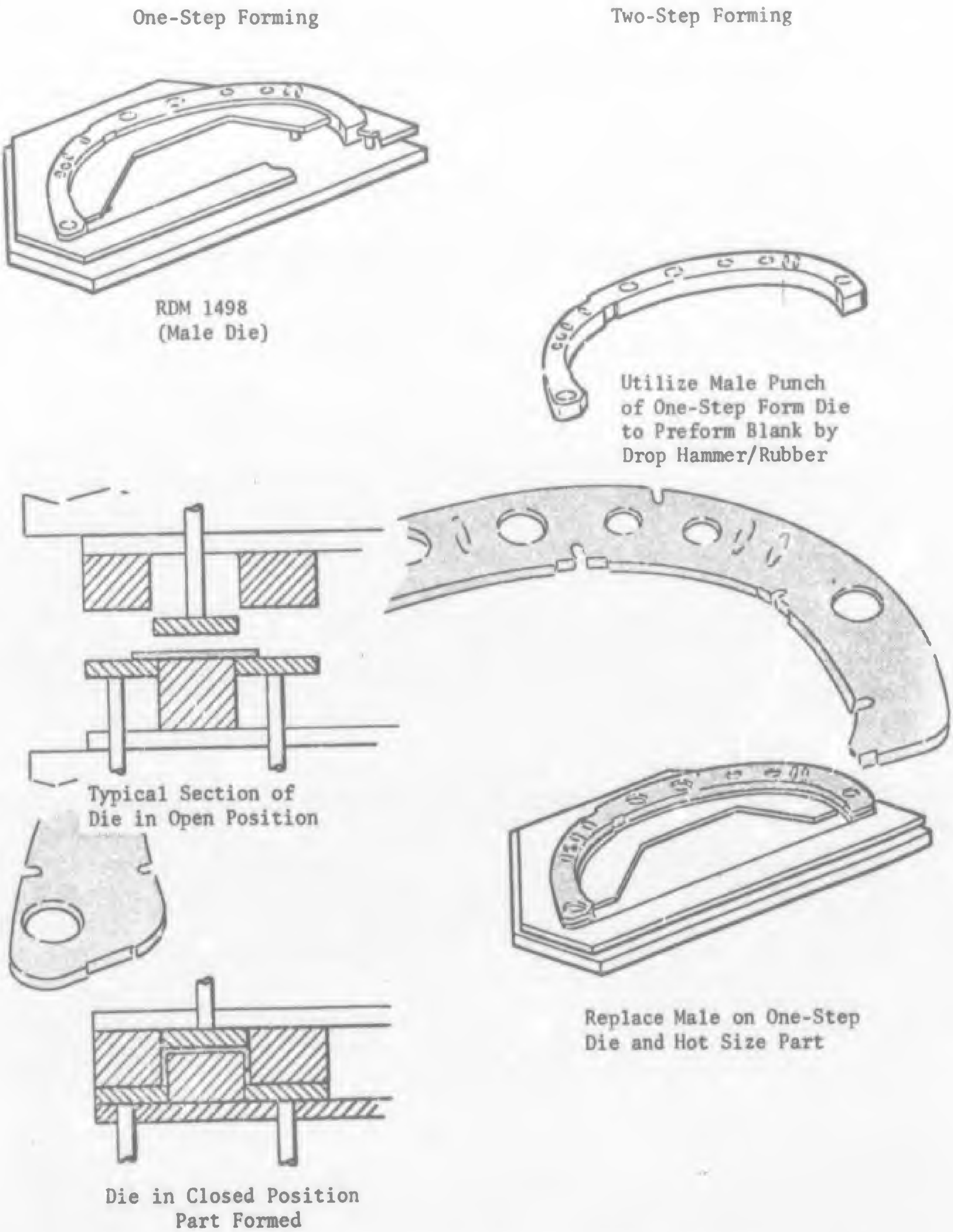


Figure 10-3 Forming Die for Test Part #5 - Frame

Figure 10-4 RDM 1498 Forming Die, Made of Incoloy 802, is Used to Form Part 5, Frame. Photo Shows Male Die (for Forming .025" Gauge) and Pressure Pads

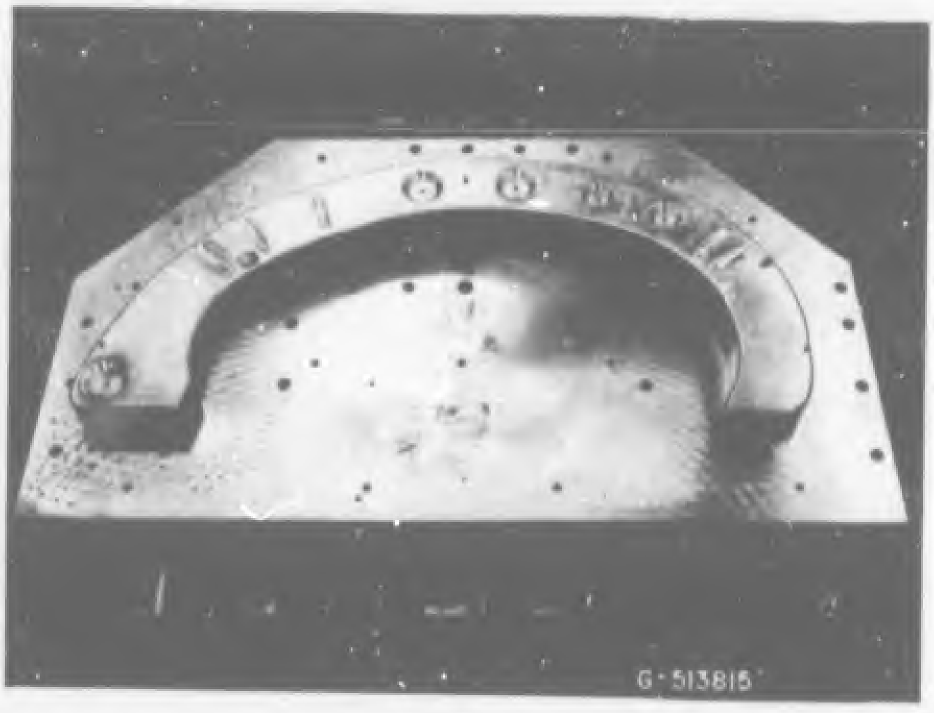


Figure 10-5 RDM 1498, Male Die for Forming .070" Gauge

Figure 10-6 RDM 1498, Showing Female and Pressure Pad in Position

Figure 10-7 RDM 1498, Showing Male Section of Die with Pressure Pads in Position on Hot Platen of USI Press

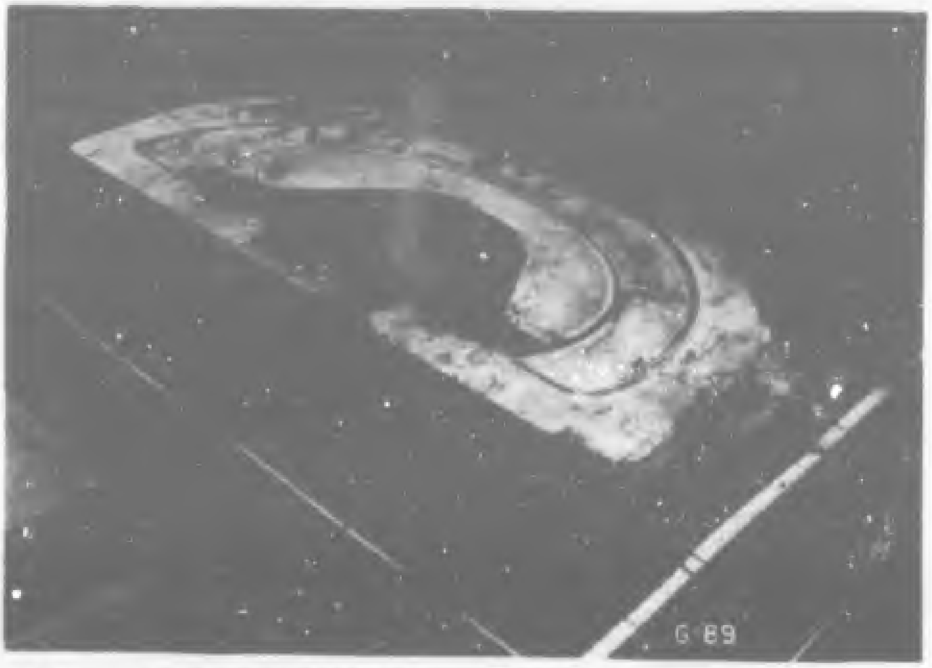


Figure 10-8 RDM 1498, Pressure Pads in the Up Position

Figure 10-9 Part 5, Frame, One-Step Forming; Foreground, Descaled Part; Center, Formed Part (.025 Gauge); Background, Flat Pattern

Figure 10-10 Enlarged Views of Part 5, Frame, Showing Tight Corner Radius

SECTION XI

FORMING PART 6, CHANNEL

1. RDM 1496, ONE-STEP FORMING

RDM 1496, is a one-step hot forming die which uses a side cushion to form Part 6, channel. The design is shown in Figure 11-1; the forming tools for the test part are shown in Figure 11-2.

Development of a horizontal draw forming technique makes it possible to form curved "hat" and channel sections with deep chordal heights. Parts of this type normally require costly pre-form operations such as brake forming, stretching, drop hammering, and rubber forming. By utilizing the horizontal draw forming technique, a single operation can usually eliminate all pre-form requirements.

The horizontal draw die used to produce a curved "hat" section is described below. For illustration purposes, the tool pictured produces a shallow contoured part. However, the forming sequence is identical for a part having a more severe contour.

Figure 11-3 shows the heated die mounted in the press. The die is secured with stainless steel (RA330) bolts to the horizontal die cushion assembly, which can be seen at the right side of the picture. The part blank can be seen loaded in the die, positioned between the draw ring (heavy section) and the female die (channeled section). The female die is then moved in by actuating the rear horizontal pushers (at left) to contact the part blank. The die is held in this position for one to two minutes to heat the part. To complete the forming cycle, the part is clamped between the female die and the draw ring and the rear pushers actuated to draw form the part (Figure 11-4).

After a three-to-five-minute "soak" period, the pushers retract the female die, permitting removal of the formed part by the operator (Figure 11-5). The finished formed part can be seen in Figure 11-6. In Figure 11-7 the part is being checked on the cold die.

Figure 11-8 shows the horizontal forming die for the channel member (RDM 1496, one-step). The left side utilizes bed cushion pressure and the right side uses clamp pressure. Both pressures are adjustable on the USI press. This photograph was taken after completion of seventy-two pieces.

Figure 11-9 shows the flat pattern in the foreground and the finished formed channel in the background. (See Table A-17.)

2. RDM 1510, TWO-STEP FORMING

RDM 1510 is a hot sizing die for Part 6, channel. (See design, Figure 11-10.) Twelve pieces of each alloy and thickness (a total of seventy-two pieces) were preheated to 1000°F and preformed by the drop hammer/rubber technique utilizing RDM 1510. In the preforming operation, the flat patterns were pre-heated to 1000°F on a portable heated platen. This operation was followed by hot sizing the seventy-two pieces and all checked out within the target tolerances (Table A-18).

3. CONCLUSION

For this part tool fabrication costs for the two-step method are substantially higher and savings can be realized in the part-forming time required by using the one-step method. (See chart below.) In contrast to the one-step method, the two-step method requires a drop hammer set-up, part heat-up time, and additional time to set up the die for hot sizing. Although in this case both methods work well, the one-step die produces a better quality part at a lower cost; therefore, the one step method is the preferred technique.

COST COMPARISON

	One-Step	Two-Step	Time Saved	Preferred Technique
Tool Mfg. Time	260 hr	310 hr*	50 hr	One-Step
Average Part Forming Time	12 min	17 min	5 min	

* Includes cost of a drop hammer die.

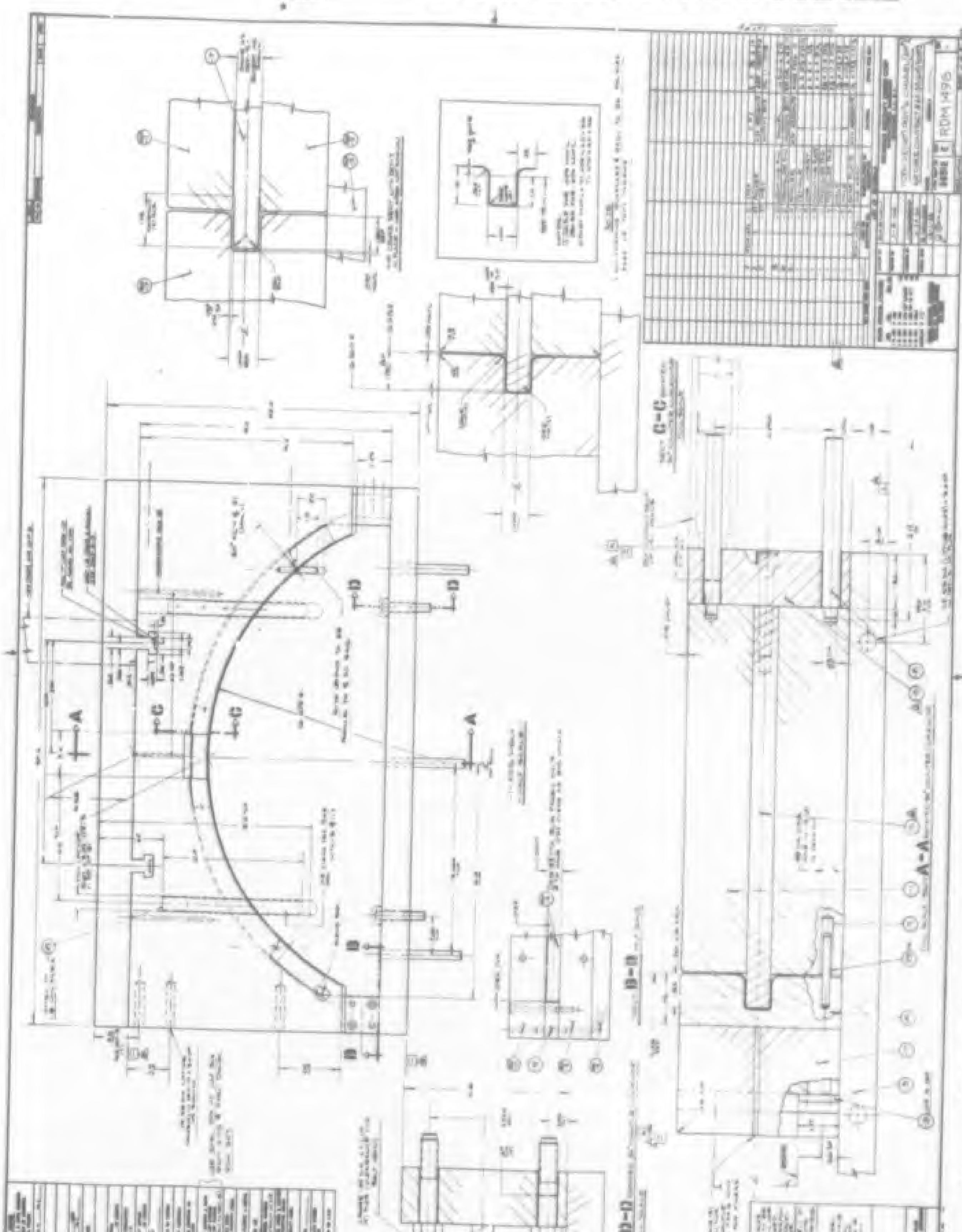


Figure 11-1 RDM 1496 - One-Step Hot Form Die Using Side Cushion for Part #6 - Channel

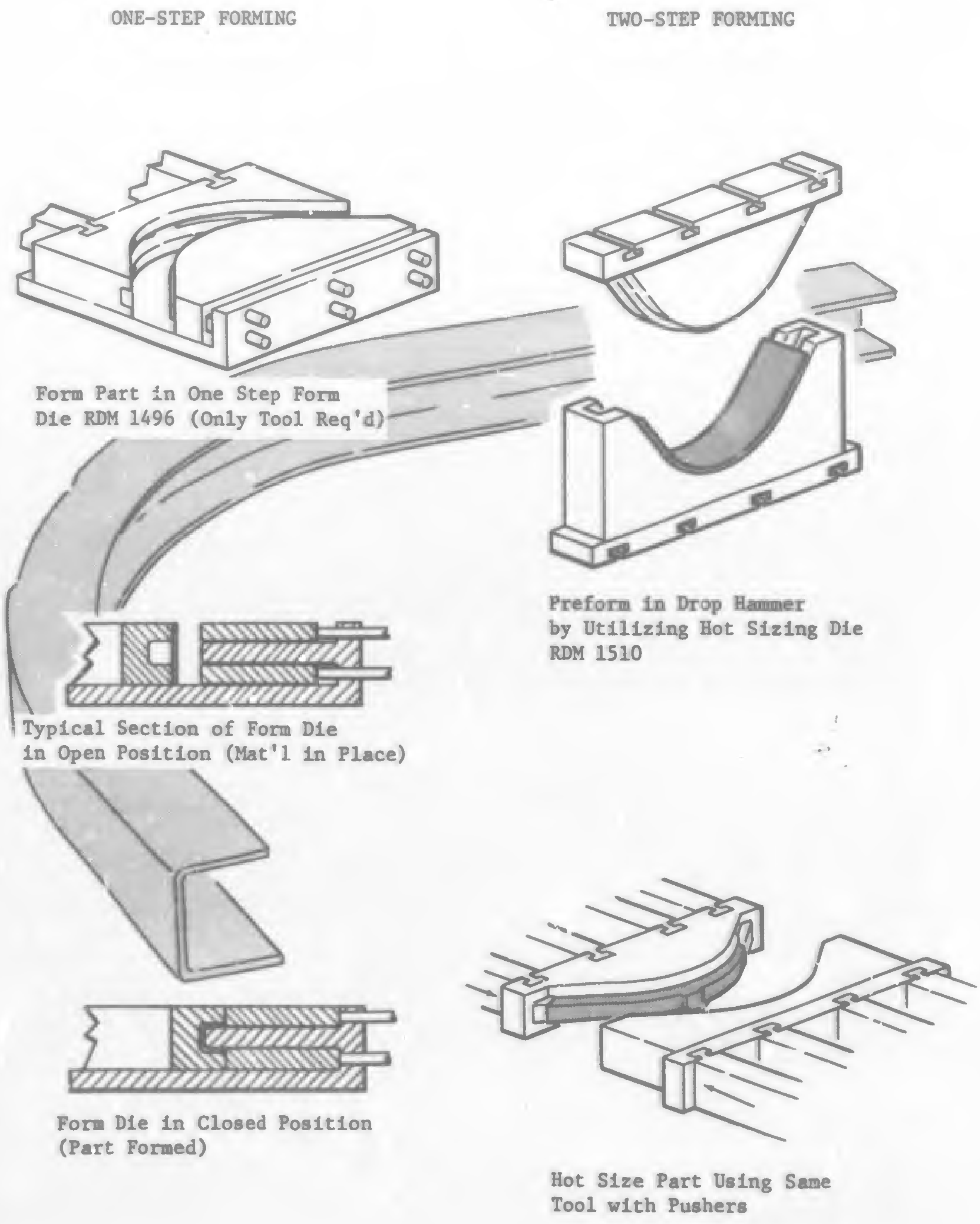


Figure 11-2 Forming Tools for Test Part #6 - Channel

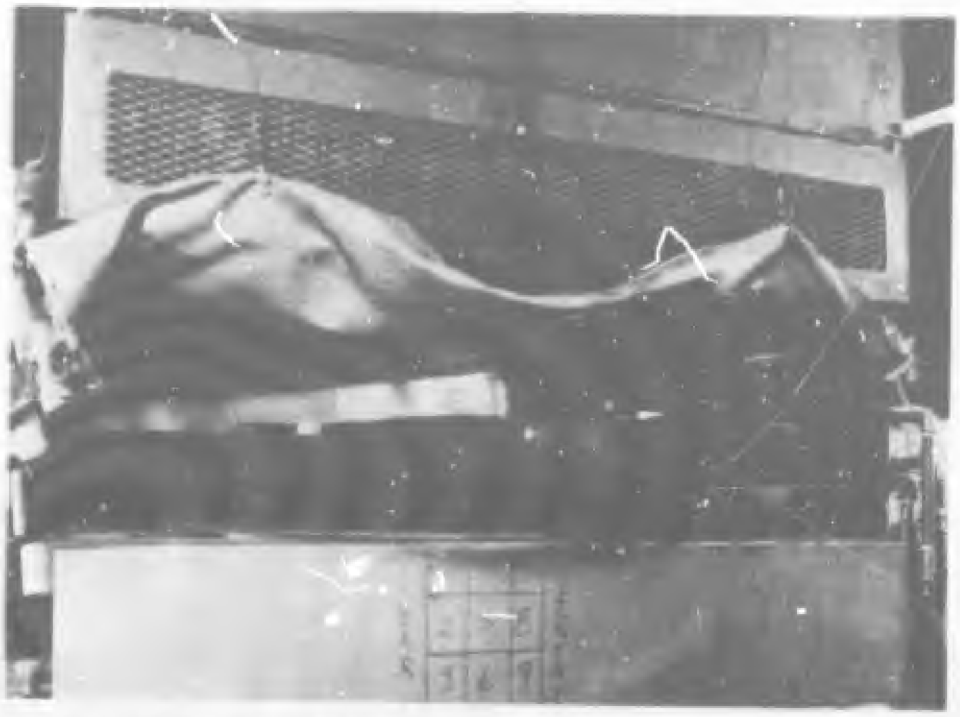


Figure 11-3 The Horizontal Draw Die Mounted in the Press

Figure 11-4 The Rear Pushers are Actuated to Draw Form the Part

Figure 11-5 The Formed Part Being Removed by the Operator

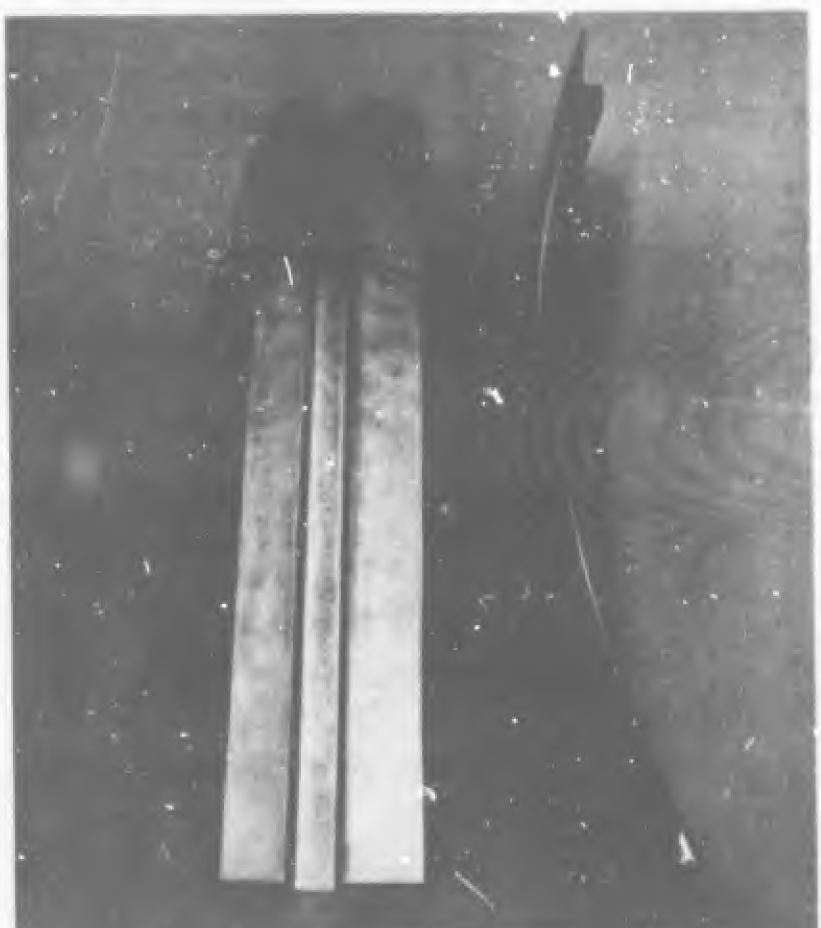


Figure 11-6 The Finished Curved "Hat" Section as Formed in One Operation

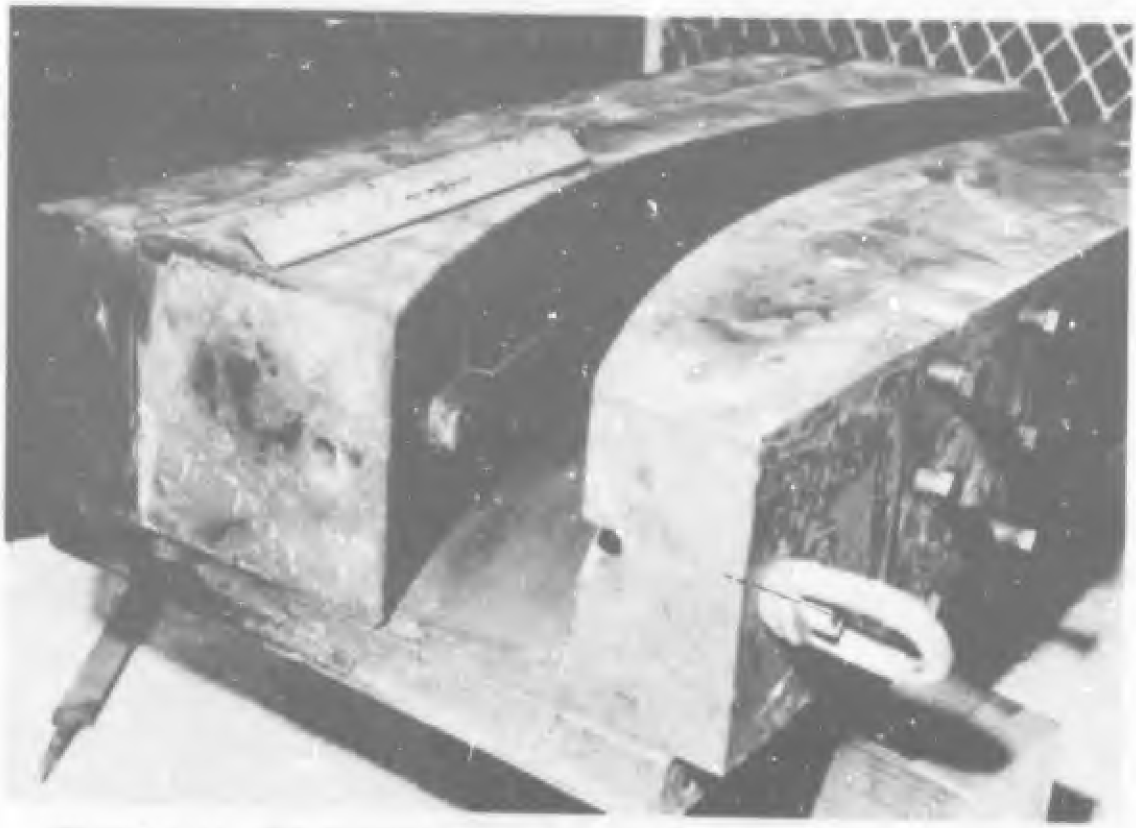


Figure 11-7 The Finished Formed Part is Checked on the Cold Die

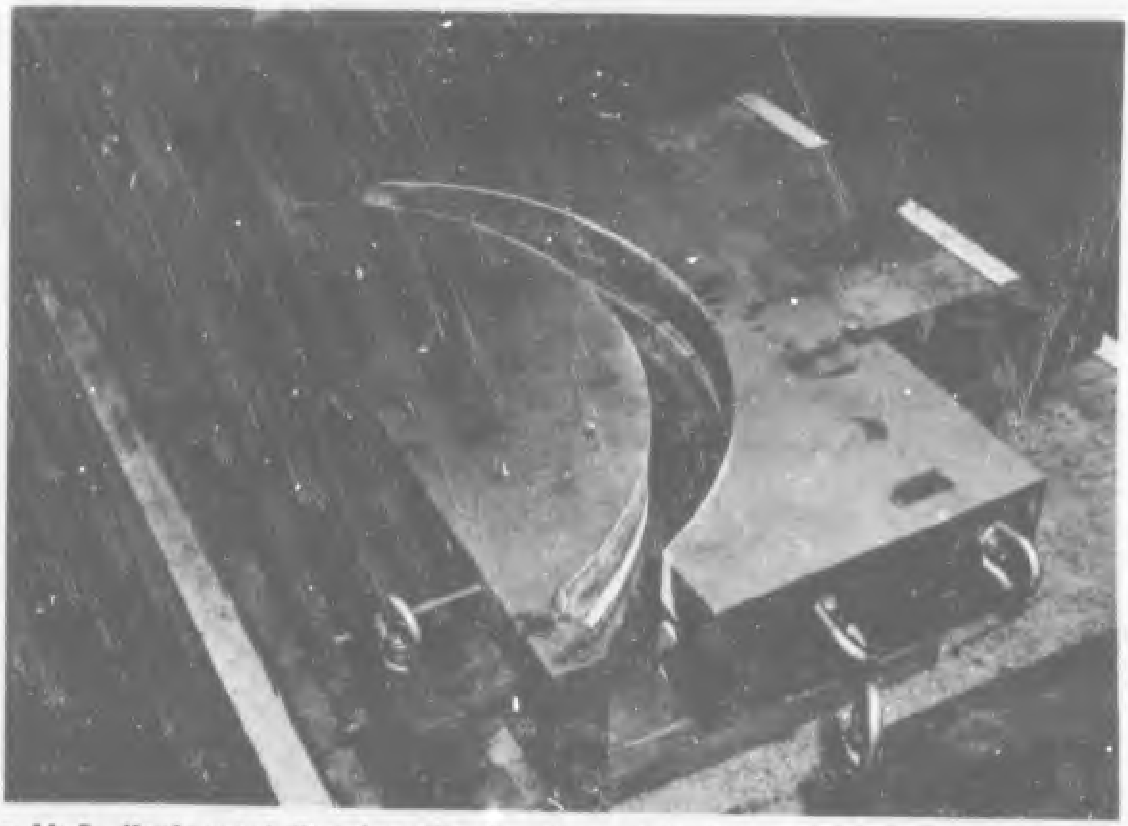


Figure 11-8 Horizontal Forming Die for Channel Member (RDM 1496, One-Step); Left Side Utilizes Bed Cushion Pressure, Right Side Utilizes Clamp Pressure

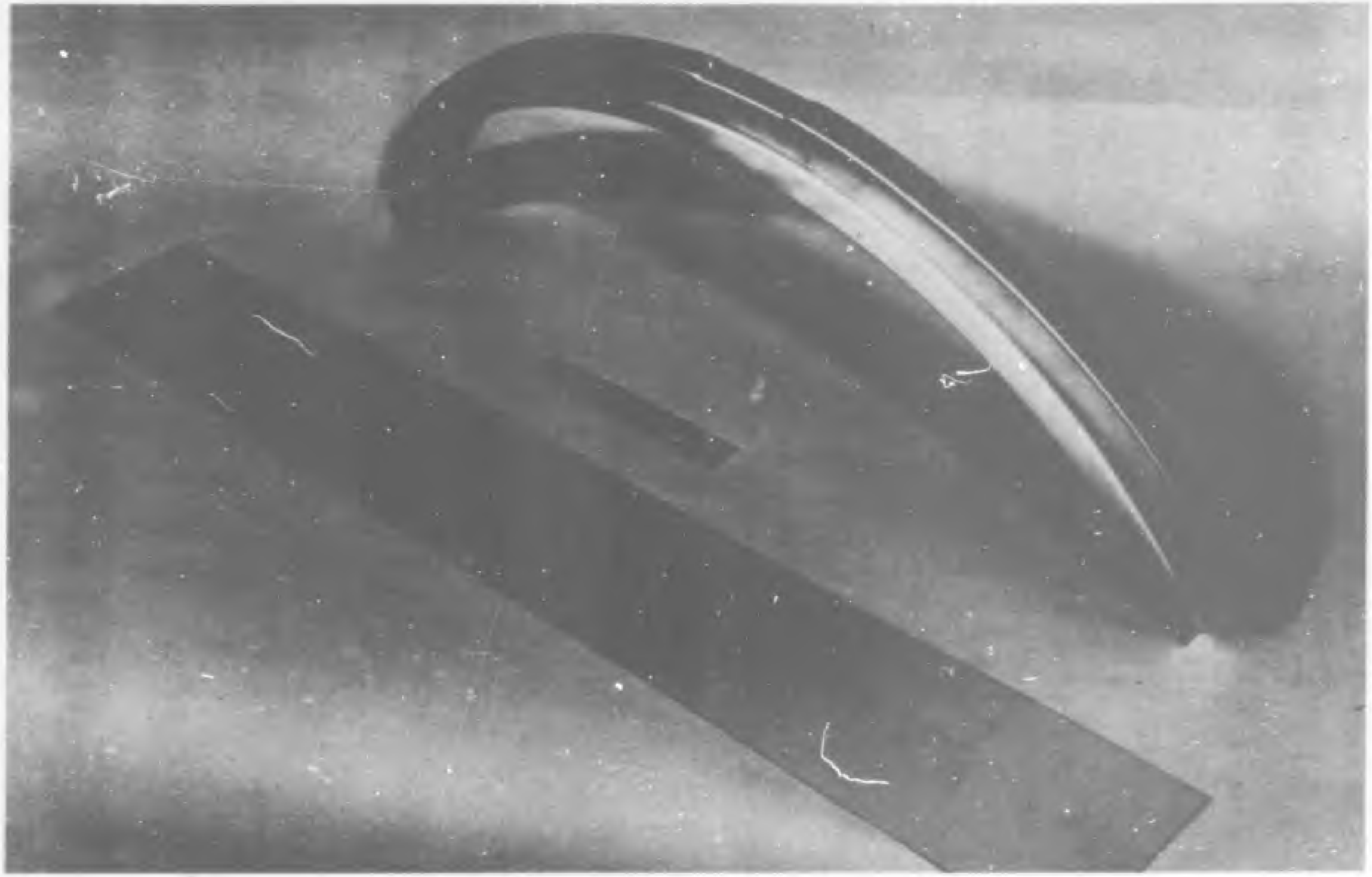


Figure 11-9 Foreground - Flat Pattern for Part 6, Channel
Background - Finished Formed Part (One-Step)

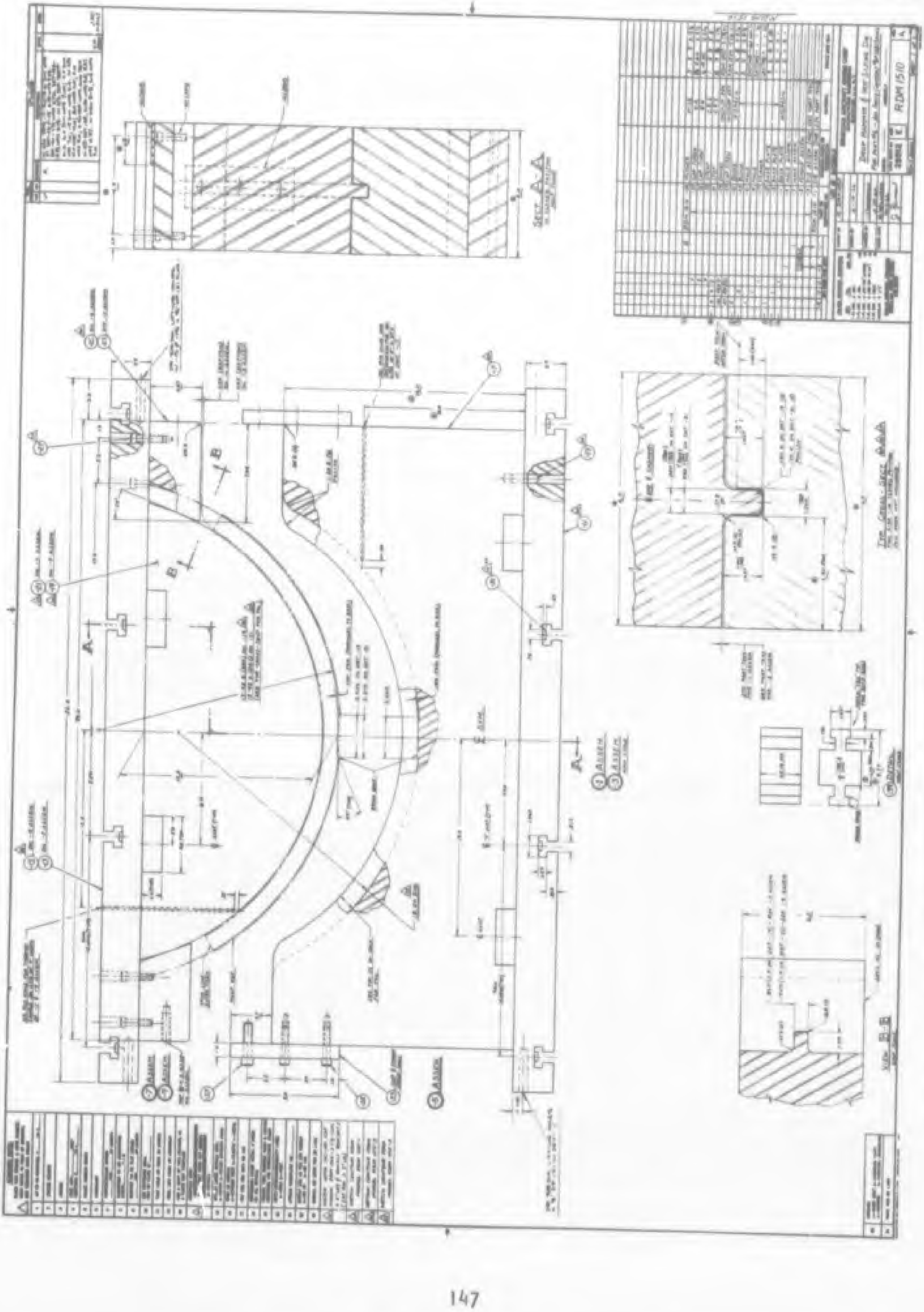


Figure 11-10 RDM 1510 - Two-Step Cold Preform and Hot Sizing Die for Part #6 - Channel

SECTION XII

SIMULTANEOUS FORMING AND AGING

1. 6Al-4V TITANIUM ALLOY

This particular 6Al-4V test program has been completed. It shows the feasibility of simultaneous forming and aging of production parts from solution-treated 6Al-4V titanium alloys using short-time aging cycles (Table 12-1).

The problem was to develop an optimum time-temperature cycle within which detail parts could be age-formed in a single operation while evidencing satisfactory aged mechanical properties. Another consideration was to keep springback to a minimum, while using a short aging time so as to be within economic press operating time.

a. Short Time Aging of Ti 6Al-4V

The initial series of laboratory tests on short time aging cycles applied to .025" thick solution-treated Ti 6Al-4V using the aging temperature range of 800°F through 1100°F. The specimens were lubricated before heating and then heated by inserting them between hot steel plates; they were subsequently descaled to closely simulate actual hot forming and cleaning parameters. Aging times of five through forty minutes were checked to keep within an economical time for use in a forming press. The complete data is shown in Table 12-1 and graphically illustrated in Figure 12-1.

The tabular and graphical data clearly show the 1000°F aging temperature to result in the highest yield while only being exceeded in ultimate by 900° and 950° aging. This table also shows the 1000°F aging to result in elongation values equal to the lower strength 1050°F and 1100°F aged material while exceeding those resulting from the lower temperature aging.

More tests were then run on .040" thick material in the laboratory, using various aging times at the chosen 1000°F temperature (Figure 12-2 and Table 12-2.). Data taken from tensile tests of laboratory-aged material in .025" and .040" thickness established that more than adequate mechanical properties could be obtained by using a time/temperature aging cycle of forty minutes at 1000°F. Forming tests were then conducted in the Williams White hot press using various times and temperatures to determine springback characteristics. Constant springback values between 1 1/2 to 2° were obtained at the 40 min/1000°F cycle. It was also found that the same springback values could be obtained in twenty minutes at 1050°F. (See Table 12-3)

Several existing production hot forming dies were chosen and utilized to form a number of production type F-111 details (ten each) at 1000°F for 40 minutes on the Williams White hot press. These parts were small angular bracket shapes with joggles. The details all formed satisfactorily, with the exception of a 2° springback (Figure 12-3).

Typical detail parts with annular ring and zee configurations were form-aged from .025" and .070" solution-treated Ti 6Al-4V alloy sheet in the USI hot presses (six pieces each) using two short-time aging cycles of forty minutes at 1000°F and twenty minutes at 1050°F. Although the .025" ring parts were not perfectly formed, several rings were considered acceptable parts when cut within the trim line (Figure 12-4). Improvements can be made by changes in technique and die. The .070" formed rings were good in shape and flatness, and with 1/2° angularity on the flange legs. The zee configured parts had some springback, but could be made to conform to the die contours with light finger pressure. Several parts of each configuration were then subjected to a stress relief operation in an oven at 1000°F for two hours to check for possible distortions. The small angles and zee parts showed no appreciable changes, but the ring parts tended to distort slightly. A fixture may be necessary if stress relief is mandatory. A minimum of two tensile specimens were taken from several of the annular ring and "zee" members in both .025" and .070" thickness material and tensile tested. The results indicated that the simultaneously formed and aged details could meet the minimum mechanical property specifications (160,000 psi UTS - 145,000 psi yield and 5% elongation).

Thermal stability tests were conducted on various short time/temperature aged specimens which indicated that the creep stability characteristics of short-time formed and aged solution-treated 6Al-4V titanium alloy are not adversely affected.

2. CONCLUSIONS

- Maximum tensile properties of 6Al-4V Ti alloys can be developed in 20 to 40 minutes aging times at 1000°F.

- Simultaneous forming and aging of solution-treated 6Al-4V titanium alloy is feasible and practical by production hot press work using the optimum short-time temperature of forty minutes at 1000°F, providing for springback in the dies.

TABLE 12-1 SHORT TIME AGING OF SOLUTION TREATED Ti 6Al-4V-
STATIC TENSILE PROPERTIES

Time	Aged at 800°F			Aged at 900°F			Aged at 950°F		
at Temp. (min)	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")
5	164.0	148.5	6.0	171.0	154.0	7.0	168.5	151.0	5.0
10	167.0	152.0	6.5	169.5	150.0	6.0	173.0	155.5	6.0
20	172.0	154.8	5.0	173.5	151.0	5.0	175.5	157.0	7.0
30	173.0	155.5	6.0	172.7	156.5	5.0	174.0	155.5	5.5
40	-	-	-	-	-	-	176.5	157.5	5.5

Time	Aged at 1000°F			Aged at 1050°F			Aged at 1100°F		
at Temp. (min)	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")
5	170.3	155.5*	7.0	168.0	155.5*	7.5	165.8	152.8*	7.5
10	171.0	157.4*	7.0	169.5	157.6*	7.8	168.7	156.5*	7.8
20	171.2	158.5	8.0	168.0	158.0*	6.0	164.5	155.3*	8.8
30	170.0	157.5	5.5	169.0	160.0	6.0	165.0	155.9	7.5
40	172.9	161.0	7.5	-	-	-	-	-	-

*Average of two values. All other points are individual tests.

Solution treated properties of the 0.025" sheet } 150.5 ksi ultimate strength, 130.8 ksi yield strength, 11.0% elongation in 2"

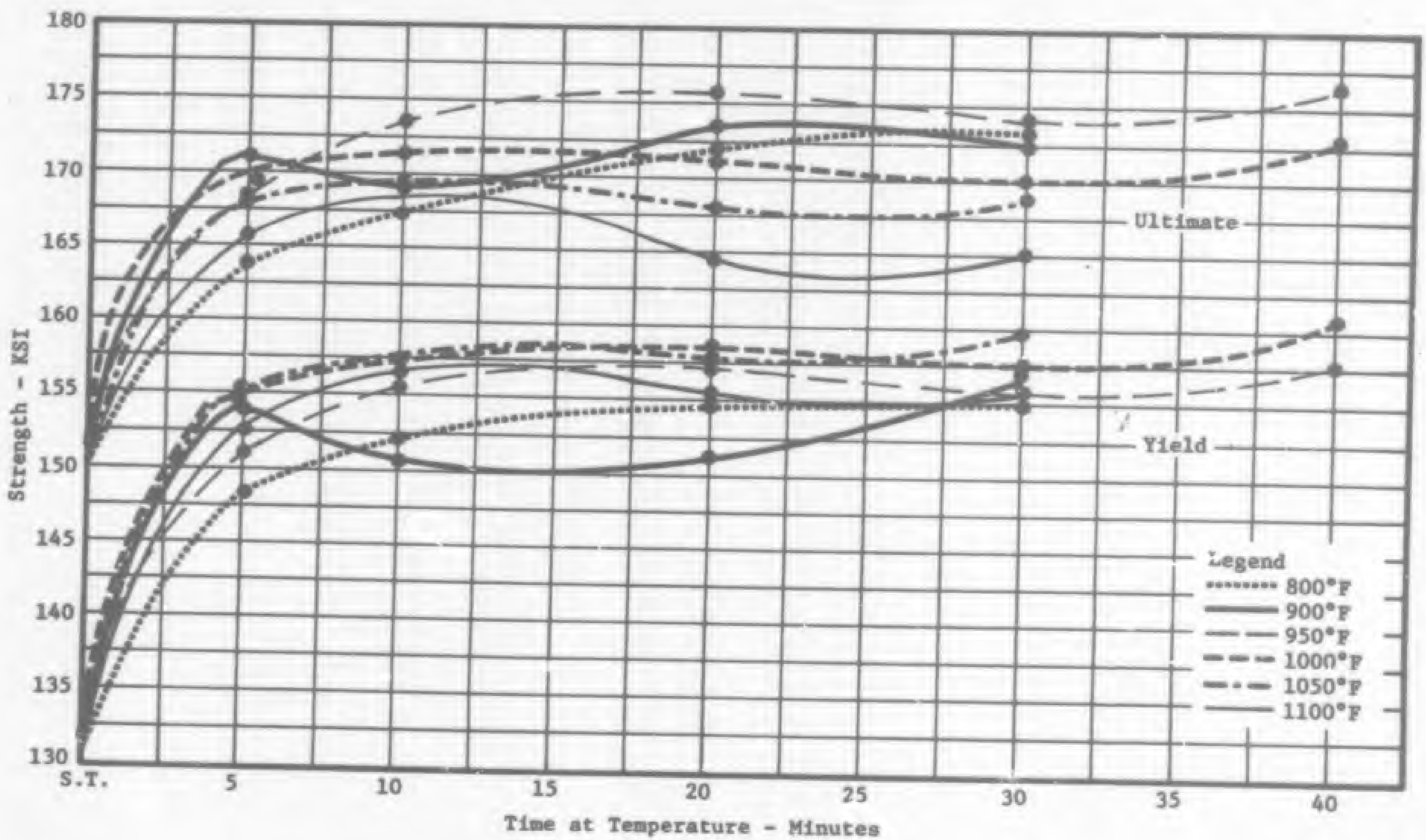


Figure 12-1 Short Time Aging of Solution-Treated Ti 6Al-4V

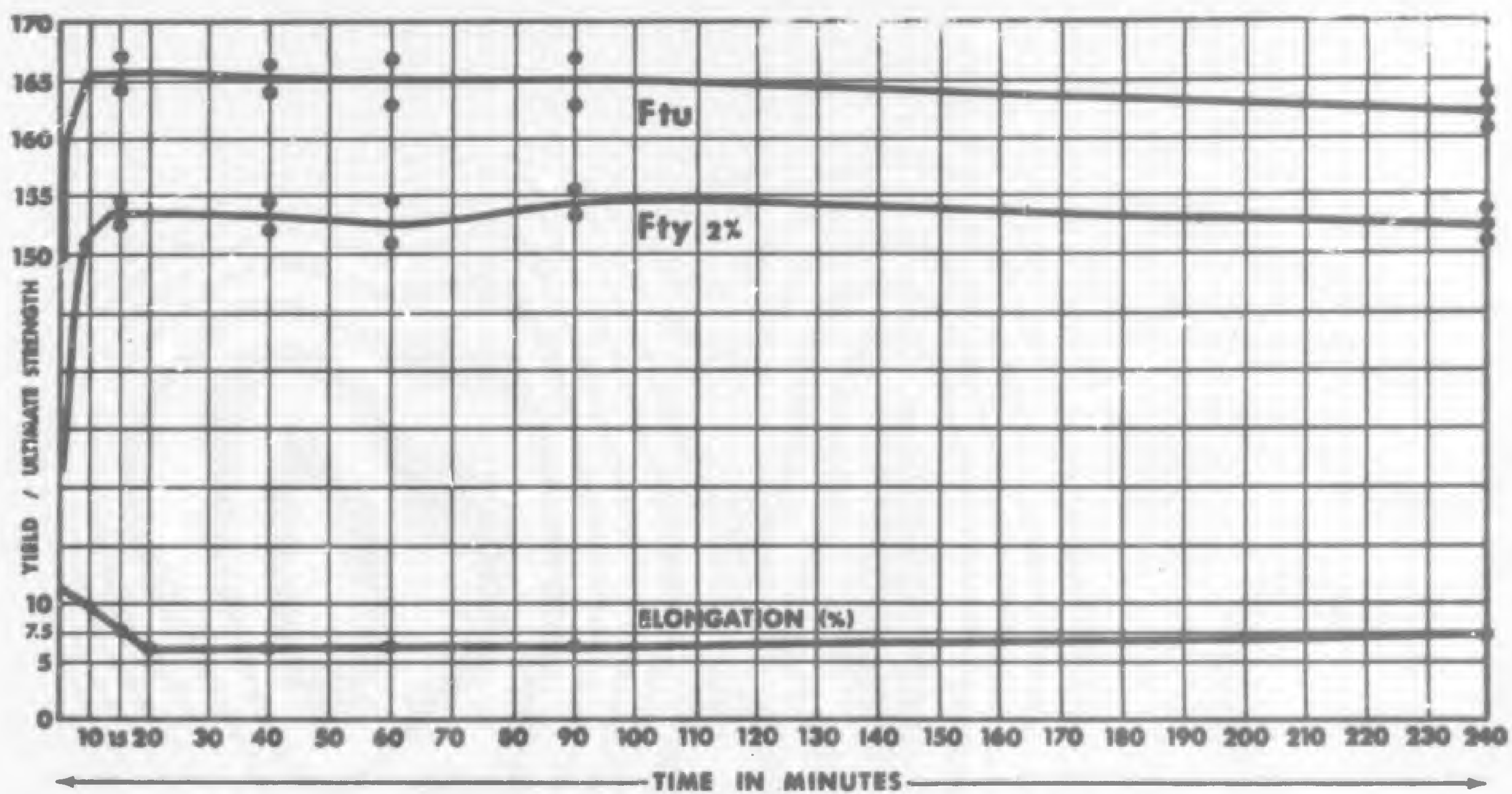


Figure 12-2 Short Time Aging Response at 1000°F Solution-Treated 6-4 Titanium, .040 Gauge, Heat 1768

TABLE 12-2 SHORT TIME AGING TIME/TEMPERATURE TESTS

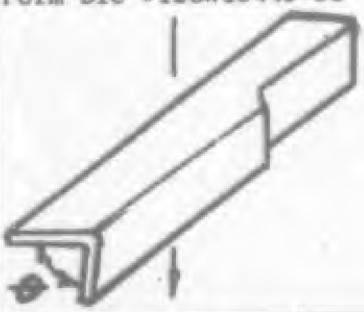
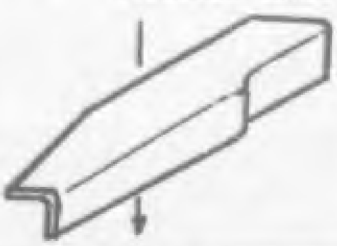
Ti Alloy 6Al-4V

Code	Gauge	Grain	Time/ Min.	Temp°F	FTY KSI	FTY KSI	Elong %	Rc	Remarks
ST1	.040	T	--	RT.	151.0	127.0	10.0		
ST2			--	RT.	147.5	121.0	11.0		As received.
Avg			--	RT.	149.3	124.0	10.5	34	
15-1	.040	T	15	1000°F	164.5	152.5	8.0		
15-2			15		167.0	154.5	7.0		
Avg			15		165.8	153.5	7.5	37-38	
20-3	.040	T	20	1000°F	168.0	148.0	6.0		
20-4			20		164.0	152.0	6.0		
Avg			20		166.0	150.0	6.0	37-38	
40-7	.040	T	40	1000°F	164.5	154.0	7.0		
40-8			40		163.7	151.5	7.0		Cooled in
Avg			40		164.1	152.8	7.0		liquid nitrogen
40-1	.040	T	40	1000°F	165.0	153.0	7.0		
40-2			40		166.0	154.5	6.0		
Avg			40		165.5	153.8	6.5	37-38	
60-1	.040	T	60	1000°F	163.0	151.0	6.0		
60-2			60		167.0	155.0	7.0		
Avg			60		165.0	153.0	6.5		
90-1	.040	T	90	1000°F	163.0	154.0	6.0		
90-2			90		167.0	155.0	6.5		
Avg			90		165.0	154.8	6.3	37-38	
4-1	.040	T	240	1000°F	161.5	152.5	7.5		
4-2			240		163.7	154.5	7.5		
Avg			240		162.6	153.5	7.5	37-38	
A	.040	T	10	1050°F	162.2	151.0	7.5		
B			10		164.2	154.9	7.0		
Avg			10		163.2	153.0	7.3	37	
C	.040	T	20	1050°F	165.5	155.4	8.0		
D			20		160.5	150.0	9.0		
Avg			20		163.0	152.7	8.5	37	
E	.040	T	30	1050°F	161.5	154.0	6.0		
F			30		161.5	154.0	8.0		
Avg			30		161.5	154.0	7.0	37	

TABLE 12-3 SPRING BACK TESTS - SOLUTION TREATED

6Al-4V Titanium

.040 gauge H 1768

Test No.	Spec No.	Grain	Temp.	Dwell	Soak Time (Min)	Avg. Spring-back Angle	Hardness Rc	Remarks
1	1	T	1000	2 Min	20	3.50	38.5	Form Die #123W10449-95
2	2				30	4.0	37.5	
3	3				40	2 - 3.0	37	
4	4				50	1.25	37	
5	5				40	1.5 - 2	37	
6	6				60	1.5	35	
7	7				40	1.5	37	
8	8				90	1.75	37	
9	9				40	2.00	37	
10	10	T	1000	2 Min	40	2.00	37	
11	11	L	1100	2 Min	5	2.0	38.5	Form Die F-111 Part #12B3060 15/16
12	11A				5	2.0	37.5	
13	12				10	.75	37.	
14	12A				10	.75	37.	
15	13				15	1.0	37.	
16	13A				15	1.0	N-T	
17	14				20	.50	37.	
18	14A				20	.50	37	
19	13A		1100		35 tot.	.25	35	
20	20	L	1050	2 Min	10	2.25	38	Die #123W10449-95
21	20A				10	2.5	38	
22	21				20	1.5	38	
23	21A				20	2.0	38	
24	22				30	1.5	38	
25	22A				30	1.5	37	
26	23				40	1.5	38	
27	23A	L	1050	2 Min	40	1.5	38	
28	24		1100	2 Min	10	1.5	38	
29	24A				10	2	38	
30	25				20	1	38	
31	25A	L	1100	2 Min	20	1	38	
32	32	T	1100	2 Min	10	1.0	37	
33	33				15	.75	37	
34	34				20	.5 - .75	37.0	
35	35		1150		5	1.75	37.0	
36	36		1150		10	.5 - 1.0	36	
37	37		1150		15	.75	36	
38	38		1200		5	1.0	37	
39	39		1200		5	.75	36	
40	40		1200		10	.0	36	

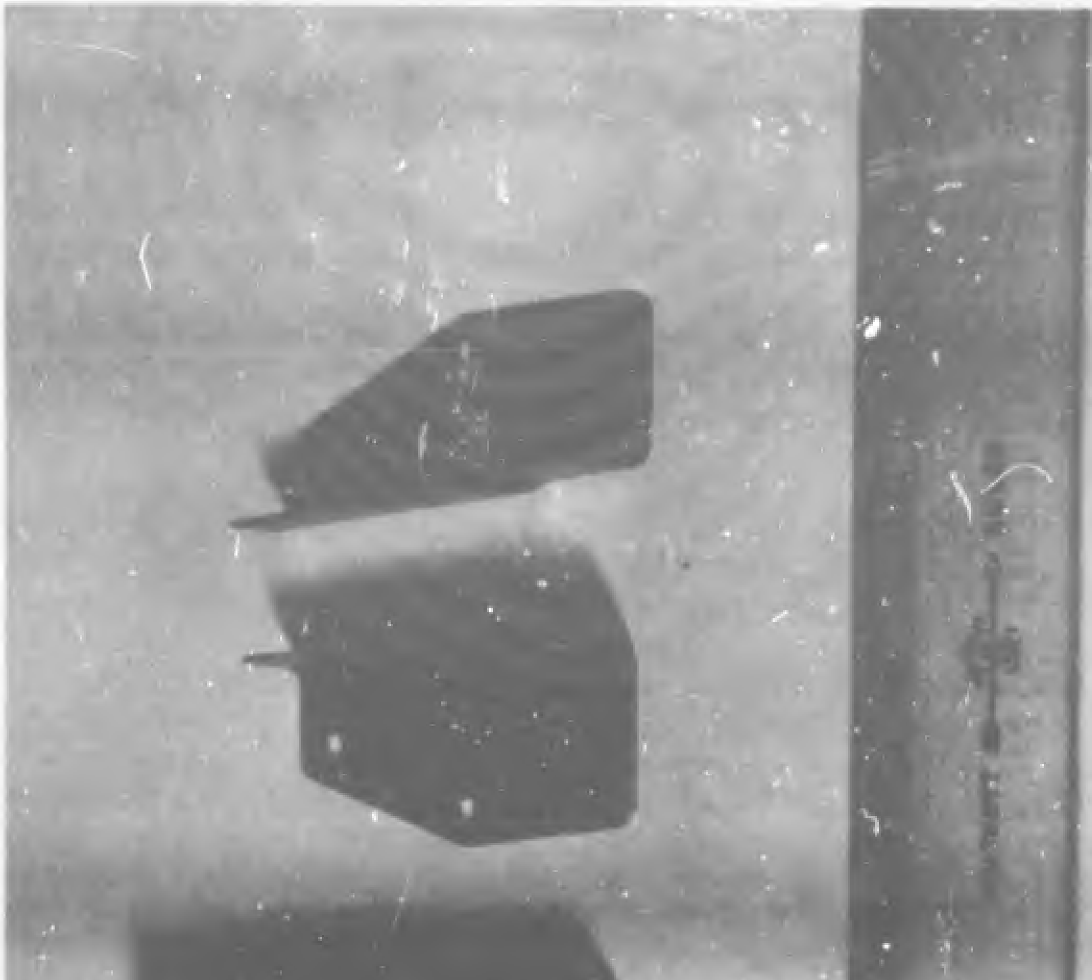
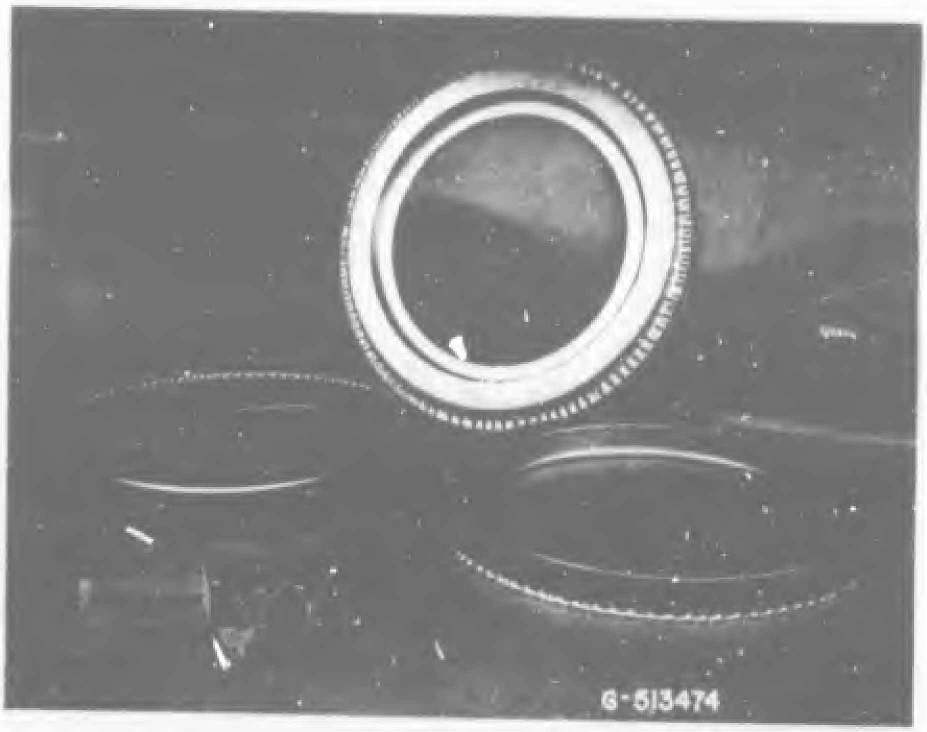


Figure 12-3 6Al-4V Titanium Simultaneously Formed and Aged



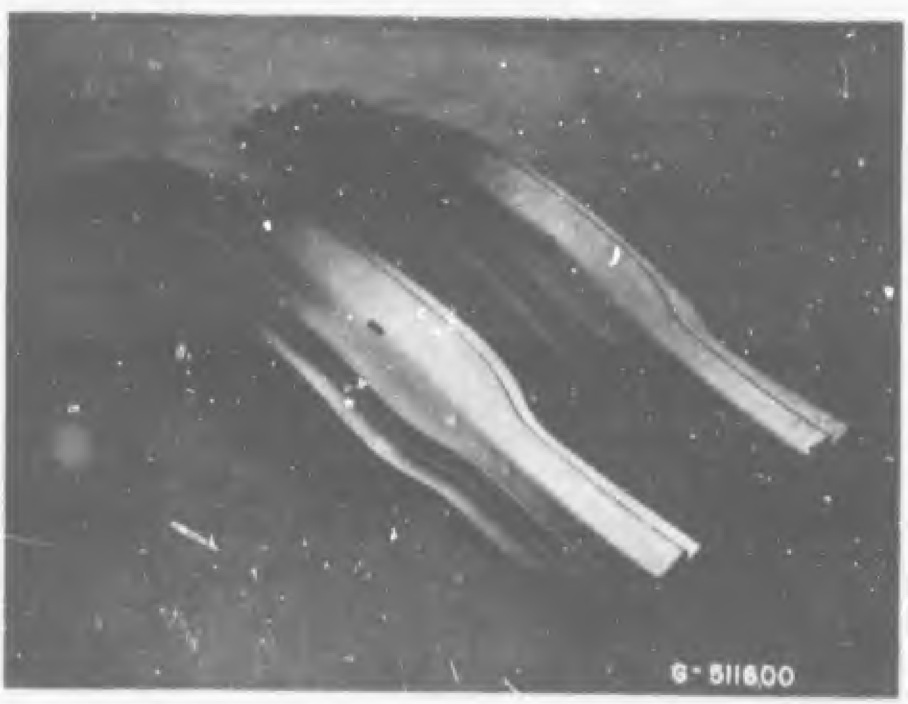


Figure 12-4 Annular Rings and Zee Configurations

SECTION XIII

METALLURGICAL TESTING

1. Ti 8Al-1Mo-1V

Simulated hot forming of duplex annealed Ti 8-1-1 indicated no degradation of strength properties when specimens were exposed in the 1300°F to 1500°F range for fifteen minutes and air-cooled. These results (average of three tests) obtained from .090-inch sheet, Heat No. D4535, are shown in Table 13-1. No degradation was expected because Ti 8-1-1 is essentially an all alpha material.

Specimen blanks used in the tests alone were cleaned and lubricated to simulate forming procedures before exposure to the hot forming range. The blanks were then descaled and final-machined to the configuration shown in Figure 13-1.

The duplex annealing cycle, added to the mill annealed cycle of Ti 8-1-1, falls into the hot forming range utilized in the evaluation of the duplex annealed material (See Table 13-2.) It was considered possible that mill annealed material might be purchased at a savings over duplex annealed material and converted to duplex annealed material during the hot forming cycle. With this consideration, mill annealed Ti 8-1-1 material was subjected to a range of temperatures encompassing the hot forming cycle. The resultant properties are tabulated in Table 13-3 and shown graphically in Figure 13-2.

The results showed that strength properties (ultimate and yield strengths) decrease with increasing exposure temperature. While the values plotted are essentially the five-minute exposure data, inspection of Table 13-3 reveals that the thirty-minute exposure data varies by less than 1% from the five-minute exposure data. Both curves undergo an inflection at approximately 1300°F (entering the annealing range) and tend to level out after 1450°F (the duplex annealing cycle). This data tends to indicate that, if material stock identification were not a problem, mill annealed material (cheaper than duplex annealed) might be used where duplex annealed properties are required and hot forming techniques are to be utilized.

2. Ti 6Al-6V-2Sn

The effect of simulated hot forming cycles on the properties of annealed Ti 6Al-6V-2Sn sheet material was investigated. Thermal exposure of a heat of .080-inch material (Heat No. D5869) to temperatures above 900°F for times of five to thirty minutes, followed by air cooling, resulted in a degradation in strength properties. The loss in strength increased with increasing exposure temperature to 1350°F. Another heat of material, .055-inch sheet Heat No. D2430, exposed to temperatures from 1000°F to 1300°F for times of five and fifteen minutes, also showed increased strength losses as exposure temperature was increased. These results for both heats of material are shown in Tables 13-4 and 13-5 and Figure 13-3 (a and b).

The strength loss which occurs with high temperature exposure has been attributed to heating into the alpha plus beta range, where a partial solution treating effect is obtained with the relatively fast air cool from the alpha plus beta field. This reasoning is supported by data generated in another Grumman program wherein subsequent aging at 950°F for two hours resulted in a noticeable restoration of strength. Also in this program, Knoop hardness readings on material exposed at 1350°F and air-cooled were noticeably lower than those of either the as-mill annealed material or material exposed at 1350°F and subsequently aged at 950°F for two hours. (See Table 13-6.) This is indicative of a phase change occurring during the thermal cycling.

The details of this other Grumman-sponsored program are discussed in the following paragraphs. The program was performed by Grumman to further investigate the effect of simulated hot forming cycles on the properties of annealed Ti 6Al-6V-2Sn sheet materials. Exposure to temperatures in the range of 1050°F to 1350°F for time periods of five, fifteen, and thirty minutes were conducted on fully-machined tensile specimens (Figure 13-1) which were alkaline cleaned and coated with Form Kote T-50 prior to the elevated temperature exposure. The specimens were cut from sheet thicknesses ranging from .025 to .125 inch to determine if the resultant properties were a function of material thickness. Approximately one-half of the specimens were subsequently aged at 950°F for two hours prior to testing; the remainder were tested without having undergone the aging cycle. In all cases, the specimens were air-cooled following exposure to temperature. Testing was performed using a Riehle FH-60 tensile tester at a constant strain rate of .005 inch/inch/minute.

Tables 13-7 through 13-11 summarize the results of tensile tests on specimens subjected to a variety of thermal cycles. The results shown represent the average of duplicate tests except where otherwise noted. Referring to the tables, it is noted that the temperature attained during the heating cycles was the controlling factor on the resultant mechanical properties. Increasing the time at temperature had an insignificant effect.

Figures 13-4 through 13-7 illustrate the effect of strength versus simulated forming temperature for the various sheet thicknesses tested. The curves represent the averaged strength values of specimens held at temperature for five, fifteen, and thirty minutes. The loss in strength with increasing temperature is readily apparent. Superimposed on these curves are the resultant strengths obtained after subsequent aging at 950°F for two hours for the respective sheet thicknesses. The restoration in strength as a result of the aging cycle is apparent.

It was noted that in all cases, specimens exposed to 1350°F and subsequently aged at 950°F for two hours demonstrated strengths greater than that of the original as-mill annealed material. As a result, further consideration should be given to an evaluation of forming temperatures above 1350°F (say 1400°F to 1500°F) followed by aging at 950°F for two hours. Such a forming cycle may result in significantly increased strength in the final formed parts over that of as-mill annealed Ti-6Al-6V-2Sn sheet. Strength levels approaching that of the solution treated and aged condition are possible. In fact, this reasoning was verified (as part of the AF program) on an actual zee-member part which was formed from annealed Ti 6-6-2 .025-inch material at 1400°F for three minutes and subsequently aged two hours at 950°F.

After having formed the zee member three minutes at 1400°F, the part was examined and tensile specimens were removed from several areas of the part to check its material properties (Figure 13-8). Yield strength was drastically reduced while the ultimate strength was reduced only to what would have been expected by extrapolation of the simulated forming curves. Additional tensile specimens were then removed from several areas of the part (Figure 13-8) and aged two hours at 950°F in an attempt to restore mechanical properties. The resultant aged properties showed an increase in ultimate and yield strengths. These "as formed" and "as formed plus aged" tensile results are shown in Table 13-12.

Photomicrographs in Figure 13-9 show the microstructures of the original annealed material, the hot formed material, and the hot formed plus aged material. The microstructure (Figure 13-9c) of the hot formed plus aged material appears like that of solution-treated and aged material. The tensile data of Table 13-12 and the microstructures in Figure 13-9 substantiate the reasoning that intimate tool contact and the thin gauge involved had allowed the 1400°F and air quench to partially solution-treat the material.

The 950°F age was not intended to be an optimum age nor was the 1400°F intended as an optimum solution treating temperature. The results, however, indicate that high strength Ti 6Al-6V-2Sn parts might be obtained by forming in the 1500-1600°F range and aging in the 950-1100°F range. The starting stock could be annealed material, which would generally average $1.00 per pound less than the solution-treated material required if simultaneous forming and aging were considered.

The results of simulated hot forming of annealed Ti 6Al-6V-2Sn sheet can be summarized as follows:

- Thermal exposure to temperatures above 900°F for times of five to thirty minutes, followed by air cooling, results in a degradation of strength properties from the as-mill annealed condition.
- The loss in strength increases with increasing exposure temperature, with very slight losses at 900°F to approximately 9-10% losses at 1350°F.
- The loss in strength is dependent on the exposure temperature. Increasing the time at temperature (up to thirty minutes) has an insignificant effect.
- The loss in strength associated with high temperature exposure is independent of material thickness in the range of 0.025 to 0.125 inch. Further consideration should be given to the effect of elevated temperature exposure on material thicknesses greater than 0.125 inch.

- Aging at 950°F for two hours subsequent to exposure results in a restoration of strength. The higher the exposure temperature (higher in the alpha plus beta field), the greater was the response to the aging cycle.

3. Ti 6Al-4V

a. Ti 6Al-4V, Annealed

Tests were performed on annealed Ti 6Al-4V, 0.080-inch (Heat No. 301174) to determine the effects of simulated hot forming temperatures on the resultant properties, as were done for Ti 8-1-1 and Ti 6-6-2. The ultimate strength of the Ti 6-4 material showed a slight decrease in strength over the range 900°F to 1300°F; while the yield strength was only very slightly affected until exposure temperatures exceeded 1100°F. Exposure to the highest temperature investigated (1300°F) caused only slight reductions in subsequent tensile properties, i.e., 5% reduction in ultimate strength and 3% reduction in yield strength. The results are shown in Table 13-13 and Figure 13-10.

Since the alpha-beta make-up of this material may result in some solution treatment occurring when air cooling from the higher forming temperatures, both slow-cooled and faster air-cooled specimens were tested. If partial solution treatment had occurred at the high exposure temperatures, a strength loss could be expected for the air-cooled and slow-cooled specimens. The drop-off in strength would be more noticeable for the air-cooled specimens. The resulting properties (Table 13-13), however, showed no significant differences between air-cooled and slow-cooled specimens and (as stated above) only slight strength reductions for either at the highest exposure temperatures. Therefore, these tests indicate that any effects due to partial solution treatment were not retained at room temperature after exposure to these temperatures.

Exposure testing was accomplished on fully-machined tensile specimens that had been cleaned in an alkaline bath and coated with T50 molydisulphide lubricant. Lubricated specimens were placed on a stainless steel hearth plate (1/4-inch thick) in an air oven. For the air-cooled tests, only the specimens were removed from the furnace. For the slow-cooled tests, the hearth plate was removed with the specimens and allowed to cool in still air. The specimens were chemically cleaned in a nitric-actane bath prior to mechanical testing.

Additional data has been generated on the effect of simulated hot forming temperatures on the room temperature strength of annealed Ti 6Al-4V. This was part of another Grumman-sponsored program. This data was generated on .125-inch annealed sheet and extended temperatures of simulated hot forming to 1500°F.

Duplicate tensile specimens (Figure 13-1) were tested following eight-minute exposure at 1200,1300,1400, and 1500°F. Temperature exposure was accomplished on fully machined tensile specimens that had been cleaned and coated with Fel-Pro C-300 lubricant. The specimens were air-cooled following the short time exposure at temperature and then de-scaled in a nitric-actane bath prior to testing.

The ultimate tensile strength of the .125-inch Ti 6-4 material was generally unaffected at all temperatures, while the yield strength experienced a slight decrease above 1300°F, i.e., 3.2% at 1400°F and 4.7% at 1500°F. The results are tabulated in Table 13-14. (These tests on .125-inch material indicate, as did the tests on .080-inch material, that any effects due to partial solution treatment were not retained at room temperature after exposure to these temperatures.)

b. Ti 6Al-4V, STA

An initial series of short time aging cycles on solution-treated Ti 6Al-4V, .025-inch sheet material, investigated the aging temperature range of 800°F through 1100°F. The specimens were lubricated before heating and then heated by inserting them between hot steel plates. They were subsequently descaled to simulate actual hot forming and cleaning procedures. Aging times of five to forty minutes were checked to keep within an economic time for use in a forming press. The data is shown in Table 13-15 and plotted in Figure 13-11.

The tabular and graphical data indicate that the highest yield strengths result when aging at 1000°F and 1050°F, whereas the highest ultimate strengths result at 950°F. Elongation values are highest for the higher aging temperatures, 1000°F, 1050°F, and 1100°F.

A second heat of solution-treated Ti 6Al-4V, .040-inch sheet, was subsequently aged at 1000°F and 1050°F for various time cycles. This work concentrated mainly on 1000°F aging where cycles were performed which included up to the standard four-hour aging cycle. In addition, thermal stability checks were performed on specimens aged at 1000°F to determine if differences existed between standard solution treated-and-aged material and the short-time aged material. The results of these tests are shown in Table 13-16.

Short-time aging at 1000°F showed higher strengths than at 1050°F, however, elongation was slightly better at 1050°F. Aging two hours at 1000°F subsequent to short-time aging at 1050°F showed a slight increase in tensile strength (compared to short-time aging at 1050°F).

Thermal stability checks for material aged at 1000°F showed less than 1% loss in tensile strength for any short-time age cycle and approximately 4% yield strength losses for most cycles including the standard aging cycle (four hours at 1000°F). There was no degradation of elongation for any specimens, in fact, values were higher by significant amounts. Initial strength values were higher for short-time aged material as compared to the standard four-hour aged material. Therefore, with respect to thermal stability, there were no detrimental effects of short-time aging cycles on Ti 6Al-4V as compared to the standard four-hour aging cycle.

Using the data generated above on the short-time aging of solution-treated Ti 6Al-4V, actual parts were hot formed and aged. These parts were simultaneously formed and aged from .025-inch and .070-inch solution-treated sheet material into annular rings and zee members. Tensile specimens were removed from the outer edges of the rings and the upper surfaces of the zees and tested. Specimens were also tested that were removed from the same heats of sheet material and subjected to simulated forming and aging cycles (no actual forming performed) similar to those cycles performed on the parts. The results of the above tests are tabulated in Table 13-17. A typical annular ring, before and after forming, is shown in Figure 13-12 and a typical zee member in Figure 13-13.

These tests on solution-treated material, although limited in number, indicate that parts can successfully be simultaneously formed and aged from solution-treated Ti 6Al-4V using short-time aging cycles. Further testing is recommended, however, before any definite conclusions are made.

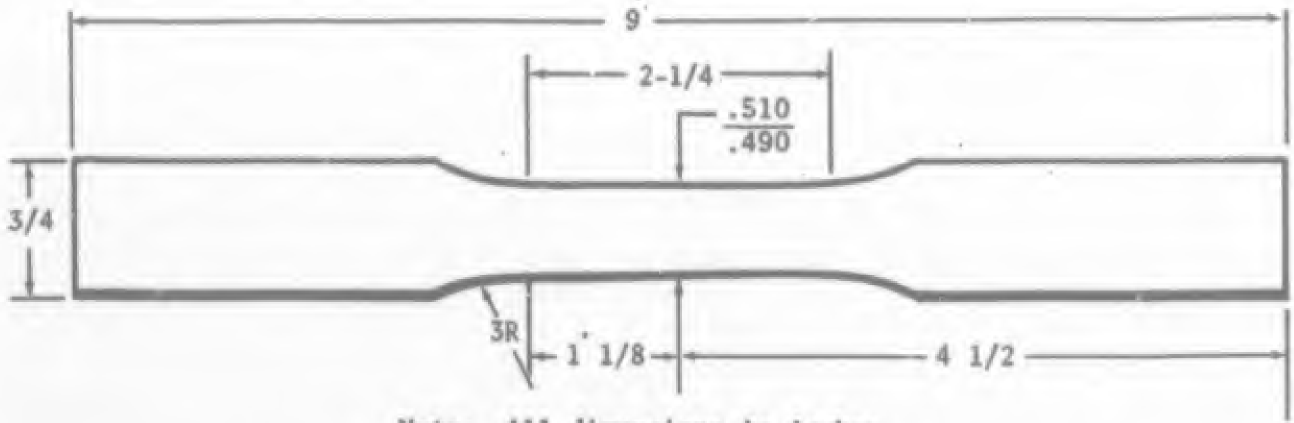
TABLE 13-1

EFFECTS OF SIMULATED HOT FORMING CYCLES ON DUPLEX ANNEALED TITANIUM ALLOY Ti 8Al-1Mo-1V .090" SHEET, HEAT No. D4535

Thermal Cycle*	Ultimate** Stress (ksi)	.2% Yield** Stress (ksi)	% Elongation** (in 2")
Vendor Certificate	143.7	135.0	14.5
1300°F (15 min) AC	145.3	135.3	14.2
1350°F (15 min) AC	141.8	132.1	14.2
1400°F (15 min) AC	143.8	133.0	14.2
1450°F (15 min) AC	144.0	133.5	14.2
1500°F (15 min) AC	144.7	133.1	14.2

NOTE: *Specimens were exposed at temperature for 15 minutes and then air cooled.

**Each value represents the average of three tests performed.



Note: All dimensions in inches

Figure 13-1 Tensile Specimen Used in the Testing of Titanium

TABLE 13-2

ANNEALING TREATMENTS OF Ti 8Al-1Mo-1V (SHEET)

Anneal	Treatment
Single Anneal	1425°F ± 25°F for 8-10 hours, Cool 50°F/hour max. to 800°F max., Air Cool
Duplex Anneal	1450°F ± 25°F for 8-10 hours, Cool 50°F/hour max. to 800°F max., Air Cool + 1425°F ± 25°F for 1/2-1 hour, Air Cool

TABLE 13-3

EFFECTS OF SIMULATED HOT FORMING CYCLES ON MILL ANNEALED TITANIUM ALLOY Ti 8Al-1Mo-1V 0.080 SHEET (HEAT 30513)

Thermal Cycle	Ultimate (ksi)	Yield* (ksi)	Elongation (% in 2")
Mill Annealed	161.7	154.8	13.5
1100°F (5 min) AC	158.3	155.7	15.0
1100°F (30 min) AC	157.0	154.4	15.3
1200°F (5 min) AC	157.2	153.7	14.0
1200°F (30 min) AC	157.4	154.1	14.0
1250°F (5 min) AC	156.2	152.9	13.7
1250°F (30 min) AC	156.3	152.5	14.2
1300°F (5 min) AC	155.8	151.2	14.1
1300°F (30 min) AC	155.5	150.5	14.0
1350°F (5 min) AC	153.8	147.6	12.5
1350°F (30 min) AC	151.6	145.9	15.2
1400°F (5 min) AC	152.3	145.2	14.0
1400°F (30 min) AC	152.1	145.0	14.2
1450°F (5 min) AC	151.2	143.2	14.2
1450°F (30 min) AC	151.3	143.8	13.8
1500°F (5 min) AC	150.5	141.8	13.2
1500°F (30 min) AC	148.7	140.0	15.3
1550°F (5 min) AC	150.8	141.9	14.8
1550°F (30 min) AC	149.2	139.9	15.5

* 0.2% Offset Yield

All values are the average of three (3) tests.

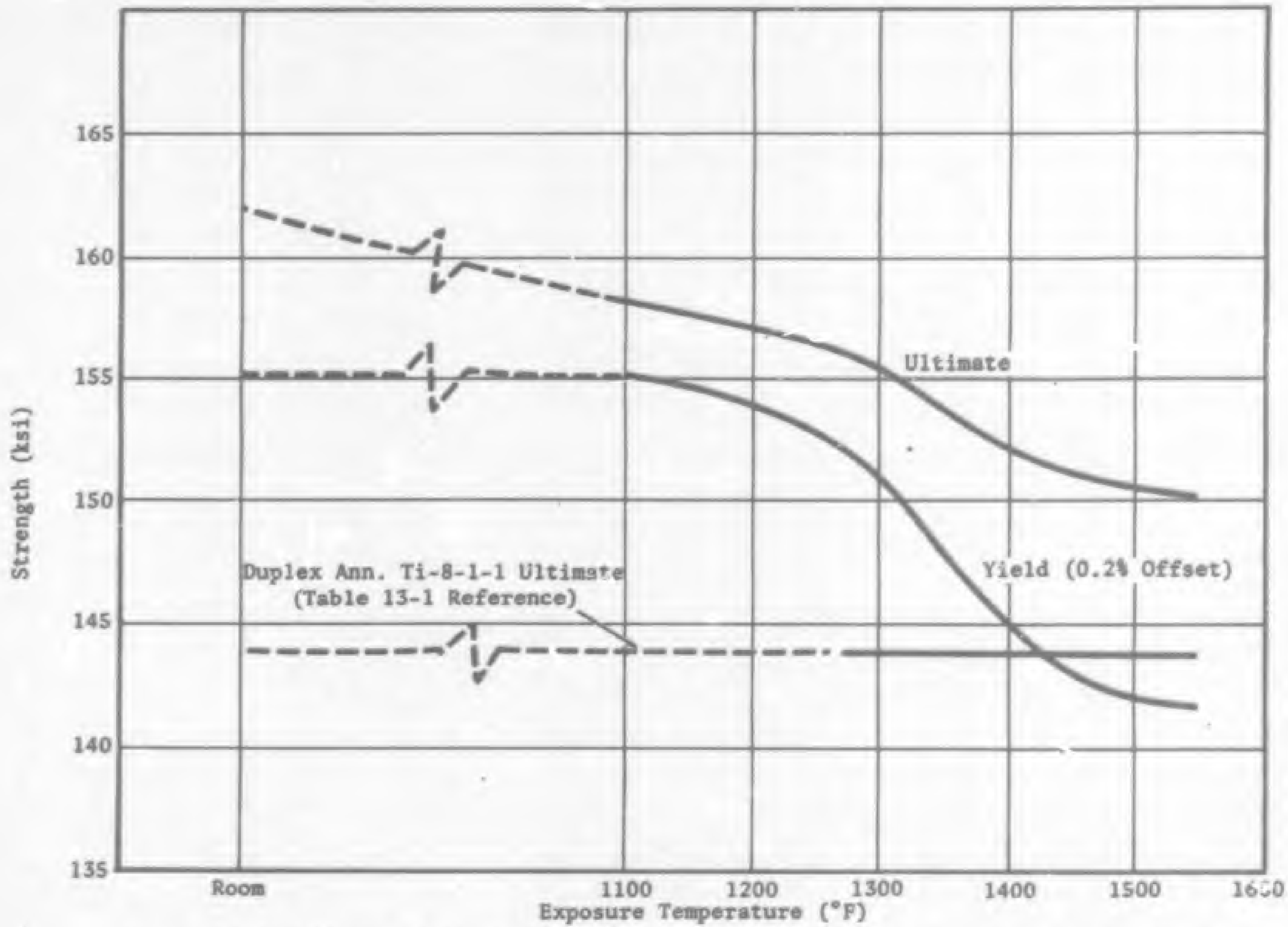


Figure 13-2 Effects of Simulated Hot Forming Cycles on Mill Annealed Ti8Al-1Mo-1V 0.080"Sheet (Heat 30513)

TABLE 13-4

EFFECTS OF SIMULATED HOT FORMING CYCLES ON ANNEALED TITANIUM ALLOY Ti 6Al-6V-2Sn 0.080 SHEET (HEAT D5869)

Thermal Cycle	Ultimate (ksi)	.2% Yield (ksi)	Elongation (% in 2")
Mill Annealed	167.3	158.4	10.0
900F (5 min) AC	168.5	158.2	12.5
900F (15 min) AC	167.3	157.2	12.7
900F (30 min) AC	168.1	157.4	14.0
1000F (5 min) AC	167.5	158.5	15.0
1000F (15 min) AC	167.2	158.0	12.2
1000F (30 min) AC	164.8	156.1	12.5
1050F (5 min) AC	165.6	155.7	13.2
1050F (15 min) AC	166.2	153.8	14.0
1050F (30 min) AC	165.1	156.4	13.2
1100F (5 min) AC	165.2	151.6	12.7
1100F (15 min) AC	163.6	152.3	13.7
1100F (30 min) AC	162.4	151.1	11.2
1150F (5 min) AC	162.2	150.0	12.5
1150F (15 min) AC	160.7	149.6	13.7
1150F (30 min) AC	159.8	148.8	12.5
1200F (5 min) AC	159.1	148.0	12.7
1200F (15 min) AC	158.2	147.0	14.0
1200F (30 min) AC	156.8	146.0	12.2
1250F (5 min) AC	155.8	144.8	12.5
1250F (15 min) AC	154.6	144.7	12.2
1250 (30 min) AC	153.2	142.1	11.2
1300F (5 min) AC	152.9	143.8	12.5
1300F (15 min) AC	152.1	142.0	12.0
1300F (30 min) AC	151.7	142.9	13.2
1350F (5 min) AC	152.9	143.8	11.7
1350F (15 min) AC	151.4	141.4	11.0
1350F (30 min) AC	150.1	143.6	11.2

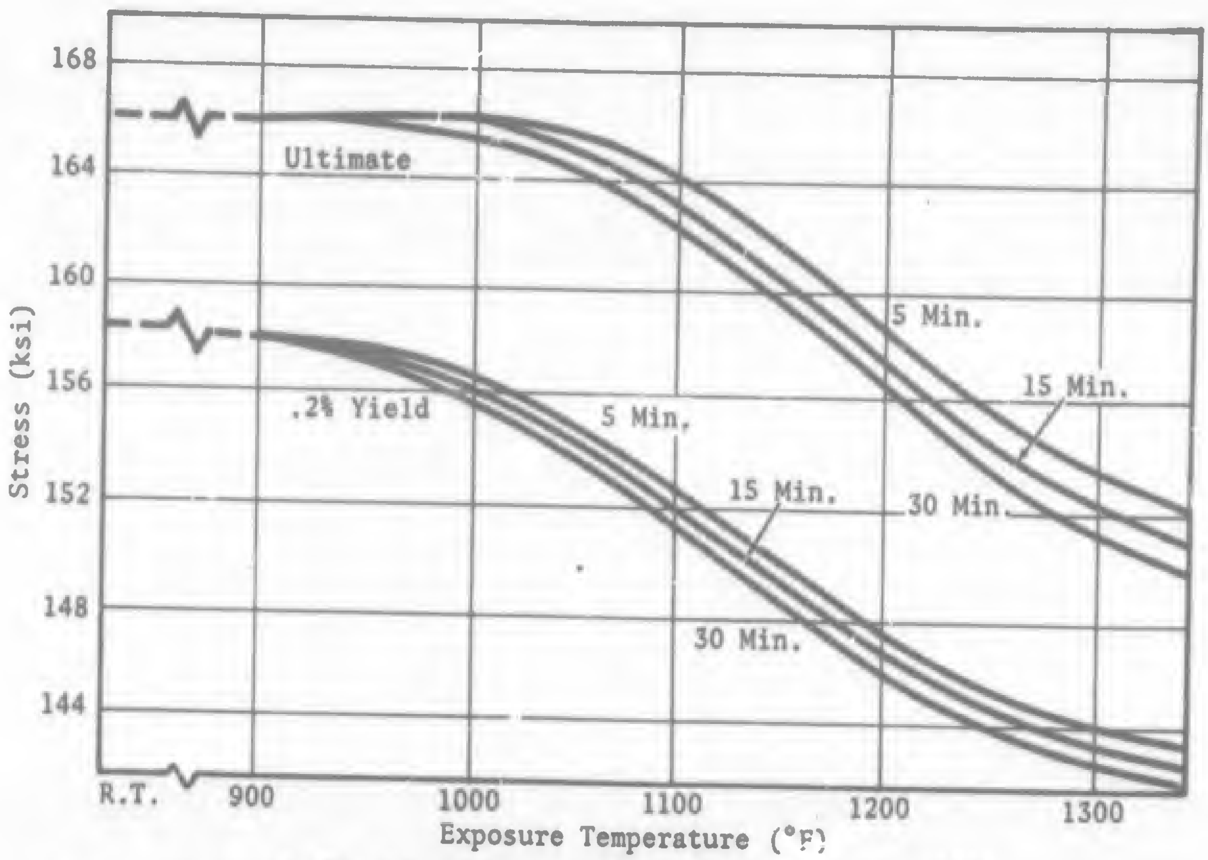
All values are average of two (2) tests.

TABLE 13-5

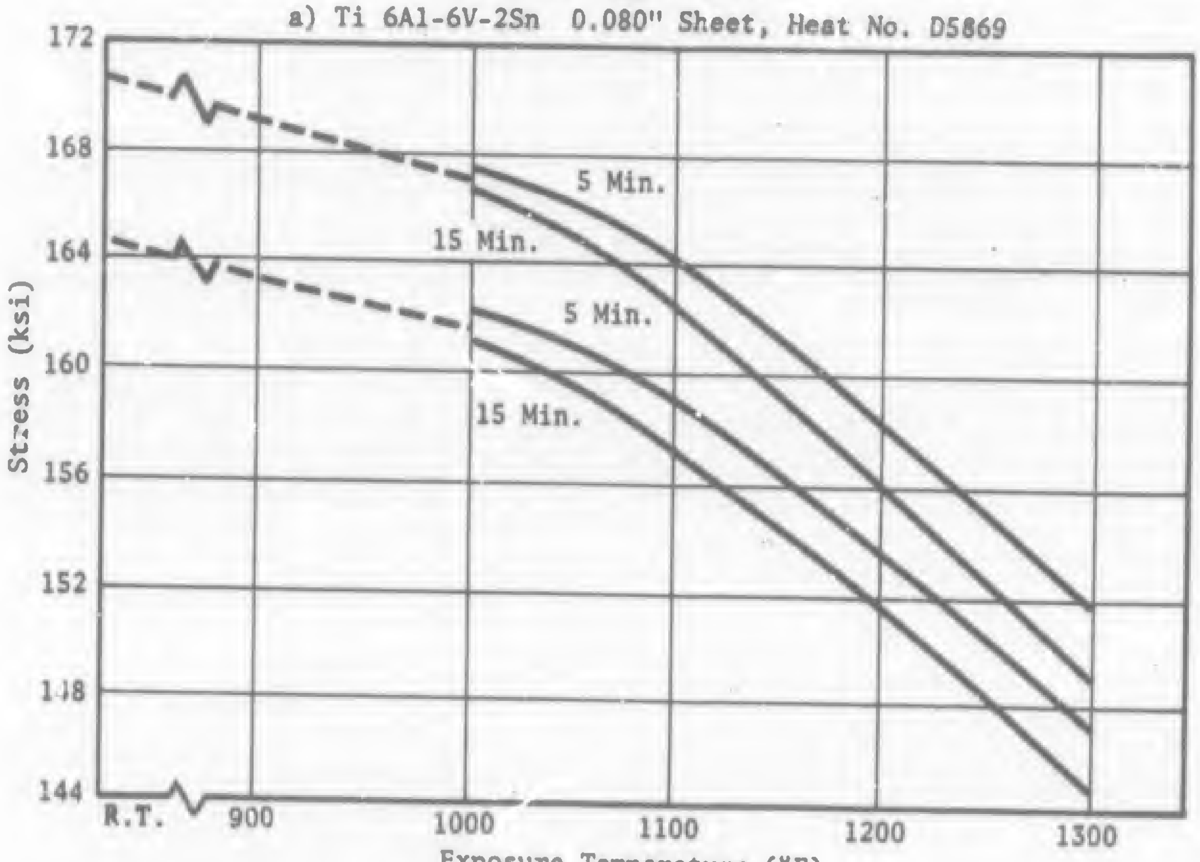
EFFECTS OF SIMULATED HOT FORMING CYCLES ON ANNEALED TITANIUM ALLOY Ti 6Al-6V-2Sn 0.055 SHEET (HEAT D5869)

Thermal Cycle	Ultimate (ksi)	.2% Yield (ksi)	Elongation (% in 2")
Mill Annealed	171.0	164.7	15.3
1000°F (5 min) AC	166.8	161.9	14.7
1000°F (15 min) AC	167.1	162.2	13.7
1100°F (5 min) AC	164.0	158.9	15.0
1100°F (15 min) AC	161.7	155.3	13.0
1150°F (5 min) AC	162.7	157.7	13.0
1150°F (15 min) AC	159.3	154.0	13.7
1200°F (5 min) AC	157.8	154.8	12.2
1200°F (15 min) AC	156.7	151.7	13.0
1250°F (5 min) AC	155.8*	149.0*	13.5*
1250°F (15 min) AC	155.7	150.3	11.1
1300°F (5 min) AC	150.6	145.5	13.3
1300°F (15 min) AC	149.0*	145.0*	12.5*

*These values are the average of three (3) tests, except two (2) tests where asterisked in table.



a) Ti 6Al-6V-2Sn 0.080" Sheet, Heat No. D5869



b) Ti 6Al-6V-2Sn 0.055" Sheet, Heat No. D2430

Figures 13-3 Effects of Simulated Hot Forming Cycles on Annealed Titanium Alloy

TABLE 13-6 - KNOOP HARDNESS DATA

Spec No.	Material Thickness - in.	Thermal Cycle	Knoop Hardness(1)
B51	.125	As-Mill Annealed	333
B10	.125	1050°F (30 min) AC	338
B12	.125	1050°F (30 min) AC + 950°F (2 hrs) AC	335
B45	.125	1350°F (30 min) AC	307
B47	.125	1350°F (30 min) AC + 950°F (2 hrs) AC	336
C52	.050	As-Mill Annealed	302
C10	.050	1050°F (30 min) AC	304
C11	.050	1050°F (30 min) AC + 950°F (2 hrs) AC	301
C46	.050	1350°F (30 min) AC	291
C47	.050	1350°F (30 min) AC + 950°F (2 hrs) AC	316
D50	.025	As-Mill Annealed	278
D9	.025	1050°F (30 min) AC	279
D11	.025	1050°F (30 min) AC + 950°F (2 hrs) AC	273
D46	.025	1350°F (30 min) AC	263
D48	.025	1350°F (30 min) AC + 950°F (2 hrs) AC	293

(1) Knoop hardness values are the average of at least 4 readings

TABLE 13-7

EFFECT OF SIMULATED HOT FORMING CYCLES ON
THE TENSILE PROPERTIES OF Ti-6Al-6V-2Sn (1)
(.025" GAUGE)

Thermal Cycle	Ultimate (ksi)	.2% Yield (ksi)	% Elong. (in 2")
As-Mill Annealed(2)	156.8	151.0	11.0
1050°F (5 min) AC	143.2	138.5	10.5
" (15 min) AC	144.5	140.0	10.5
" (30 min) AC	150.0	145.5	11.0
" (5 min) AC + 950°F (2 hrs) AC	148.5	144.0	10.0
" (15 min) AC + 950°F (2 hrs) AC	155.5	150.5	10.5
" (30 min) AC + 950°F (2 hrs) AC	154.5	149.2	11.0
1150°F (5 min) AC	150.0	141.2	11.0
" (15 min) AC	151.5	145.0	11.5
" (30 min) AC	149.5	144.0	10.0
" (5 min) AC + 950°F (2 hrs) AC	153.5	148.0	12.0
" (15 min) AC + 950°F (2 hrs) AC	153.0	147.5	11.5
" (30 min) AC + 950°F (2 hrs) AC	153.5	147.5	10.5
1250°F (5 min) AC	145.5	139.7	10.5
" (15 min) AC	146.5	140.5	10.5
" (30 min) AC	146.0	140.0	11.5
" (5 min) AC + 950°F (2 hrs) AC	152.5	146.3	12.0
" (15 min) AC + 950°F (2 hrs) AC	154.0	147.5	11.0
" (30 min) AC + 950°F (2 hrs) AC	154.0	147.0	11.0
1350°F (5 min) AC	143.0	139.0	9.0
" (15 min) AC	145.0	141.3	7.5
" (30 min) AC	142.7	139.0	7.0
" (5 min) AC + 950°F (2 hrs) AC	167.2	159.8	8.0
" (15 min) AC + 950°F (2 hrs) AC	165.0	158.0	9.0
" (30 min) AC + 950°F (2 hrs) AC	165.0	158.0	7.5

(1) Test values are the average of duplicate tests

(2) Guaranteed minimum properties of annealed Ti-6-6-2 sheet are F_{tu} = 155, F_{ty} = 145, e = 10%

TABLE 13-8 - EFFECT OF SIMULATED HOT FORMING CYCLES ON THE TENSILE PROPERTIES OF Ti-6Al-6V-2Sn (1) (.032" GAUGE)

Thermal Cycle	Ultimate (ksi)	.2% Yield (ksi)	% Elong. (in 2")
As-Mill Annealed	163.8	160.7	11.5
"	163.2	160.0	11.3
"	161.5	159.2	14.0
"	163.2	160.0	13.0
1250°F (15 min) AC	152.2	148.6	11.0
" (30 min) AC	152.0	148.8	11.0
" (15 min) AC + 950°F (2 hrs) AC	164.5	160.6	11.0
" (30 min) AC + 950°F (2 hrs) AC	158.3	155.5	11.5
1350°F (15 min) AC	146.4	145.7	9.5
" (30 min) AC	142.8	141.5	10.0
" (15 min) AC + 950°F (2 hrs) AC	169.9	166.7	9.0
" (30 min) AC + 950°F (2 hrs) AC	166.9	164.5	9.0

(1) Recorded values are the average of 4 tests except for the as-mill annealed data.

TABLE 13-9 - EFFECT OF SIMULATED HOT FORMING CYCLES ON THE TENSILE PROPERTIES OF Ti-6Al-6V-2Sn (1)
(.050" GAUGE)

Thermal Cycle	Ultimate (ksi)	.2% Yield (ksi)	% Elong. (in 2")
As-Mill Annealed (2) (3)	166.0	157.0	15.0
1050°F (5 min) AC	165.0	156.0	14.0
" (15 min) AC	164.0	155.0	12.5
" (30 min) AC	165.0	156.5	13.0
" (5 min) AC + 950°F (2 hrs) AC	166.5	159.0	14.5
" (15 min) AC + 950°F (2 hrs) AC	166.0	158.5	13.0
" (30 min) AC + 950°F (2 hrs) AC	166.5	159.0	15.0
1150°F (5 min) AC	163.5	156.0	11.0
" (15 min) AC	163.0	155.0	12.0
" (30 min) AC	160.0	151.0	12.0
" (5 min) AC + 950°F (2 hrs) AC	166.5	158.0	12.0
" (15 min) AC + 950°F (2 hrs) AC	165.0	157.0	13.5
" (30 min) AC + 950°F (2 hrs) AC	164.5	156.0	13.5
1250°F (5 min) AC	152.5	146.0	12.5
" (15 min) AC	153.0	146.0	12.0
" (30 min) AC	155.5	148.5	11.5
" (5 min) AC + 950°F (2 hrs) AC	158.5	150.5	12.5
" (15 min) AC + 950°F (2 hrs) AC	160.0	151.5	13.5
" (30 min) AC + 950°F (2 hrs) AC	161.0	152.5	12.5
1350°F (5 min) AC	152.5	146.0	10.0
" (15 min) AC	151.5	146.0	12.5
" (30 min) AC	150.5	145.5	10.0
" (5 min) AC + 950°F (2 hrs) AC	171.5	164.5	10.5
" (15 min) AC + 950°F (2 hrs) AC	169.5	162.5	12.5
" (30 min) AC + 950°F (2 hrs) AC	168.5	161.0	11.0

(1) Test values are the average of duplicate tests

(2) Test values are the average of 3 tests

(3) Guaranteed minimum properties of annealed Ti-6-6-2 sheet are F_{tu} = 155, F_{ty} = 145, e = 10%

TABLE 13-10 - EFFECT OF SIMULATED HOT FORMING CYCLES ON THE TENSILE PROPERTIES OF Ti-6Al-6V-2Sn[1] (.100" GAUGE)

Thermal Cycle	Ultimate (ksi)	.2% Yield (ksi)	% Elong. (in 2")
As-Mill Annealed [2]	170.5	161.0	15.0
1150°F (5 min) AC	166.0	158.0	13.5
" (15 min) AC	166.5	158.5	14.5
" (30 min) AC	165.0	157.5	14.0
" (5 min) AC + 950°F (2 hrs) AC	170.0	162.0	14.5
" (15 min) AC + 950°F (2 hrs) AC	168.0	161.5	13.5
" (30 min) AC + 950°F (2 hrs) AC	168.0	159.5	15.0
1250°F (5 min) AC	162.0	153.0	13.5
" (15 min) AC	160.0	153.0	12.0
" (30 min) AC	160.0	152.5	13.5
" (5 min) AC + 950°F (2 hrs) AC	168.0	158.5	14.5
" (15 min) AC + 950°F (2 hrs) AC	168.0	159.5	13.5
" (30 min) AC + 950°F (2 hrs) AC	168.0	158.0	14.0
1350°F (5 min) AC	158.5	152.5	11.0
" (15 min) AC	144.0	138.0	10.5
" (30 min) AC	144.0	138.0	10.0
" (5 min) AC + 950°F (2 hrs) AC	179.0	170.1	12.5
" (15 min) AC + 950°F (2 hrs) AC	167.0	158.5	8.5
" (30 min) AC + 950°F (2 hrs) AC	167.5	160.5	10.5

(1) Test values are the average of duplicate tests

(2) Guaranteed minimum properties of annealed Ti-6-6-2 sheet are F_{tu} = 155, F_{ty} = 145, e = 10%

TABLE 13-11 - EFFECT OF SIMULATED HOT FORMING CYCLES[(1)]
ON THE TENSILE PROPERTIES OF Ti-6Al-6V-2Sn
(.125" GAUGE)

Thermal Cycle	Ultimate (ksi)	.2% Yield (ksi)	% Elong. (in 2")
As-Mill Annealed (2) (3)	169.0	163.5	16.0
1050°F (5 min) AC	168.0	162.5	15.5
" (15 min) AC	166.0	161.5	16.0
" (30 min) AC	167.5	163.0	16.0
" (5 min) AC + 950°F (2 hrs) AC	168.0	163.5	15.5
" (15 min) AC + 950°F (2 hrs) AC	169.0	163.5	16.5
" (30 min) AC + 950°F (2 hrs) AC	167.5	163.0	15.5
1150°F (5 min) AC	164.0	158.5	15.0
" (15 min) AC	165.0	159.0	15.0
" (30 min) AC	163.0	155.5	15.5
" (5 min) AC + 950°F (2 hrs) AC	167.5	163.0	15.5
" (15 min) AC + 950°F (2 hrs) AC	166.0	161.0	16.0
" (30 min) AC + 950°F (2 hrs) AC	166.5	160.0	16.5
1250°F (5 min) AC	161.0	154.5	15.5
" (15 min) AC	158.5	153.5	16.0
" (30 min) AC	160.5	154.0	14.5
" (5 min) AC + 950°F (2 hrs) AC	165.5	159.0	16.0
" (15 min) AC + 950°F (2 hrs) AC	166.5	162.5	14.0
" (30 min) AC + 950°F (2 hrs) AC	168.5	163.0	15.5
1350°F (5 min) AC	156.5	151.0	14.0
" (15 min) AC	157.5	151.5	14.0
" (30 min) AC	156.0	150.0	12.5
" (5 min) AC + 950°F (2 hrs) AC	179.0	173.0	13.5
" (15 min) AC + 950°F (2 hrs) AC	176.5	170.0	12.0
" (30 min) AC + 950°F (2 hrs) AC	177.5	171.5	13.0

(1) Test values are the average of duplicate tests

(2) Test values are the average of 4 tests

(3) Guaranteed minimum properties of annealed Ti-6-6-2 sheet are F_{tu} =155, F_{ty} = 145, e = 10%

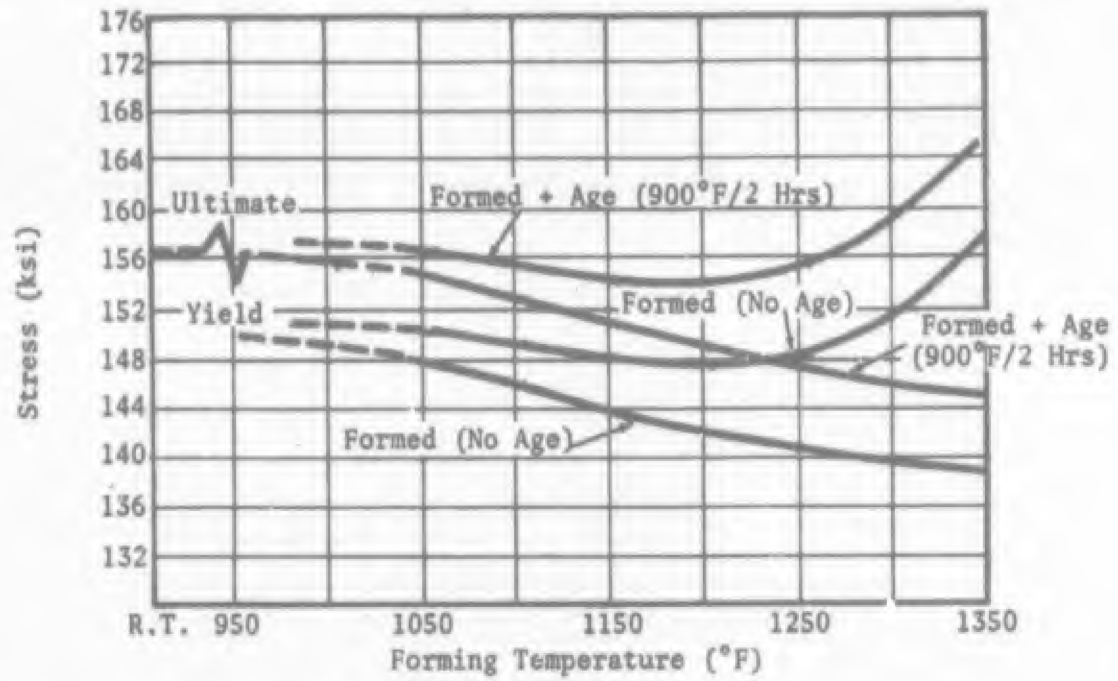


Figure 13-4 Room Temperature Strength after Simulated Hot Forming Cycles, Titanium 6Al-6V-2Sn Annealed Sheet .025" Thick

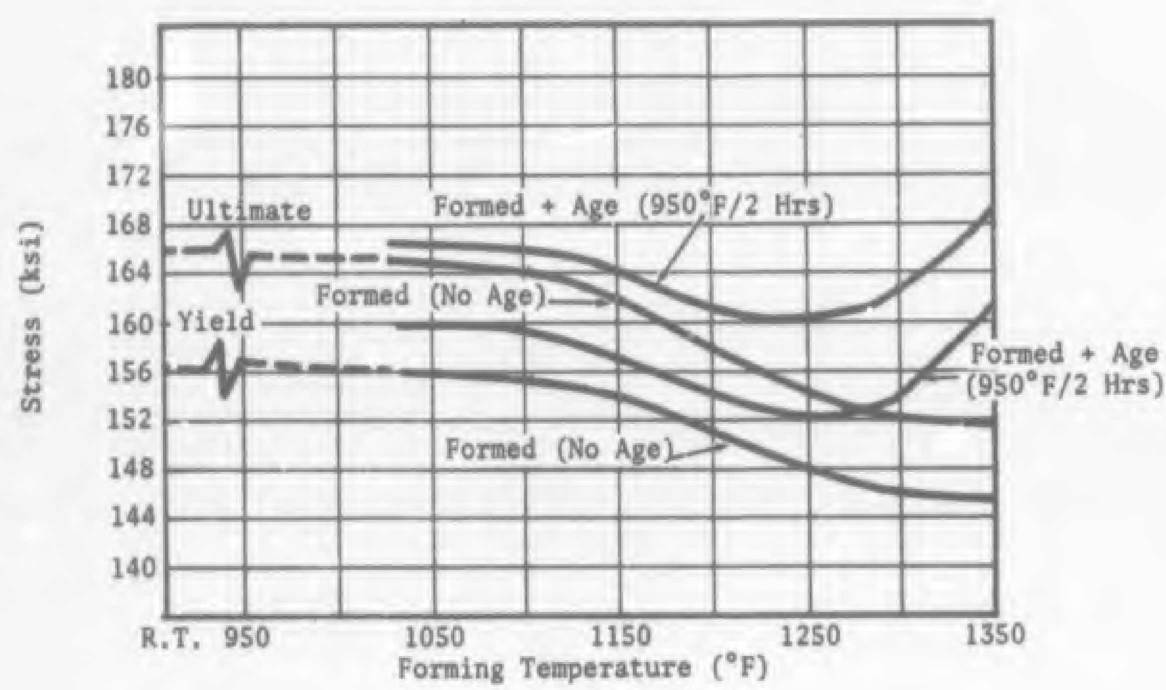


Figure 13-5 Room Temperature Strength after Simulated Hot Forming Cycles, Titanium 6Al-6V-2Sn Annealed Sheet .050" Thick

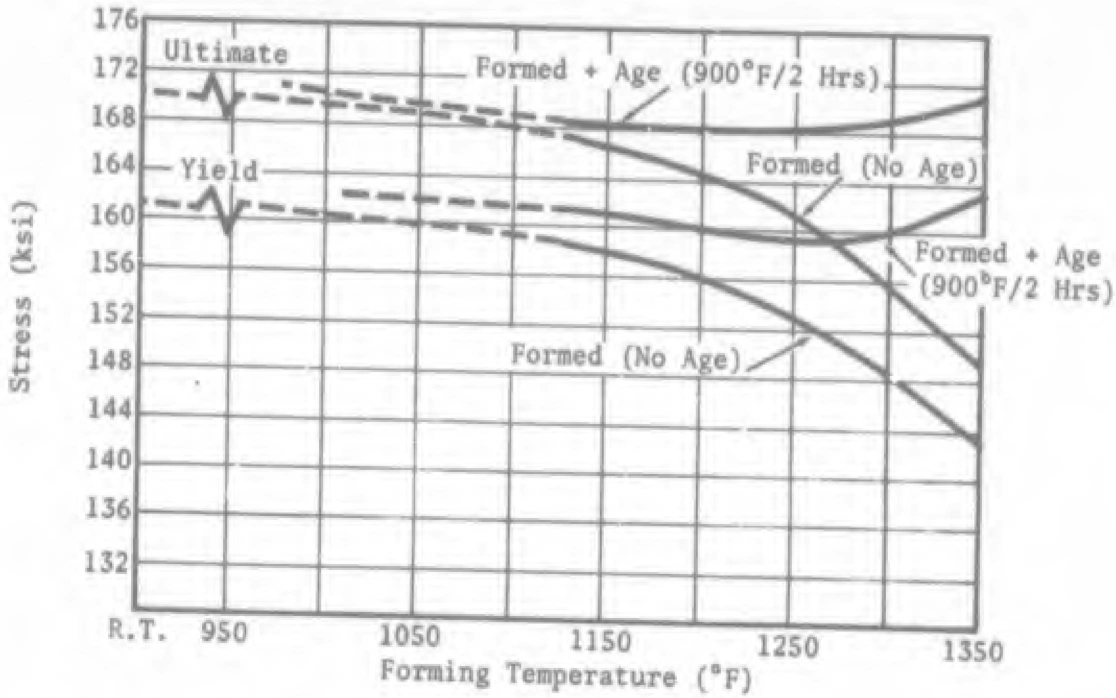


Figure 13-6 Room Temperature Strength after Simulated Hot Forming Cycles, Titanium 6Al-6V-2Sn Annealed Sheet .100" Thick

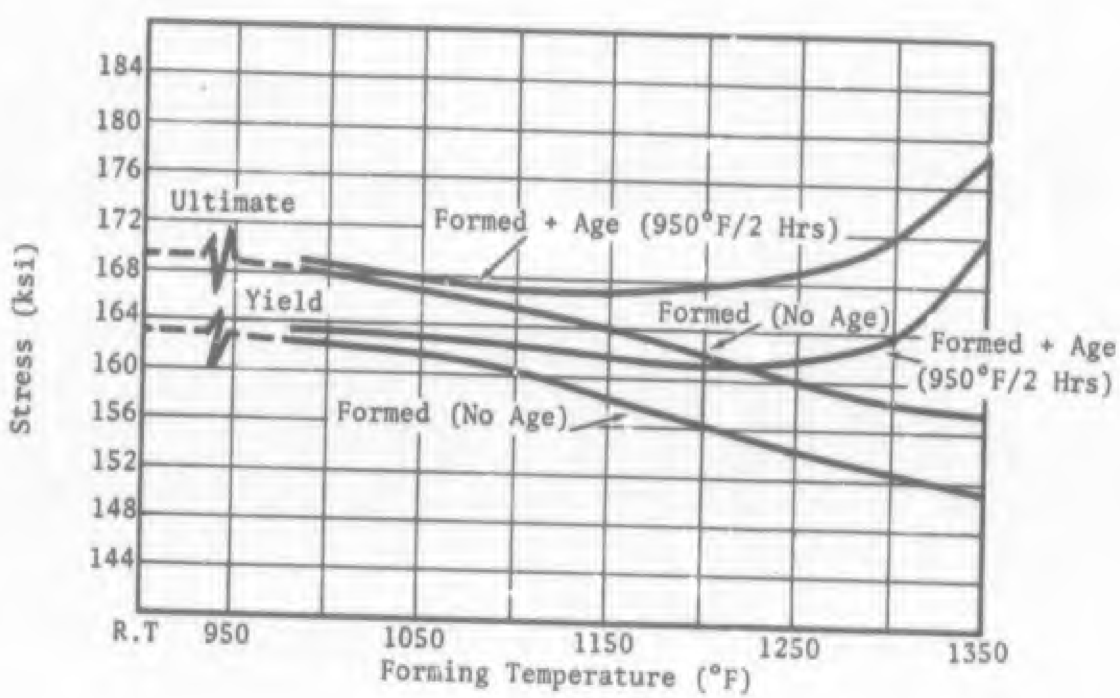


Figure 13-7 Room Temperature Strength after Simulated Hot Forming Cycles, Titanium 6Al-6V-2Sn Annealed Sheet .125" Thick

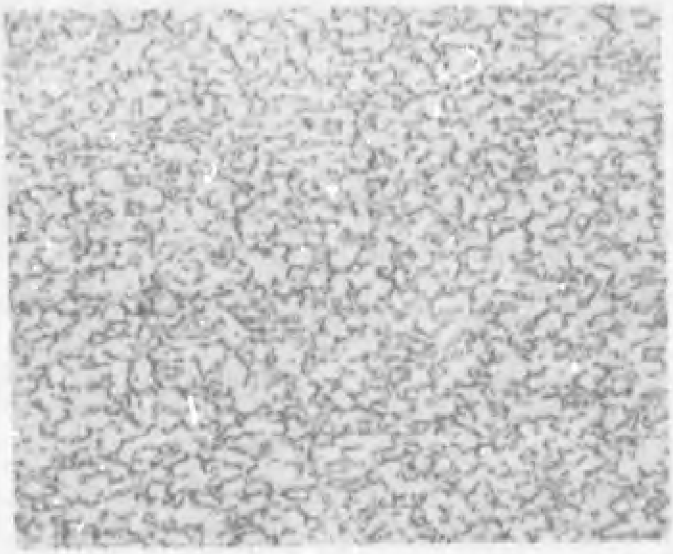
Figure 13-8 Sketch of Zee Members Made on Die RDM 1435 at 1400°F, Showing Location of Specimens Tested to Show the "As Formed" and "As Formed Plus Aged" Properties

TABLE 13-12 TENSILE PROPERTIES OF HOT FORMED PART OF Ti 6Al-6V-2Sn (.025")

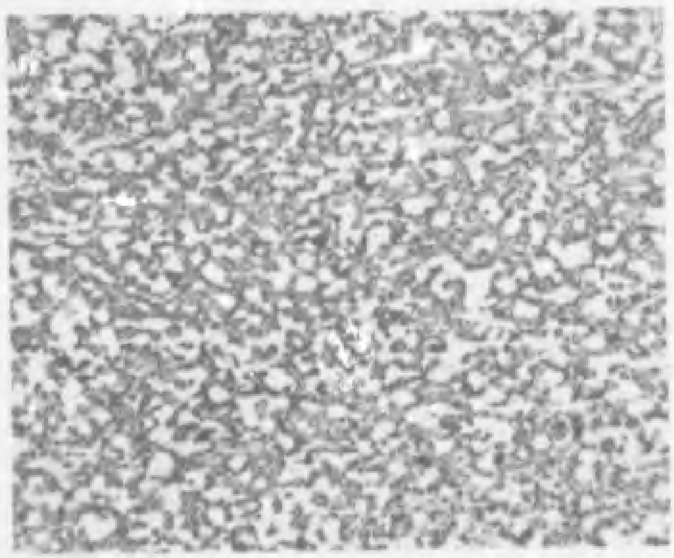
Condition	Specimen (1)	Ultimate Strength (ksi)	0.2% Yield Strength (ksi)	Elongation (% in 2")
Annealed (Flat Sheet - .025")	6	171.5	161.5	14.0
	7	174.5	165.5	14.0
	8	170.5	157.5	14.0
	Avg.	172.2	161.3	14.0
Hot Formed 3 min @ 1400° F	1	150.5	119.0	11.0
	2	161.5	106.5	9.0
	3	156.5	117.0	10.0
	4	164.0	95.8	9.0
	5	158.0	96.6	10.0
	Avg.	158.1	107.0	9.8
Hot Formed 3 min @ 1400° F + Aged 2 hrs @ 950° F	2-1	197.0	188.0	4.0
	2-2	197.0	190.0	4.0
	2-3	184.0	*	5.0
	2-4	195.0	186.0	4.0
	2-5	195.0	192.5	4.0
	Avg.	196.0	189.2	4.2

(1) See Figure 13-8 for specimen locations on formed part.

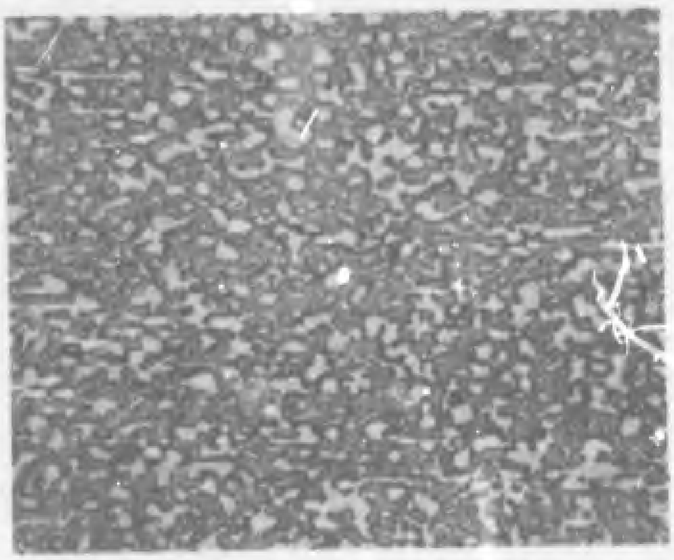
* Extensometer slipped from specimen as it approached yield.



a) "As received" annealed sheet, 0.025 gauge



b) Hot formed at 1400°F; three minutes at temperature; air cool



c) Aged at 950°F for two hours after hot forming

Figure 13-9 Ti 6Al-6V-2Sn Material Showing the Effects of Hot Forming at 1400°F (500X magnification). Etch: 10 HF, 20 HNO_3, 100 Lactic

TABLE 13-13

EFFECTS OF SIMULATED HOT FORMING CYCLES ON ANNEALED TITANIUM ALLOY
Ti 6Al-4V 0.080 SHEET (HEAT 301174)

Thermal Exposure	Ultimate (ksi)	0.2% Yield (ksi)	Elongation (% in 2")
900°F. 5 min.	142.3	138.2	9.3
900°F. 30 min.	142.2	136.3	11.0
1000°F. 5 min.	142.1	136.7	10.7
1000°F. 30 min.	139.5	135.1	11.2
1000°F. 5 min.*	139.2	135.3	11.2
1000°F. 30 min.*	140.1	135.9	11.9
1050°F. 5 min.	139.5	136.0	10.2
1050°F. 30 min.	139.9	136.9	11.0
1100°F. 5 min.	139.6	135.7	10.7
1100°F. 30 min.	139.6	135.5	10.5
1100°F. 5 min.*	140.3	137.1	11.2
1100°F. 30 min.*	139.7	136.8	11.5
1150°F. 5 min.	139.2	135.1	11.0
1150°F. 30 min.	138.2	135.0	10.7
1200°F. 5 min.	137.0	133.7	11.7
1200°F. 30 min.	138.5	135.2	11.0
1200°F. 5 min.*	139.1	135.7	11.3
1200°F. 30 min.*	137.3	134.3	10.8
1250°F. 5 min.	136.8	133.7	11.0
1250°F. 30 min.	137.3	133.4	11.3
1300°F. 5 min.	136.1	132.2	10.7
1300°F. 30 min.	136.5	132.5	10.0
1300°F. 5 min.*	137.6	132.6	10.2

All values are the average of three tests.

*Slow cooled to below 900°F

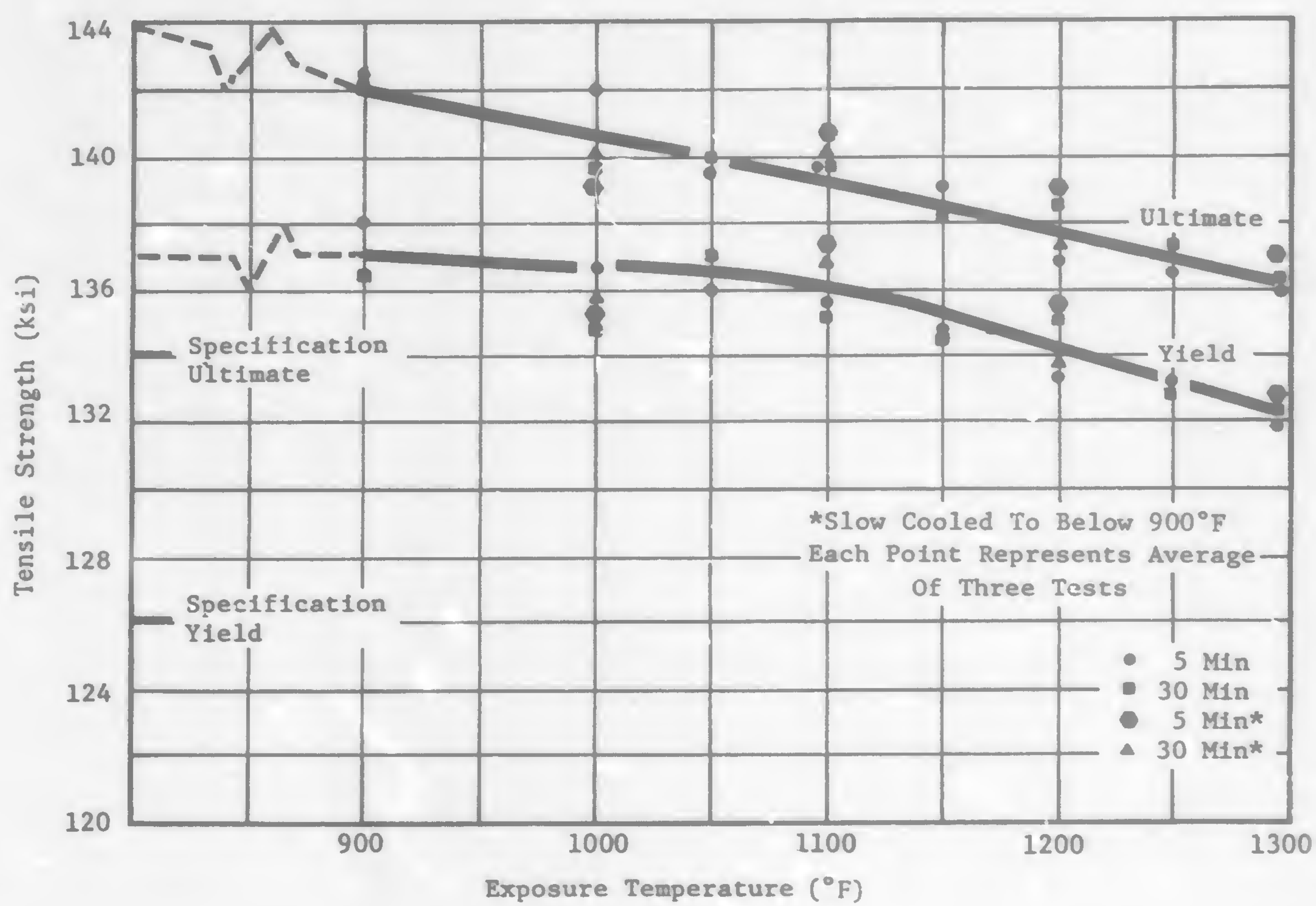


Figure 13-10 Room Temperature Tensile Strength of Ti 6Al-4V Annealed .080" Sheet (Heat No. 301174) Exposure to Simulated Forming Temperatures

TABLE 13-14

EFFECT OF SIMULATED HOT FORMING TEMPERATURES ON THE ROOM TEMPERATURE STRENGTH OF ANNEALED Ti-6Al-4V SHEET (.125")

Thermal Exposure	Ultimate (ksi)	.2% Yield (ksi)	% Elongation (in 2")
As Received	141.1	136.3	14.5
1200°F (8 minutes) AC	143.9	141.4	12.0
1200°F (8 minutes) AC	141.5	137.2	12.0
AVER.	142.7	139.3	12.0
1300°F (8 minutes) AC	142.9	140.6	12.0
1300°F (8 minutes) AC	139.9	133.7	14.0
AVER.	141.4	137.2	13.0
1400°F (8 minutes) AC	142.0	134.6	14.0
1400°F (8 minutes) AC	137.6	129.3	13.0
AVER.	139.8	131.9	13.5
1500°F (8 minutes) AC	142.8	132.4	12.0
1500°F (8 minutes) AC	140.0	127.0	14.0
AVER.	141.4	129.7	13.0

TABLE 13-15 SHORT TIME AGING OF SOLUTION TREATED Ti 6Al-4V-
STATIC TENSILE PROPERTIES (.025" SHEET)

Time at Temp. (min)	Aged at 800°F			Aged at 900°F			Aged at 950°F		
	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")
5	164.0	148.5	6.0	171.0	154.0	7.0	168.5	151.0	5.0
10	167.0	152.0	6.5	169.5	150.0	6.0	173.0	155.5	6.0
20	172.0	154.8	5.0	173.5	151.0	5.0	175.5	157.0	7.0
30	173.0	155.5	6.0	172.7	156.5	5.0	174.0	155.5	5.5
40	-	-	-	-	-	-	176.5	157.5	5.5

Time at Temp. (min)	Aged at 1000°F			Aged at 1050°F			Aged at 1100°F		
	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")	F_{tu} (ksi)	F_{ty} (ksi)	% El. (in 2")
5	170.3	155.5*	7.0	168.0	155.5*	7.5	165.8	152.8*	7.5
10	171.0	157.4*	7.0	169.5	157.6*	7.8	168.7	156.5*	7.8
20	171.2	158.5	8.0	168.0	158.0*	6.0	164.5	155.3*	8.8
30	170.0	157.5	5.5	169.0	160.0	6.0	165.0	155.9	7.5
40	172.9	161.0	7.5	-	-	-	-	-	-

*Average of two values. All other points are individual tests.

Solution treated properties of the 0.025" sheet } 150.5 ksi ultimate strength, 130.8 ksi yield strength, 11.0% elongation in 2"

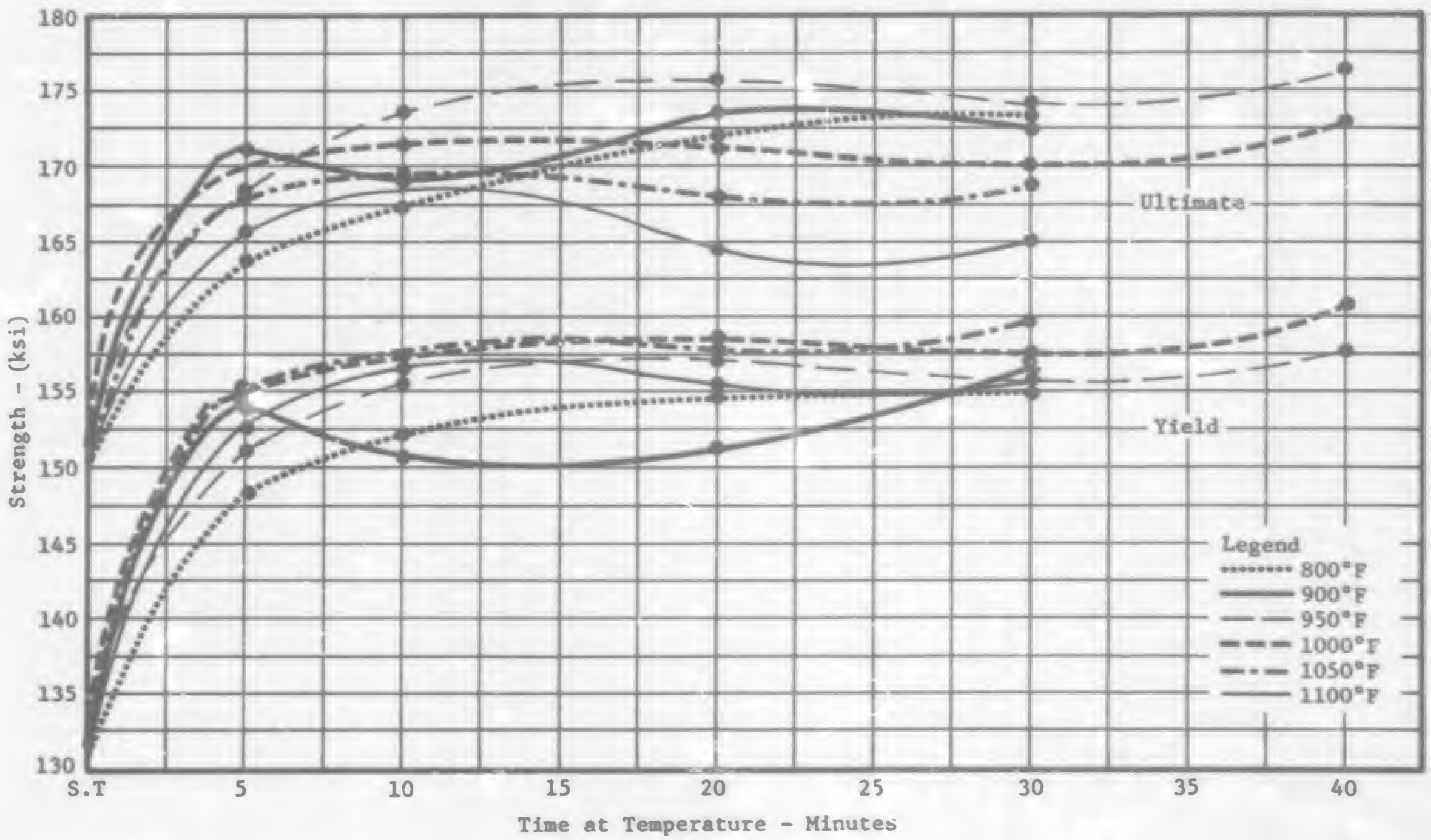


Figure 13-11 Short Time Aging of Solution-Treated Ti 6Al-4V (.025" Sheet)

TABLE 13-16

TENSILE AND ELEVATED CREEP STABILITY DATA OF SOLUTION TREATED AND AGED Ti-6Al-4V (.040-INCH SHEET, TRANSVERSE GRAIN DIRECTION)

Thermal Cycle	Room Temperature Tensile Properties			Strength at Room Temperature After 150 Hours Sustained Stress at 45ksi at 800°F**		
	F_{tu} (ksi)	.2% F_{ty} (ksi)	% Elong. (in 2")	F_{tu} (ksi)	.2% F_{ty} (ksi)	% Elong. (in 1")
Solution Treated	149.3	124.0	10.5			
1000°F (15 min) AC	165.8	153.8	7.5	166.3	147.8	14.0
1000°F (40 min) AC	165.5	153.8	6.5	164.0	146.5	10.0
1000°F (60 min) AC	165.0	153.0	6.5	164.5	153.0	14.0
1000°F (90 min) AC	165.0	154.8	6.3	163.6	149.0	9.0
*1000°F (4 hrs) AC	162.6	153.5	7.5	161.8	147.5	15.0
1050°F (10 min) AC	163.2	153.0	7.3			
1050°F (20 min) AC	163.0	152.7	8.5			
1050°F (30 min) AC	161.5	154.0	7.0			
1050°F (20 min) AC + 1000°F (2 hrs) AC	164.0	152.5	7.5			

NOTE: Test values are the average of duplicate tests.

* 4 Hours @ 1000°F is the standard aging cycle for solution-treated Ti-6Al-4V.

** No creep was noted on any specimens.

TABLE 13-17

TENSILE PROPERTIES OF HOT FORMED AND AGED PARTS OF SOLUTION TREATED Ti-6Al-4V**

Specimen	Tensile Specimen Removed From	Hot Form Temperature And Aging Cycle*	Tensile Properties F_{tu} (ksi)	.2% F_{ty} (ksi)	% Elong. (in 2")
25-1	.025" Sheet*	1000°F - 40 Min.	162.5	152.0	8.5
25-2	.025" Sheet*	1000°F - 40 Min.	159.3	145.2	7.5
AVG.			160.9	148.6	8.0
25-3	.025" Sheet*	1050°F - 20 Min.	161.5	151.1	8.5
25-4	.025" Sheet*	1050°F - 20 Min.	157.8	148.8	7.0
AVG.			159.7	150.0	7.8
35-1	.025" Zee Members	1000°F - 40 Min.	170.5	158.3	6.0
35-2	.025" Zee Members	1000°F - 40 Min.	168.5	158.5	7.0
AVG.			169.5	158.4	6.5
36-1	.025" Zee Members	1100°F - 40 Min.	166.1	155.9	6.5
36-2	.025" Zee Members	1100°F - 40 Min.	168.1	159.4	8.0
AVG.			167.1	157.7	7.3
74	.025" Annular Ring	1000°F - 40 Min. (Formed) +1000°F - 2 Hrs. (Stress Relieved)	161.0	148.2	7.5
70-1	.070" Sheet*	1000°F - 40 Min.	159.3	148.3	8.0
70-2	.070" Sheet*	1000°F - 40 Min.	160.4	144.4	9.0
AVG.			159.9	146.4	8.5
70-3	.070" Sheet*	1050°F - 20 Min.	158.9	147.5	8.0
70-4	.070" Sheet*	1050°F - 20 Min.	157.5	146.6	10.0
AVG.			158.2	147.1	9.0
80-1	.070" Annular Ring	1000°F - 40 Min	165.0	150.0	7.5
80-2	↓	↓	166.3	152.0	7.5
82-1			165.5	147.7	8.0
82-2			163.9	146.7	8.0
84-1			171.0	155.1	8.5
84-2			167.0	151.8	7.5
AVG.			166.5	150.6	7.8
85-1	.070" Annular Ring	1050°F - 20 Min.	170.5	154.8	8.0
85-2	.070" Annular Ring	1050°F - 20 Min.	164.0	150.5	7.5
AVG.			167.3	152.7	7.8

* Sheet material controls

** .025-inch material - Heat No. G 3720
.070-inch material - Heat No. G 3716

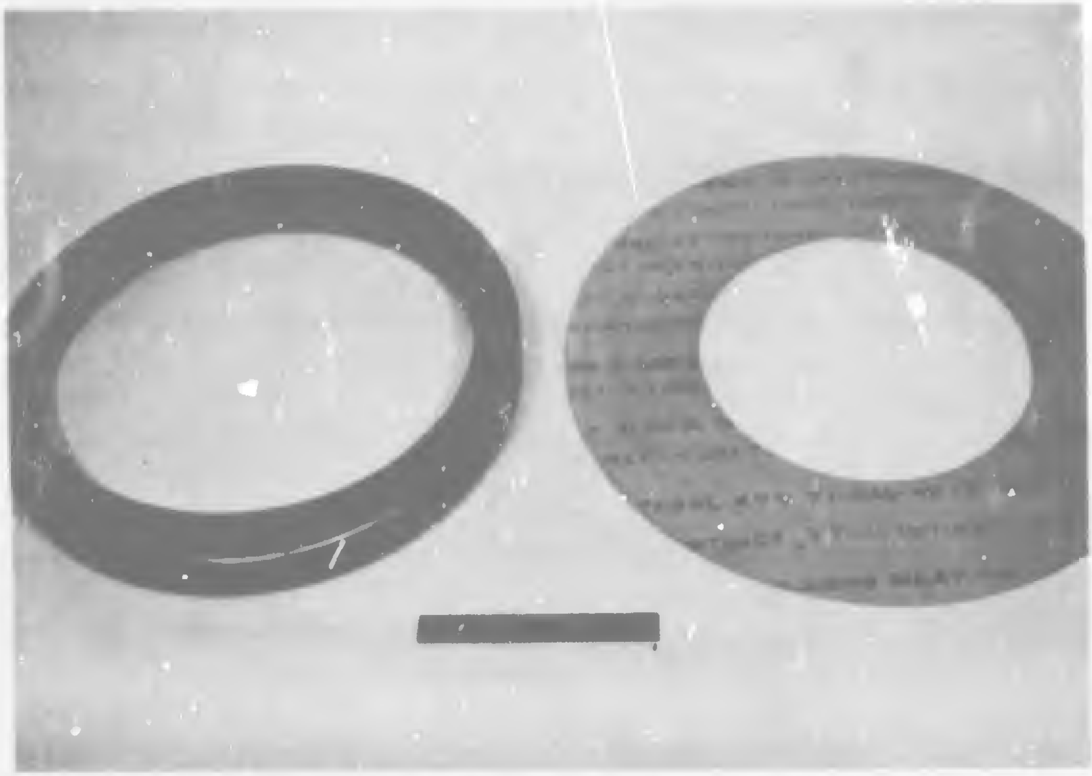


Figure 13-12 Typical Annular Ring Formed From 6A1-4V Titanium

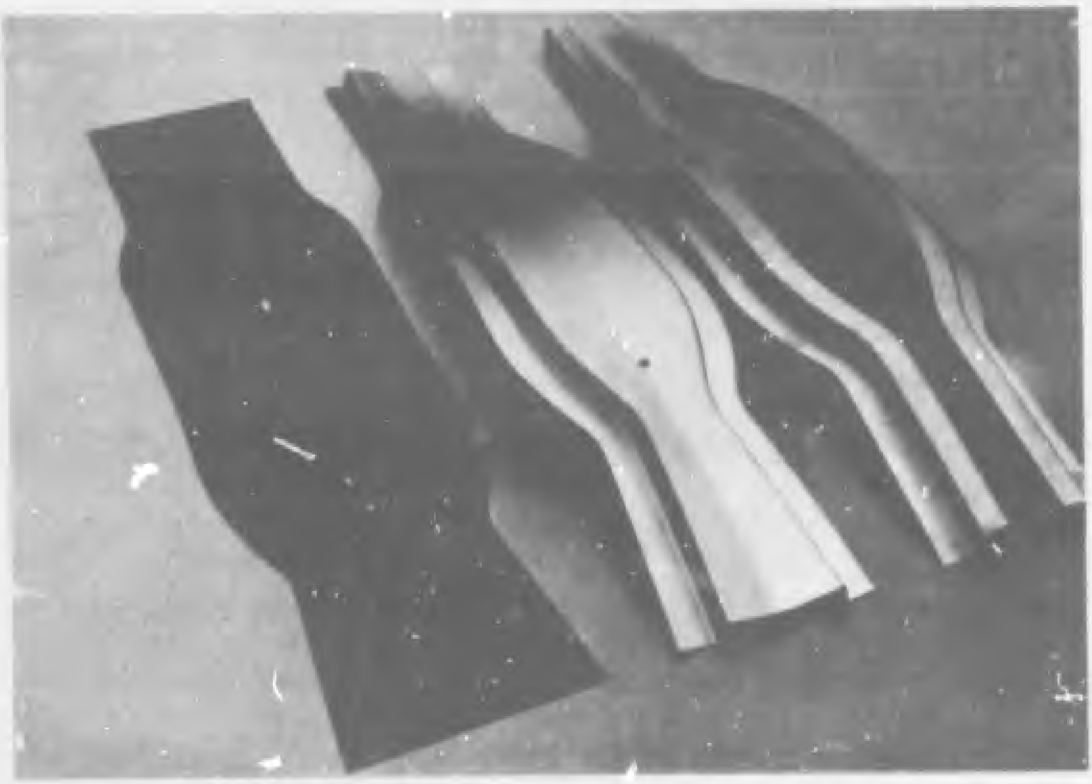


Figure 13-13 Flat Blank, Formed Zee Part Left-and Right-Hand Details

SECTION XIV

TIME-TEMPERATURE PARAMETERS TO DETERMINE SPRINGBACK AND MINIMUM BEND RADII

1. TEST PROGRAM

The following laboratory test program was designed to determine the elevated temperature dwell and soak time needed to produce zero springback in the shortest time at the lowest temperature while least affecting the mechanical properties of the selected titanium alloys. The information obtained from these tests will be used as a guide in establishing forming criteria such as minimum bend radii, heat-up time periods, and hot forming time cycle parameters.

a. Equipment

- USI press and Williams White press.
- RDM-1440 minimum bend radii (Hastelloy X die with six different radii - .020, .040, .060, .080, .100, and .120-inch). (See Figures 14-1, 14-2 and 14-3.)
- Honeywell single-point recorder (Model 15361, OPS-24-20).

b. Variable

- Material alloy - Titanium 6A1-6V-2Sn annealed and titanium 6A1-4V annealed.
- Material thickness - .016 to .125-inch, a minimum of five different thicknesses to be tested per alloy.
- Dwell time-(X) minutes, time required to heat a part to the forming temperature, will be determined by thermocouples attached to the bend specimens at the bend line for each thickness.
- Temperature - 1000°F, a minimum of four temperature levels to be tested per alloy.
- Minimum bend radii - radius/thickness ratio determined by examination under 50 X magnification.

c. Notes

- The number of material thicknesses to be tested are limited due to availability.
- The Engineering Metallurgy Group will conduct the necessary metallurg-

ical tests to document the time and temperature cycles that will least affect the mechanical properties of the titanium alloys.

- Additional Test Conditions - All specimens will be subjected to the following:

  (1) Before forming:

  Deburred
  Degreased
  Coated with Everlube Form Kote T-50 lubricant
  Air-dried

  (2) After forming:

  Air-cooled
  Cleaned per production procedure
  Measure springback angle

2. TEST PROCEDURE FOR DWELL TIME

Chroml-Alumel thermocouples were attached to 1 1/2 x 3 1/2-inch bend specimens for each of the material thicknesses of titanium 6Al-6V-2Sn and titanium 6Al-4V that were to be tested. The thermocouples were attached at the bend line of the specimens by spotwelding with a commercially pure titanium cap which was spotwelded over the hot junction (Figure 14-4). The cap was filled with a ceramic cement to add strength.

The RDM 1440 minimum bend radii die was mounted on the USI press with thermocouples in the lower and upper halves registering temperatures on the press Wheelco gauges. Once the press platens reached the set temperature and leveled off, they were balanced by adjusting the individual zone controls. The die was allowed to reach the set temperature before the tests were begun. A Honeywell single-point recorder was connected to the terminal end of the bend specimen thermocouple. The recorder ranged from 0°F to 2000°F and the chart moved at a rate of 1/64 of an inch each 3 1/2 seconds, thereby recording the time to temperatures (Figure 14-5 and 14-6).

Each individual test specimen with the thermocouple attached was placed in the middle of the die. The upper press platen was lowered until the upper die just touched the specimen. Two spacer blocks were used on the die to provide uniform height of the upper platen during the test run, a means of assuring definite specimen contact by slightly deforming it (Figure 14-7). This was performed for each of the material thicknesses at each of the test temperatures. Time-to-temperature values were calculated from the graphs developed by the single-point recorder. This was done by drawing a line tangent to the graph as it leveled off and then measuring horizontally the distance from tangent point to the starting point. Distance was then converted into time and graphically depicted (Figure 14-8 and 14-9).

Results: From the data generated, it was determined on a practical basis that dwell time (X) for titanium 6Al-6V-2Sn and titanium 6Al-4V material thickness of .020 to .060-inch would require a two-minute dwell time and that material thicknesses of .061 to .125-inch would require a three-minute dwell time for hot forming.

3. TEST PROCEDURE FOR SOAK TIME

Based on the above information, several sets of titanium 6Al-6V-2Sn bend specimens of different thicknesses were fully bent and held in the closed die for time periods of one, three and five minutes at temperatures of 900°F, 1000°F, 1050°F and 1100°F. The objective was to form a 90-degree angle with zero springback. The time and temperature combinations that were low enough to produce positive springback would be indications of the minimum hot forming parameters. It was observed, however, that the bend specimens showed no positive springback. It was believed that a definite coining action was taking place above 900°F and that springback values from a pure bending action could not be obtained from this particular set-up.

The negative springback values that were obtained above 900°F indicated that the USI press was applying pressure even though the pressure gauge read zero. This undetermined force was compressing the inside fibers of the bend specimens into the material, thereby creating tension rather than compression on the inside fibers. Upon releasing the specimens from the die, the inside fibers tend to close up rather than open up the bend angle. A Webster Force Gauge (from 0 to 10,000 pounds) was placed on the lower platen to determine the nature of the undetermined force. A steel column was placed over the force gauge diaphragm so as to completely fill the distance between the upper and lower platens. The upward ram force was then turned off and the ram set in the stop position. The force gauge indicator started to accelerate up the scale, thereby indicating a downward force of the ram while its pressure gauge still read zero.

It was determined by a representative of USI that a backup pressure was building up in the top cavity of the ram cylinder and that the addition of a bleeder valve was required to correct this problem. To verify this connective action, the Webster Force Gauge was set up in the press again with a hand-operated hydraulic jack and a steel column while the ram was activated in the upward direction (Figure 14-10). By pre-loading the hydraulic jack to 1,000 pounds, any slight deviation of the ram's force could be detected. The ram was set in the stop position and no deviation was detected by the force gauge.

To eliminate the sizing effect of any possible future slippage of the downward acting ram, .100-inch thick 321 stainless steel shims were used on both ends of the minimum bend radii die (RDM 1440). This prevented the die from closing all the way and allowed the specimens to be formed to a three-point 80-degree pure bend. By using the .100-inch thick shim (plus an additional shim equal to the test specimen thickness), a .100-inch gap could be maintained between the die and the specimen, regardless of the specimen thickness. This, in turn, will allow the specimen to freely bow according to the stresses developed during the bending action and to spring open in response to those developed stresses. The greater the stress, the greater the springback. But, the higher the time-temperature combination, the greater the degree of stress relieving, which leads us to our objective of locating time-temperature forming parameters for zero springback.

The photograph (Figure 14-11) of two .025-inch thick titanium 6Al-6V-2Sn bend specimens formed at 1100°F for one-minute soak (one specimen with the shim technique and the other matched die forming) illustrates the difference between the two test procedures. The data for the shim technique was compiled so that the different thicknesses were grouped individually for each alloy.(Table 14-1 and 14-2) Each thickness was graphically depicted in a three-dimensional graph, the X-axis representing temperature, the Y-axis representing time, and the Z-axis representing the average springback values for an 80 degree pure bend. Where the individual temperature graphs cross the X-Y plane, the time value is considered to be the experimental values needed to obtain zero springback. These values were then graphically depicted on a time-temperature curve from which time-temperature parameters for zero springback can be selected. for titanium 6Al-6V-2Sn and titanium 6Al-4V (Figures 14-12 and 14-13) It should be noted that these parameters are dependent on the amount of stress build-up during the hot forming operation.

<u>Results</u>: From the data generated, it was determined on a practical basis that the <u>minimum</u> hot forming time-temperature parameter for titanium 6Al-6V-2Sn was four minutes soak time at 1125°F, while titanium 6Al-4V was four minutes soak time at 1200°F.

4. TEST PROCEDURE FOR MINIMUM BEND RADII

Test temperatures of R.T.(room temperature) and 1200°F. were selected for both titanium alloys so as to provide a basis of comparison between them. To determine minimum bend radii values, the lowest acceptable radius-to-thickness ratio, six bend specimens of the same thickness were formed at the same time at both test temperature levels. Each position on the die represents a different punch radius from .020 to .120-inch in .020-inch increments. For each material thickness, the test was repeated four times so as to allow for possible metallurgical deviations which can affect the materials' minimum bend radii value. All specimens were bent in the transverse direction, cleaned by standard production processes, and then examined for microcracks under 50X magnification.

An acceptable bend specimen would be considered to be free of all microcracks and excessive "orange peelings" (grain separation) along the deformed surface. For each thickness of material, the lowest radius with all four bend specimens passing inspection divided by the material thickness would be considered the experimental value for minimum bend radii for that particular thickness (Tables 14-3 and 14-4). The highest experimental R.T.

value of all the thicknesses, plus an additional IT safety factor, then becomes the acceptable minimum bend radii value for production application.

Results: The acceptable minimum bend radii value for titanium 6Al-6V-2Sn is 4.0T at R.T. and 1.5T at 1200°F, while titanium 6Al-4V is 4.0T at R.T. (Room Temperature), 2.25T at 1200°F, and 1.32T at 1350°F (Figure 14-14).

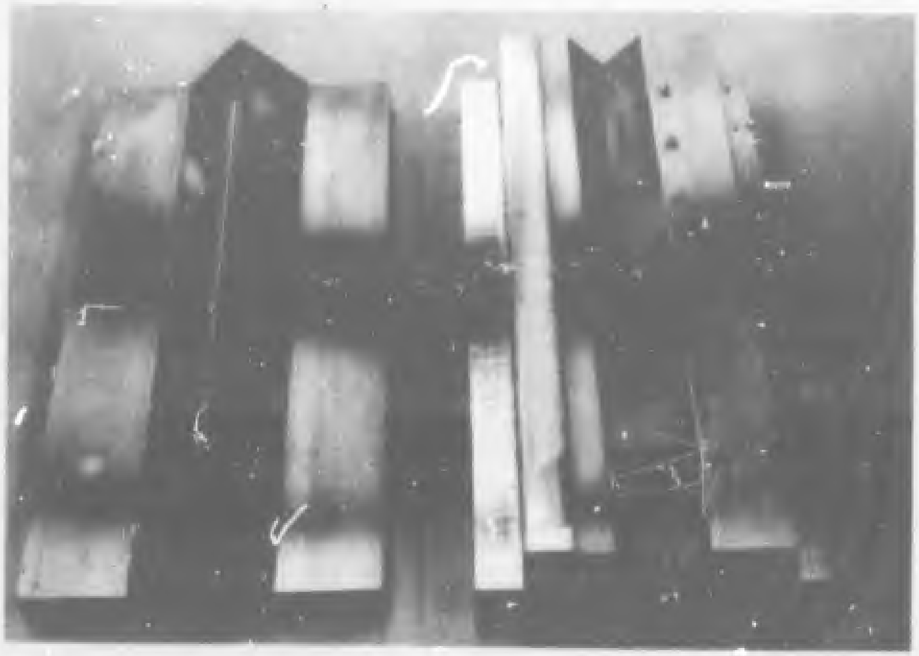


Figure 14-1 RDM 1440 Minimum Bend Radii Die

Figure 14-2 Die in Closed Position

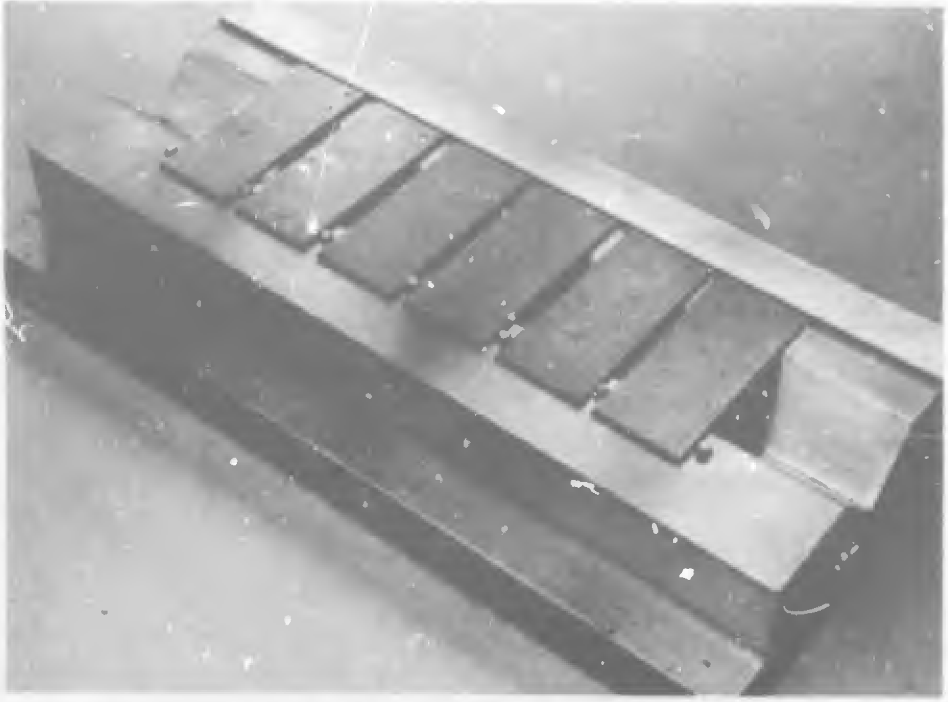


Figure 14-3 Die with Six Specimens in Position

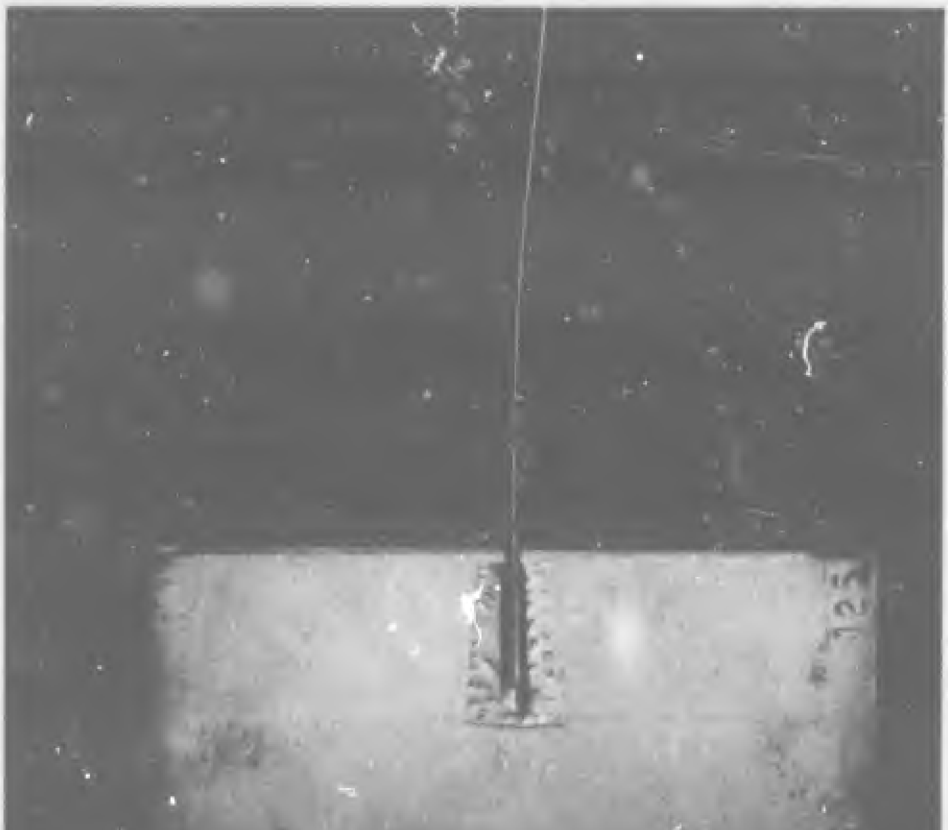


Figure 14-4 Thermocouple Attached to the Bend Line of a Specimen by Spot Welding

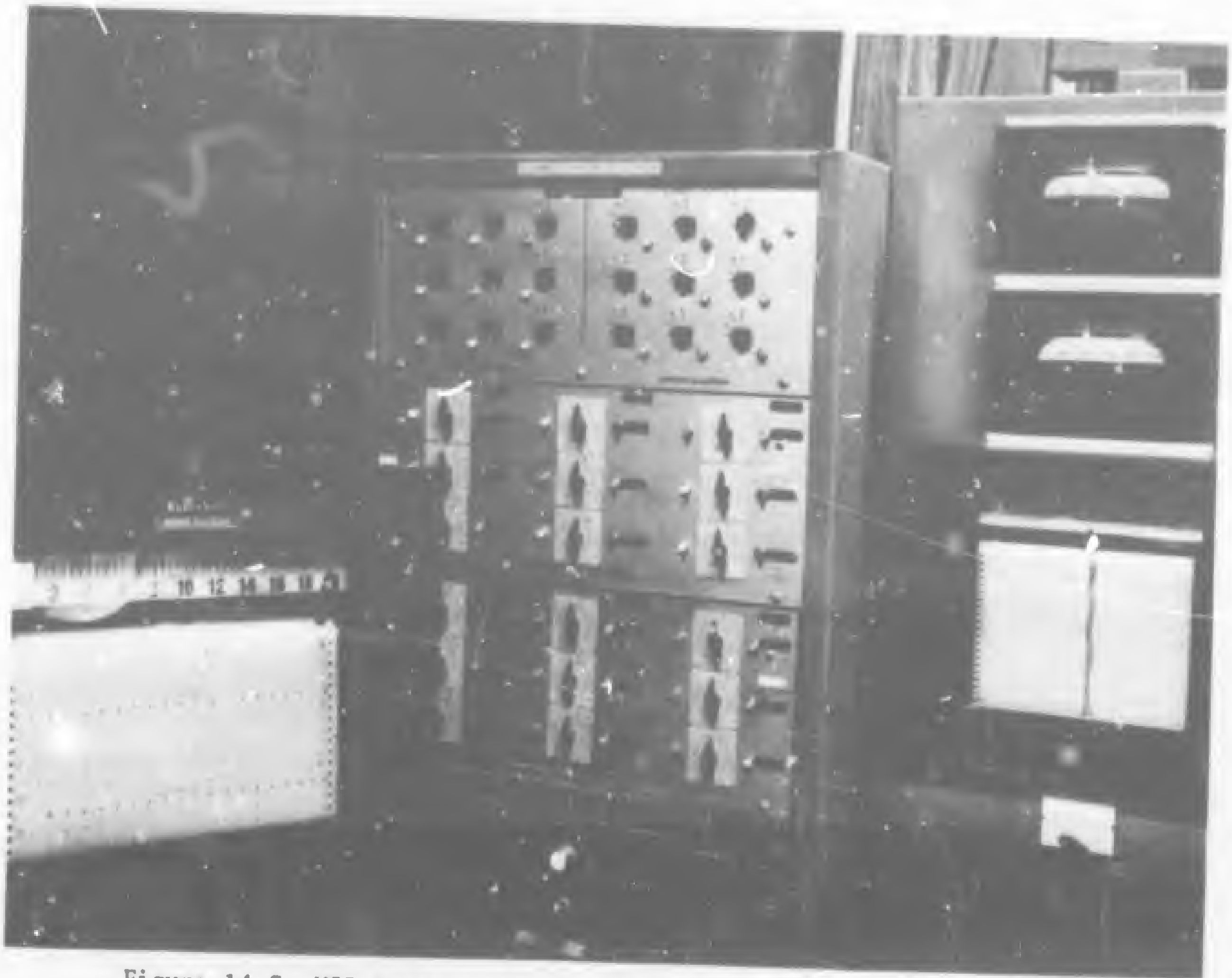


Figure 14-5 USI Press Control Panel and Single-Point Pen Recorder

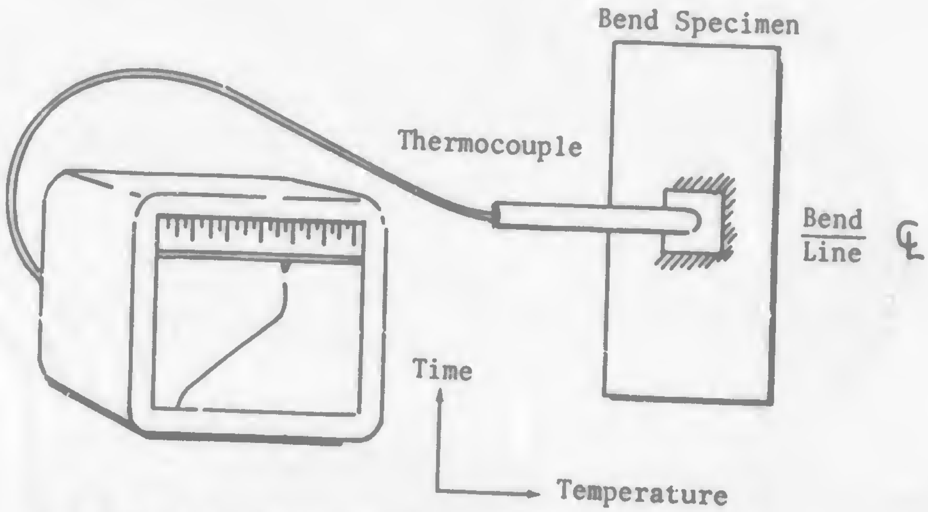


Figure 14-6 Time-to-Temperature Recording Technique

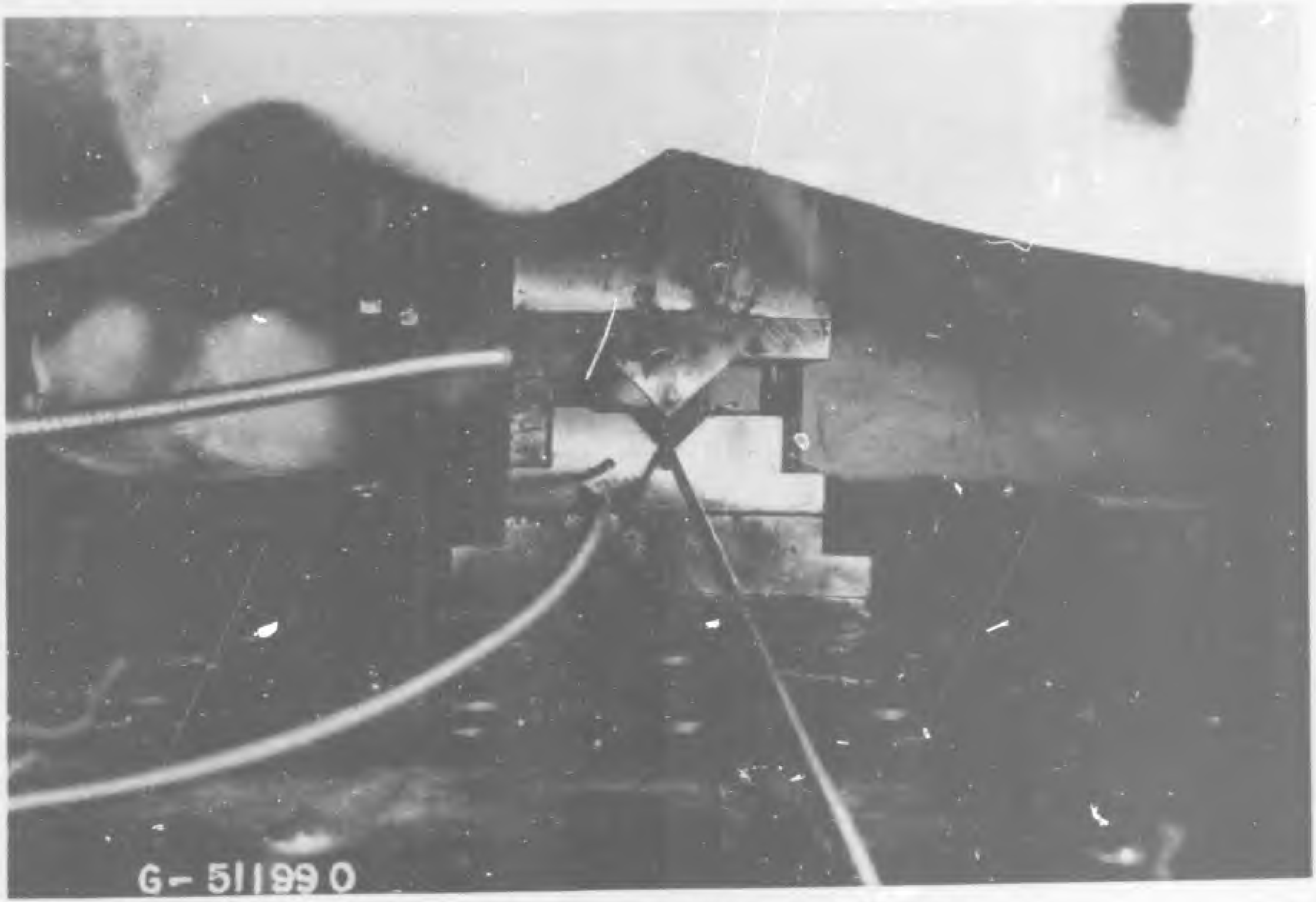
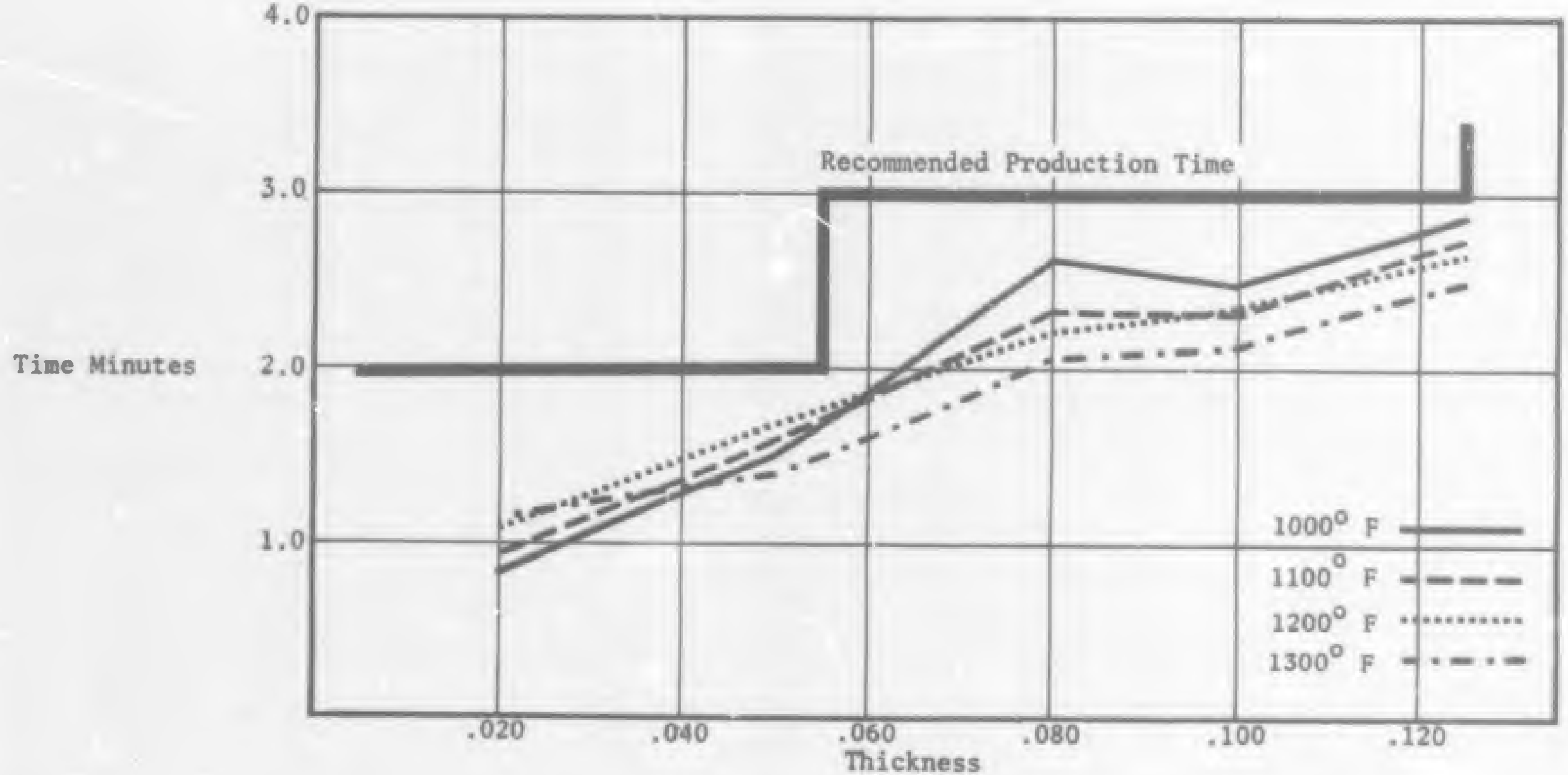
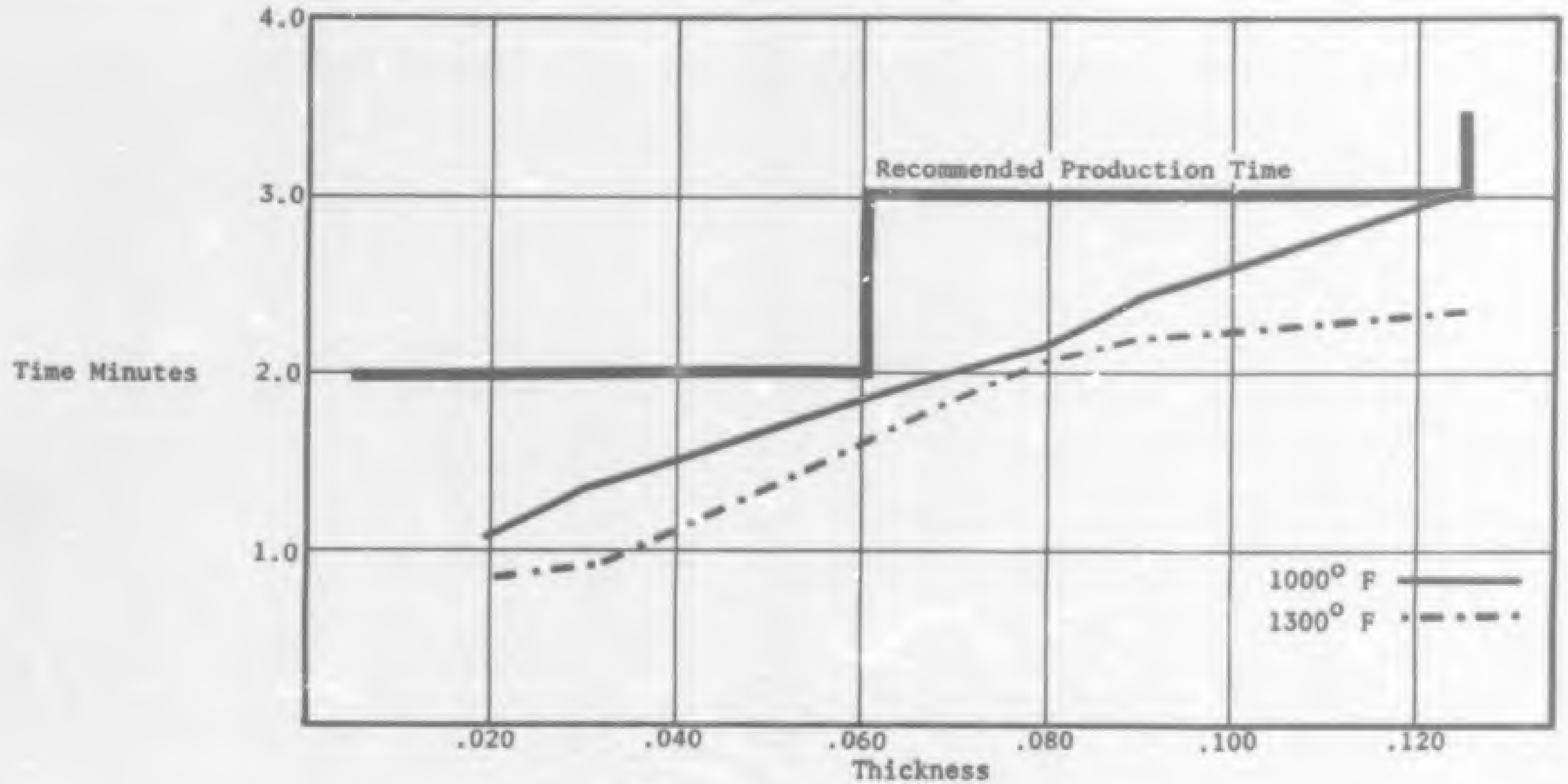


Figure 14-7 Die Set-up for Time-to-Temperature Test



Material Thickness	Test Temperature			
	1000°F	1100°F	1200°F	1300°F
.020	49.0 sec.	56.0 sec.	63.0 sec.	66.5 sec.
.050	91.0	94.5	101.5	87.5
.080	157.5	136.5	133.0	126.0
.100	150.5	136.5	140.0	129.5
.125	171.5	164.5	161.0	164.5

Figure 14-8 Time to Temperature Values for Ti-6Al-6V-2Sn



Material Thickness	Test Temperature 1000°F	1300°F
.020	63.0 sec.	47.3 sec
.032	80.5	54.3
.080	129.5	122.5
.090	145.3	133.0
.125	180.3	141.8

Note: Average Time of Two Readings

Figure 14-9 Time to Temperature Values for Ti-6Al-4V

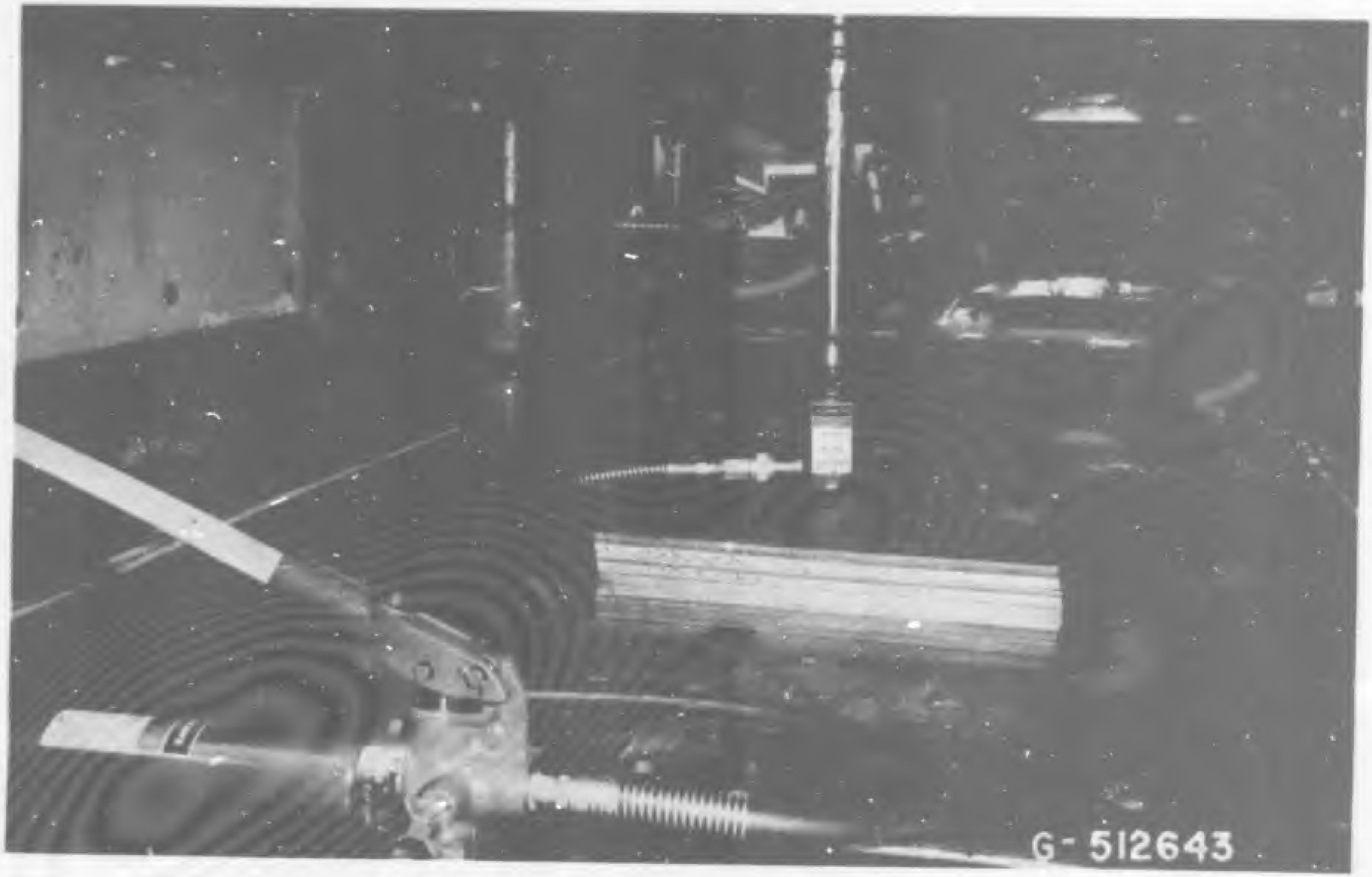


Figure 14-10 Hydraulic Jack with Webster Force Gauge Used to Determine Pressure of Ram under Stop Conditions

Figure 14-11 Outside Bend Specimen Hot Formed 1100°F 2-Minute Soak and 1-Minute Dwell, 80° Angle Pure Bend

Inside Bend Specimen, Same Conditions, 90° Angle Matched Die Bend

TABLE 14-1

SUMMARY OF DATA FOR ZERO SPRINGBACK (Ti 6Al-6V-Sn)

Springback Test for Soak Time Ti 6Al-6V-2Sn

.100 Shim, 80° Pure Bend, Temperature ± 20°F.

Thickness inches	Time Min. Dwell/Soak	1000°F		1050°F		1100°F		1200°F	
		Range	Average Springback	Range	Average Springback	Range	Average Springback	Range	Average Springback
.025	2/1	5	13.5			4	10.2	3	2.0
	2/3	4	12.5	3	7.8	2	-0.5		
	2/5	2	11.0	2	8.5	1	-0.8		
	2/7	3	8.7	1	5.8	1	-2.3		
	2/27	0	2.0	1	-3.5				
.080	3/1	4	4.5			3	0.2	3	-5.0
	3/3	3	0.5	2	-0.5	3	-3.8		
	3/5	3	0.3	2	-0.8	1	-5.2		
	3/7	3	-1.5	2	-3.3	2	-6.3		
.100	3/1	3	6.3			4	1.5	4	-4.2
	3/3	3	2.2	3	0.5	3	-3.0		
	3/5	3	1.3	2	-1.2	3	-3.6		
	3/7	3	1.0	2	-1.5	2	-3.3		
.125	3/1	4	2.5			3	1.8	3	-2.8
	3/3	3	1.2	2	-1.5	2	-1.5		
	3/5	2	0.5	2	-2.2	2	-3.2		
	3/7	2	-0.3	3	-2.5	3	-3.5		
	3/14			3	-4.0				

NOTE: Average springback values were obtained by averaging the deviation from 80°∠ for each of the six different forming radii (.020-.120R).

TABLE 14-2

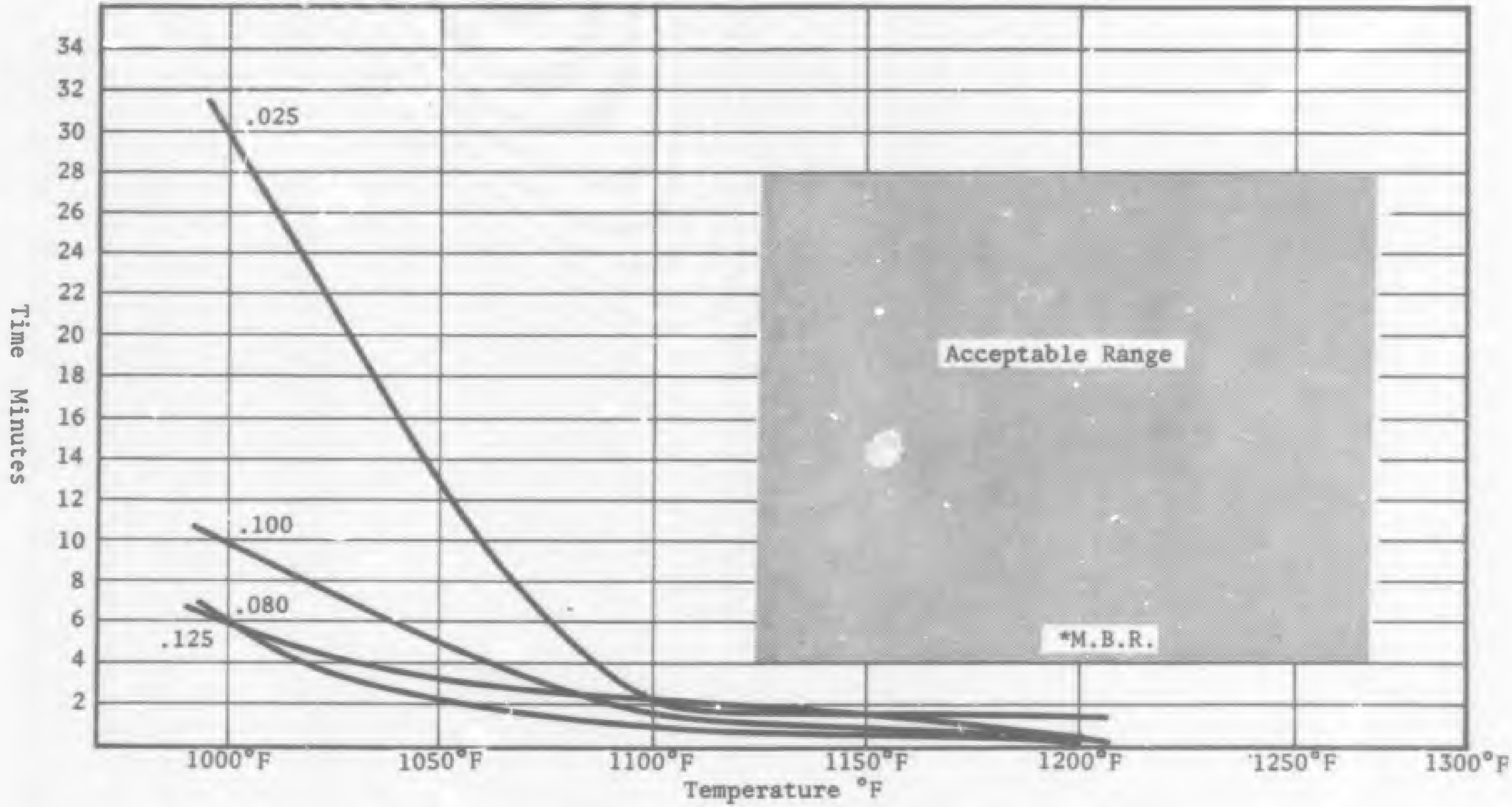
SUMMARY OF DATA FOR ZERO SPRINGBACK (Ti 6A1-4V)

Springback Test for Soak Time Ti 6A1-4V

.100 Shim, 80° Pure Bend, Temperature ± 20°F.

Thickness inches	Time Min. Dwell/Soak	1000°F Range	1000°F Average Springback	1100°F Range	1100°F Average Springback	1170°F Range	1170°F Average Springback	1300°F Range	1300°F Average Springback
.020	2/0.5	4	25.0	1	21.5	3	11.5	0	-2.0
	2/5	2	16.0	2	15.5	1	-2.5	4	-7.5
	2/10	4	12.0	1	0.5	1	-6.5	0	-11.0
	2/15	1	8.5	1	-1.5				
.032	2/0.5	2	20.0	1	16.5	3	10.5	1	-0.5
	2/5			1	3.5	3	-1.5	2	-7.0
	2/10	3	8.5	3	-0.5	3	-4.5	2	-8.0
	2/15			3	-1.5				
.080	3/0.5	3	6.5	3	6.5	4	3.0	2	-2.0
	3/5	2	3.0	4	0.5	3	-3.5	3	-4.5
	3/10	3	2.5	2	-2.0	2	-4.0	3	-5.5
	3/15	3	0.5	3	-2.5				
.090	3/0.5	4	7.0	2	6.0	3	3.5	3	-0.5
	3/5	3	4.5	1	1.5	2	-2.0	3	-3.5
	3/10	4	3.0	2	0.0	2	-3.0	4	-5.0
	3/15	3	1.5	2	-1.0				
.125	3/0.5	2	6.0	2	4.0	1	1.5	2	-1.0
	3/5	3	3.5	3	0.5	4	-2.0	2	-3.0
	3/10	2	2.0	2	-1.0	3	-3.5	1	-3.5
	3/15	2	1.0	3	-1.5				

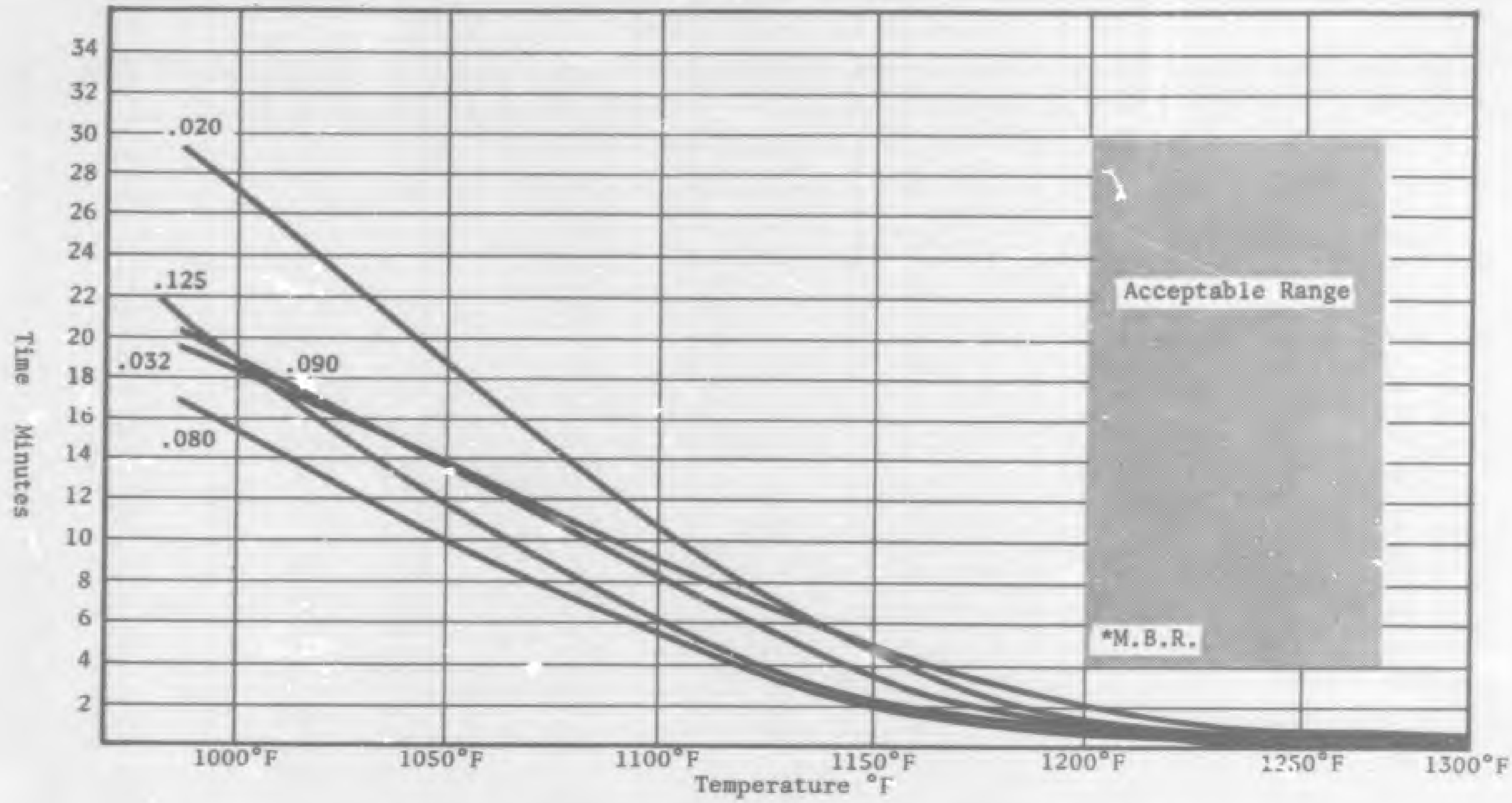
NOTE: Average springback values were obtained by averaging the deviation from 80° ∡ for each of the two extreme forming radii (.020 and .120R).



Material Thickness	Test Temperature			
	1000°F	1050°F	1100°F	1200°F
.025	30.0 Min.	13.0 Min.	2.0 Min.	1.5 Min.
.080	6.0	2.0	1.0	0.5
.100	10.0	5.0	1.5	0.5
.125	6.0	3.0	2.0	0.5

Zero Springback For Ti-6Al-6V-2Sn, Pure Bend - 80° ∡

Figure 14-12 Zero Springback Curves For Ti-6Al-6V-2Sn



Material Thickness	Test Temperature			
	1000°F	1100°F	1170°F	1300°F
.020	27.3 Min.	10.5 Min.	3.2 Min.	0.1 Min.
.032	18.2	9.0	3.9	0.3
.080	15.5	5.3	1.2	0.1
.090	18.5	10.0	2.0	0.2
.125	18.7	5.9	1.6	0.1

Zero Springback For Ti-6Al-4V, Pure Bend - 80° ∡

Figure 14-13 Zero Springback Curves For Ti-6Al-4V

TABLE 14-3

SUMMARY OF MINIMUM BEND RADII DATA, Ti 6Al-6V-2Sn

Titanium 6Al-6V-2Sn at R.T.

Position Radii	1 .020	2 .040	3 .060	4 .080	5 .100	6 .120	7 .140	8 .160	9 .180	10 .200	11 .220	12 .240	Acceptable M.B.R.	M.B.R. plus IT Safety Factor
Thickness														
.016	3/4	(4)	4	4	4	4							2.50T	3.50T
.020	0/4	2/4	(4)	4	4	4							3.00T	4.00T
.025	0/4	3/4	(4)	4	4	4							2.40T	3.40T
.032	0/4	1/4	(4)	4	4	4							1.88T	2.88T
.040	0/4	3/4	(4)	4	4	4							1.50T	2.50T
.050	0/4	0/4	0/4	0/4	(4)	4							2.00T	3.00T
.100							0/4	1/4	(4)	4	4	4	1.80T	2.80T
.125							0/4	0/4	0/4	0/4	0/4	0/4	--	--

Titanium 6Al-6V-2Sn at 1200°F

Thickness	1 .020	2 .040	3 .060	4 .080	5 .100	6 .120	Acceptable M.B.R.	M.B.R. plus IT Safety Factor
.016	(4)	4	4	4	4	4	--	--
.020	(4)	4	4	4	4	4	--	--
.025	(4)	4	4	4	4	4	--	--
.032	(4)	4	4	4	4	4	--	--
.040	(4)	4	4	4	4	4	--	--
.050	(4)	4	4	4	4	4	--	--
.080	0/4	(4)	4	4	4	4	.50T	1.50T
.125	2/4	(4)	4	4	4	4	.32T	1.32T

○ Lowest acceptable bend.

TABLE 14-4

SUMMARY OF MINIMUM BEND RADII DATA, Ti 6Al-4V

Titanium 6Al-4V at R.T.

Position Radii	1 .020	2 .040	3 .060	4 .080	5 .100	6 .120	7 .140	8 .160	9 .180	10 .200	11 .220	12 .240	Acceptable M.B.R.	M.B R. plus IT Safety Factor
Thickness														
.020	0/4	2/4	(4)	4	4	4							3.00T	4.00T
.032	0/4	0/4	1/4	(4)	4	4							2.50T	3.50T
.080							0/4	0/4	0/4	1/4	0/4	1/4	--	--
.090							0/4	C/4	0/4	0/4	0/4	0/4	--	--
.125														

Titanium 6Al-4V at 1200°F

Position Radii	1 .020	2 .040	3 .060	4 .080	5 .100	6 .120	Acceptable M.B.R.	M.B R. plus IT Safety Factor
.020	(4)	4	4	4	4	4	--	---
.032	3/4	(4)	4	4	4	4	1.25T	2.25T
.080	0/4	0/4	(4)	4	4	4	.75T	1.75T
.090	2/4	1/4	(4)	4	4	4	.67T	1.67T
.125	0/4	2/4	3/4	(4)	4	4	.64T	1.64T

Titanium 6Al-4V at 1350°F

Position Radii	1 .020	2 .040	3 .060	4 .080	Acceptable M.B.R.	M.B R. plus IT Safety Factor
.020	(4)	4	4	4	--	--
.032	(4)	4	4	4	--	--
.080	(4)	4	4	4	--	--
.090	(4)	4	4	4	--	--
.125	2/4	(4)	4	4	.32T	1.32T

○ Lowest Acceptable Bend

Minimum Bend Radii - R/T Ratio

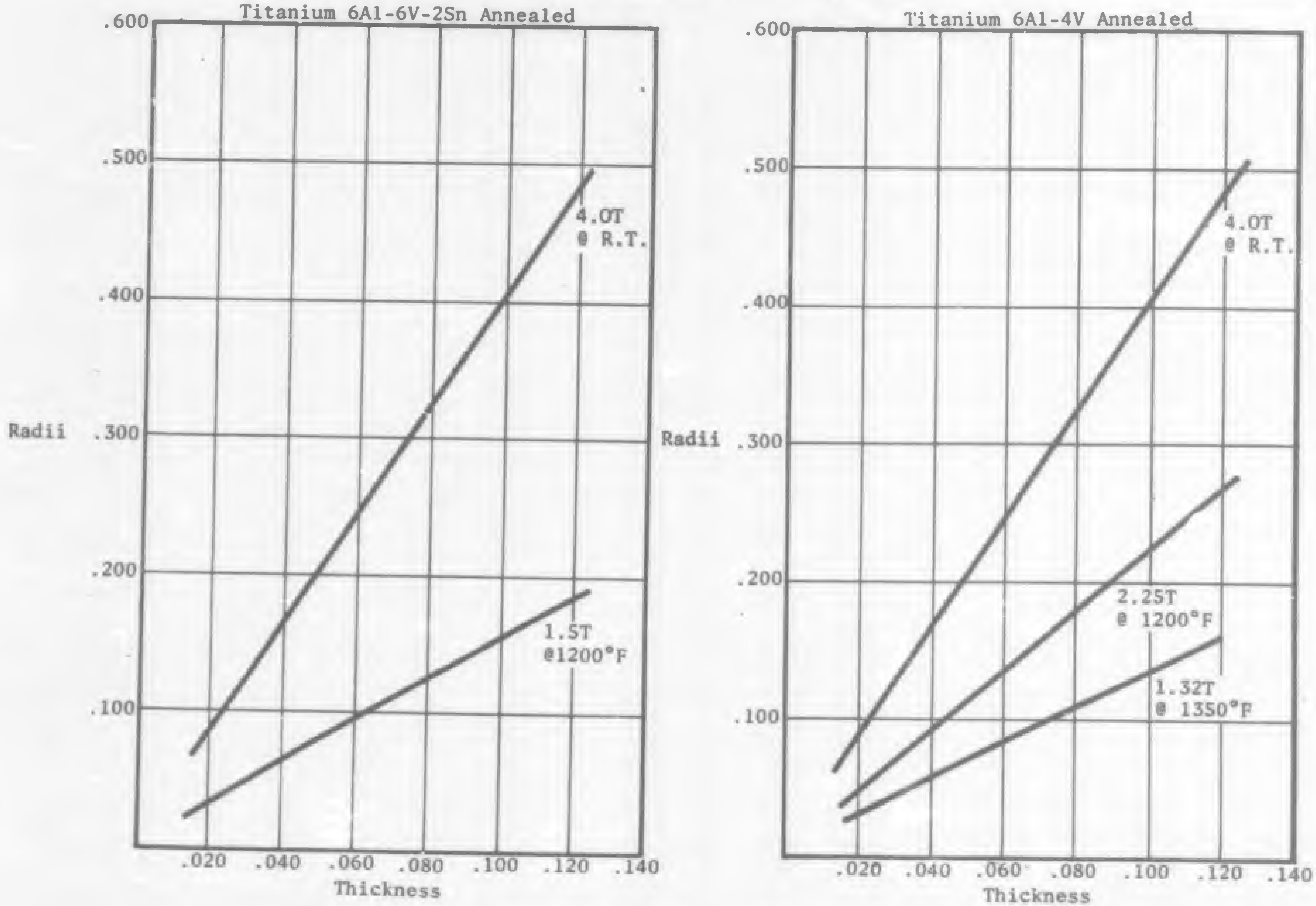


Figure 14-14 Minimum Bend Radii Graphs for Ti-6Al-6V-2Sn + Ti-6Al-4V

SECTION XV

MATERIAL RECEIPT AND INSPECTION

1. DELIVERY

Approximately 90% of the material ordered for this project was received at Bethpage by 31 January, 1967. The balance was received shortly afterwards.

2. CONTROL DATA

In order to determine and derive the optimum utilization of material, control data was catalogued at the time of delivery. The Certificate of Test Data (Table 15-1) incorporated the primary data required, such as:

- Material type
- Material dimensions
- Heat number
- Yield strength
- Tensile strength
- Bend test
- Elongation
- Hydrogen content
- Oxygen content
- Titanium alloy

The supplier submitted the certified data to Grumman in accordance with contractual agreements.

3. INSPECTION

The quality inspection of materials was made just prior to submission for tests. At this time the precise properties and characteristics were noted and recorded to verify the Certificate of Test Data. No significant variations were detected.

4. MATERIAL HISTORY

By referring to the data shown in Table 15-1, it was possible to determine the exact status and condition of any material from origin to disposition after forming. The three critical stages that required close examination were:

- Properties at the shipping-receiving phase
- Properties prior to test
- Properties subsequent to test

TABLE 15-1 CERTIFICATE OF TEST DATA FOR ALL TITANIUM RECEIVED

MATERIAL FOR PART NO.	ITEM NO.	REF. P.O. SHEET NOS.	VENDOR	TITANIUM ALLOY	NO. OF PCS.	THICK-NESS	SIZE	YIELD STRENGTH LONG.	YIELD STRENGTH TRANS.	TEN. STRENGTH LONG.	TEN. STRENGTH TRANS.	ELONGATION LONG	ELONGATION TRANS.	BEND TEST LONG	BEND TEST TRANS.	HEAT NO.	H_2 CONTENT	O_2 CONTENT
1 3	1	2,3,4,5,6	T.M.C.A.*	Annealed 6Al-6V-2Sn	5	.025	20 x 80	151,500	Typ.	160,800	Typ.	13.0	Typ.	3.0	Typ.	G-393	.007-.010	.12
1	1	1,2,3,4			4	.025	20 x 80	156,600	Typ.	164,800	Typ.	13.0	Typ.	3.5	Typ.	G-1537	.005-.006	.17
2	2	1,1-1,2, 2-1,3			5	.025	36 x 48	164,000	Typ.	173,800	Typ.	13.5	Typ.	4.0	Typ.	G-881	.007	.16
2	2	3			1	.025	36 x 48	153,100	166,000	165,600	179,200	11.5	15.5	3.5	3.5	G-1537	.008	.17
4	3	1,2,3			3	.025	23 15/16x80	155,700	Typ.	162,700	Typ.	14.0	Typ.	3.5	Typ.	G-3104	.010-.011	.15
4	4	5			1	.025	18 x 80	156,900	159,000	171,500	167,400	16.0	13.0	3.0	3.0	G-1537	.005	.17
4	4	6			1	.025	18 x 80	157,200	156,500	172,300	164,200	15.5	12.0	3.0	3.0	G-1537	.005	.17
5	5	1,2,3,4, 5,6			6	.025	30 x 104	157,600	Typ.	165,700	Typ.	13.5	Typ.	3.5	Typ.	G-3106	.011-.014	.15
6	6	3			1	.025	36 x 72	161,900	158,500	175,800	166,800	14.0	10.0	3.5	3.5	D-2429	.008	.17
1	7	11			1	.070	20 x 80	154,200	160,600	164,000	168,400	13.5	15.5	4.0	4.0	G-2443	.006	.16
1	7	12			1	.070	20 x 80	154,800	161,100	165,100	169,100	14.0	16.0	4.0	4.0	G-2443	.006	.16
3	7	2,3,4			3	.070	20 x 80	159,500	Typ.	161,500	Typ.	14.5	Typ.	4.0	Typ.	G-3614	.005	.15
1	7	1			1	.070	20 x 80	153,400	158,100	161,400	163,100	13.5	15.0	4.0	4.0	G-3024	.005	.15
1	7	50			1	.070	20 x 80	158,300	157,600	165,300	163,900	13.5	15.0	4.0	4.0	G-3024	.004	.15
1	7	13			1	.070	20 x 80	155,200	160,100	165,800	166,900	14.5	14.0	4.0	4.0	G-3107	.005	.14
1	7	1			1	.070	20 x 80	151,800	158,000	158,200	164,200	14.0	16.5	4.0	4.0	G-391	.004	.11
2	8	9,9-1			2	.070	36 x 48	154,800	161,100	165,100	169,100	14.0	16.0	4.0	4.0	G-2443	.007	.16
2	8	1,1-1			2	.070	36 x 48	160,700	162,300	165,700	164,400	16.0	15.0	4.0	4.0	G-3614	.006	.15
2	8	2,2-1			2	.070	36 x 48	158,100	161,900	163,100	164,600	15.5	14.5	4.0	4.0	G-3614	.005	.15
4	9	47			1	.070	23 15/16x80	154,300	158,000	165,200	165,800	15.0	15.0	3.5	3.5	G-1133	.004	.18
4	9	10			1	.070	23 15/16x80	154,900	158,300	165,300	165,300	15.0	15.5	3.0	3.0	G-168	.004	.18
4	9	11			1	.070	23 15/16x80	154,100	159,700	164,200	169,800	13.5	16.5	3.0	3.0	G-168	.004	.18
4	10	12,12-1			2	.070	18 x 80	153,500	159,300	162,500	169,700	13.5	17.5	3.0	3.0	G-168	.004	.15
5	11	1,2,3,4,5			5	.070	30 x 104	158,000	Typ.	165,500	Typ.	14.0	Typ.	3.5	Typ.	G-3614	.006-.007	.15
5	11	1	T.M.C.A.*	Annealed 6Al-6V-2Sn	1	.070	30 x 104	154,500	163,200	162,200	169,600	10.5	16.0	3.5	3.5	G-3024	.005	.15

*T.M.C.A. - Titanium Metals Corporation of America

(Sheet 1 of 4)

TABLE 15-1 CERTIFICATE OF TEST DATA FOR ALL TITANIUM RECEIVED (CONT'D)

MATERIAL FOR PART NO.	ITEM NO.	REF. P.O. SHEET NOS.	VENDOR	TITANIUM ALLOY	NO. OF PCS.	THICK-NESS	SIZE	YIELD STRENGTH LONG.	YIELD STRENGTH TRANS.	TENSILE STRENGTH LONG.	TENSILE STRENGTH TRANS.	ELONGATION LONG.	ELONGATION TRANS.	BEND TEST LONG.	BEND TEST TRANS.	HEAT NO.	H_2 CONTENT	O_2 CONTENT
6	12	2	T.M.C.A.*	Annealed 6Al-6V-2Sn	1	.070	.071x36x97	153,300	152,700	163,400	159,000	14.0	Typ.	4.0	Typ.	G-2443	.005	.16
3	13	1,3,4,5, 6,7		Sol. Treat 6Al-4V	6	.025	20 x 80	128,500	Typ.	144,000	Typ.	9.0	Typ.	4.0	Typ.	G-3720	.008	.11
4	14	2,3,4			3	.025	23 15/16x80	127,500	Typ.	145,000	Typ.	11.0	Typ.	4.0	Typ.	G-3607	.008-.009	.11
4	15	1,1-1			2	.025	18 x 80	144,600	132,300	160,600	150,400	7.5	11.0	4.0	4.0	G-1914	.009	.12
1	16	2,3,5,6, 7,8			6	.070	20 x 80	129,500	Typ.	152,000	Typ.	9.5	Typ.	4.0	Typ.	G-3715	.007-.008	.12
4	17	2			1	.070	23 15/16x80	128,000	135,400	147,400	152,700	10.5	7.5	4.0	4.0	G-3578	.009	.09
4	17	1			1	.070	23 15/16x80	126,800	137,700	150,400	157,900	13.5	7.5	4.0	4.0	G-3381	.008	.12
4	17	2			1	.070	23 15/16x80	135,700	134,300	154,400	151,800	10.0	8.5	4.0	4.0	G-3720	.008	.11
4	18	1,1-1		Sol. Treat 6Al-4V	2	.070	18 x 80	136,700	128,400	153,100	148,100	10.0	13.0	4.0	4.0	G-3720	.008	.11
1 & 3	19	1 thru 9		Duplex Annealed 8Al-1 Mo-1V	9	.025	20 x 20	136,000	Typ.	148,500	Typ.	13.0	Typ.	3.5	Typ.	G-3292	.011-.014	.08
2	20	1,1-1,2, 2-1,4			5	.025	36 x 48	134,000	Typ.	149,500	Typ.	12.0	Typ.	3.5	Typ.	D-7696	.011-.014	.10
2	20	1			1	.025	36 x 48	138,000	Typ.	150,400	Typ.	12.0	Typ.	3.5	Typ.	D-8423	.012	.09
4	21	8			1	.025	23 15/16x80	136,700	131,000	150,000	145,900	12.0	11.5	3.5	3.5	D-8423	.011	.09
4	21	1			1	.025	23 15/16x80	136,100	131,500	146,800	146,500	11.5	12.5	3.5	3.5	G-3290	.011	.09
4	21	2			1	.025	23 15/16x80	132,500	133,000	145,700	147,000	14.0	10.5	3.5	3.5	G-3290	.011	.09
4	22	14,14-1			2	.025	18 x 80	135,900	135,900	151,700	150,500	13.5	11.5	4.0	4.0	G-3290	.012	.09
5	23	1 thru 6			6	.025	30 x 104	134,500	Typ.	147,500	Typ.	12.0	Typ.	3.5	Typ.	G-3290	.004-.005	.09
6	24	1			1	.025	36 x 72	130,700	129,600	143,800	141,700	11.5	12.5	3.5	3.5	D-8423	.010	.09
3	25	1,1-1			2	.070	20 x 80	130,000	140,100	146,200	156,500	10.0	13.0	4.0	4.0	G-758	.008	.09
3	25	2			1	.070	20 x 80	142,700	135,500	153,800	147,500	13.5	13.5	4.0	4.0	G-3290	.015	.09
1	25	1			1	.070	20 x 80	135,800	135,400	146,900	145,100	15.5	15.0	3.5	3.5	G-3292	.007	.08
1	25	2	T.M.C.A.*	Duplex Annealed 8Al-1 Mo-1V	1	.070	20 x 80	135,400	134,700	145,200	145,500	13.5	14.5	3.5	4.5	G-3292	.007	.08

*T.M.C.A. - Titanium Metals Corporation of America

(Sheet 2 of 4)

TABLE 15-1 CERTIFICATE OF TEST DATA FOR ALL TITANIUM RECEIVED (CONT'D)

MATERIAL FOR PART NO.	ITEM NO.	REF. P.O. SHEET NOS.	VENDOR	TITANIUM ALLOY	NO. OF PCS.	THICK-NESS	SIZE	YIELD STRENGTH LONG.	YIELD STRENGTH TRANS.	TENSILE STRENGTH LONG.	TENSILE STRENGTH TRANS.	ELONGATION LONG.	ELONGATION TRANS.	BEND TEST LONG.	BEND TEST TRANS.	HEAT NO.	H_2 CONTENT	O_2 CONTENT
2	26	2,2-1	T.M.C.A.*	Duplex Annealed 8Al-1 Mo-1V	2	.070	36 x 48	131,400	134,100	146,300	147,500	15.5	14.5	3.5	3.5	G-3292	.008	.08
2	26	3			1	.070	36 x 48	137,800	136,100	149,000	148,000	15.0	15.0	3.5	3.5	G-3292	.007	.08
4	27	14,14-1			2	.070	23 15/:6x80	137,200	133,100	151,600	148,500	15.5	14.5	3.5	3.5	D-9947	.013	.09
4	28	1			1	.070	18 x 80	138,500	141,800	152,800	157,600	12.5	14.5	4.0	4.0	G-3290	.013	.09
5	29	11			1	.070	30 x 104	158,300	136,700	151,400	150,300	13.5	15.0	3.5	3.5	D-9947	.013	.09
5	29	13			1	.070	30 x 104	137,200	133,100	151,600	148,500	15.5	14.5	3.5	3.5	D-9947	.013	.09
6	29	8			1	.070	30 x 104	131,500	138,400	148,100	153,700	11.0	14.0	4.0	4.0	G-758	.007	.09
6	30	1		Duplex Annealed 8Al-1 Mo-1V	1	.070	36 x 72	138,200	132,100	150,000	144,200	13.0	13.5	3.5	4.0	G-1651	.008	.08
1 & 3	31	1,3,4,5,6,7,9,19		Annealed 6Al-4V	8	.025	20 x 80	134,700	Typ.	146,400	Typ.	12.5	Typ.	4.0	Typ.	G-2480	.007-.008	.09
3	31	1			1	.025	20 x 80	136,000	136,400	146,400	145,100	11.0	14.0	3.5	3.5	G-2793	.008	.12
2	32	1,1-1			2	.025	36 x 48	132,800	138,700	143,000	146,800	11.5	12.5	3.5	3.5	G-2566	.010	.11
2	32	4,4-1			2	.025	36 x 48	131,800	141,100	142,200	146,300	11.5	11.0	3.0	3.0	G-2566	.010	.11
2	32	4,4-1			2	.025	36 x 48	131,300	138,200	145,300	144,600	12.5	12.0	3.5	3.5	G-2566	.010	.11
4	33	2			1	.025	23 15/16x80	143,300	132,700	148,000	143,400	12.5	12.0	4.0	4.0	G-862	.008	.11
4	33	3			1	.025	23 15/16x80	142,400	132,100	150,500	143,000	11.5	10.0	4.0	4.0	G-862	.008	.11
4	33	18			1	.025	23 15/16x80	134,100	136,900	143,500	144,000	11.5	12.0	4.0	4.0	G-2860	.008	.12
4	34	29			1	.025	18 x 50	136,400	139,500	145,100	146,300	12.5	12.0	4.0	4.0	G-2480	.008	.09
4	34	30			1	.025	18 x 80	137,700	137,900	146,700	146,000	10.5	12.5	4.0	4.0	G-2480	.008	.09
5	35	1 thru 6			6	.025	30 x 104	141,800	Typ.	148,700	Typ.	12.5	Typ.	4.0	Typ.	G-3606	.006-.007	.11
6	36	1			1	.025	36 x 72	135,700	136,200	145,400	143,100	12.5	12.5	4.0	4.0	G-2731	.007	.11
3	37	2,3,4			3	.070	20 x 80	132,800	Typ.	141,700	Typ.	13.0	Typ.	4.0	Typ.	G-3609	.004-.008	.11
1	37	3			1	.070	20 x 80	136,000	135,600	145,700	142,900	12.5	13.5	4.5	4.5	G-3659	.002	.12
1	37	4	T.M.C.A.*	Annealed 6Al-4V	1	.070	20 x 80	136,400	137,300	143,600	145,900	13.0	10.0	4.5	4.5	G-3659	.003	.12

*T.M.C.A. - Titanium Metals Corporation of America

(Sheet 3 of 4)

TABLE 15-1 CERTIFICATE OF TEST DATA FOR ALL TITANIUM RECEIVED (CONT'D)

MATERIAL FOR PART NO.	ITEM NO.	REF. P.O. SHEET NOS.	VENDOR	TITANIUM ALLOY	NO. OF PCS.	THICK-NESS	SIZE	YIELD STRENGTH LONG.	YIELD STRENGTH TRANS.	TENSILE STRENGTH LONG.	TENSILE STRENGTH TRANS.	ELONGATION LONG.	ELONGATION TRANS.	BEND TEST LONG.	BEND TEST TRANS.	HEAT NO.	H_2 CONTENT	O_2 CONTENT
2	38	15	T.M.C.A.*	Annealed 6Al-4V	1	.070	36 x 48	135,400	133,100	144,000	140,900	13.5	12.5	4.5	4.5	G-3017	.004	.11
2	38	29			1	.070	36 x 48	131,700	135,000	140,700	142,000	13.5	13.0	4.5	4.5	G-3017	.004	.11
2	38	8			1	.070	36 x 48	137,800	138,500	142,900	142,200	13.5	13.0	4.5	4.5	G-3230	.006	.10
4	39	1			1	.070	23 15/16x80	134,900	136,000	143,000	141,800	14.0	15.0	4.0	4.0	G-3256	.006	.11
4	39	1			1	.070	23 15/16x80	131,200	132,800	139,400	139,900	11.0	13.5	4.0	4.0	G-3609	.005	.11
6	40	14			1	.070	18 x 80	137,000	145,400	143,200	148,800	13.5	13.0	4.0	4.0	G-3498	.004	.10
5	41	1			1	.070	30 x 104	134,800	137,000	142,700	141,500	13.0	14.0	4.5	4.5	G-3794	.002	.10
5	41	2			1	.070	30 x 104	134,700	136,700	142,000	141,400	14.5	14.5	4.5	4.5	G-3794	.002	.10
5	41	1			1	.070	30 x 104	130,500	138,200	139,300	142,700	14.5	14.5	4.5	4.5	G-3528	.004	.09
6	42	4	T.M.C.A.*	Annealed 6Al-4V	1	.070	36 x 72	136,300	140,300	142,600	144,100	13.0	13.0	4.5	4.5	G-3256	.005	.11
1	1		R.M.I**	Duplex Annealed 8Al-1Mo-1V	4	.070	20 x 80	131,800	136,900	145,700	146,300	12.0	13.0	5.0	5.0	292865	33(PPM)	.076
4	2				1	.070	23 15/16x80	143,300	136,000	155,600	145,800	13.0	12.0	4.5	4.5	292865	102(PPM)	.085
4	5				1	.070	18 x 80	143,300	136,000	155,600	145,800	13.0	12.0	4.5	4.5	292865	82(PPM)	.099
5	4				3	.070	30 x 104	134,200	143,700	144,300	153,200	10.0	11.0	4.5	4.5	301177	82(PPM)	.099
2	5				2	.070	36 x 48	141,100	140,000	152,600	149,000	12.0	12.0	5.0	5.0	292865	136(PPM)	.095
2	5			Duplex Annealed 8Al-1Mo-1V	1	.070	36 x 48	130,300	142,300	141,100	156,000	15.0	15.0	4.5	4.5	300826	80(PPM)	.102
1	6			Annealed 6Al-4V	4	.070	20 x 80	132,900	132,900	141,500	141,600	11.0	11.0	4.5	4.5	302017	45(PPM)	.115
2	7				3	.070	36 x 48	130,200	133,500	140,100	140,900	11.0	11.0	4.5	4.5	302017	43(PPM)	.121
5	8				1	.070	30 x 104	125,000	155,000	137,000	142,500	11.0	12.0	4.0	4.0	292671	44(PPM)	.116
5	8				2	.070	30 x 104	127,500	133,500	140,200	142,000	10.0	11.0	4.5	4.5	302017	45(PPM)	.118
4	9				1	.070	23 15/16x80	129,300	132,000	140,800	141,900	13.0	11.0	1.5	4.5	302017	43(PPM)	.109
6	10		R.M.I.**	Annealed 6Al-4V	1	.070	18 x 80	129,300	132,000	140,800	141,900	13.0	11.0	4.5	4.5	302017	43(PPM)	.109

*T.M.C.A. - Titanium Metals Corporation of America
**R.M.I. - Reactive Metals Incorporated

(Sheet 4 of 4)

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APPENDIX

OPERATION AND DATA SHEETS

CONVERSION CHART

Gauge Reading in psi		Tons Per Pin
1120	=	.98
1000	=	.88
875	=	.77
750	=	.66
500	=	.44
375	=	.33
210	=	.19
125	=	.11

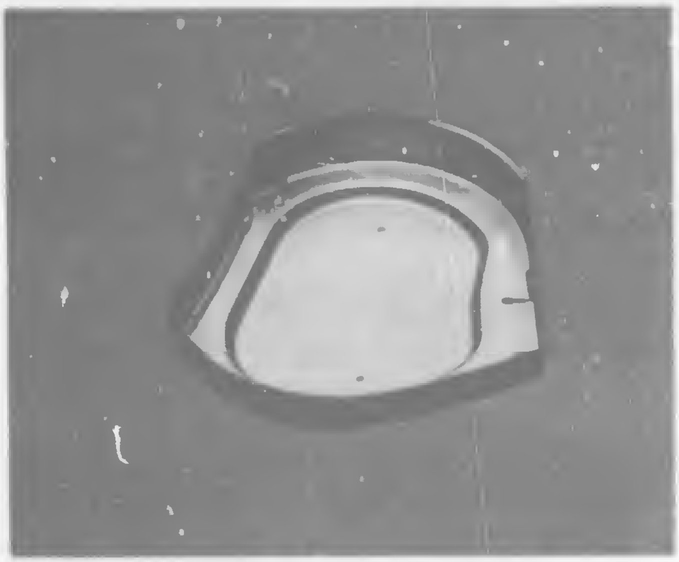
To find total cushion pressure, multiply number of pins by tons per pin.

TABLE A-1

PART 1, TAIL CONE FRAME

ONE-STEP FORMING, RDM 1500

(Sheet 1 of 3)



NOTES:
* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	37	38	39	40	41	42	43	44	45	46	47	48
SHEET NO.	11	11	1-1	12	12	12	12	13	13	13	13	1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G2423	G2423	G3614	G2443	←	→	G2443	G3107	←	→	G3107	G3024
TEST	F9902	F9902	J1053	F9902	←	→	F9902	F9900	←	→	F9900	F9856
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1250°	1250°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
UPPER INDICATOR READING AT	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°
LOWER INDICATOR READING AT	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	12	12	12	12	12	12	12	15	15	15	15	15
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO	O.K. ✓											
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-1

PART 1, TAIL CONE FRAME

ONE-STEP FORMING, RDM 1500

(Sheet 2 of 3)

NOTES:

* 1. See page A-1 for conversion of psi to tonnage

** 2. Part jammed in die

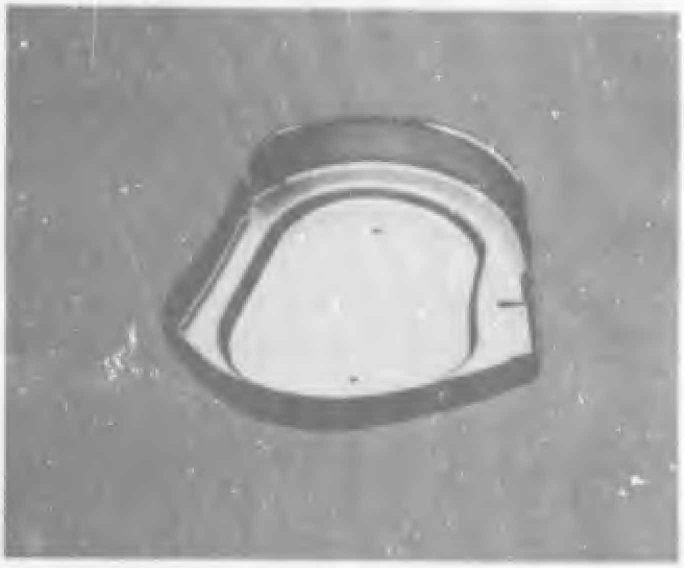
TITANIUM	Ti-6Al-4V											
PART IDENT NO.	49	50	51	52	53	54	55	56	57	58	59	60
SHFET NO.	4	4	4	4	3	3	3	3	RM1	RM1	RM1	RM1
VENDOR RMI; TIMET = T	T	←					→	T	RM1	RM1	RM1	RM1
HT	G3659	←					→	G3659	302017	←	→	302017
TEST	J0965	←					→	J0965				
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1400°	1400°	1400°	1400°	1400°	1400°	1350°	1350°	1380°	1380°	1380°	1380°
UPPER INDICATOR READING AT	1350°	1350°	1350°	1350°	1350°	1350°	1300°	1300°	1340°	1340°	1320°	1340°
LOWER INDICATOR READING AT	1350°	1350°	1350°	1350°	1350°	1350°	1300°	1340°	1340°	1350°	1360°	1350°
LUBE	T50	←					→	T50	JGAW #1	←	→	JGAW #1
SOAK - NO. OF MINS.	2	2	2	2	2	**	3	2	2	2	2	2
DWELL IN CLOSED POSITION	13	13	13	10	10	**	12	10	10	10	10	10
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-1

PART 1, TAIL CONE FRAME

ONE-STEP FORMING, RDM 1500

(Sheet 3 of 3)



NOTES:
* 1. See page A-1 for conversion of psi to tonnage

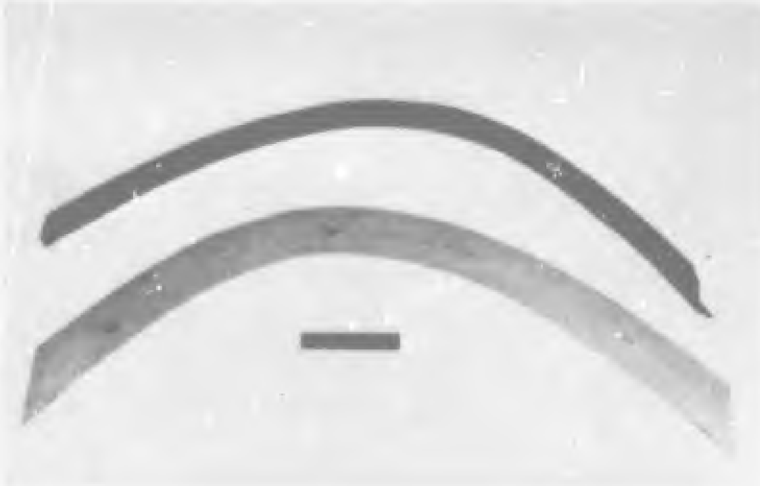
TITANIUM	Ti-8Al-1Mo-1V											
PART IDENT NO.	61	26	63	64	65	66	67	68	69	70	71	72
SHEET NO.	RM1	RM1	RM1	RM1	2	2	2	2	1	1	1	1
VENDOR RMI; TIMET = T	RM1	RM1	RM1	RM1	T	T	T	T	T	T	T	T
HT	292865	←	→	292865	G3292	←					→	G3292
TEST	J1220	←									→	J1220
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1520	1520	1520	1520	1520	1520	1520	1520	1520	1520	1520	1520
UPPER INDICATOR READING AT	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450
LOWER INDICATOR READING AT	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450
LUBE	JGAW #1	←									→	JGAW #1
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	3	3	3	3	3	3	3	3	3	10	10
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
ALKO-N-PROCESS									✓		✓	
TURCO PROCESS												
ZYGLO		O.K. ✓	O.K. ✓									
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-2

PART 2, DOOR CHANNEL

ONE-STEP FORMING, RDM 1502

(Sheet 1 of 6)



NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	1	2	3	4	5	6	7	8	9	10	11	12
SHEET NO.	1-1	1-1	1-1	1-1	1	1	1	1	3	3	3	3
VENDOR RMI; TIMET = T	T	←									→	T
HT	G881	G881	G881	G881	G881	G881	G881	G881	G1537	G1537	G1537	G1537
TEST	J1055	J1055	J1055	J1055	J1055	J1055	J1055	J1055	J1216	J1216	J1216	J1216
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°
UPPER INDICATOR READING AT	1200°	1200°	1200°	1200°	1200°	1200°	1200°	1200°	1200°	1200°	1200°	1200°
LOWER INDICATOR READING AT												
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	8
DWELL IN CLOSED POSITION	12	12	7	5	5	5	5	5	5	5	5	5
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-2

PART 2, DOOR CHANNEL

ONE-STEP FORMING, RDM 1502

(Sheet 2 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

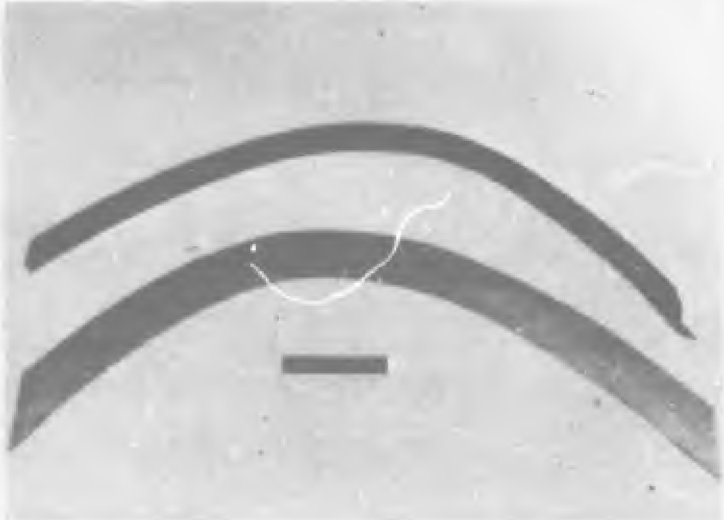
TITANIUM	Ti-6Al-4V											
PART IDENT NO.	13	14	15	16	17	18	19	20	21	22	23	24
SHEET NO.	1-1	1-1	1-1	1-1	4-1	4-1	4-1	4-1	4	4	4	4
VENDOR RMI; TIMET = T	T	←									→	T
HT	G2566	←									→	G2566
TEST	F9940	←	→	F9940	F9942	←	→	F9942	F9940	←	→	F9940
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1350°	1350°	1340°	1350°	1350°	1350°	1350°	1350°	1350°	1350°	1350°	1350°
UPPER INDICATOR READING AT	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
LOWER INDICATOR READING AT												
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	12	12	5	5	5	5	5	5	5	5	5	5
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO				O.K. ✓	O.K. ✓	O.K. ✓						
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-2

PART 2, DOOR CHANNEL

ONE-STEP FORMING, RDM 1502

(Sheet 3 of 6)



NOTE:
*See page A-1 for conversion of psi to tonnage

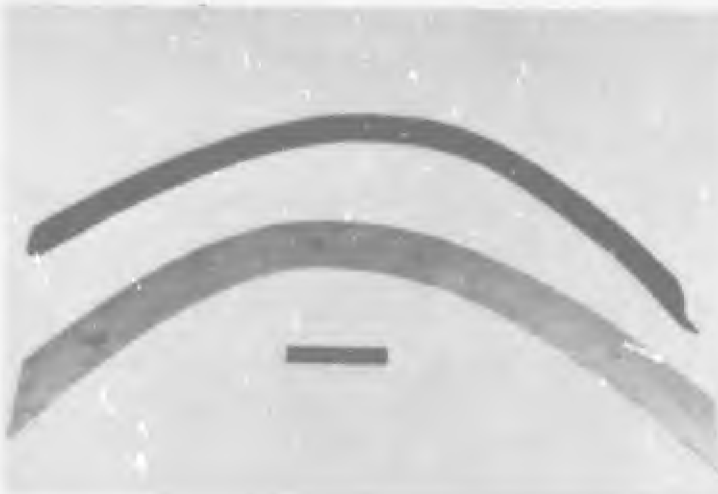
TITANIUM	Ti-8Al-1Mo-1V										
PART IDENT NO.	25	26	27	28	29	30	31	32	33	34	35	36
SHEET NO.	1-1	1-1	1-1	1-1	1	1	1	1	4-1	4-1	4-1	4-1
VENDOR RMI; TIMET = T	T	←									→	T
HT	D7696	←									→	D7696
TEST	J0817	←									→	J0817
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°
UPPER INDICATOR READING AT	1420°	1420°	1420°	1420°	1420°	1420°	1420°	1420°	1420°	1420°	1420°	1420°
LOWER INDICATOR READING AT												
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	1	1	1	1	1	1	1	1	1	1	1	1
DWELL IN CLOSED POSITION	8	8	8	6	6	5	5	5	5	5	5	5
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-2

PART 2, DOOR CHANNEL

ONE-STEP FORMING, RDM 1502

(Sheet 4 of 6)



NOTE:
*See page A-1 for conversion of psi to tonnage

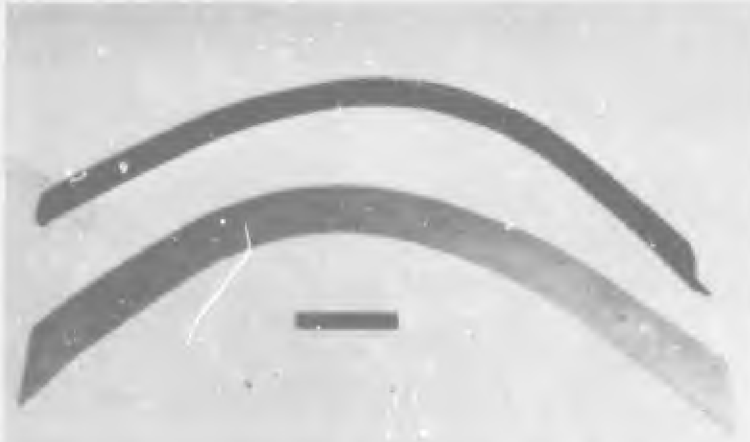
TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	37	38	39	40	41	42	43	44	45	46	47	48
SHEET NO.	1	1	1	1	1	1	1	1	2	2	2	2
VENDOR RMI; TIMET = T	T	←—									—→	T
HT	G3614	←—									—→	G3614
TEST	J1053	←—									—→	J1053
GAUGE	.070	←—									—→	.070
TEMPERATURE RECORDER AT	1260°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
UPPER INDICATOR READING AT	1250°											
LOWER INDICATOR READING AT		1250°	1250°	1250°	1250°	1250°	1250°	1250°	1200°	1200°	1200°	1200°
LUBE	T50	←—									—→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	12	12	12	12	10	10	7	7	7	5	5	5
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER CAEC SPEC.	✓	✓			✓	✓						
ALKO-N-PROCESS			✓				✓	✓	✓			
PRE-COAT TURCO T50 PROCESS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TURCO DE-SCALING PROCESS				✓						✓	✓	✓
* SLIDE CUSHION (psi)		800	800	800	800	800	800	800	800	800	800	800
ZYGLO												

TABLE A-2

PART 2, DOOR CHANNEL

ONE-STEP FORMING, RDM 1502

(Sheet 5 of 6)



NOTE:
*See page A-1 for conversion of psi to tonnage

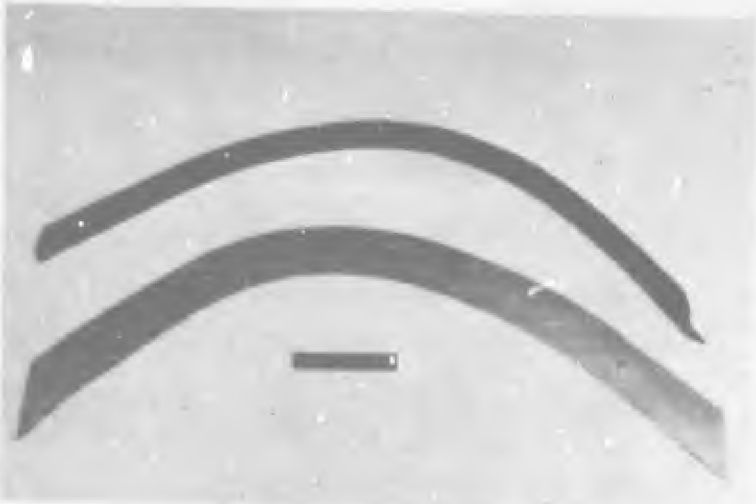
TITANIUM	Ti-6Al-4V											
PART IDENT NO.	49	50	51	52	53	54	55	56	57	58	59	60
SHEET NO.												
VENDOR RMI; TIMET = T	RM1	←									→	RM1
HT	30217	←									→	30217
TEST												
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°
UPPER INDICATOR READING AT	1300°	1300°	1300°	1280°	1280°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
LOWER INDICATOR READING AT												
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	7	5	5	5	5	5	5	5	5	5	5	5
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓			✓	✓	✓						
ALKO-N-PROCESS		✓					✓	✓	✓			
PRE-COAT TURCO PROCESS T50	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TURCO DE-SCALING PROCESS			✓							✓	✓	✓
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
ZYGLO												

TABLE A-2

PART 2, DOOR CHANNEL

ONE-STEP FORMING, RDM 1502

(Sheet 6 of 6)



NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-8Al-1Mo-1V											
PART IDENT NO.	61	62	63	64	65	66	67	68	69	70	71	72
SHEET NO.	2-1	2-1	2-1	2-1	3	3	3	3	2	2	2	2
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3292	←									→	G3292
TEST	J1217	←									→	J1217
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°
UPPER INDICATOR READING AT	1450°	1450°	1450°	1456°	1460°	1460°	1450°	1450°	1450°	1450°	1460°	1460°
LOWER INDICATOR READING AT												
LUBE	T50	←						→	T50	RD 81X	RD 81X	RD 81X
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	10	8	8	8	8	8	8	8	8	8	8
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓		✓	✓	✓							
ALKO-N-PROCELS		✓					✓	✓	✓			
PRE-COAT TURCO PROCESS T50	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
TURCO DE-SCALING PROCESS			✓							✓	✓	✓
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
ZYGLO				O.K. ✓	O.K. ✓	O.K. ✓						

TABLE A-3

PART 2, DOOR CHANNEL

TWO-STEP FORMING, RDM 1509

(Sheet 1 of 3)

TITANIUM	Ti-6A1-6V-2Sn										
PART IDENT NO.	1	2	3	4	5	6	7	8	9	10	11	12
SHEET NO.	2	2	2	2	3	3	3	3	2-1	2-1	2-1	2-1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G881	←									→	G881
TEST	J1055	←									→	J1055
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1200°			1300°	1200°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
UPPER INDICATOR READING AT												
LOWER INDICATOR READING AT	1200°			1200°	1200°	1200°	1200°	1200°	1200°	1200°	1200°	1200°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	2			3	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	15			12	15	10	10	10	10	10	10	10
TONS		PART DAMAGED IN TOOL PROVING	PART DAMAGED IN TOOL PROVING									
NO. OF CLAMPS AT 16 TONS PER	5			5	5	5	5	5	5	5	5	5
BED CUSHION (psi)												
AIR COOLED IMMED.	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.												
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
SLIDE CUSHION (psi)												

TABLE A-3

PART 2, DOOR CHANNEL

TWO-STEP FORMING, RDM 1509

(Sheet 2 of 3)

TITANIUM	Ti-6Al-4V											
PART IDENT NO.	13	14	15	16	17	18	19	20	21	22	23	24
SHEET NO.	1											
VENDOR RMI; TIMET = T	T											
HT	G2566											
TEST	F9940											
GAUGE	.025											
TEMPERATURE RECORDER AT	1400°											
UPPER INDICATOR READING AT				PARTS 1 THROUGH 13 HAVE BEEN PREFORMED, DROP HAMMER/RUBBER HOT AT 1000°F AND HOT SIZED IN RDM 1509 DIE AS PER CHART. PARTS 14 THROUGH 72 HAVE BEEN PREFORMED ONLY.								
LOWER INDICATOR READING AT	1340°											
LUBE	T50											
SOAK - NO. OF MINS.	2											
DWELL IN CLOSED POSITION	8											
TONS												
NO. OF CLAMPS AT 16 TONS PER	5											
BED CUSHION (psi)												
AIR COOLED IMMED.	✓											
DESCALED AS PER GAEC SPEC.												
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
SLIDE CUSHION (psi)												

TABLE A-3

PART 2, DOOR CHANNEL

TWO-STEP FORMING, RDM 1509

(Sheet 3 of 3)

TITANIUM	8Al-1Mo-1V											
PART IDENT NO.	25	26	27	28	29	30	31	32	33	34	35	36
SHEET NO.												
VENDOR RMI; TIMET = T												
HT												
TEST												
GAUGE												
TEMPERATURE RECORDER AT												
UPPER INDICATOR READING AT				PARTS 1 THROUGH 13 HAVE BEEN PREFORMED, DROP HAMMER/RUBBER HOT AT 1000° F AND HOT SIZED IN RDM 1509 DIE AS PER CHART. PARTS 14 THROUGH 72 HAVE BEEN PREFORMED ONLY.								
LOWER INDICATOR READING AT												
LUBE												
SOAK - NO. OF MINS.												
DWELL IN CLOSED POSITION												
TONS												
NO. OF CLAMPS AT 16 TONS PER												
BED CUSHION (psi)												
AIR COOLED IMMED.												
DESCALED AS PER GAEC SPEC.												
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
SLIDE CUSHION (psi)												

TABLE A-4

PART 3, ANNULAR RING

ONE-STEP FORMING, RDM 1497

(Sheet 1 of 8)

NOTES
* 1. See page A-1 for conversion of psi to tonnage

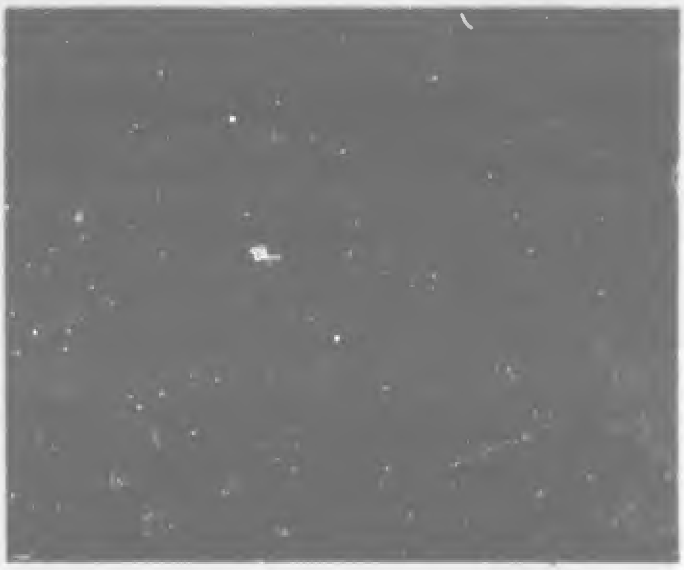
TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	1	2	3	4	5	6	7	8	9	10	11	12
SHEET NO.	2 (2-1)	←	→	2 (2-1)	4 (4-1)	←	→	4 (4-1)	6-1 (6)	←	→	6-1 (6)
VENDOR RMI; TIMET = T	T	←									→	T
HT	G393	←									→	G393
TEST	F9227	←									→	F9227
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1200°	1200°	1200°	1200°	1200°	1200°	1200°	1300°	1300°	1300°	1300°	1300°
UPPER INDICATOR READING AT	1160°	1200°	1200°	1200°	1200°	1200°	1200°	1300°	1300°	1250°	1250°	1250°
LOWER INDICATOR READING AT	1220°	1200°	1200°	1200°	1200°	1200°	1200°	1300°	1300°	1300°	1350°	1300°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	2	3	3	3	3	3	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	10	10	10	10	10	6	5	5	5	5	5
TONS	60	60	60	0	0	60	0	60	60	0	60	60
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	300	200	300	300	300	1000	1200	1100	1100	1100	1100	1100
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	300	0	300	300	300	1000	0	900	900	900	900	900

TABLE A-4

PART 3, ANNULAR RING

ONE-STEP FORMING, RDM 1497

(Sheet 2 of 8)



NOTES
* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V											
PART IDENT NO.	13	14	15	16	17	18	19	20	21	22	23	24
SHEET NO.	6	6	6	6	18	18	18	18	1	1	1	1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G2480	←					→	G2480	G2793	←	→	G2793
TEST	F9084	←					→	F9084	F9734	←	→	F9734
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1300°	1340°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1400°	1300°	1300°
UPPER INDICATOR READING AT	1275°	1280°	1280°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
LOWER INDICATOR READING AT	1300°	1320°	1340°	1340°	1340°	1340°	1360°	1360°	1360°	1360°	1300°	1300°
LUBE	T50	DAG 41	DAG 41	DAG 41	DAG 41	T50	←				→	T50
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	8	8	3	3	3	3	3	3	3	3	3
TONS	60	60	60	60	60	60	60	60	60	60	68	68
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100	1100
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO										O.K. ✓	O.K. ✓	O.K. ✓
* SLIDE CUSHION (psi)	900	900	900	900	900	900	900	900	900	900	1100	1100

TABLE A-4

PART 3, ANNULAR RING

ONE-STEP FORMING, RDM 1497

(Sheet 3 of 8)

NOTES
* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-8Al-1-Mo-1V										
PART IDENT NO.	25	26	27	28	29	30	31	32	33	34	35	36
SHEET NO.	3	3	3	3	1	1	1	1	2	2	2	2
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3292	←									→	G3292
TEST	J1218	←									→	J1218
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1440°	1440°	1500°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°
UPPER INDICATOR READING AT	1400°	1400°	1500°	1400°	1380°	1400°	1400°	1400°	1400°	1400°	1400°	1400°
LOWER INDICATOR READING AT												
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	1	1	1	1	2	1	1	1	1	1	1	1
DWELL IN CLOSED POSITION	12	12	12	8	8	8	8	8	8	8	8	8
TONS	68	68	68	0	0	0	0	0	0	0	0	0
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	1100	1100	1100	800	800	800	800 1200	800 1200	800 1200	800 1200	800 1200	800 1200
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	0	0	700	800	800 0	800	800	800	800

TABLE A-4

PART 3, ANNULAR RING

ONE-STEP FORMING, RDM 1497

(Sheet 4 of 8)

NOTES
* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	37	38	39	40	41	42	43	44	45	46	47	48
SHEET NO.	4	4	4	4	2	2	2	2	3	3	3	3
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3614	←									→	G3614
TEST	J1054	←									→	J1054
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1300°	1300°	1300°	1300°	1320°	1320°	1320°	1320°	1320°	1320°	1320°	1320°
UPPER INDICATOR READING AT	1240°	1250°	1220°	1220°	1220°	1220°	1220°	1220°	1220°	1220°	1220°	1220°
LOWER INDICATOR READING AT	1280°	1250°	1240°	1240°	1240°	1240°	1240°	1240°	1240°	1240°	1240°	1240°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	10	10	10	10	15	15	15	15	20	20	20	20
TONS	0	70	70	70	70	70	70	70	70	70	70	70
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO	O.K. ✓	O.K. ✓	O.K. ✓									
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-4

PART 3, ANNULAR RING

ONE-STEP FORMING, RDM 1497

(Sheet 5 of 8)

NOTES

* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V											
PART IDENT NO.	49	50	51	52	53	54	55	56	57	58	59	60
SHEET NO.	3	3	3	3		2	2		4	4	4	4
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3609	←									→	G3609
TEST	J1028	←									→	J1028
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1350°	1350°	1340°	1380°		1360°	1380°		1380°	1450°	1450°	1450°
UPPER INDICATOR READING AT	1320°	1320°	1260°	1280°		1300°	1300°		1300°	1350°	1350°	1350°
LOWER INDICATOR READING AT	1340°	1320°	1300°	1320°		1320°	1320°		1320°	1350°	1350°	1350°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	2	3	3	3		3	3		3	2	2	2
DWELL IN CLOSED POSITION	3	5	5	5		12	12		12	8	8	8
TONS	70	70	70	70		70	70		70	0	0	0
NO. OF CLAMPS AT 16 TONS PER					DAMAGED PART			DEFECTIVE MATERIAL				
* BED CUSHION (psi)	800	800	800	800		950	950		950	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	800		950	950		950	800	800	800

TABLE A-4

PART 3, ANNULAR RING

ONE-STEP FORMING, RDM 1497

(Sheet 6 of 8)

NOTES
* 1. See page A-1 for conversion of psi to tonnage

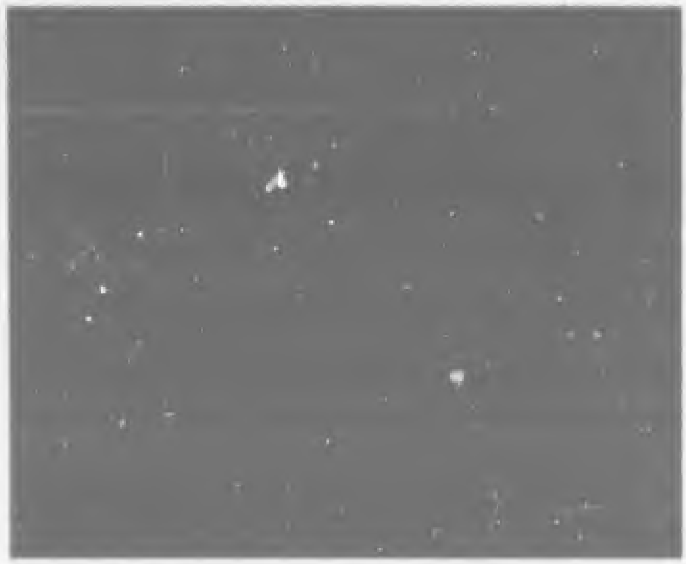
TITANIUM	Ti-8Al-1-Mo-1V											
PART IDENT NO.	61	62	63	64	65	66	67	68	69	70	71	72
SHEET NO.	1	1	1	1	1-1	1-1	1-1	1-1	2	2	2	2
VENDOR RMI; TIMET = T	T ←										→	T
HT	G758 ←						→	G758	G3290 ←		→	G3290
TEST	J1242 ←						→	J1242	J0559 ←		→	J0559
GAUGE	.070 ←										→	.070
TEMPERATURE RECORDER AT	1450°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°
UPPER INDICATOR READING AT	1400°	1500°	1500°	1480°					1475°			
LOWER INDICATOR READING AT	1400°	1500°	1500°		1475°	1480°	1480°	1480°		1500°	1500°	1500°
LUBE	T50 ←										→	T50
SOAK - NO. OF MINS.	1	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	12	10	8	8	8	8	8	8	8	8	8	8
TONS	0	0	0	0	65	0	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-4

PART 3, ANNULAR RING

ONE-STEP FORMING, RDM 1497

(Sheet 7 of 8)



NOTES
* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V-STA										
PART IDENT NO.		74	75	76	77	78	79	80	81	82	83	84
SHEET NO.		1 3	1 3	1 3	1 3	1 3	8	8	8	8	7	7
VENDOR RMI; TIMET = T		T	←								→	T
HT		G3720	←		→	G3720	G3716	←	→	G3716	G3715	G3715
TEST		J1187	←		→	J1187	J1249	←			→	J1249
GAUGE		.025	.025	025	.025	.025	.070	.070	.070	.070	.070	.070
TEMPERATURE RECORDER AT		1000°	1000°	1000°	1050°	1050°	1000°	1000°	1100°	1100°	1100°	1080°
UPPER INDICATOR READING AT		1000°	1000°	1000°	1050°	1050°	1000°	1000°	1000°	1050°	1040°	1050
LOWER INDICATOR READING AT		1000°	1000°	1000°	1050°	1050°	1000°	1000°	1000°	1050°	1100°	1050°
LUBE		T50	←								→	T50
SOAK - NO. OF MINS.		2	2	2	2	2	3	4	4	4	4	4
DWELL IN CLOSED POSITION		40	40	40	30	40	20	40	40	70	20	40
TONS		0	0	0	0	0	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)		1200	1200	1200	1200	1200	800	800	600	800	300	800
AIR COOLED IMMED.		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)		1200	1200	1200	1200	1200	800	800	100	800	0	800

TABLE A-4

PART 3, ANNULAR RING

ONE-STEP FORMING, RDM 1497

(Sheet 8 of 8)

NOTES

* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V-STA											
PART IDENT NO.	85	86										
SHEET NO.	7	7										
VENDOR RMI; TIMET = T	T	T										
HT	G3715	G3715										
TEST	J1249	J1249										
GAUGE	.070	.070										
TEMPERATURE RECORDER AT	1080°	1080°										
UPPER INDICATOR READING AT	1060°	1040°										
LOWER INDICATOR READING AT	1070°	1060°										
LUBE	T50	T50										
SOAK - NO. OF MINS.	4	4										
DWELL IN CLOSED POSITION	20	20										
TONS	65	65										
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓	✓										
DESCALED AS PER GAEC SPEC.	✓	✓										
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

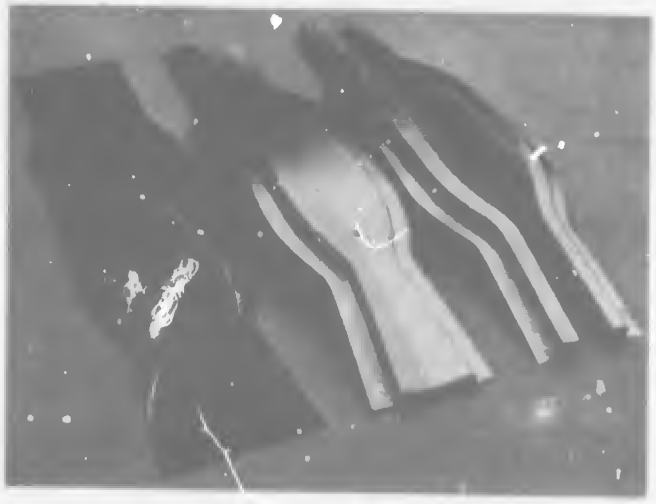


TABLE A-5

PART 4, ZEE MEMBER

ONE-STEP FORMING, RDM 1435

(Sheet 1 of 7)

NOTES:

* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-6Al-6V-2Sn						Ti-6Al-4V			
PART IDENT NO.	1	2	3	4	5	8	9	10	11	12
SHEET NO.	2-1	50-1	50	50	47-1		18	18	18	18
VENDOR RMI; TIMET = T	T	←							→	T
HT	G1095	G1539	G1539	G1539	G1539	9798	G2860	G2860	G2860	G2860
TEST	F8360	F8415	F8415	F8415	F8415		J0273	J0273	J0273	J0273
GAUGE	.025	←							→	.025
TEMPERATURE RECORDER AT	1400°	1450°	1400°	1400°	1450°	1500°	1400°	1400°	1450°	1500°
UPPER INDICATOR READING AT	1340°	1425°	1340°	1340°	1425°	1425°	1340°	1365°	1380°	1440°
LOWER INDICATOR READING AT	1340°	1425°	1340°	1340°	1425°	1425°	1340°			
LUBE	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50
SOAK - NO. OF MINS.	1	1	1	1	1	1	2	1 1/2	0	1
DWELL IN CLOSED POSITION	3	3	1 1/2	2	2	2	10	5	7	2
TONS	50	65	50	50	65	50	50	65	65	65
NO. OF CLAMPS AT 16 TONS PER										
* BED CUSHION (psi)	600	900	600	600	900	600	600	600	600	700
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS										
TURCO PROCESS										
ZYGLO					O.K. ✓		O.K. ✓	O.K. ✓		
* SLIDE CUSHION (psi)	640	900	640	650	900	650	650	600	600	600

TABLE A-5

PART 4, ZEE MEMBER

ONE-STEP FORMING, RDM 1435

(Sheet 2 of 7)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-6Al-4V								Ti-8Al-1Mo-1V			
PART IDENT NO.	13	14	15	16	17	18	19	20	21	22	23	24
SHEET NO.	2	2	2	2	3	3	3	3	1	1	1	1
VENDOR RMI; TIMET = T	T	←					→	T	T	←	→	T
HT	G862	G862	G862	G862	G862	G862	G862	G862	G3290	G3290	G3290	G3290
TEST	J0724	J0724	J0724	J0724	J0724	J0724	J0724	J0724	J1219	J1219	J1219	J1219
GAUGE	.025	←					→	.025	.025	←	→	.025
TEMPERATURE RECORDER AT	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1600°	1600°	1600°
UPPER INDICATOR READING AT	1440°	1440°	1440°	1460°	1460°	1450°	1450°	1480°	1450°	1530°	1520°	1500°
LOWER INDICATOR READING AT												
LUBE	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50
SOAK - NO. OF MINS.	2	2	2	1	1	1	1	1	1/2	1	1	1
DWELL IN CLOSED POSITION	3	3	3	2	2	2	2	2	2	2	2	2
TONS	65	65	65	65	65	60	60	60	60	60	60	60
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	600	600	600	600	600	600	600	600	600	600	600	600
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	600	600	600	500	600	600	600	600	600	600	600	600

TABLE A-5

PART 4, ZEE MEMBER

ONE-STEP FORMING, RDM 1435

(Sheet 3 of 7)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-8Al-1Mo-1V								Ti-6Al-4V-STA			
PART IDENT NO.	25	26	27	28	29	30	31	32	33	34	35	36
SHEET NO.	2	2	2	2	8	8	8	8	1-1	1-1	1-1	1-1
VENDOR RMI; TIMET = T	T	←					→	T	T	T	T	T
HT	G3290	G3290	G3290	G3290	D8423	D8423	D8423	D8423	G1914	G1914	G1914	G1914
TEST	J1219	J1219	J1219	J1219	J0177	J0177	J0177	J0177	F8658	F8658	F8658	F8658
GAUGE	.025	←					→	.025	.025	.025	.025	.025
TEMPERATURE RECORDER AT	1600°	1500°	1500°	1500°	1500°	1500°	1600°	1600°	1000°	1000°	1000°	1000°
UPPER INDICATOR READING AT	1480°	1450°	1450°	1450°	1450°	1450°	1540°	1540°	1000°	1000°	1000°	1000°
LOWER INDICATOR READING AT									1000°	1000°	1000°	1000°
LUBE	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50
SOAK - NO. OF MINS.	1	1/2	1	2	1	1	1	1	2/4	2 1 1/2	2 1/2	2 1 1/2
DWELL IN CLOSED POSITION	2	2	2	5	2	2	2	2	40	40	40	40
TONS	60	60	60	60	60	60	60	60	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	600	600	600	600	600	600	600	600	350	900	900	1000
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	600	600	6000	600	600	600	600	600	580	900	900	1000

TABLE A-5

PART 4, ZEE MEMBER

ONE-STEP FORMING, RDM 1435

(Sheet 4 of 7)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	37	38	39	40	41	42	43	44	45	46	47	48
SHEET NO.	47	47	47	47	11	11	11	11	10	10	10	10
VENDOR RMI; TIMET = T	T	T	T	T	T	T	T	T	T	T	T	T
HT	G1133	G1133	G1133	G1133	G168	G168	G168	G168	G168	G168	G168	G168
TEST	F7249	F7249	F7249	F7249								
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1160°	1200°	1260°	1260°	1260°	1300°	1300°	1300°	1280°	1280°	1280°	1280°
UPPER INDICATOR READING AT	1150°	1180°	1200°	1200°	1180°	1200°	1200°	1180°	1180°	1180°	1180°	1180°
LOWER INDICATOR READING AT				1150°	1160°	1150°	1150°	1150°	1150°	1150°	1150°	1150°
LUBE	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50
SOAK - NO. OF MINS.	3	3	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	12	12	5	3	5	5	5	5	5	5	5	5
TONS	60	60	60	60	60	60	60	60	60	60	60	60
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	900	700	850	850	825	900	850	850	850	850	850	850
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO		O.K. ✓		O.K. ✓				O.K. ✓				
* SLIDE CUSHION (psi)	900	700	850	850	825	900	850	850	850	850	850	850

TABLE A-5

PART 4, ZEE MEMBER

ONE-STEP FORMING, RDM 1435

(Sheet 5 of 7)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-8Al-1Mo-1V											
PART IDENT NO.	49	50	51	52	53	54	55	56	57	58	59	60
SHEET NO.	14-1	14-1	14-1	14-1	14	14	14	14				
VENDOR RMI; TIMET = T	T	T	T	T	T	T	T	T	RMI	RMI	RMI	RMI
HT	D9947	D9947	D9947	D9947	D9947	D9947	D9947	D9947	292865	292865	292865	292865
TEST	F4610	F4610	F4610	F4610	F4610	F4610	F4610	F4610				
GAUGE	.070	.070	.070	.070	.070	.070	.070	.070	.070	.070	.070	.070
TEMPERATURE RECORDER AT	1400°	1450°	1450°	1450°	1450°	1460°	1460°	1460°	1440°	1460°	1460°	1460°
UPPER INDICATOR READING AT						1420°	1420°	1420°	1400°	1420°	1420°	1420°
LOWER INDICATOR READING AT						1420°	1420°	1420°	1400°	1420°	1420°	1420°
LUBE	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50
SOAK - NO. OF MINS.	3	3	3	4	3	2	2	2	2	3	3	3
DWELL IN CLOSED POSITION	12	12	10	10	10	10	5	8	10	10	12	12
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	900	900	900	900	900	900	900	900	900	900	900	900
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	900	900	900	900	900	900	900	900	900	900	900	900

TABLE A-5

PART 4, ZEE MEMBER

ONE-STEP FORMING, RDM 1435

(Sheet 6 of 7)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	TI-6Al-4V											
PART IDENT NO.	61	62	63	64	65	66	67	68	69	70	71	72
SHEET NO.					1	1	1	1	1	1	1	1
VENDOR RMI; TIMET = T	RMI	RMI	RMI	RMI	T	T	T	T	T	T	T	T
HT	302017	302017	302017	3C2017	G3256	G3256	G3256	G3256	G3609	G3609	G3609	G3609
TEST					J0589	J0589	J0589	J0589	J1028	J1028	J1028	J1028
GAUGE	.070 ←											→ .070
TEMPERATURE RECORDER AT	1360°	1360°	1360°	1250°	1380°	1360°	1320°	1320°	1320°	1320°	1320°	1320°
UPPER INDICATOR READING AT	1260°	1240°	1260°	1100°	1260°	1200°	1260°	1240°	1240°	1240°	1240°	1240°
LOWER INDICATOR READING AT				1100°		1200°						
LUBE	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50	T50
SOAK - NO. OF MINS.	2	3	3	3	2	3	2	2	2	2	2	2
DWELL IN CLOSED POSITION	5	17	9	17	5	17	8	8	8	8	8	8
TONS	63	65	65	65	63	65	60	60	60	60	60	60
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	950	900	950	950	950	900	950	950	950	950	950	950
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	950	900	950	950	950	900	950	950	950	950	950	950

TABLE A-5

PART 4, ZEE MEMBER

ONE-STEP FORMING, RDM 1435

(Sheet 7 of 7)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-6Al-4V-STA											
PART IDENT NO.	73	74	75	76								
SHEET NO.	1-1	1-1	1-1	1-1								
VENDOR RMI; TIMET = T	T	T	T	T								
HT	G3720	G3720	G3720	G3720								
TEST	J1248	J1248	J1248	J1248								
GAUGE	.070	.070	.070	.070								
TEMPERATURE RECORDER AT	1000°	1000°	1150°	1080°								
UPPER INDICATOR READING AT	1000°	10002	1050°	1050°								
LOWER INDICATOR READING AT	1000°	1000°	1050°	1050°								
LUBE	T50	T50	T50	T50								
SOAK - NO. OF MINS.	2	2	3	3								
DWELL IN CLOSED POSITION	40	40	35	35								
TONS	65	65	65	65								
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	900	900	900	900								
AIR COOLED IMMED.	✓	✓	✓	✓								
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓								
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	900	900	900	900								

TABLE A-6

PART 4, ZEE MEMBER

TWO-STEP FORMING, RDM 1516

(Sheet 1 of 3)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage.
** 2. Have been pre-formed only, drop hammer rubber/hot.

TITANIUM	Ti-6Al-6V-2Sn										
PART IDENT NO.	1	2	3	4	5	6	7	8	9	10	11	12
SHEET NO.	5	5	5	5	5	5	6	6	6	6	6	6
VENDOR RMI; TIMET = T	T	←									→	T
HT	G1537	←									→	G1537
TEST	F9228	←									→	F9228
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1300°	**	1300°	1300°	**	**	**	1300°	**	1300°	1350°	**
UPPER INDICATOR READING AT	1250°		1220°					1250°		1300°	1250°	
LOWER INDICATOR READING AT				1250°						1250°		
LUBE	JGAW #1	←									→	JGAW #1
SOAK - NO. OF MINS.	3		2	3				3		3	3	
DWELL IN CLOSED POSITION	12		10	12				12		10	12	
TONS												
NO. OF CLAMPS AT 16 TONS PER	4		4	4				4		4	4	
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓		✓	✓				✓		✓	✓	
DESCALED AS PER GAEC SPEC.	✓		✓	✓				✓		✓	✓	
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO											O.K. ✓	
* SLIDE CUSHION (psi)												

TABLE A-6

PART 4, ZEE MEMBER

TWO-STEP FORMING, RDM 1516

(Sheet 2 of 3)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V											
PART IDENT NO.	13	14	15	16	17	18	19	20	21	22	23	24
SHEET NO.	30	29	30	29	29	29	30	30	29	29	30	30
VENDOR RMI; TIMET = T	T											T
HT	G2480											G2480
TEST	F9084											F9084
GAUGE	.025											.025
TEMPERATURE RECORDER AT	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1350°	1400°
UPPER INDICATOR READING AT	1300°	1300°	1300°	1300°	1280°	1300°	1300°	1300°	1300°	1300°	1350°	1350°
LOWER INDICATOR READING AT												
LUBE	JGAW #1											JGAW #1
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	12	12	12	12	12	12	12	12	15	12	12	12
TONS												
NO. OF CLAMPS AT 16 TONS PER	4	4	4	4	4	4	4	4	4	4	4	4
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-6

PART 4, ZEE MEMBER

TWO-STEP FORMING, RDM 1516

(Sheet 3 of 3)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage.
** 2. Have been pre-formed only, drop hammer rubber/hot.

TITANIUM	Ti-8Al-1Mo-1V						Ti-6Al-6V-2Sn			Ti-Al-1Mo-1V		
PART IDENT NO.	25	THRU	30	31	THRU	36	37	38	39	40	41	42
SHEET NO.	14	14	14	14-1	14-1	14-1	12	12	12	1	1	1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3290	←			→	G3290	G168	G168	G168	G3298	G3298	G3290
TEST	J0211	←			→	J0211	J0559	←			→	J0559
GAUGE	.025	←			→	.025	.070	.070	.070	.070	.070	.070
TEMPERATURE RECORDER AT	1500°	**	**	**	**	**	1300°	1300°	1300°	1300°	**	**
UPPER INDICATOR READING AT	1450°						1250°	1250°	1250°	1250°		
LOWER INDICATOR READING AT												
LUBE	T50						T50	T50	T50	T50		
SOAK - NO. OF MINS.	2						3	3	3	5		
DWELL IN CLOSED POSITION	10						12	15	15	25		
TONS								65	65			
NO. OF CLAMPS AT 16 TONS PER	4						4	4	4	4		
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓						✓	✓	✓	✓		
DESCALED AS PER GAEC SPEC.	✓						✓	✓	✓	✓		
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-7

PART 5, FRAME

ONE-STEP FORMING, RDM 1498

(Sheet 1 of 6)

NOTE:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	1	2	3	4	5	6	7	8	9	10	11	12
SHEET NO.	6	6	6	3	3	3	4	4	4	5	5	5
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3106	←									→	G3106
TEST	J1169	←									→	J1169
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
UPPER INDICATOR READING AT	1240°	1290°	1250°	1250°	1220°	1260°	1260°	1260°	1250°	1250°	1250°	1250°
LOWER INDICATOR READING AT	1320°	1340°	1320°	1320°	1260°	1260°	1260°	1260°	1250°	1250°	1250°	1250°
LUBE	T50	T50	T50	T50	JGAW #1	←					→	JGAW #1
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	2	2
DWELL IN CLOSED POSITION	10	10	12	12	10	7	5	5	5	5	3	3
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER	800	800	800	800	800	800	800	800	800	800	800	800
* BED CUSHION (psi)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.												
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-7

PART 5, FRAME

ONE-STEP FORMING, RDM 1498

(Sheet 2 of 6)

NOTE:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-6Al-4V											
PART IDENT NO.	13	14	15	16	17	18	19	20	21	22	23	24
SHEET NO.	4	4	4	1	1	1	2	2	2	3	3	3
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3687	←									→	G3687
TEST	J0896	←									→	J0896
GAUGE	025	←									→	025
TEMPERATURE RECORDER AT	1350°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°
UPPER INDICATOR READING AT	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
LOWER INDICATOR READING AT	1350°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
LUBE	T50	JGAW #1	←								→	JGAW #1
SOAK - NO. OF MINS.	3	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	6	6	6	5	5	5	5	5	5	5	5
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO							O.K. ✓	O.K. ✓	O.K. ✓			
* SLIDE CUSHION (psi)	800	800	800	800	800	600	800	800	800	800	800	800

TABLE A-7

PART 5, FRAME

ONE-STEP FORMING, RDM 1498

(Sheet 3 of 6)

NOTE:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-8Al-1Mo-1V											
PART IDENT NO.	25	26	27	28	29	30	31	32	33	34	35	36
SHEET NO.	4	4	4	3	3	3	2	2	2	1	1	1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3290	←									→	G3290
TEST	J0339	←									→	J0339
GAUGE	025	←									→	.025
TEMPERATURE RECORDER AT	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°
UPPER INDICATOR READING AT	1500°	1500°	1500°	1500°	1500°	1500°	1480°	1450°	1480°	1480°		1480°
LOWER INDICATOR READING AT	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°
LUBE	JGAW #1	←									→	JGAW #1
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	3	5	5	5	5	5	5	5	7	7	7	3
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

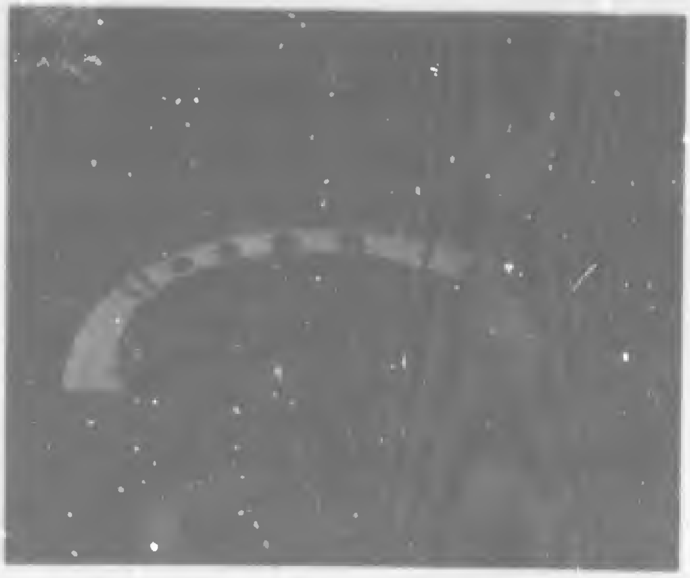


TABLE A-7

PART 5, FRAME

ONE-STEP FORMING, RDM 1498

(Sheet 4 of 6)

NOTE:
* 1. See page A-1 for conversion of psi to tonnage.

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	37	38	39	40	41	42	43	44	45	46	47	48
SHEET NO.	2	2	2	3	3	3	4	4	4	5	5	5
VENDOR RMI; TIMET = T	T											T
HT	G3614											G3614
TEST	J1167											J1167
GAUGE	.070											.070
TEMPERATURE RECORDER AT	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
UPPER INDICATOR READING AT	1260°	1280°	1280°	1280°	1280°	1260°	1280°	1280°	1280°	1280°	1280°	1280°
LOWER INDICATOR READING AT	1260°	1280°	1280°	1280°	1260°	1260°	1280°	1280°	1280°	1280°	1280°	1280°
LUBE	JGAW #1											JGAW #1
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	10	10	12	12	12	12	12	12	12	12	12	12
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	300	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO						O.K. ✓	O.K. ✓			O.K. ✓		
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

TABLE A-7

PART 5, FRAME

ONE-STEP FORMING, RDM 1498

(Sheet 5 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V										
PART IDENT NO.	49	50	51	52	53	54	55	56	57	58	59	60
SHEET NO.	2	2	2									
VENDOR RMI; TIMET = T	T	T	T	RM1	RM1	RM1	RM1	RM1	RM1	RM1	RM1	RM1
HT	G3794	←—→	G3794	292671	←—→	292671	302017	←			→	302017
TEST	J0926	←—→	J0926									
GAUGE	070	←									→	070
TEMPERATURE RECORDER AT	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°
UPPER INDICATOR READING AT	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°
LOWER INDICATOR READING AT	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°	1340°
LUBE	JGAW #1	←									→	JGAW #1
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	10	10	8	8	8	8	8	8	8	8	8
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800

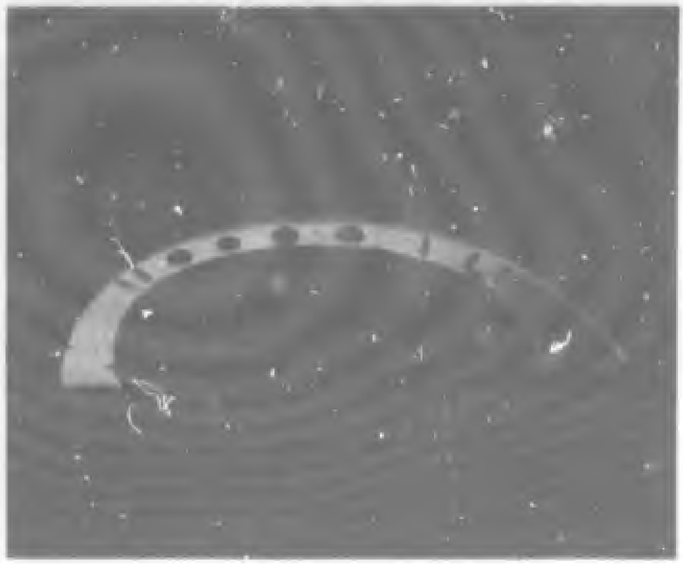


TABLE A-7
PART 5, FRAME
ONE-STEP FORMING, RDM 1498
(Sheet 6 of 6)

NOTE:
* 1. See Page A-1 for conversion of psi to tonnage.

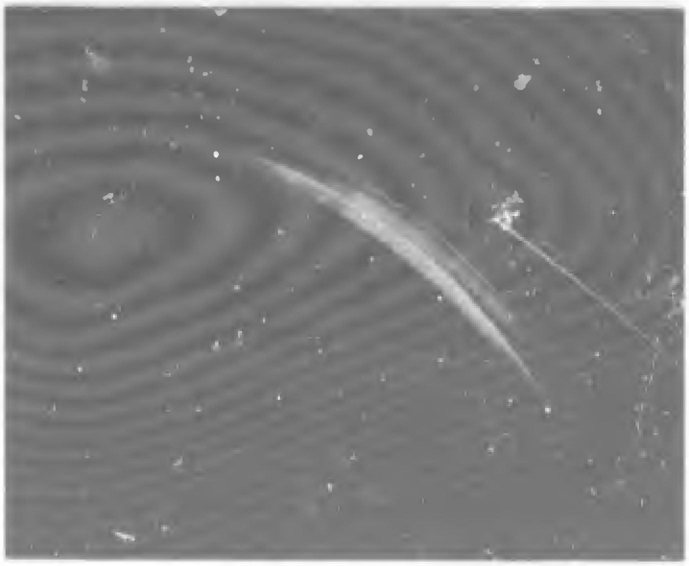
TITANIUM	Ti-8Al-1Mo-1V											
PART IDENT NO.	61	62	63	64	65	66	67	68	69	70	71	72
SHEET NO.									11	11	11	11
VENDOR RMI; TIMET = T	RMI	RMI	RMI	RMI	RMI	RMI	RMI	RMI	RMI	T	T	T
HT	301177 ←							→	301177	D9947		D9947
TEST										F4610	F4610	F4610
GAUGE	.070 ←										→	.070
TEMPERATURE RECORDER AT	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°		1500°	1500°	1500°
UPPER INDICATOR READING AT	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°		1500°	1500°	1500°
LOWER INDICATOR READING AT	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°		1500°	1500°	1500°
LUBE	JGAW #1 ←										→	JGAW #1
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2		2	2	2
DWELL IN CLOSED POSITION	8	8	10	10	10	10	10	10		10	10	10
TONS	65	65	65	65	65	65	65	65		65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	DAMAGED PART	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)	800	800	800	800	800	800	800	800		800	800	800

TABLE A-8

PART 6, CHANNEL

ONE-STEP FORMING, RDM 1496

(Sheet 1 of 6)



NOTES:
* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	1	2	3	4	5	6	7	8	9	10	11	12
SHEET NO.	3	←									→	3
VENDOR RMI; TIMET = T	T	←									→	T
HT	D2429	←									→	D2429
TEST	J1164	←									→	J1164
GAUGE	025	←									→	025
TEMPERATURE RECORDER AT	1240°	1240°	1240°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
UPPER INDICATOR READING AT												
LOWER INDICATOR READING AT	1240°	1240°	1240°	1250°	1250°	1240°	1260°	1260°	1260°	1260°	1260°	1260°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	3	3	3	3	8	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	10	10	15	20	12	17	17	10	10	15	15	8
TONS												
NO. OF CLAMPS AT 16 TONS PER	2	2	2	2	2	2	2	2	2	2	2	2
* BED CUSHION (psi)	400	500	600	600	600	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO		O.K. ✓					O.K. ✓					
* SLIDE CUSHION (psi)												

TABLE A-8

PART 3, CHANNEL

ONE-STEP FORMING, RDM 1496

(Sheet 2 of 6)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V											
PART IDENT NO.	13	14	15	16	17	18	19	20	21	22	23	24
SHEET NO.	1	1	1	1	1	1	1	1	1	1	1	1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G2731	←									→	G2731
TEST	J0042	←									→	J0042
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1300°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°	1400°
UPPER INDICATOR READING AT												
LOWER INDICATOR READING AT	1260°	1320°	1320°	1320°	1320°	1320°	1320°	1320°	1320°	1320°	1320°	1320°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	5	3	5	7	10	10	10	10	10	10	10	10
TONS												
NO. OF CLAMPS AT 16 TONS PER	2	2	2	2	2	2	2	2	2	2	2	2
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO				O.K. ✓								
* SLIDE CUSHION (psi)												

TABLE A-8

PART 6, CHANNEL

ONE-STEP FORMING, RDM 1496

(Sheet 3 of 6)

NOTES:
* 1. See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-8Al-1Mo-1V											
PART IDENT NO.	25	26	27	28	29	30	31	32	33	34	35	36
SHEET NO.	3	3	3	3	3	3	3	3	3	3	3	3
VENDOR RMI; TIMET = T	T	←									→	T
HT	D8423	←									→	D8423
TEST	J0177	←									→	J0177
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1400°	1400°	1400°	1440°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°
UPPER INDICATOR READING AT												
LOWER INDICATOR READING AT	1400°	1400°	1400°	1400°	1475°	1475°	1475°	1475°	1475°	1475°	1475°	1475°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	1	3	3	3	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	8	12	12	12	8	5	5	3	5	5	5	5
TONS												
NO. OF CLAMPS AT 16 TONS PER	2	2	2	2	2	2	2	2	2	2	2	2
* BED CUSHION (psi)	800	500	500	500	500	500	500	500	500	500	500	500
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-8

PART 6, CHANNEL

ONE-STEP FORMING, RDM 1496

(Sheet 4 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	37	38	39	40	41	42	43	44	45	46	47	48
SHEET NO.	1	←									→	1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G2443	←									→	G2443
TEST	F9543	←									→	F9543
GAUGE	.071										→	.071
TEMPERATURE RECORDER AT	1240°	1280°	1280°	1280°	1280°	1280°	1280°	1280°	1280°	1300°	1300°	1300°
UPPER INDICATOR READING AT												
LOWER INDICATOR READING AT	1220°	1250°	1250°	1250°	1250°	1250°	1220°	1220°	1220°	1220°	1220°	1220°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	12	12	12	10	7	7	7	7	7	7	7	7
TONS												
NO. OF CLAMPS AT 16 TONS PER	2	2	2	2	2	2	2	2	2	2	2	2
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO			O.K. ✓			O.K. ✓		O.K. ✓				
* SLIDE CUSHION (psi)												

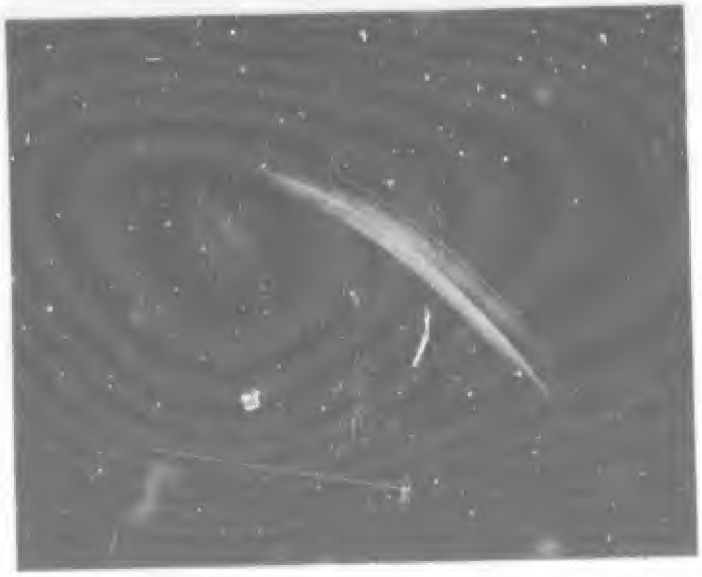


TABLE A-8

PART 6, CHANNEL

ONE-STEP FORMING, RDM 1496

(Sheet 5 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V											
PART IDENT NO.	49	50	51	52	53	54	55	56	57	58	59	60
SHEET NO.	4	4	4	4	4	4	4	4	4	4	4	4
VENDOR RMI; TIMET = T	T											T
HT	G3256											G3256
TEST	J0229											J0229
GAUGE	.070											.070
TEMPERATURE RECORDER AT	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°
UPPER INDICATOR READING AT												
LOWER INDICATOR READING AT	1350°	1350°	1350°	1300°	1300°	1300°	1350°	1350°	1350°	1350°	1350°	1350°
LUBE	T50											T50
SOAK - NO. OF MINS.	3	3	2	2	3	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	12	12	10	6	12	8	8	8	6	6	6	6
TONS												
NO. OF CLAMPS AT 16 TONS PER	2	2	2	2	2	2	2	2	2	2	2	2
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-8

PART 6, CHANNEL

ONE-STEP FORMING, RDM 1496

(Sheet 6 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-8Al-1Mo-1V											
PART IDENT NO.	61	62	63	64	65	66	67	68	69	70	71	72
SHEET NO.	1	1	1	1	1	1	1	1	1	1	1	1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G1651	←									→	G1651
TEST	J0125	←									→	J0125
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1540°	1540°	1540°	1540°	1540°	1525°	1500°	1500°	1550°	1525°	1525°	1525°
UPPER INDICATOR READING AT												
LOWER INDICATOR READING AT	1500°	1500°	1500°	1500°	1500°	1475°	1460°	1460°	1500°	1475°	1475°	1475°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	10	10	8	8	8	5	8	8	8	8	8
TONS												
NO. OF CLAMPS AT 16 TONS PER	2	2	2	2	2	2	2	2	2	2	2	2
* BED CUSHION (psi)	800	800	800	800	800	800	800	800	800	800	800	800
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-9

PART 6, CHANNEL

TWO-STEP FORMING, RDM 1510

(Sheet 1 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	1	2	3	4	5	6	7	8	9	10	11	12
SHEET NO.	1	←									→	1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3106	←									→	G3106
TEST	J1169	←									→	J1169
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1350°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
UPPER INDICATOR READING AT	1250°	1200°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°
LOWER INDICATOR READING AT	1250°	1200°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°
LUBE	JGAW #1	JGAW #1	T50	←							→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	12	12	10	10	10	10	10	10	10	10	10	10
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-9

PART 6, CHANNEL

TWO-STEP FORMING, RDM 1510

(Sheet 2 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V											
PART IDENT NO.	13	14	15	16	17	18	19	20	21	22	23	24
SHEET NO.	6 ←										→	6
VENDOR RMI; TIMET = T	T ←										→	T
HT	G3687 ←										→	G3687
TEST	J0896 ←										→	J0896
GAUGE	.025 ←										→	.025
TEMPERATURE RECORDER AT	1350°	1350°	1350°	1350°	1350°	1350°	1350°	1350°	1350°	1350°	1350°	1350°
UPPER INDICATOR READING AT	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
LOWER INDICATOR READING AT	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
LUBE	T50 ←										→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	2	2	2	3	3
DWELL IN CLOSED POSITION	10	10	10	10	10	10	10	8	8	8	10	10
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-9

PART 6, CHANNEL

ONE-STEP FORMING, RDM 1510

(Sheet 3 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-8Al-1Mo-1V											
PART IDENT NO.	25	26	27	28	29	30	31	32	33	34	35	36
SHEET NO.	6	←									→	6
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3290	←									→	G3290
TEST	J0339	←									→	J0339
GAUGE	.025	←									→	.025
TEMPERATURE RECORDER AT	1540°	1540°	1540°	1540°	1540°	1540°	1540°	1540°	1540°	1540°	1540°	1540°
UPPER INDICATOR READING AT	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°
LOWER INDICATOR READING AT	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	10	10	10	10	10	10	10	10	10	10	10
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO	O.K. ✓	O.K. ✓	O.K. ✓									
* SLIDE CUSHION (psi)												

TABLE A-9

PART 6, CHANNEL

ONE-STEP FORMING, RDM 1510

(Sheet 4 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-6V-2Sn											
PART IDENT NO.	37	38	39	40	41	42	43	44	45	46	47	48
SHEET NO.	1	←									→	1
VENDOR RMI; TIMET = T	T	←									→	T
HT	G3614	←									→	G3614
TEST	J1167	←									→	J1167
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°	1380°
UPPER INDICATOR READING AT	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°	1250°
LOWER INDICATOR READING AT	1250°	1250°	1250°	1250°	1250°							
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	3	3	3	3	3	3	3	3	3	3	3	3
DWELL IN CLOSED POSITION	10	10	10	10	10	10	10	10	10	10	10	10
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-9

PART 6, CHANNEL

ONE-STEP FORMING, RDM 1510

(Sheet 5 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-6Al-4V											
PART IDENT NO.	49	50	51	52	53	54	55	56	57	58	59	60
SHEET NO.	14	14	14	14	14	14	RM1	RM1	RM1	RM1	RM1	RM1
VENDOR RMI; TIMET = T	T	←			→	T	RM1	←			→	RM1
HT	G3498	←			→	G3498	302017	←			→	302017
TEST	J0811	←			→	J0811						
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
UPPER INDICATOR READING AT	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°	1300°
LOWER INDICATOR READING AT												
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	10	10	10	10	10	10	10	10	10	10	10
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-9

PART 6, CHANNEL

ONE-STEP FORMING, RDM 1510

(Sheet 6 of 6)

NOTE:
*See page A-1 for conversion of psi to tonnage

TITANIUM	Ti-8Al-1Mo-1V										
PART IDENT NO.	61	62	63	64	65	66	67	68	69	70	71	72
SHEET NO.	8	←									→	8
VENDOR RMI; TIMET = T	T	←									→	T
HT	C758	←									→	G758
TEST	F6062	←									→	F6068
GAUGE	.070	←									→	.070
TEMPERATURE RECORDER AT	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°	1500°
UPPER INDICATOR READING AT	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°	1450°
LOWER INDICATOR READING AT												
LUBE	T50	←									→	T50
SOAK - NO. OF MINS.	2	2	2	2	2	2	2	2	2	2	2	2
DWELL IN CLOSED POSITION	10	10	10	10	10	10	10	10	10	10	10	10
TONS	65	65	65	65	65	65	65	65	65	65	65	65
NO. OF CLAMPS AT 16 TONS PER												
* BED CUSHION (psi)												
AIR COOLED IMMED.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DESCALED AS PER GAEC SPEC.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ALKO-N-PROCESS												
TURCO PROCESS												
ZYGLO												
* SLIDE CUSHION (psi)												

TABLE A-10

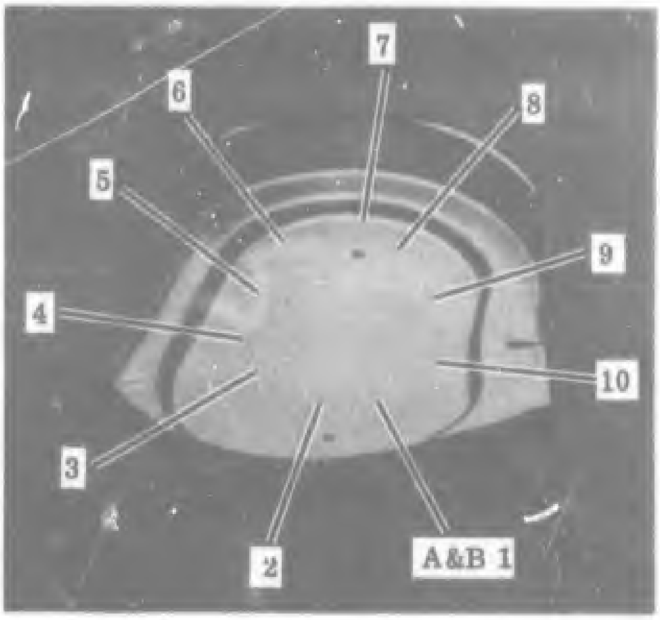
PART 1, TAIL CONE FRAME

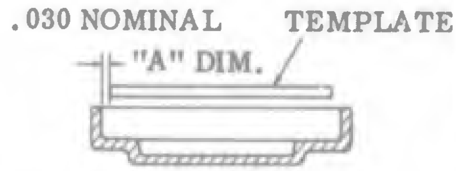
ONE-STEP FORMING, RDM 1500

NOTES:

1. This is a dimensional check of parts back to template.
2. V = 90°
3. * Bent part caused by trouble ejecting part from die.

	PART IDENT. NO.																	
ZONE	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
A1	.030	.030	.035	.030	.030	.035	.030	.030	.030	.030	.030	.030	.030	.030	*	.030	.025	.010
A2	.030	.030	.030	.030	.030	.030	.035	.030	.030	.030	.035	.025	.030	.030		.030	.025	.030
A3	.030	.060	.035	.035	.035	.035	.035	.030	.035	.035	.035	.060	.035	.030		.035	.030	.030
A4	.020	.030	.025	.020	.020	.030	.025	.015	.020	.020	.015	.030	.020	.025		.025	.010	.020
A5	.025	.050	.025	.040	.030	.035	.030	.030	.030	.030	.035	.050	.030	.040		.030	.040	.050
A6	.030	.025	.025	.030	.030	.030	.020	.030	.030	.025	.030	.030	.030	.030		.030	.030	.020
A7	.030	.005	.015	.025	.030	.030	.035	.015	.020	.020	.030	.015	.020	.015		.030	.005	.0
A8	.030	.005	.030	.025	.030	.030	.035	.030	.030	.025	.035	.000	.030	.025		.030	.005	.005
A9	.025	.005	.020	.030	.030	.030	.020	.025	.025	.020	.030	.005	.030	.025		.030	.005	.005
A10	.030	.020	.025	.050	.035	.030	.030	.040	.030	.030	.035	.040	.045	.050		.035	.060	.025
B1	v	v	v	v	v	v	v	v	v	v	v	v	v	v		v	91°	92°
B2	v	v	v	v	v	v	v	v	v	v	v	v	v	v		v	v	92°
B3	v	v	v	v	v	v	v	v	v	v	v	91°	v	v		v	v	92°
B4	v	v	v	v	v	v	v	v	v	92.5°	v	v	v	v		v	v	v
B5	v	v	v	v	v	v	v	91°	91°	92.5°	v	91°	v	v		v	v	v
B6	v	v	v	v	v	v	v	v	v	92.5°	v	v	v	v		v	v	92°
B7	v	v	v	v	v	v	v	v	v	v	v	v	v	v		v	v	92°
B8	v	v	v	v	v	v	v	v	v	v	v	v	v	v		v	v	91°
B9	v	v	v	v	v	v	v	92°	92°	92.5°	v	v	v	v		v	v	v
B10	v	v	v	91.5°	v	v	v	92°	92°	92.5°	v	93°	91°	91.5		v	v	91°





TYP CROSS
SECT OF PART
GAUGE .070

	PART IDENT. NO.																	
ZONE	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
A1	.010	.030	.050	.030	.030	.030	Damaged in Tool Proving.	.035	.030	.030	.030	.030	.030	.030	.030	.030	.030	.030
A2	.005	.030	.030	.030	.030	.030		.030	.030	.030	.030	.030	.030	.030	.035	.030	.030	.030
A3	.015	.030	.040	.030	.030	.040		.035	.030	.035	.030	.030	.035	.030	.040	.030	.030	.030
A4	.015	.035	.020	.025	.030	.030		.030	.030	.030	.025	.030	.030	.030	.030	.030	.030	.020
A5	.015	.020	.025	.030	.045	.030		.030	.030	.030	.030	.030	.030	.030	.035	.035	.035	.030
A6	.0	.030	.010	.025	.030	.020		.035	.035	.030	.030	.025	.030	.035	.035	.035	.035	.035
A7	.0	.030	.015	.030	.020	.015		.035	.035	.035	.025	.030	.035	.030	.030	.030	.030	.030
A8	.015	.030	.025	.035	.020	.020		.035	.035	.035	.030	.030	.035	.035	.035	.035	.035	.035
A9	.015	.020	.025	.030	.010	.010		.030	.030	.030	.030	.025	.020	.030	.030	.030	.030	.030
A10	*	.020	.035	.040	.040	.050		.035	.035	.035	.035	.030	.030	.035	.035	.035	.035	.035
B1	*	94°	94°	v	93°	93°		v	v	v	v	v	v	v	v	v	v	v
B2	*	98°	93°	v	v	92°		v	v	v	v	v	v	v	v	v	v	v
B3	92°	98°	91°	v	v	v		v	v	v	v	v	v	v	v	v	v	v
B4	92°	98°	92°	v	v	v		v	v	v	v	v	v	v	v	v	v	v
B5	92°	98°	93.5°	v	93°	93°		v	v	v	v	v	v	v	v	v	v	v
B6	92°	98°	93.5°	v	93°	93°		v	v	v	v	v	v	v	v	v	v	v
B7	v	98°	v	v	v	v		v	v	v	v	v	v	v	v	v	v	v
B8	v	98°	92°	v	92°	v		v	v	v	v	v	v	v	v	v	v	v
B9	v	93.5°	94°	v	92°	93°		v	v	v	v	v	v	v	v	v	v	v
B10	*	93.5°	94°	92°	92°	93°		v	v	v	91°	v	v	v	v	v	v	v
	*	*	*															

(Sheet 2 of 2)

TABLE A-11

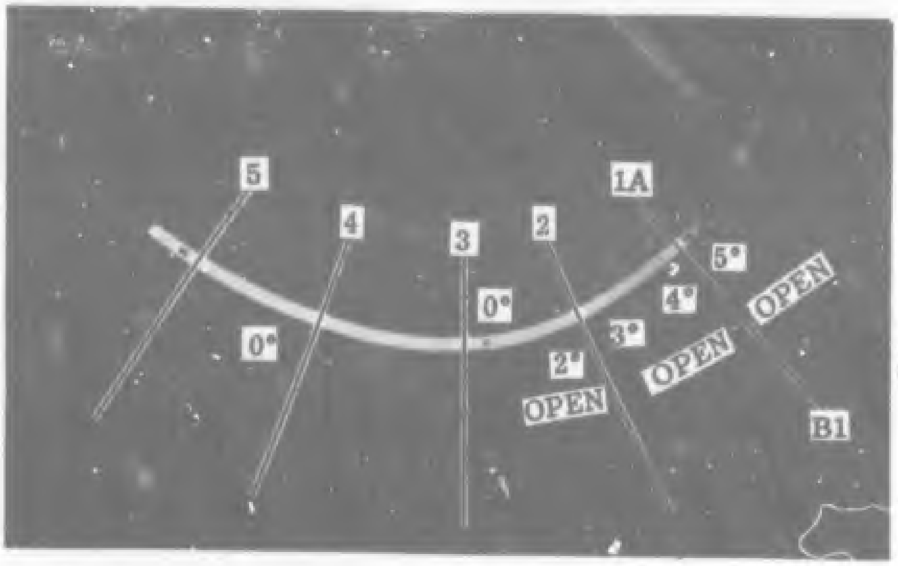
PART 2, DOOR CHANNEL

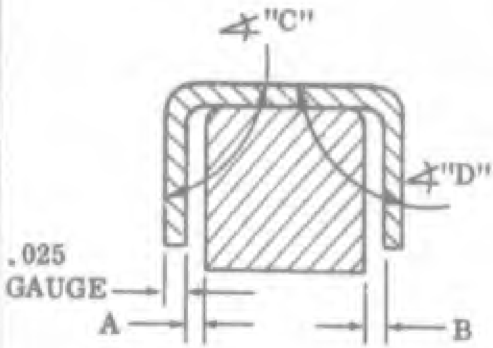
ONE-STEP FORMING, RDM 1502

NOTE:
1. This chart is a dimensional check of parts back to the cold die.
2. v = Little or no finger pressure lays "dead" to male die.

	PART IDENT. NO.																	
ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
∡ 1C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 2C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 3C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 4C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 5C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 1D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 2D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 3D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 4D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 5D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

(Sheet 1 of 4)





TYPICAL CROSS SECTION

	PART IDENT. NO.																	
ZONE	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1A	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2A	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3A	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4A	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5A	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1B	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2B	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3B	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4B	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5B	.0	.005	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
∡1C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡2C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡3C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡4C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡5C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡1D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡2D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡3D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡4D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡5D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

TABLE A-11

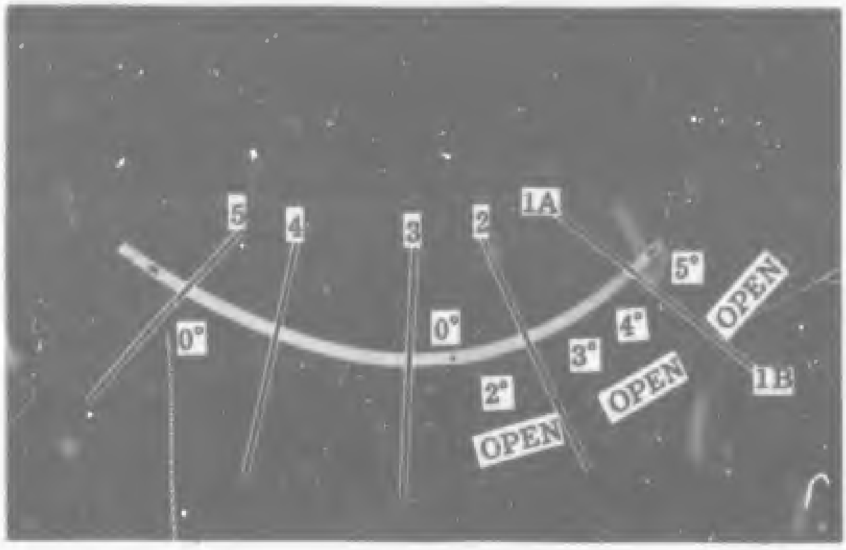
PART 2, DOOR CHANNEL

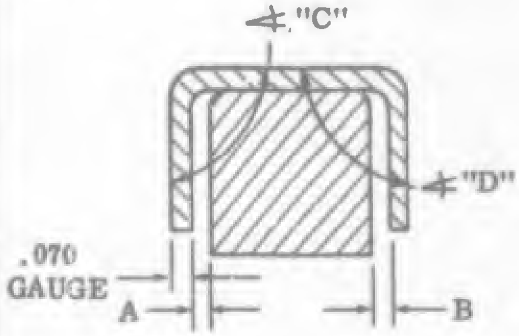
ONE-STEP FORMING, RDM 1502

NOTES:
1. This chart is a dimensional check of parts back to the cold die.
2. v = O.K.
3. * Part used for tool proving.

	PART IDENT. NO.																	
ZONE	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
1A	.005	.005	.005	.005	.005	.005	.005	.005	.005	*	*	*	.005	.005	.005	.005	.005	.005
2A	.005	.005	.005	.005	.005	.005	.005	.005	.005				.005	.005	.005	.005	.005	.005
3A	.005	.005	.005	.005	.005	.005	.005	.005	.005				.005	.005	.005	.005	.005	.005
4A	.005	.005	.005	.005	.005	.005	.005	.005	.005				.005	.005	.005	.005	.005	.005
5A	.005	.005	.005	.005	.005	.005	.005	.005	.005				.005	.005	.005	.005	.005	.005
1B	.005	.005	.005	.005	.005	.005	.005	.005	.005				.005	.005	.005	.005	.005	.005
2B	.005	.005	.005	.005	.005	.005	.005	.005	.005				.005	.005	.005	.005	.005	.005
3B	.005	.005	.005	.005	.005	.005	.005	.005	.005				.005	.005	.005	.005	.005	.005
4B	.005	.005	.005	.005	.005	.005	.005	.005	.005				.005	.005	.005	.005	.005	.005
5B	.005	.005	.005	.005	.005	.005	.005	.005	.005				.005	.005	.005	.005	.005	.005
∡1C	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v
∡2C	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v
∡3C	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v
∡4C	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v
∡5C	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v
∡1D	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v
∡2D	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v
∡3D	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v
∡4D	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v
∡5D	v	v	v	v	v	v	v	v	v				v	v	v	v	v	v

(Sheet 3 of 4)





	PART IDENT. NO.																	
ZONE	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
1A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
2A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
3A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
4A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
5A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
1B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
2B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
3B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
4B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
5B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
∢ 1C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢ 2C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢ 3C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢ 4C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢ 5C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢ 1D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢ 2D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢ 3D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢ 4D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢ 5D	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

(Sheet 4 of 4)

TABLE A-12

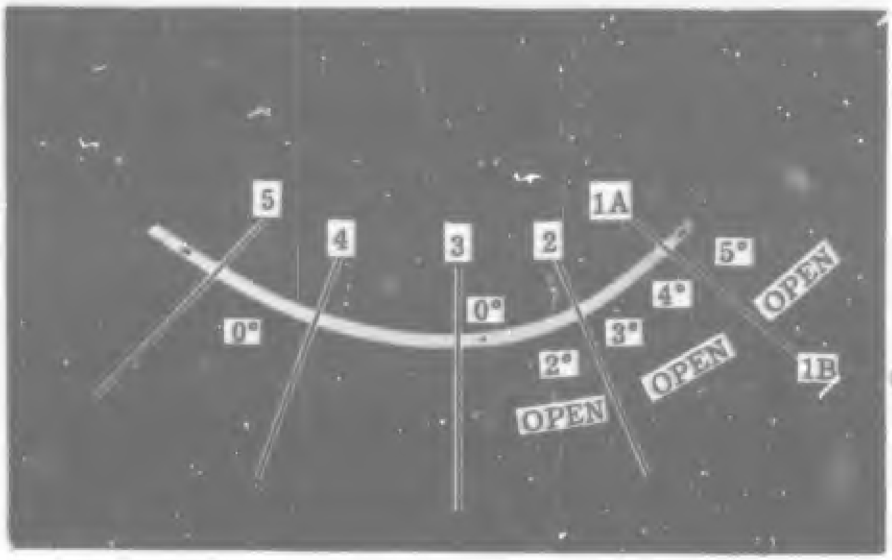
PART 2, DOOR CHANNEL

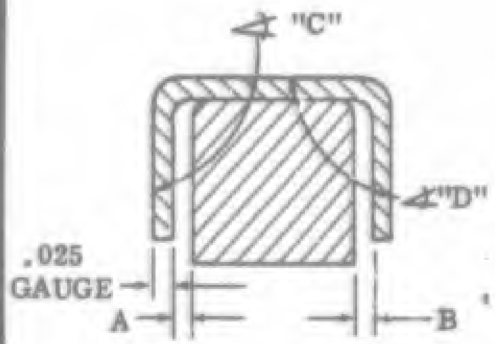
TWO-STEP FORMING, RDM 1509

NOTES:
1. This chart is a dimensional check of parts back to the cold die.
2. v = O.K.
3. * Part used for tool proving.

	PART IDENT. NO.																	
ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1A	Damaged in Tool Proving.	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	Nos. 13 thru 36 and Nos. 37 thru 72 (.070 gauge) have been pre-formed only at drop hammer rubber/hot.					
2A		.0	.0	.0	.0	.0	.0		.0	.0	.0	.0						
3A		.0	.0	.0	.0	.0	.0		.0	.0	.0	.0						
4A		.0	.0	.0	.0	.0	.0		.0	.0	.0	.0						
5A		.0	.0	.0	.0	.0	.0		.0	.0	.0	.0						
1B		.0	.0	.0	.0	.0	.0		.0	.0	.0	.0						
2B		.0	.0	.0	.0	.0	.0		.0	.0	.0	.0						
3B		.0	.0	.0	.0	.0	.0		.0	.0	.0	.0						
4B		.0	.0	.0	.0	.0	.0		.0	.0	.0	.0						
5B		.0	.0	.0	.0	.0	.0		.0	.0	.0	.0						
∡1C		v	v	v	v	v	v		v	v	v	v						
∡2C		v	v	v	v	v	v		v	v	v	v						
∡3C		v	v	v	v	v	v		v	v	v	v						
∡4C		v	v	v	v	v	v		v	v	v	v						
∡5C		v	v	v	v	v	v		v	v	v	v						
∡1D		v	v	v	v	v	v		v	v	v	v						
∡2D		v	v	v	v	v	v		v	v	v	v						
∡3D		v	v	v	v	v	v		v	v	v	v						
∡4D		v	v	v	v	v	v		v	v	v	v						
∡5D		v	v	v	v	v	v		v	v	v	v						

(Sheet 1 of 2)

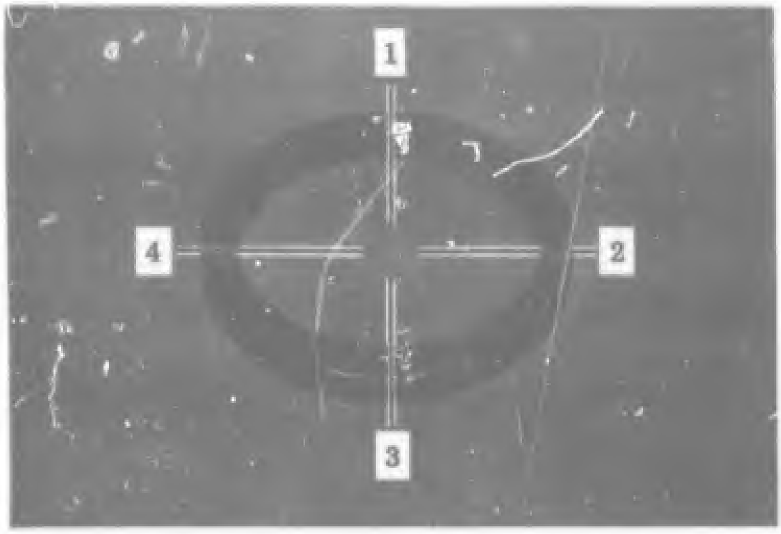




	PART IDENT. NO.																	
ZONE	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1A																		
2A																		
3A																		
4A																		
5A																		
1B																		
2B																		
3B																		
4B																		
5B																		
∠1C																		
∠2C																		
∠3C																		
∠4C																		
∠5C																		
∠1D																		
∠2D																		
∠3D																		
∠4D																		
∠5D																		

Nos. 13 thru 36 and Nos. 37 thru 72 (.070 gauge) have been pre-formed only at drop hammer rubber/ hot.

(Sheet 2 of 2)



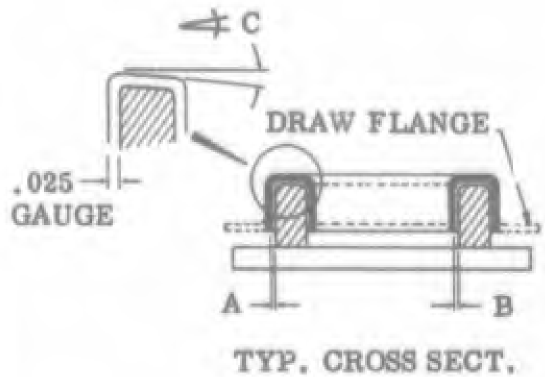


TABLE A-13 RDM - 1497 PART #3 - ANNULAR RING - DIMENSIONAL CHECK OF FORMED PARTS BACK TO COLD DIE

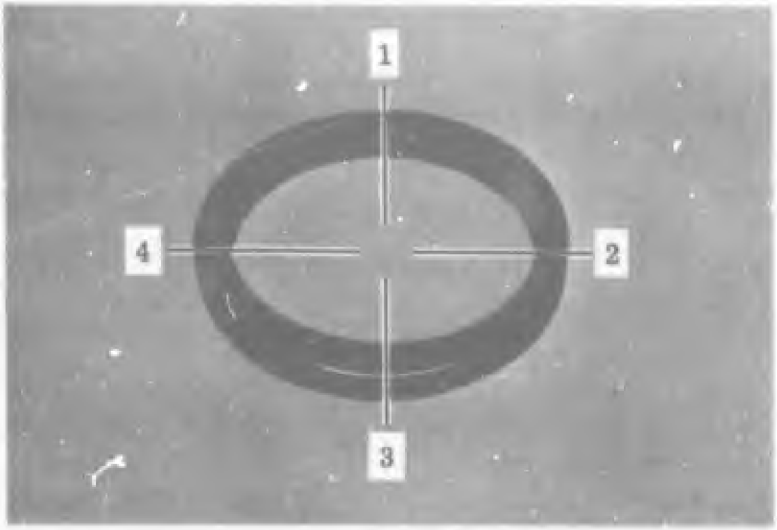
Part Ident. No.	Titanium	Zone					Draw Flange	Remarks
			1	2	3	4		
1	.025 6Al-6V-2Sn	A	.016	.016	.016	.016	None	
		B	.0	.0	.0	.0		
		C	0° Constant					
2	.025 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	0° To 4°					
3	.025 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	0° To 1°					
4	.025 6Al-6V-2Sn	A	.0	.0	.0	.0	Yes	
		B	.0	.0	.0	.0		
		C	0° Constant					
5	.025 6Al-6V-2Sn	A	.0	.0	.0	.0	Yes	
		B	.0	.0	.0	.0		
		C	0° To 1°					
6	.025 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	0° To 1°					
7	.025 6Al-6V-2Sn	A	.015	.015	.015	.015	Yes	
		B	.0	.0	.0	.0		
		C	0° To 1.5°					
8	6Al-6V-2Sn	A	.0	.0	.0	.0	None	Cycle Time Too Short
		B	.0	.0	.0	.0		
		C	5° To 7°					
9	.025 6Al-6V-2Sn	A	.0	.0	.0	.0	None	Cycle Time Too Short
		B	.0	.0	.0	.0		
		C	5° To 6°					
10	.025 6Al-6V-2Sn	A	.0	.0	.0	.0	None	Cycle Time Too Short
		B	.0	.0	.0	.0		
		C	4° To 7°					

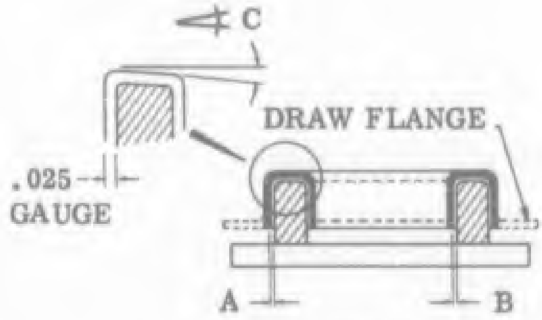
(Sheet 1 of 6)

TABLE A-13 (Cont'd)

Part Ident. No.	Titanium		Zone 1	Zone 2	Zone 3	Zone 4	Draw Flange	Remarks
11	.025 6Al-6V-2Sn	A	.0	.0	.0	.0	None	Cycle Time Too Short
		B	.0	.0	.0	.0		
		C	6° Constant					
12	.025 6Al-6V-2Sn	A	.0	.0	.0	.0	None	Cycle Time Too Short
		B	.0	.0	.0	.0		
		C	6° Constant					
13	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	2° Constant					
14	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	2° Constant					
15	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	0° To 2°					
16	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	2° Constant					
17	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	3° To 4°					
18	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	5° Constant					
19	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	2° To 4°					
20	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	0° Constant					
21	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	0° Constant					
22	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	0° Constant					
23	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	2° Constant					
24	.025 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	2° Constant					
25	.025 8Al-1Mo-1V	A	Part shrunk will not go				None	
		B	on cold die					
		C	1° To 2°					
26	.025 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	2° To 4°					

(Sheet 2 of 6)



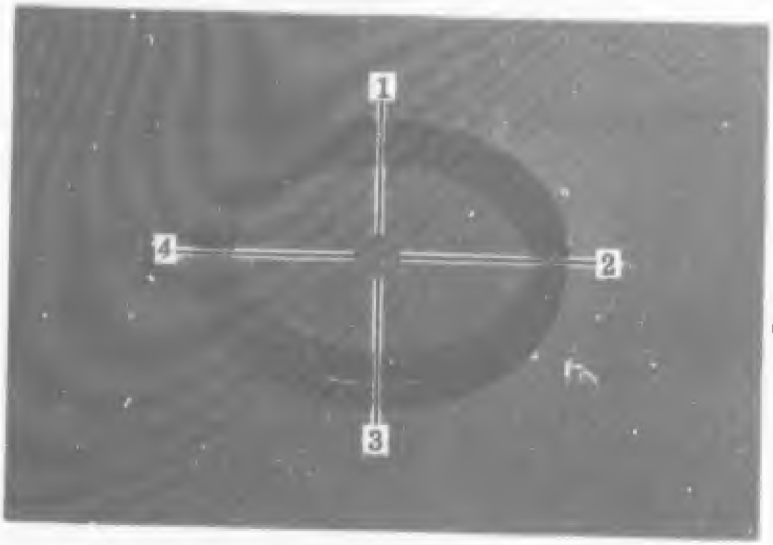


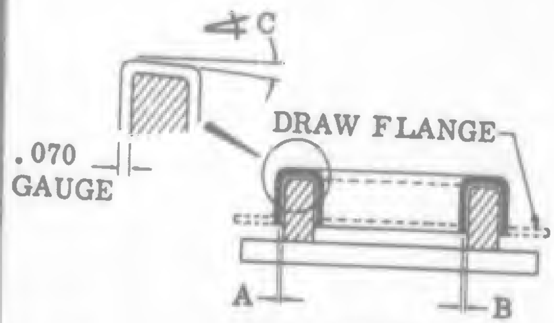
TYP. CROSS SECT.

TABLE A-13 Cont'd)

Part Ident. No.	Titanium	Zone					Draw Flange	Remarks
			1	2	3	4		
27	.025 8Al-1Mo-1V	A	Damaged part Ejecting same				None	Trouble with Die Rwk. Same
		B						
		C						
28	.025 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	0° Constant					
29	.025 8Al-1Mo-1V	A	.020	.020	.020	.020	Yes	
		B	.0	.0	.0	.0		
		C	0° Constant					
30	.025 8Al-1Mo-1V	A	.020	.005	.020	.005	Yes	⎍ This Condition Exists
		B	.0	.0	.0	.0		
		C	See Remarks					
31	.025 8Al-1Mo-1V	A	.0	.0	.0	.0	Yes	Cracked Part in One Area
		B	.0	.0	.0	.0		
		C	0° Constant					
32	.025 8Al-1Mo-1V	A	.0	.0	.0	.0	Yes	
		B	.0	.0	.0	.0		
		C	0° Constant					
33	.025 8Al-1Mo-1V	A	.0	.0	.0	.0	Yes	
		B	.0	.0	.0	.0		
		C	0° Constant					
34	.025 8Al-1Mo-1V	A	.0	.0	.0	.0	Yes	
		B	.0	.0	.0	.0		
		C	0° Constant					
35	.025 8Al-1Mo-1V	A	.0	.0	.0	.0	Yes	Cracked Part
		B	.0	.0	.0	.0		
		C	0° Constant					
36	.025 8Al-1Mo-1V	A	.020	.020	.020	.020	Yes	Cracked Part
		B	.0	.0	.0	.0		
		C	0° Constant					

(Sheet 3 of 6)





TYP. CROSS SECT.

NOTE:

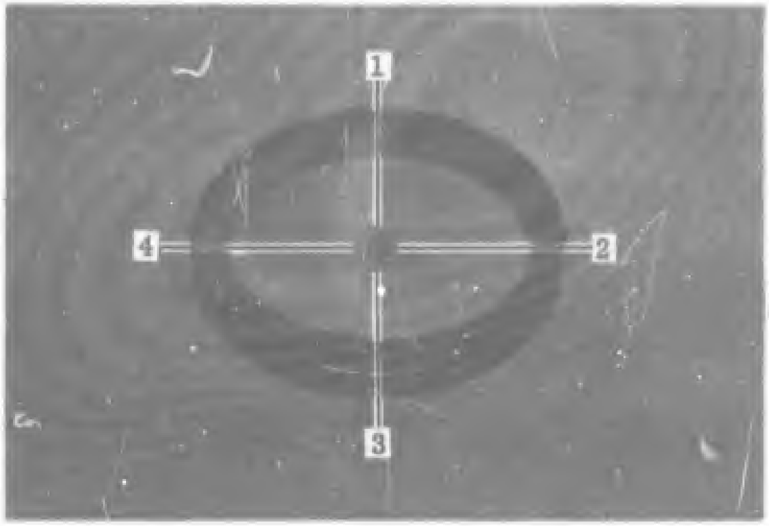
CL = CLOSED
OP = OPEN

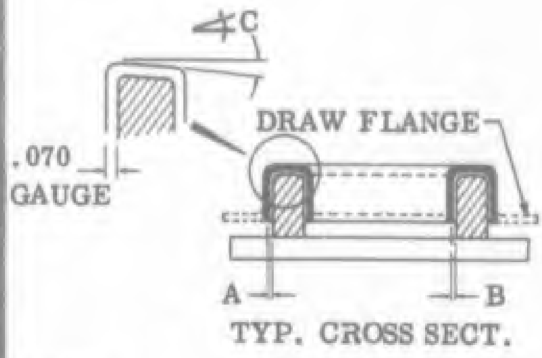
TABLE A-13 RDM - 1497 PART #3 - ANNULAR RING - DIMENSIONAL CHECK OF FORMED PARTS BACK TO COLD DIE

Part Ident. No.	Titanium	Zone					Draw Flange	Remarks
			1	2	3	4		
37	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	Cycle Time Too Short
		B	.0	.0	.0	.0		
		C	1°OP	1°OP	1°OP	1°OP		
38	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	Cycle Time Too Short
		B	.0	.0	.0	.0		
		C	1°CL	4°CL	2°CL	3°CL		
39	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	Cycle Time Too Short
		B	.0	.0	.0	.0		
		C	2°CL	1°OP	2°CL	2°CL		
40	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	Cycle Time Too Short
		B	.0	.0	.0	.0		
		C	3°CL	1°CL	1°CL	1°CL		
41	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	2°CL	1°CL	90°	90°		
42	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	1°CL	1°CL	1°CL	1°CL		
43	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	2°CL	2°CL	1°CL	1°CL		
44	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	1°CL	1°CL	90°	90°		
45	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	3°CL	3°CL	3°CL	3°CL		
46	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		

TABLE A-13 (Cont'd)

Part Ident. No.	Titanium	Zone	1	2	3	4	Draw Flange	Remarks
47	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
48	.070 6Al-6V-2Sn	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
49	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
50	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
51	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
52	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
53	.070 6Al-4V	A						Flat Pattern Damaged, Did Not Run
		B						
		C						
54	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
55	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
56	.070 6Al-4V	A						Material Received Too Short For Flat Pattern
		B						
		C						
57	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
58	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
59	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
60	.070 6Al-4V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
61	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	5°CL	90°	90°		
62	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		





NOTE:

CL = CLOSED
OP = OPEN

TABLE A-13 (Cont'd)

Part Ident No.	Titanium	Zone					Draw Flange	Remarks
			1	2	3	4		
63	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
64	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	1°CL	1°CL	1°CL	1°CL		
65	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
66	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
67	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
68	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	1°CL	1°CL	1°CL	1°CL		
69	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
70	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
71	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		
72	.070 8Al-1Mo-1V	A	.0	.0	.0	.0	None	
		B	.0	.0	.0	.0		
		C	90°	90°	90°	90°		

(Sheet 6 of 6)

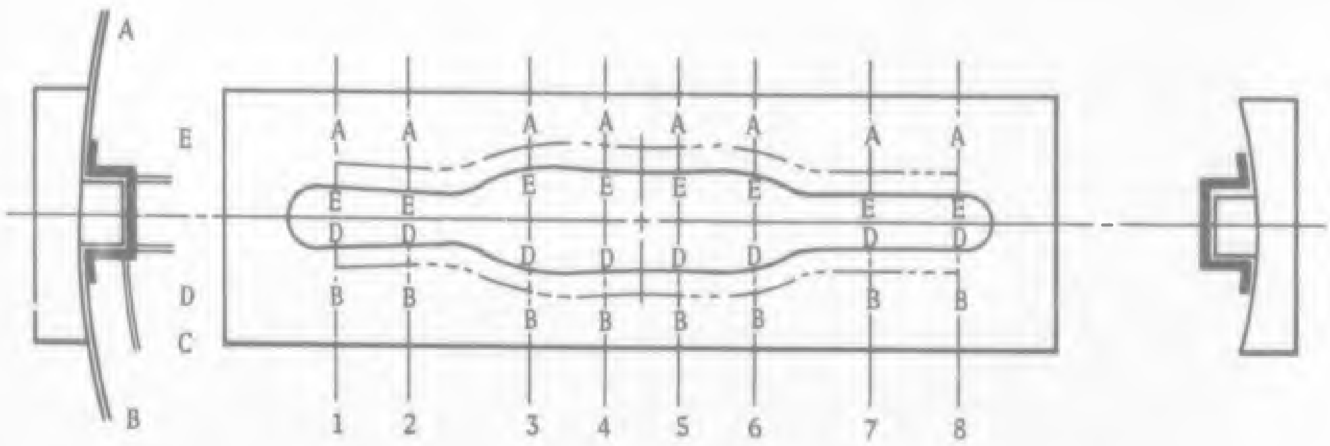


TABLE A-14 PART #4, ZEE MEMBER RDM 1435 DIMENSIONAL CHECK OF PARTS BACK TO COLD DIE

Part Identification Number	Zone								
		1	2	3	4	5	6	7	8
1 .025 6Al-6V-2Sn	A	X	.005	X	X	X	.005	.005	X
	B	.020	.015	.020	.020	.015	.020	.015	.020
	C	X	X	X	X	X	X	X	X
	D	.005	.005	.005	.005	.005	.005	.005	.005
	E	.005	.005	.005	.005	.005	.005	.005	.005
2 .025 6Al-6V-2Sn	A	.015	.004	.004	X	X	X	X	X
	B	.004	X	.003	.004	.004	.005	.004	.005
	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
5 .025 6Al-6V-2Sn	A	X	X	X	X	X	.008	.003	X
	B	.005	.005	.002	.002	.005	.005	.002	X
	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
8 .025 6Al-6V-2Sn	A	.005	X	X	X	X	.005	.005	X
	B	.020	.015	.020	.020	.015	.020	.015	.020
	C	X	X	X	X	X	X	X	X
	D	.005	.005	.005	.005	.005	.005	.005	.005
	E	.005	.005	.005	.005	.005	.005	.005	.005
9 .025 6Al-4V Ann	A	.005	X	X	X	.005	.010	.004	X
	B	.020	.020	.020	.018	.018	.020	.010	.015
	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
10 .025 6Al-4V Ann	A	X	X	X	X	X	.008	.010	.015
	B	.015	.010	.010	.015	.020	.025	.015	.020
	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X

LEGEND: X means part lays dead to punch surface with little or no finger pressure

(Sheet 1 of 8)

TABLE A-14 (Cont'd)

Part Identification Number		Zone 1	2	3	4	5	6	7	8
11	A	.010	.003	.002	X	X	.005	.004	X
.025	B	.020	.015	.020	.020	.020	.020	.015	.020
6Al-4V Ann	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
12	A	X	X	.010	.015	.015	.020	X	X
.025	B	X	X	.010	.010	.010	.010	X	X
6Al-4V Ann	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
13	A	X	.010	.020	.020	.025	.025	.005	X
.025	B	X	X	.008	.015	.010	.008	X	X
6Al-4V Ann	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
14	A	X	X	X	X	.005	.005	X	X
.025	B	X	.005	.005	.005	.005	.004	.003	X
6Al-4V Ann	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
15	A	X	X	X	X	X	X	X	X
.025	B	X	X	.005	.005	.008	.006	.005	.005
6Al-4V Ann	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
16	A	X	X	X	X	X	X	X	X
.025	B	X	X	.010	.010	.010	.006	.004	X
6Al-4V Ann	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
17	A	X	X	X	.010	.010	.015	X	X
.025	B	X	X	.008	.008	.008	.004	X	X
6Al-4V Ann	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
18	A	X	X	X	X	X	X	X	X
.025	B	.005	.008	.020	.025	.020	.018	.005	X
6Al-4V Ann	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
21	A	X	X	X	X	X	X	X	X
.025	B	X	.002	.005	.005	.004	.005	X	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
22	A	.005	X	.003	.015	.015	.015	X	X
.025	B	X	.005	.015	.015	.015	.008	X	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X

LEGEND: X means part lays dead to punch surface with little or no finger pressure

(Sheet 2 of 8)

TABLE A-14 (Cont'd)

Part Identification Number		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
23	A	X	.005	X	X	X	X	X	X
.025	B	X	.005	.018	.020	.025	.015	.005	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
24	A	X	X	X	X	X	X	X	X
.025	B	X	X	.012	.015	.015	.010	X	.005
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
25	A	X	X	X	X	.007	.010	.005	.003
.025	B	X	.010	.030	.035	.030	.015	X	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
26	A	X	X	X	X	X	X	X	X
.025	B	X	X	.005	.005	.005	.005	X	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
27	A	X	X	X	X	X	X	X	X
.025	B	X	X	X	X	X	X	X	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
28	A	X	X	X	X	X	X	X	X
.025	B	X	X	X	X	X	X	X	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
29	A	X	X	X	.005	.015	.020	X	X
.025	B	.005	.005	X	X	X	X	X	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
30	A	X	X	X	X	X	X	X	X
.025	B	X	X	X	X	X	X	X	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X
31	A	X	X	X	X	X	X	X	X
.025	B	X	X	X	X	X	X	X	X
8Al-1Mo-1V	C	X	X	X	X	X	X	X	X
	D	X	X	X	X	X	X	X	X
	E	X	X	X	X	X	X	X	X

LEGEND: X means part lays dead to punch surface with little or no finger pressure

Part numbers not indicated were damaged in tool proving.

(Sheet 3 of 8)

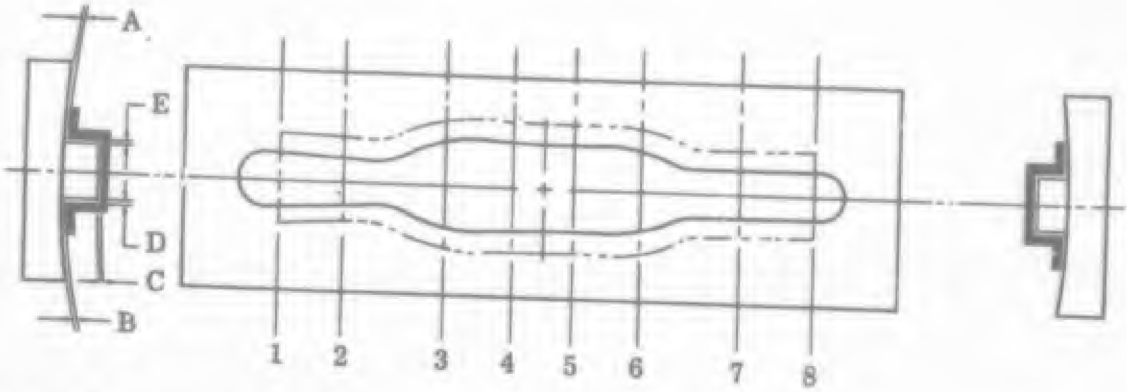


TABLE A-14 PART #4, ZEE MEMBER RDM 1435 DIMENSIONAL CHECK OF PARTS BACK TO COLD DIE

Part Identification Number		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
37 .070-6Al-6V-2Sn	A	X	X	.005	.005	.005	.008	X	X
	B	X	X	.005	.005	.005	.008	X	X
	C	.005							X
	D	X							X
	E	X							.005
38 .070-6Al-6V-2Sn	A	X	X	X	X	X	.005	X	X
	B	X	X	X	X	X	.005	X	X
	C	.005							X
	D	X							X
	E	X							.005
39 .070-6Al-6V-2Sn	A	X	X	.005	.005	.005	.008	X	X
	B	X	X	.005	.005	.005	.008	X	X
	C	.005							X
	D	X							X
	E	X							.005
40 .070-6Al-6V-2Sn	A	X	X	.005	.005	.005	.008	X	X
	B	X	X	.005	.005	.005	.008	.005	X
	C	.005							X
	D	X							.005
	E	X							.005
41 .070-6Al-6V-2Sn	A	X	X	.005	.005	.005	.006	X	X
	B	X	X	.004	.005	.005	.008	X	X
	C	.008							X
	D	X							.005
	E	.005							.005
42 .070-6Al-6V-2Sn	A	X	X	.004	.004	.005	.005	X	X
	B	X	X	.005	.005	.008	.005	X	X
	C	.005							X
	D	.003							.003
	E	.003							.005

LEGEND: "X" means part lays dead to punch surface with little or no finger pressure.

TABLE A-14 (Cont'd)

Part Identification Number		Zone 1	2	3	4	5	6	7	8
43 .070-6Al-6V-2Sn	A	X	X	.005	.005	.005	.005	X	X
	B	X	X	.005	.005	.005	.005	X	X
	C	.005							X
	D	.003							.005
	E	.003							.005
44 .070-6Al-6V-2Sn	A	X	X	.005	.005	.005	.005	X	X
	B	X	X	.005	.005	.005	.009	X	X
	C	.008							.005
	D	.003							X
	E	.003							X
45 .070-6Al-6V-2Sn	A	X	X	.005	.003	.005	.008	X	X
	B	X	X	.005	.005	.005	.008	X	X
	C	.005							X
	D	X							.005
	E	X							X
46 .070-6Al-6V-2Sn	A	X	X	.005	.005	.005	.008	X	X
	B	X	X	.003	.005	.005	.006	X	X
	C	.008							X
	D	X							.003
	E	X							.003
47 .070-6Al-6V-2Sn	A	X	X	.005	.005	.005	.006	X	X
	B	X	X	.005	.005	.005	.006	X	X
	C	.005							X
	D	.005							.005
	E	.005							.005
48 .070-6Al-6V-2Sn	A	X	X	.005	.005	.005	.008	X	X
	B	X	X	.005	.005	.005	.008	X	X
	C	.005							X
	D	X							.005
	E	X							.005
49 .070-8Al-1Mo-1V	A	X	X	X	.005	.005	.008	X	X
	B	X	X	.005	.005	.005	.010	X	X
	C	.010							X
	D	X							X
	E	.005							.005
50 .070-8Al-1Mo-1V	A	X	X	X	X	X	.005	X	X
	B	X	X	X	.005	.005	.005	X	X
	C	.005							X
	D	.005							X
	E	.005							.005
51 .070-8Al-1Mo-1V	A	X	X	X	X	.005	.005	X	X
	B	X	X	.005	.005	.005	.005	X	X
	C	.005							.005
	D	.005							X
	E	.005							.005

LEGEND: "X" means part lays dead to punch surface with little or no finger pressure.

(Sheet 5 of 8)

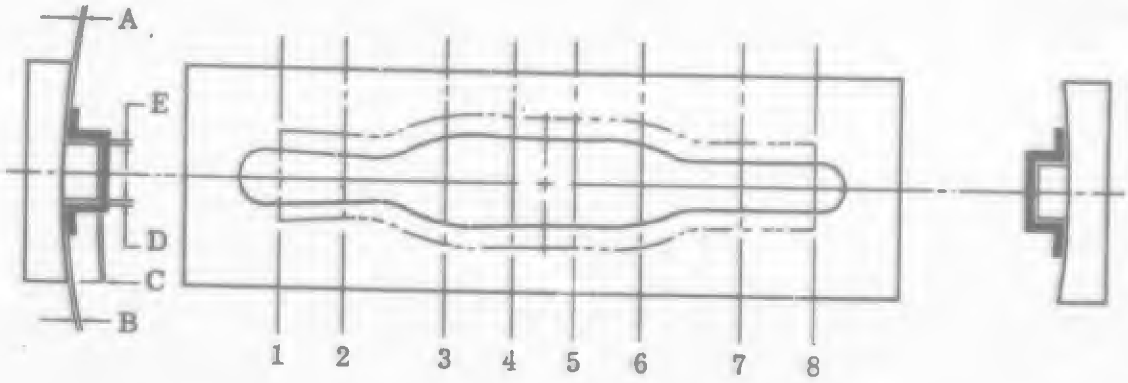


TABLE A-14 (Cont'd)

Part Identification Number		Zone 1	2	3	4	5	6	7	8
52 .070-8Ai-1Mo-1V	A	X	X	X	X	X	X	X	X
	B	X	X	X	X	X	X	X	X
	C	X							X
	D	X							X
	E	X							X
53 .070-8Al-1Mo-1V	A	X	X	X	X	X	X	X	X
	B	X	X	X	X	X	X	X	X
	C	X							X
	D	X							X
	E	X							X
54 .070-8Al-1Mo-1V	A	X	X	X	X	X	X	X	X
	B	X	X	X	X	X	X	X	X
	C	X							X
	D	X							X
	E	X							X
55 .070-8Al-1Mo-1V	A	X	X	X	X	X	X	X	X
	B	X	X	X	X	X	X	X	X
	C	X							X
	D	X							X
	E	X							X
56 .070-8Al-1Mo-1V	A	X	X	X	X	X	X	X	X
	B	X	X	.005	.005	.005	.005	X	X
	C	.005							X
	D	X							.005
	E	X							X
57 .070-8Al-1Mo-1V	A	X	X	X	X	.002	.002	X	X
	B	X	X	X	.003	.003	.002	X	X
	C	.003							X
	D	X							X
	E	X							X

LEGEND: "X" means part lays dead to punch surface with little or no finger pressure.

TABLE A-14 (Cont'd)

Part Identification Number		Zone 1	2	3	4	5	6	7	8
	A	X	X	X	X	X	X	X	
58	B	X	X	X	X	X	X	X	X
.070-8Al-1Mo-1V	C	X							X
	D	X							X
	E	X							X
	A	X	X	X	X	X	X	X	X
59	B	X	X	X	X	X	X	X	X
.070-8Al-1Mo-1V	C	X							X
	D	X							X
	E	X							X
	A	X	X	X	X	X	X	X	
60	B	X	X	X	X	X	X	X	X
.070-8Al-1Mo-1V	C	X							X
	D	X							X
	E	X							X
	A	X	X	X	X	X	X	X	X
61	B	X	X	X	X	X	X	X	X
.070-6Al-4V	C	X							X
	D	X							X
	E	X							X
	A	X	X	X	X	X	X	X	X
62	B	X	X	X	X	X	X	X	X
.070-6Al-4V	C	X							X
	D	X							X
	E	X							.005
	A	X	X	X	X	X	X	X	X
63	B	X	X	.005	.005	.005	.012	X	X
.070-6Al-4V	C	.005							X
	D	X							.005
	E	X							.005
	A	X	X	.005	.005	.005	.010	.007	X
64	B	X	X	.005	.005	.005	.015	.008	X
.070-6Al-4V	C	X							.010
	D	.005							
	E	X							
	A	X	X	X	X	X	X	X	X
65	B	X	X	X	X	X	X	X	X
.070-6Al-4V	C	X							X
	D	X							X
	E	X							X
	A	X	X	X	X	X	X	X	X
66	B	X	X	X	X	X	X	X	X
.070-6Al-4V	C	X							X
	D	X							X
	E	.005							X

LEGEND: "X" means part lays dead to punch surface with little or no finger pressure.

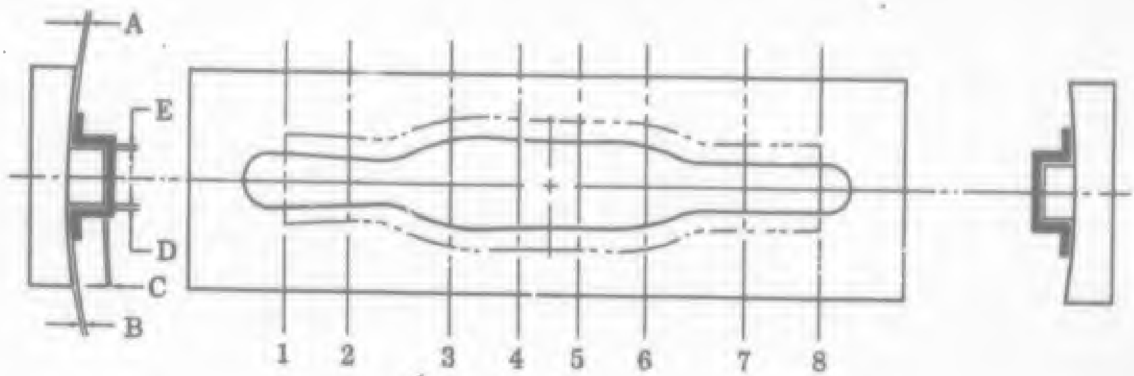


TABLE A-14 (Cont'd)

Part Identification Number		Zone 1	2	3	4	5	6	7	8
67 .070-6Al-4V	A	X	X	X	X	X	X	X	X
	B	X	X	X	X	X	X	X	X
	C	X							X
	D	X							X
	E	X							X
68 .070-6Al-4V	A	X	X	X	X	X	X	X	X
	B	X	X	X	X	.005	X	X	X
	C	.005							X
	D	X							X
	E	.005							.005
69 .070-6Al-4V	A	X	X	X	X	.005	.005	X	X
	B	X	X	.005	.005	.005	.005	X	X
	C	X							X
	D	X							X
	E	.005							.005
70 .070-6Al-4V	A	X	X	.003	.003	.003	.005	X	X
	B	X	X	.005	.005	.005	.005	X	X
	C	X							X
	D	X							X
	E	.005							.005
71 .070-6Al-4V	A	X	X	.003	.003	.005	.005	X	X
	B	X	X	.005	.005	.005	.008	X	X
	C	.005							X
	D	X							X
	E	X							X
72 .070-6Al-4V	A	X	X	.003	.003	.005	.005	X	X
	B	X	X	.005	.005	.005	.008	X	X
	C	.005							X
	D	X							X
	E	X							.005

LEGEND: "X" means part lays dead to punch surface with little or no finger pressure.

(Sheet 8 of 8)

TABLE A-15

PART 4, ZEE

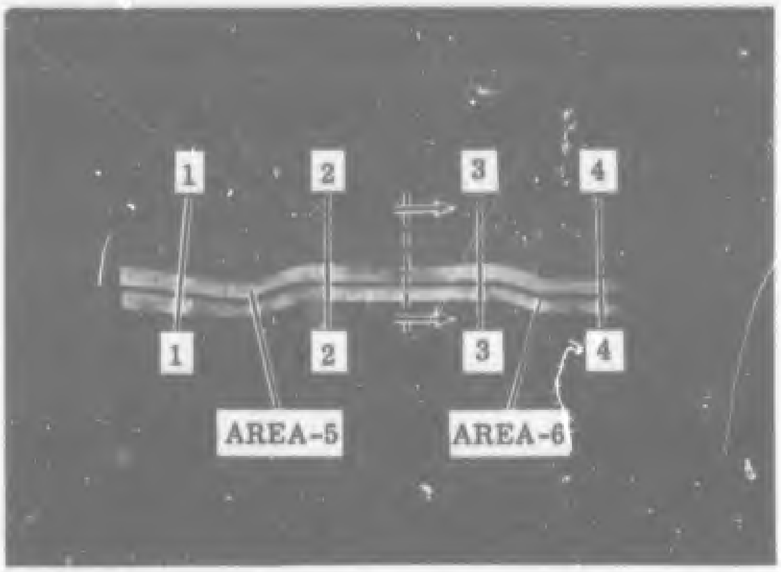
TWO-STEP FORMING, RDM 1516

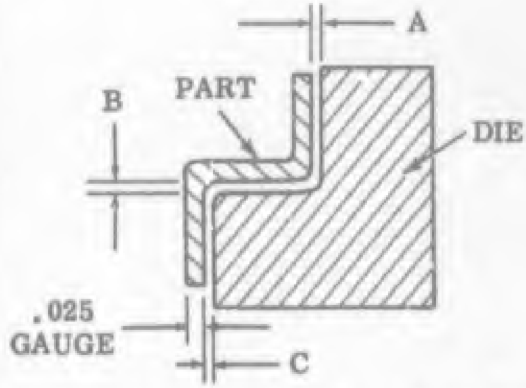
NOTES:

1. This chart is a dimensional check of parts back to the cold die.
2. v = Lays dead to die surface with little or no finger pressure.
3. x = Wrinkled area

	PART IDENT. NO.																	
ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1A	v		v	v				v		v	v		v	v	v	v	v	v
1B	v		v	v				v		v	v		v	v	v	v	v	v
1C	v		v	v				v		v	v		v	v	v	v	v	v
2A	v		v	v				v		v	v		v	v	v	v	v	v
2B	v		v	v				v		v	v		v	v	v	v	v	v
2C	v		v	v				v		v	v		v	v	v	v	v	v
3A	v		v	v				v		v	v		v	v	v	v	v	v
3B	v		v	v				v		v	v		v	v	v	v	v	v
3C	v		v	v				v		v	v		v	v	v	v	v	v
4A	v		v	v				v		v	v		v	v	v	v	v	v
4B	v		v	v				v		v	v		v	v	v	v	v	v
4C	v		v	v				v		v	v		v	v	v	v	v	v
Area 5	v		v	x				v		v	x		x	x	v	x	x	x
Area 6	x		x	x				x		x	x		x	x	x	x	x	x

(Sheet 1 of 2)





TYPICAL CROSS SECTION OF DIE

	PART IDENT. NO.																	
ZONE	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1A	v	v	v	Used For Tool Proving.	v	v	v	Used For Tool Proving.	v	v								
1B	v	v	v		v	v	v		v	v								
1C	v	v	v		v	v	v		v	v								
2A	v	v	v		v	v	v		v	v								
2B	v	v	v		v	v	v		v	v								
2C	v	v	v		v	v	v		v	v								
3A	v	v	v		v	v	v		v	v								
3B	v	v	v		v	v	v		v	v								
3C	v	v	v		v	v	v		v	v								
4A	v	v	v		v	v	v		v	v								
4B	v	v	v		v	v	v		v	v								
4C	v	v	v		v	v	v		v	v								
Area 5	x	v	x		v	x	v		x	x								
Area 6	x	x	x		x	x	x		x	x								

(Sheet 2 of 2)

TABLE A-16

PART 5, FRAME

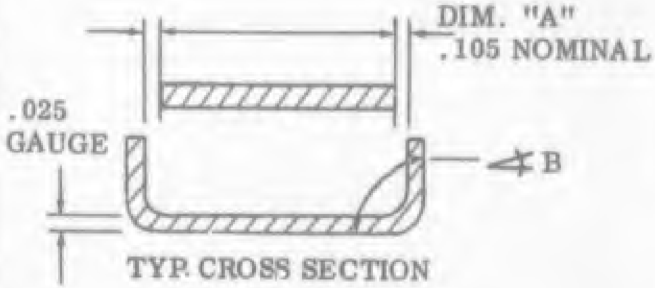
ONE-STEP FORMING, RDM 1498

NOTES:

1. This chart is a dimensional check of parts to the checking fixture.
2. v = 90°

	PART IDENT. NO.																	
ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A1	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
A2	.105	.100	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
A3	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
A4	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
A5	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
A6	.105	.105	.100	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
A7	.105	.105	.100	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
A8	.105	.105	.090	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
A9	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
A10	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105
B1	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B2	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B3	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B4	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B5	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B6	v	v	93°	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B7	v	v	93°	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B8	v	v	93°	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B9	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B10	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

(Sheet 1 of 4)



	PART IDENT. NO.																	
ZONE	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
A1	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
A2	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
A3	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
A4	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
A5	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
A6	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
A7	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
A8	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
A9	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
A10	.105	.105	.105	.105	.105	.105	.105	.105	.105	.105	.100	.105	.105	.105	.100	.105	.105	.105
B1	v	v	v	v	v	v	v	v	v	v	v	"	v	v	v	v	v	v
B2	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B3	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B4	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B5	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B6	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B7	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B8	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B9	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B10	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

TABLE A-16

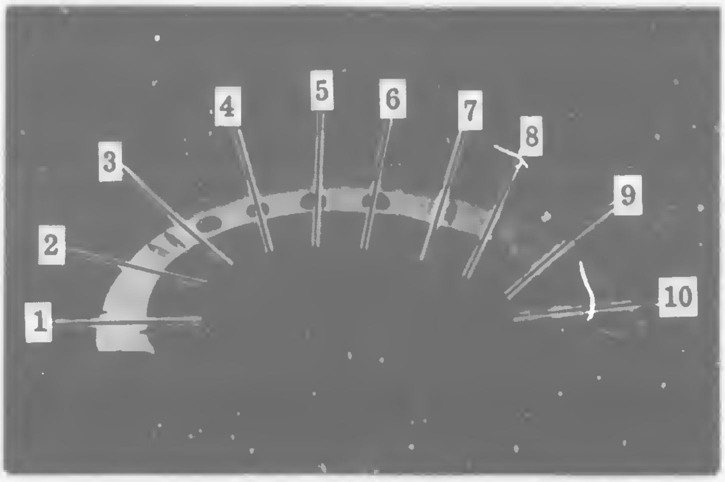
PART 5, FRAME

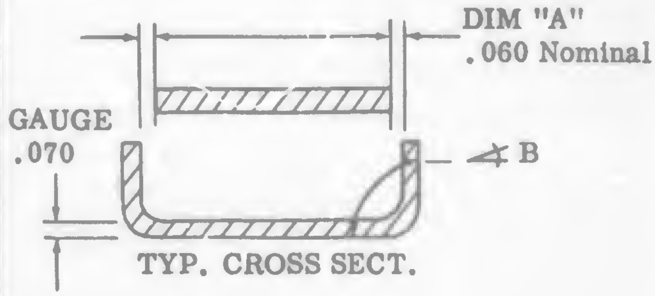
ONE-STEP FORMING, RDM 1498

NOTES:
1. This chart is a dimensional check of parts to the checking fixture.
2. v = 90°

	PART IDENT. NO.																	
ZONE	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
A1	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A2	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A3	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A4	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A5	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A6	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A7	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A8	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A9	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A10	.070	.060	.060	.060	.060	.060	.055	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
B1	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B2	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B3	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B4	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B5	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B6	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B7	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B8	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B9	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B10	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

(Sheet 3 of 4)





	PART IDENT. NO.																	
ZONE	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
A1	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A2	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A3	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A4	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A5	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A6	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A7	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A8	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A9	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
A10	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060	.060
B1	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B2	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B3	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B4	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B5	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B6	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B7	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B8	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B9	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
B10	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

(Sheet 4 of 4)

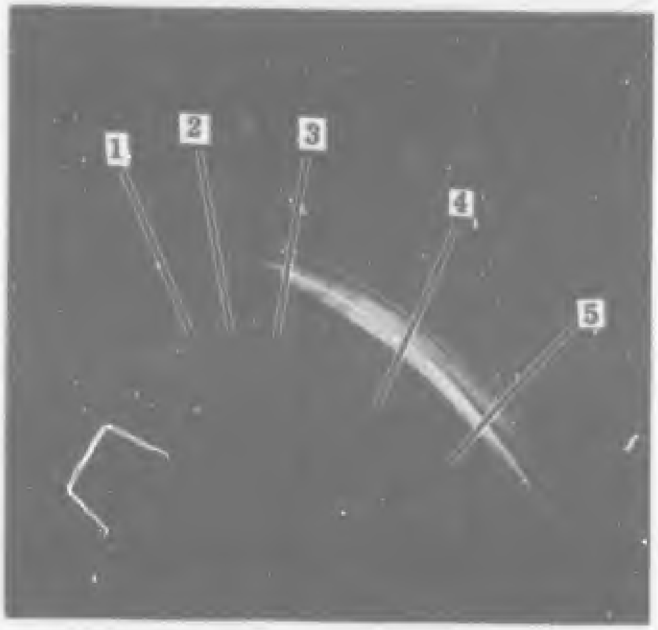
TABLE A-17

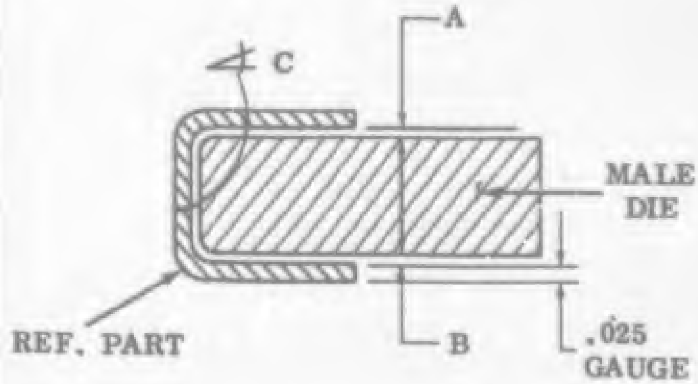
PART 6, CHANNEL

ONE-STEP FORMING, RDM 1496

NOTES:
1. This chart is a dimensional check of parts back to the cold die.
2. v = 90°
3. *Part used for tool proving.
4. **Cracked area.

	PART IDENT. NO.																	
ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1A	.005	.0	.005	.003	.003	.003	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2A	.005	.0	.005	.003	.003	.003	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3A	.005	.0	.005	.003	.003	.003	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4A	.005	.0	.005	.003	.003	.003	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5A	.005	.0	.005	.003	.003	.003	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1B	.005	.005	.005	.003	.003	.003	.005	.005	.0	.0	.0	.005	.0	.0	.0	.0	.0	.0
2B	.005	.005	.005	.003	.003	.003	.005	.005	.0	.0	.0	.005	.0	.0	0	.0	.0	.0
3B	.005	.005	.005	.003	.003	.003	.005	.005	.0	.0	.0	.005	.0	.0	.0	.0	.0	.0
4B	.005	.005	.005	.003	.003	.003	.005	.005	.0	.0	.0	.005	.0	.0	.0	.0	.0	.0
5B	.005	.005	.005	.003	.003	.003	.005	.005	.0	.0	.0	.005	.0	.0	.0	.0	.0	.0
∠ 1C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∠ 2C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∠ 3C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∠ 4C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∠ 5C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v





	PART IDENT. NO.																	
ZONE	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1A	.0	.0	.0	.0	.0	.0	*	**	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2A	.0	.0	.0	.0	.0	.0		**	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3A	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4A	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5A	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1B	.0	.0	.0	.0	.0	.0		**	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2B	.0	.0	.0	.0	.0	.0		**	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3B	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4B	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5B	.0	.0	.0	.0	.0	.0		.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
∡ 1C	v	v	v	v	v	v		v	v	v	v	v	v	v	v	v	v	v
∡ 2C	v	v	v	v	v	v		v	v	v	v	v	v	v	v	v	v	v
∡ 3C	v	v	v	v	v	v		v	v	v	v	v	v	v	v	v	v	v
∡ 4C	v	v	v	v	v	v		v	v	v	v	v	v	v	v	v	v	v
∡ 5C	v	v	v	v	v	v		v	v	v	v	v	v	v	v	v	v	v

TABLE A-17

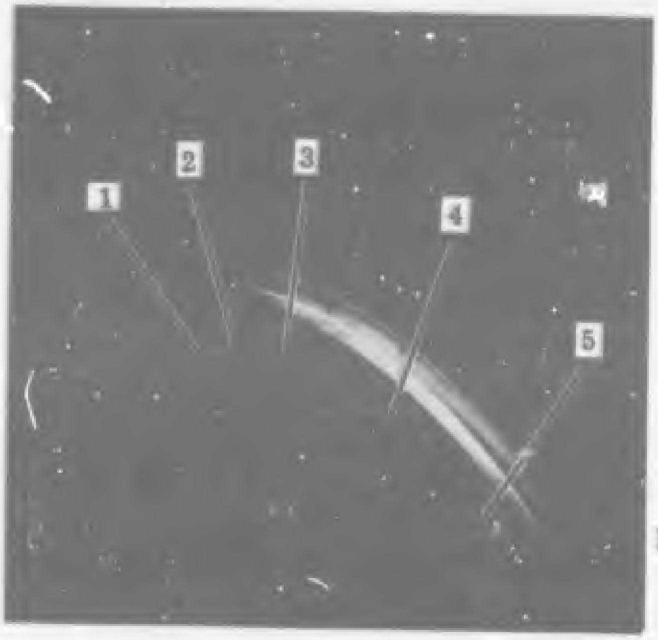
PART 6, CHANNEL

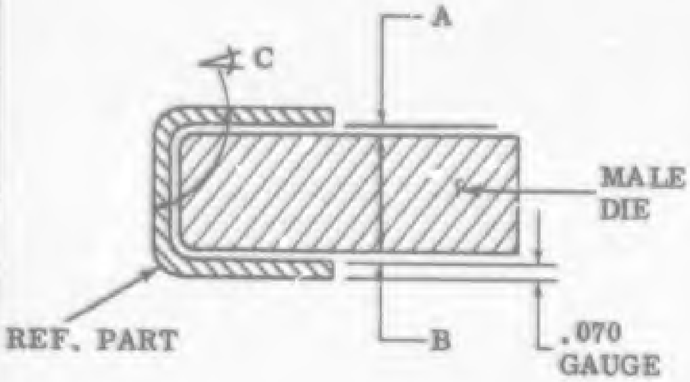
ONE-STEP FORMING, RDM 1496

NOTES:

1. This chart is a dimensional check of parts back to the cold die.
2. v = 90°

	PART IDENT. NO.																	
ZONE	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
1A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
∡1C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡2C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡3C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡4C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡5C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v





	PART IDENT. NO.																	
ZONE	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
1A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5A	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
1B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
2B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
3B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
4B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
5B	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
∢1C	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
∢2C	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
∢3C	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
∢4C	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
∢5C	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V

TABLE A-18

PART 6, CHANNEL

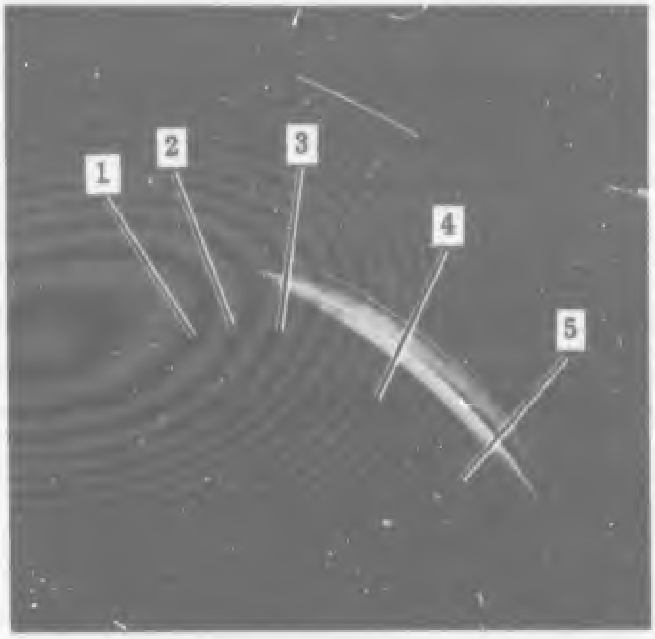
TWO-STEP FORMING, RDM 1510

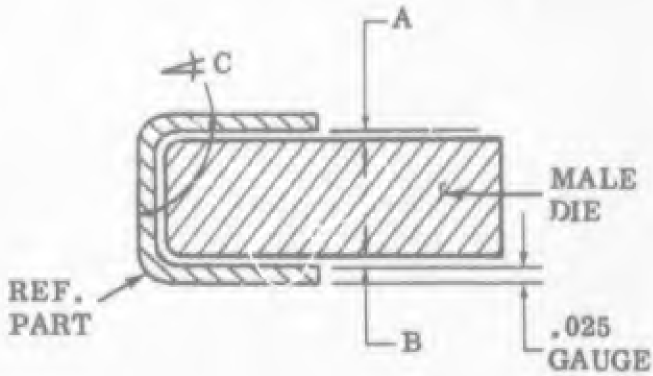
NOTES:

1. This chart is a dimensional check of parts back to the cold die.
2. X = Little or no finger pressure; lays "dead" to die surface.
3. v = 90°

	PART IDENT. NO.																	
ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
2A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
3A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
4A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
5A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
1B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
2B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
3B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
4B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
5B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
∡ 1C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 2C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 3C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 4C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡ 5C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

(Sheet 1 of 4)





	PART IDENT. NO.																	
ZONE	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
2A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
3A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
4A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
5A	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
1B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
2B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
3B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
4B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
5B	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X	.X
∠1C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∠2C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∠3C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∠4C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∠5C	v	v	v	v	v	v	v	v	v	v	v	v		v	v	v	v	v

(Sheet 2 of 4)

TABLE A-18

PART 6, CHANNEL

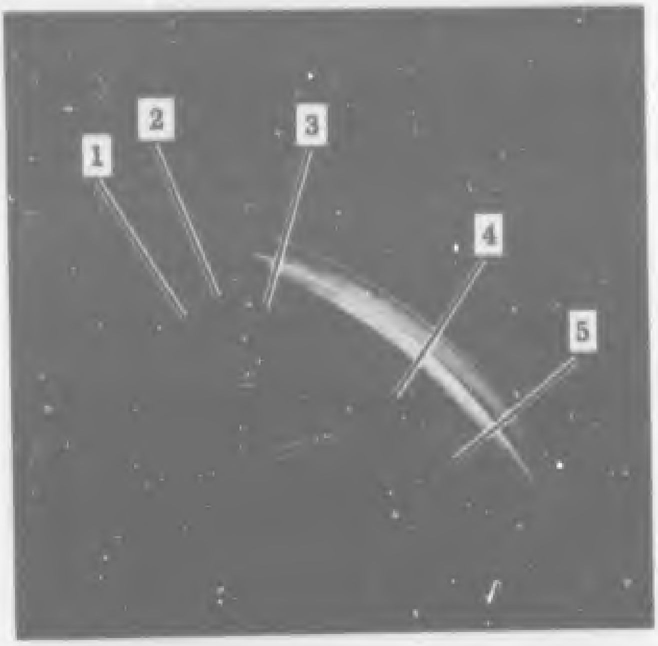
TWO-STEP FORMING, RDM 1510

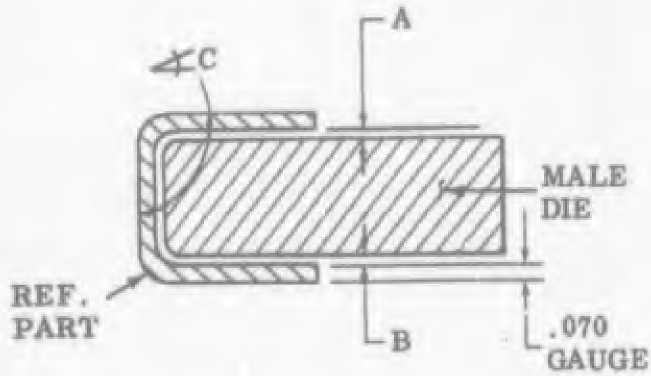
NOTES:

1. This chart is a dimensional check of parts back to the cold die.
2. v = 90°

	PART IDENT. NO.																	
ZONE	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
1A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
2A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
3A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
4A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
5A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
1B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
2B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
3B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
4B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
5B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
∡1C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡2C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡3C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡4C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∡5C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

(Sheet 3 of 4)





ZONE	PART IDENT. NO. 55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
1A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
2A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
3A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
4A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
5A	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
1B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
2B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
3B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
4B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
5B	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
∢1C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢2C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢3C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢4C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v
∢5C	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v	v

(Sheet 4 of 4)

EMPIRICAL TIME AND TEMPERATURE CHARTS

These charts represent the time-temperature variables utilized during the testing of each die which resulted in the forming of acceptable parts. As can be readily seen, there are wide variations of time-temperature conditions.

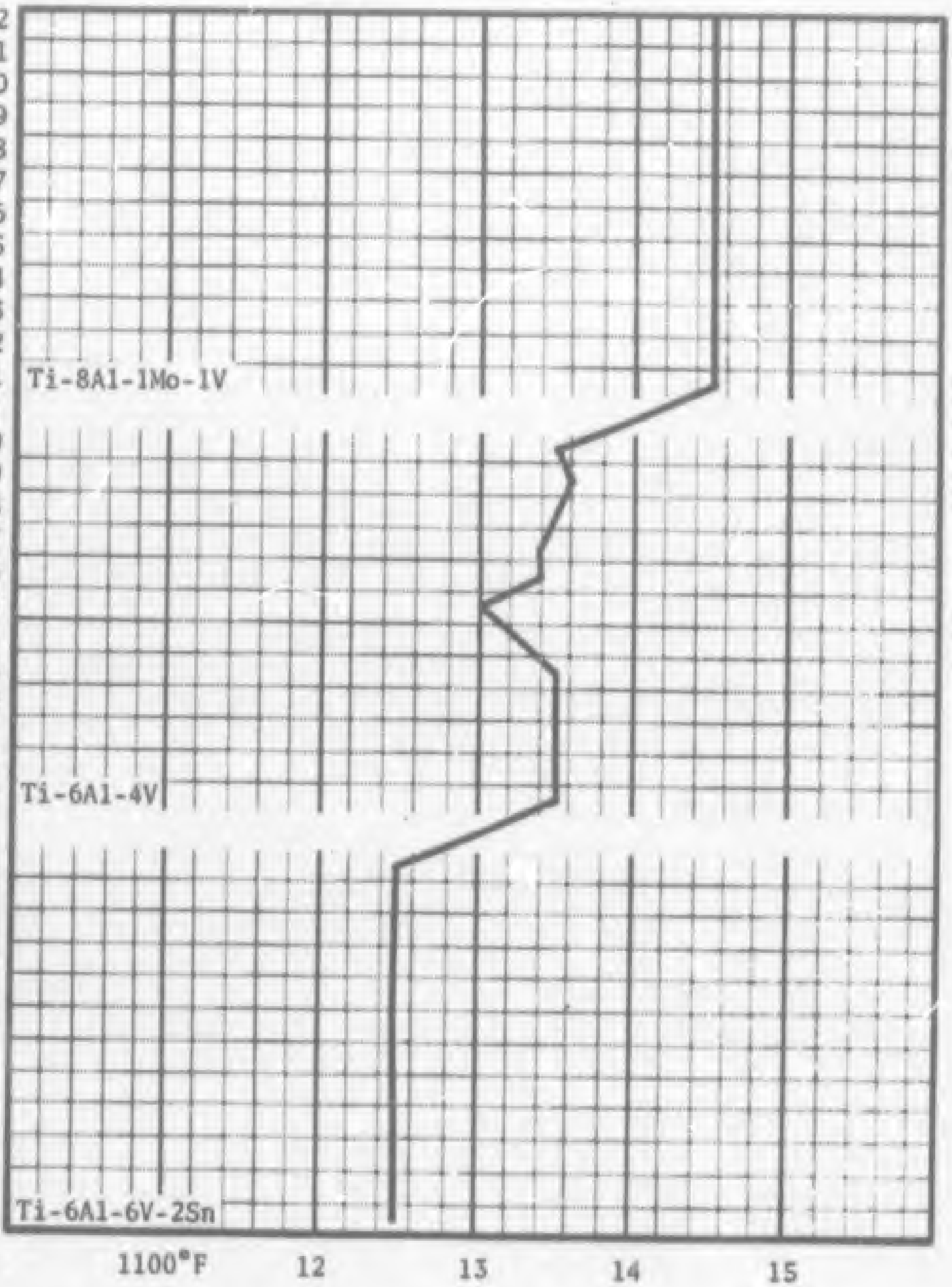
Since only twelve details were formed for each alloy, additional time-temperature variations were tried for each part. The optimum empirical time-temperature combinations were found to be largely dependent upon part geometry and the type of forming operation. The higher the temperature, the lower the cycle time; however, in the case of 6Al-6V-2Sn, it should be noted that the degradation of the resulting properties increases in direct relationship to the increase in temperature.

Draw forming and pressure pad forming take approximately one-half the forming time as compared to hot sizing (after preforming) operations for any given temperature.

To utilize the information presented in these charts, along with the other information in sections VI - XI, and to apply it to other parts, the following steps should be followed:

- Match the new part geometry as closely as possible to one of the six shapes depicted in this report.
- Select the lowest time-temperature combination for the particular alloy to be used.
- Select the type of tool to be used (draw form, pressure pad, or hot sizing) based on the geometric complexity of the part and the ability of the tool to provide complete forming.

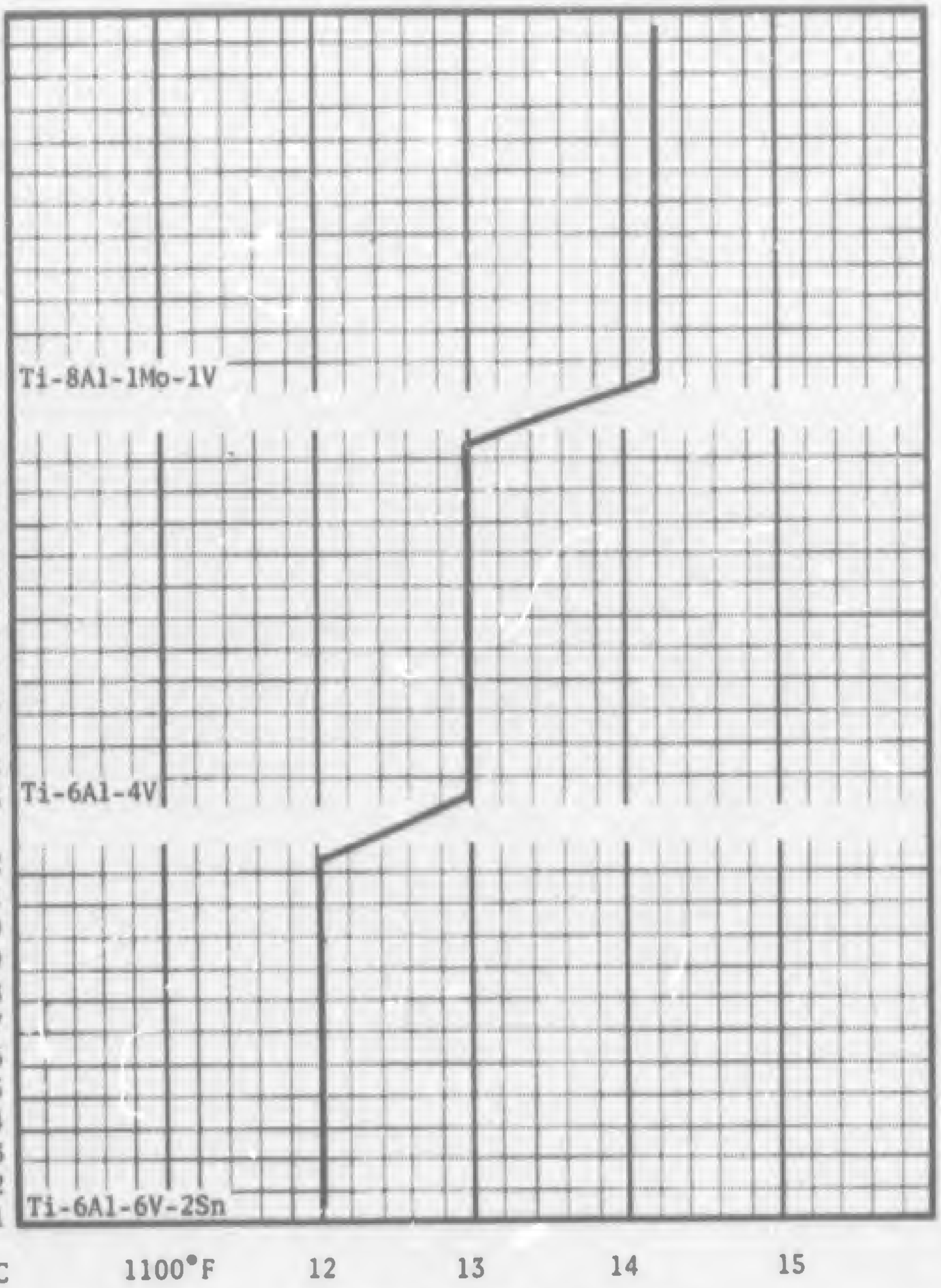
A	B	C
2	10	72
2	10	71
2	3	70
2	3	69
2	3	68
2	3	67
2	3	66
2	3	65
2	3	64
2	3	63
2	3	62
2	10	61
2	10	60
2	10	59
2	10	58
2	10	57
2	10	56
3	12	55
		54
2	10	53
2	10	52
2	13	51
2	13	50
2	13	49
3	15	48
3	15	47
3	15	46
3	15	45
3	15	44
3	12	43
3	12	42
3	12	41
3	12	40
3	12	39
3	12	38
3	12	37



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1500 ONE STEP .070 GAUGE
PART 1 TAIL CONE FRAME

A	B	C
1	5	36
1	5	35
1	5	34
1	5	33
1	5	32
1	5	31
1	5	30
1	6	29
1	6	28
1	8	27
1	8	26
1	8	25
3	5	24
3	5	23
3	5	22
3	5	21
3	5	20
3	5	19
3	5	18
3	5	17
3	5	16
3	5	15
3	12	14
3	12	13
5	8	12
3	5	11
3	5	10
3	5	9
3	5	8
3	5	7
3	5	6
3	5	5
3	5	4
3	7	3
3	12	2
3	12	1



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1502 ONE STEP .025 GAUGE
PART 2 DOOR CHANNEL

A	B	C
2	8	72
2	8	71
2	8	70
2	8	69
2	8	68
2	8	67
2	8	66
2	8	65
2	8	64
2	8	63
2	10	62
2	10	61
3	5	60
3	5	59
3	5	58
3	5	57
3	5	56
3	5	55
3	5	54
3	5	53
3	5	52
3	5	51
3	5	50
3	7	49
3	5	48
3	5	47
3	5	46
3	7	45
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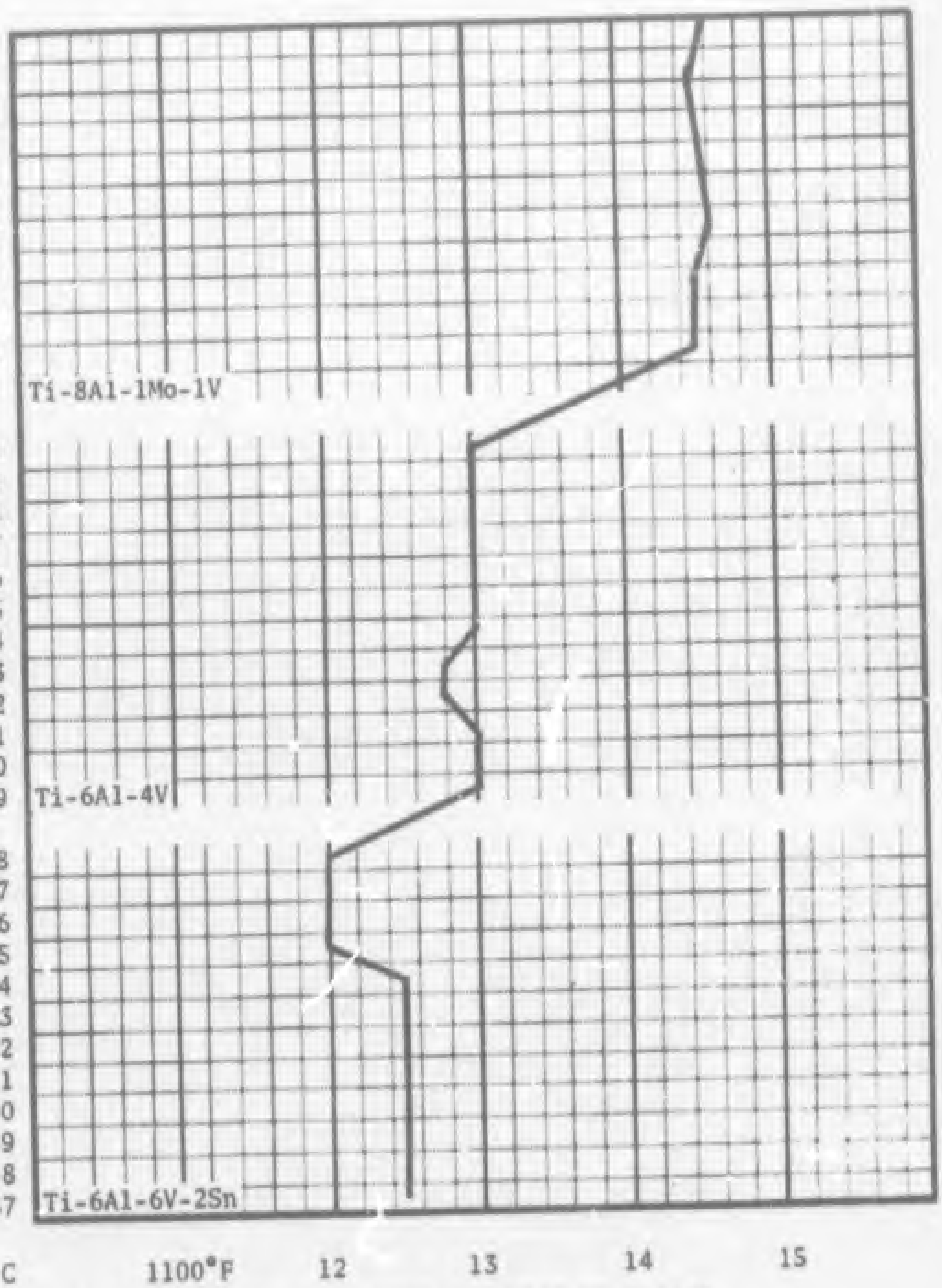
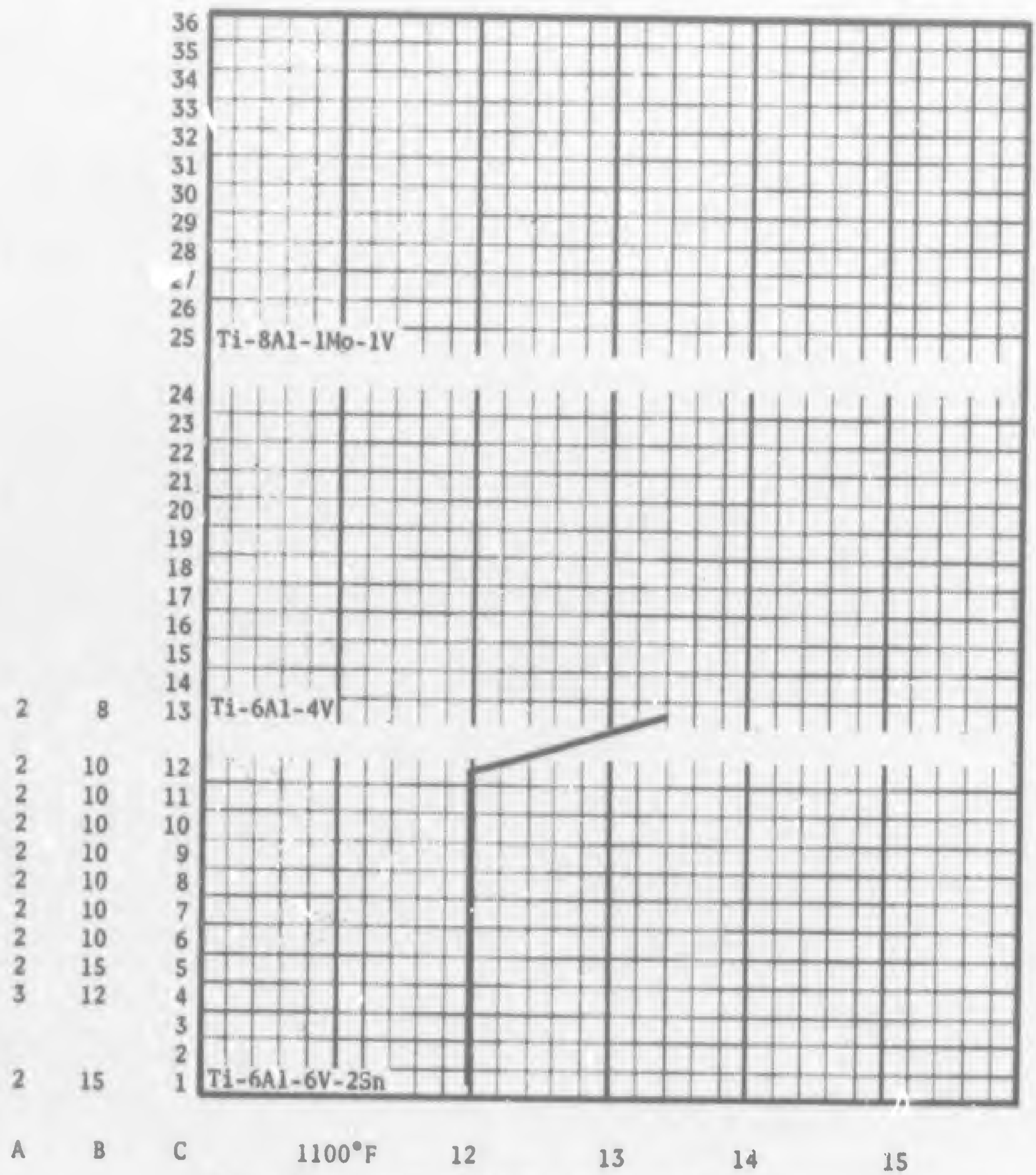
3	12	38
3	12	37



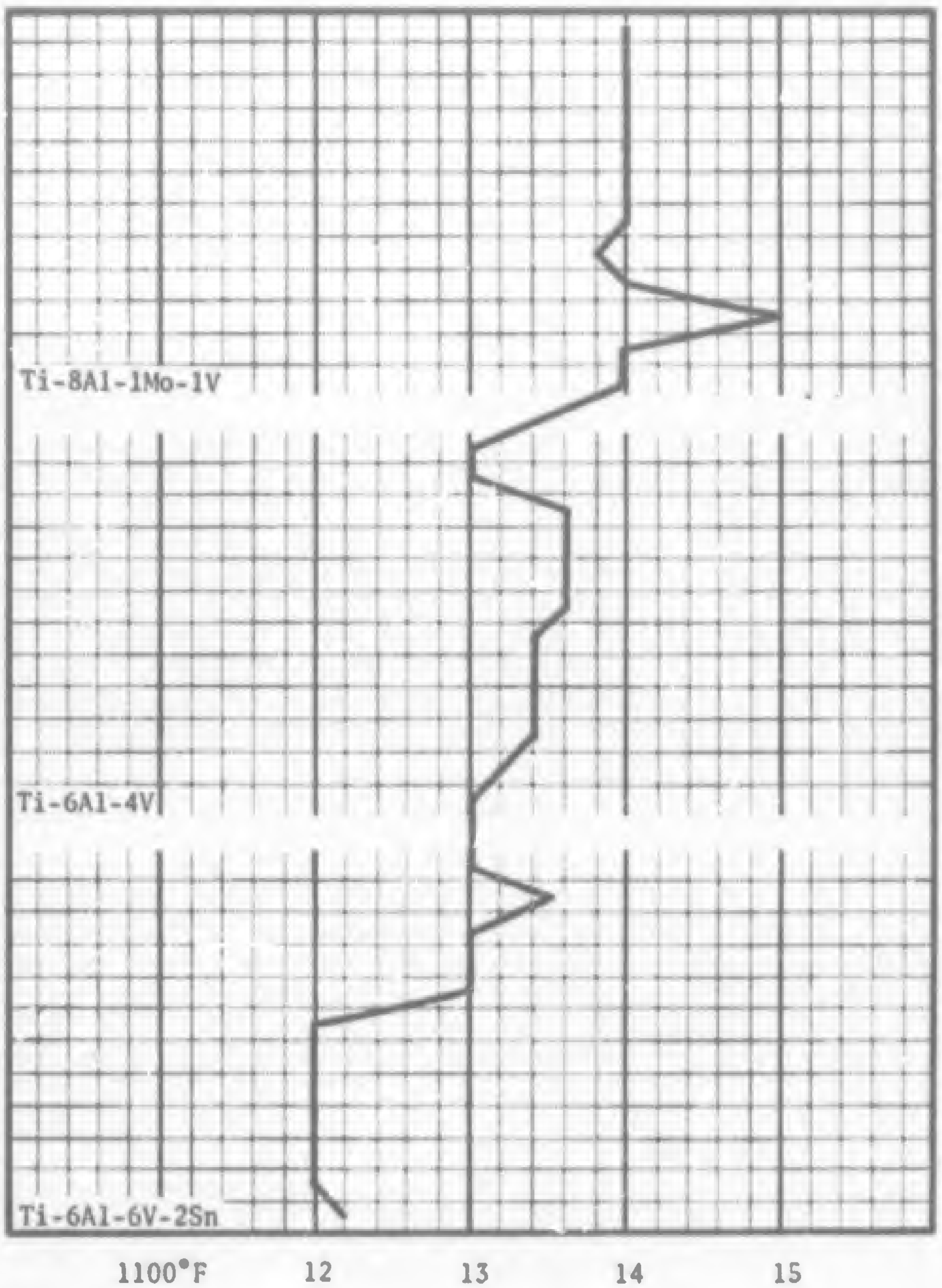
A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1502 ONE STEP .070 GAUGE
PART 2 DOOR CHANNEL



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1509 TWO STEP .025 GAUGE
PART 2 DOOR CHANNEL

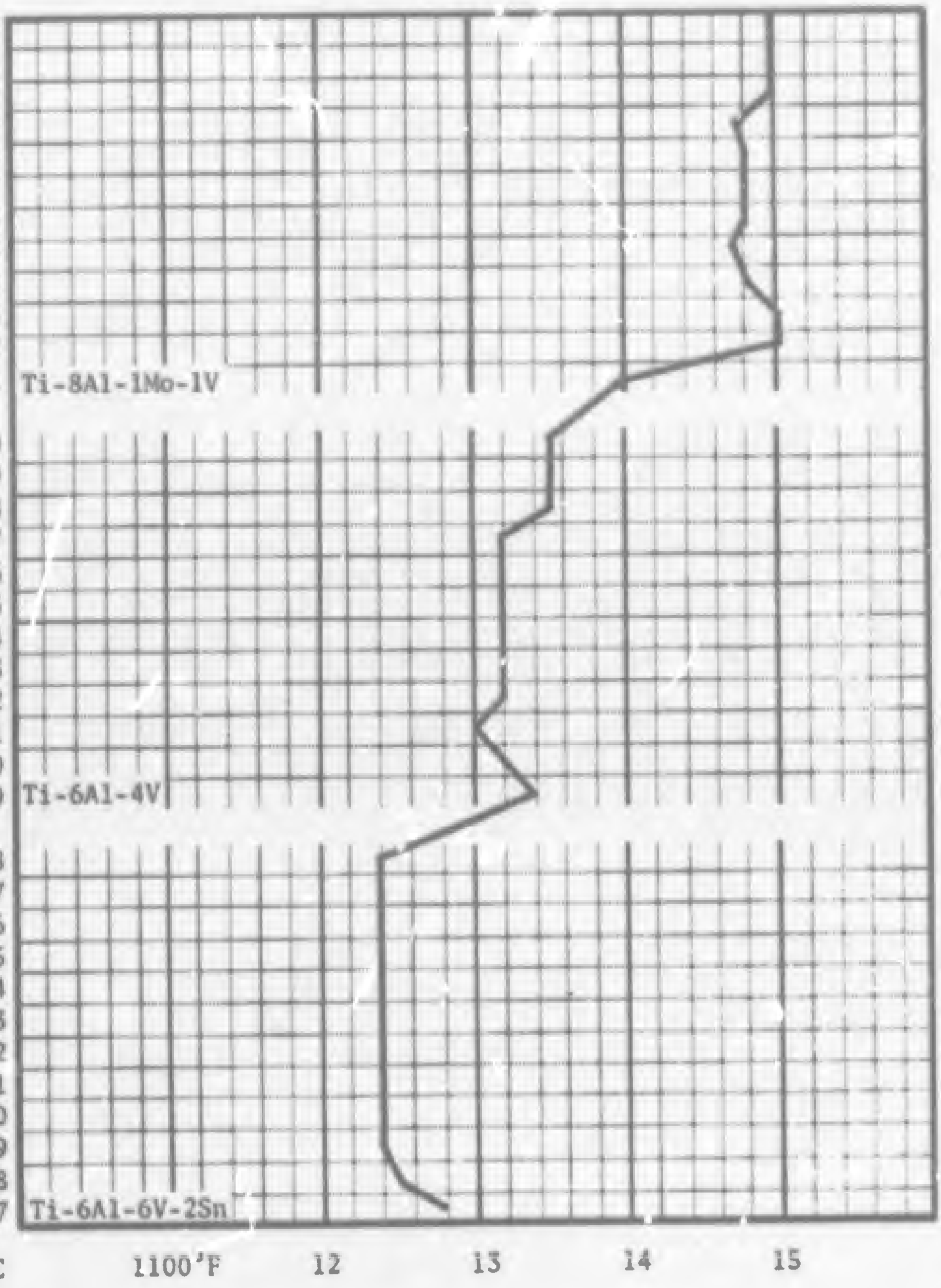


A	B	C
1	8	36
1	8	35
1	8	34
1	8	33
1	8	32
1	8	31
1	8	30
2	8	29
1	8	28
1	12	27
1	12	26
1	12	25
2	3	24
2	3	23
2	3	22
2	3	21
2	3	20
2	3	19
2	3	18
2	3	17
2	3	16
2	8	15
2	8	14
2	10	13
2	5	12
2	5	11
2	5	10
2	5	9
2	5	8
2	6	7
3	10	6
3	10	5
3	10	4
3	10	3
3	10	2
2	10	1

A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1497 ONE STEP .025 GAUGE
PART 3 ANNULAR RING

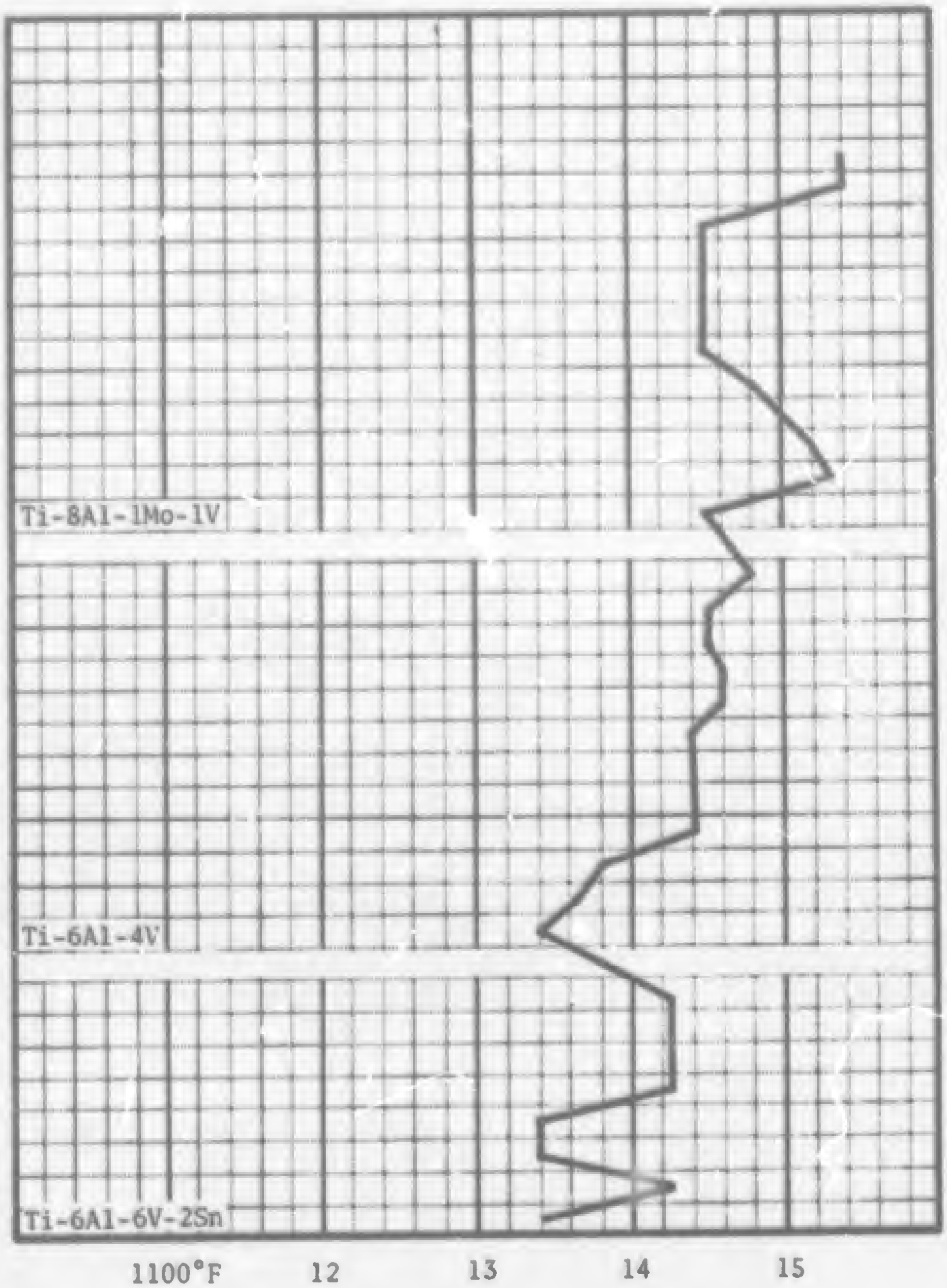
A	B	C
2	8	72
2	8	71
2	8	70
2	6	69
2	8	68
2	8	67
2	8	66
2	8	65
2	8	64
2	8	63
2	10	62
1	12	61
2	8	60
2	8	59
2	8	58
3	12	57
		56
3	12	55
3	12	54
		53
3	5	52
3	5	51
3	5	50
2	3	49
3	20	48
3	20	47
3	20	46
3	20	45
3	15	44
3	15	43
3	15	42
3	15	41
3	10	40
3	10	39
3	10	38
3	10	37



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1497 ONE STEP .070 GAUGE
PART 3 ANNULAR RING

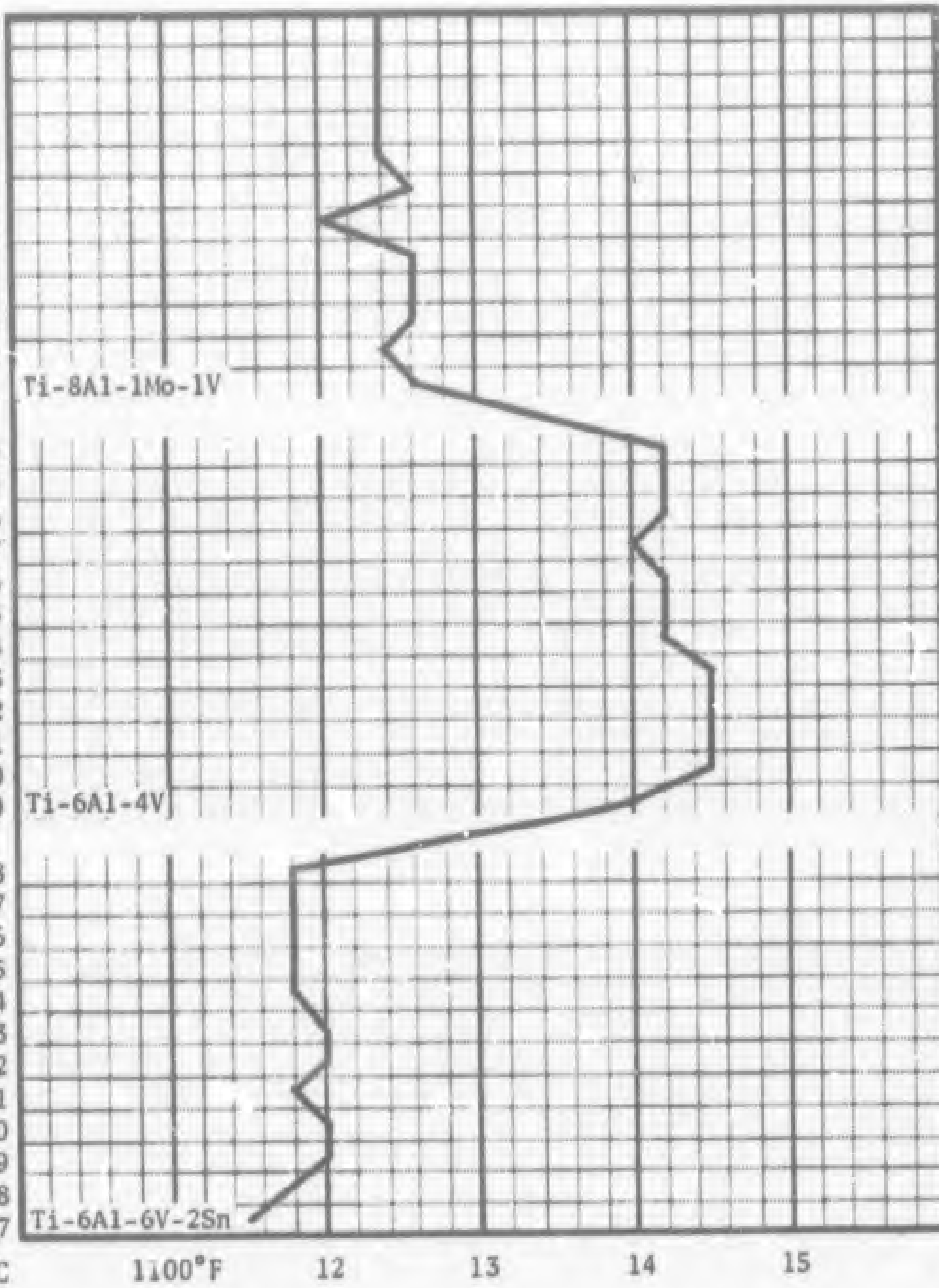
A	B	C
		36
		35
		34
		33
1	2	32
1	2	31
1	2	30
1	2	29
2	5	28
2	5	27
1.5	2	26
1	2	25
1	2	24
1	2	23
1	2	22
.5	2	21
1	2	20
1	2	19
1	2	18
1	2	17
1	2	16
2	3	15
2	3	14
2	3	13
1	2	12
0	7	11
1.5	5	10
2	10	9
1	2	8
		7
		6
1	2	5
1	2	4
1	1.5	3
1	3	2
1	3	1



A = "SOAK (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1435 ONE STEP .025 GAUGE
PART 4 ZEE MEMBER

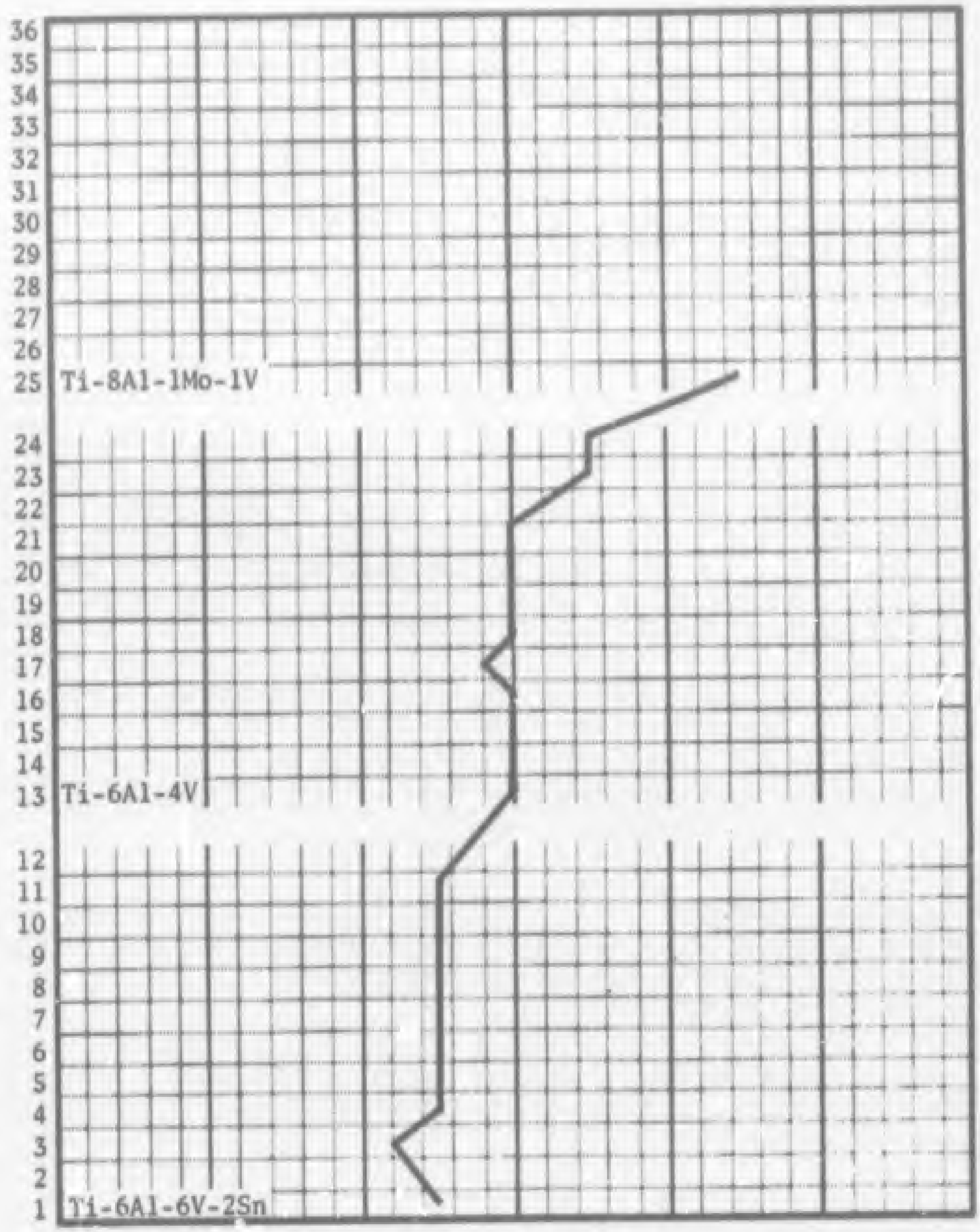
A	B	C
2	8	72
2	8	71
2	8	70
2	8	69
2	8	68
2	8	67
3	17	66
2	5	65
3	17	64
3	9	63
3	17	62
2	5	61
3	12	60
3	12	59
3	10	58
2	10	57
2	8	56
2	5	55
2	10	54
3	10	53
4	10	52
3	10	51
3	12	50
3	12	49
2	5	48
2	5	47
2	5	46
2	5	45
2	5	44
2	5	43
2	5	42
2	5	41
2	3	40
2	5	39
3	12	38
3	12	37



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER

RDM 1435 ONE STEP .070 GAUGE
PART 4 ZEE MEMBER

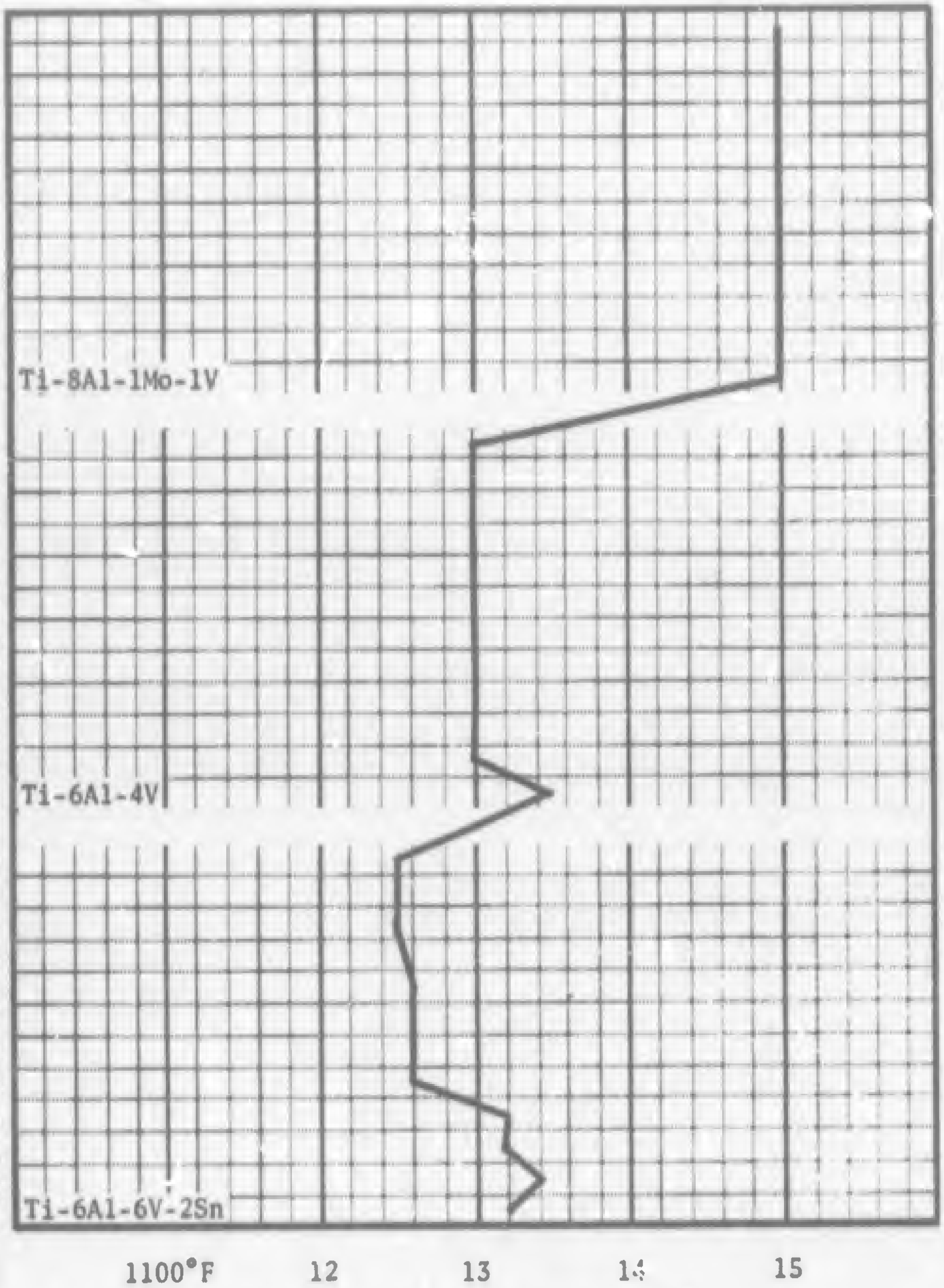
A	B	C
2	10	25
3	12	24
3	12	23
3	12	22
3	15	21
3	12	20
3	12	19
3	12	18
3	12	17
3	12	16
3	12	15
3	12	14
3	12	13
3	12	11
3	10	10
3	12	8
3	12	4
2	10	3
3	12	1



A = "SOAK (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1516 TWO STEP .025 GAUGE
PART 4 ZEE MEMBER

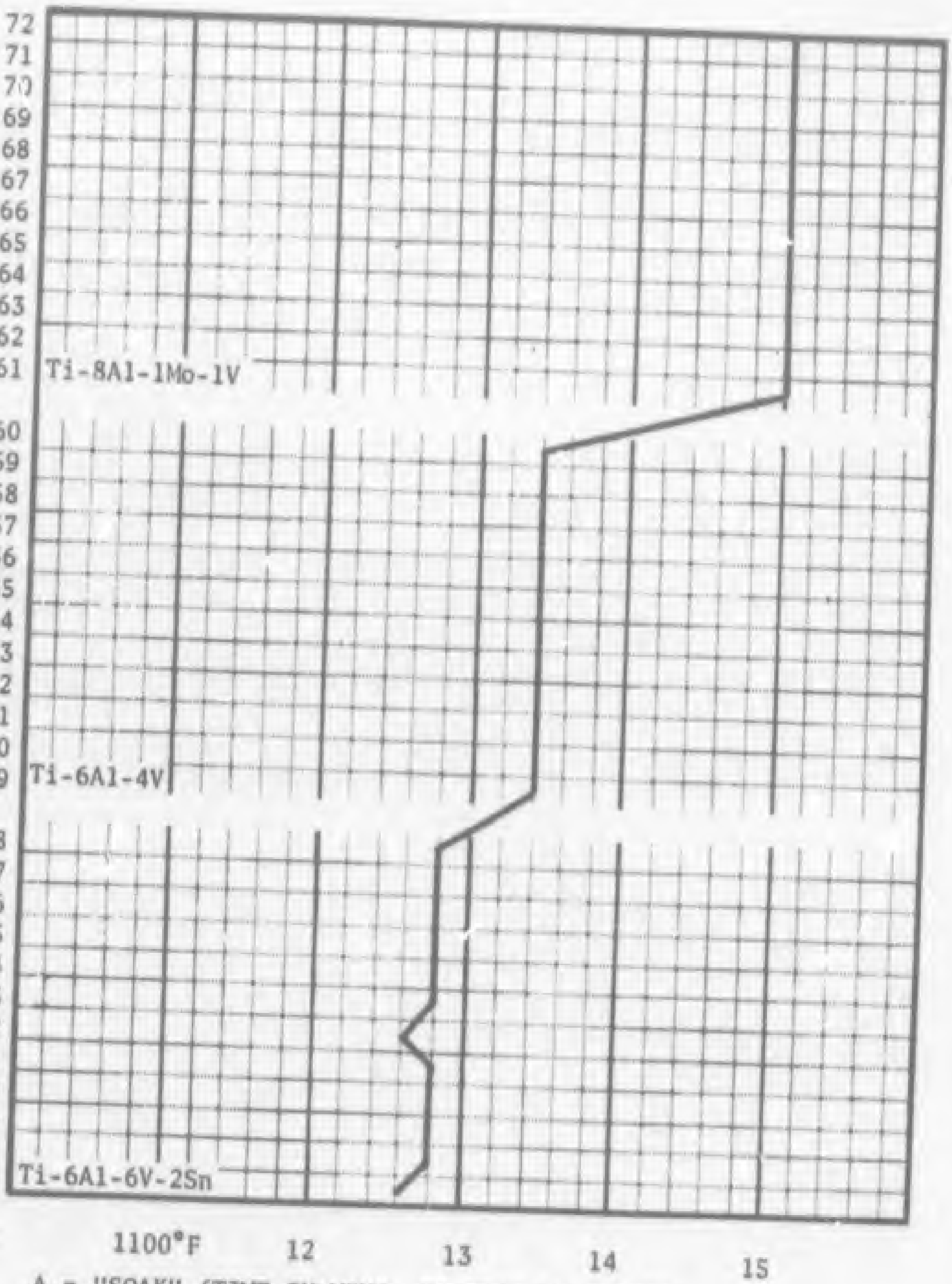
A	B	C
2	5	36
2	7	35
2	7	34
2	7	33
2	5	32
2	5	31
2	5	30
2	5	29
2	5	28
2	5	27
2	5	26
2	3	25
2	5	24
2	5	23
2	5	22
2	5	21
2	5	20
2	5	19
2	5	18
2	5	17
2	6	16
2	6	15
2	6	14
3	10	13
2	3	12
2	3	11
3	5	10
3	5	9
3	5	8
3	5	7
3	7	6
3	10	5
3	12	4
3	12	3
3	10	2
3	10	1



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1498 ONE STEP .025 GAUGE
PART 5 FRAME

A	B	C
2	10	72
2	10	71
2	10	70
2	10	69
2	10	68
2	10	67
2	10	66
2	10	65
2	10	64
2	10	63
2	8	62
2	8	61
2	8	60
2	8	59
2	8	58
2	8	57
2	8	56
2	8	55
2	8	54
2	8	53
2	8	52
2	10	51
2	10	50
2	10	49
3	12	48
3	12	47
3	12	46
3	12	45
3	12	44
3	12	43
3	12	42
3	12	41
3	12	40
3	12	39
3	10	38
3	10	37



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1498 ONE STEP .070 GAUGE
PART 5 FRAME

A	B	C
2	5	36
2	5	35
2	5	34
2	5	33
2	3	32
2	5	31
2	5	30
2	8	29
3	12	28
3	12	27
3	12	26
1	8	25
2	10	24
2	10	23
2	10	22
2	10	21
2	10	20
2	10	19
2	10	18
2	10	17
2	7	16
2	5	15
2	3	14
2	5	13
3	8	12
3	15	11
3	15	10
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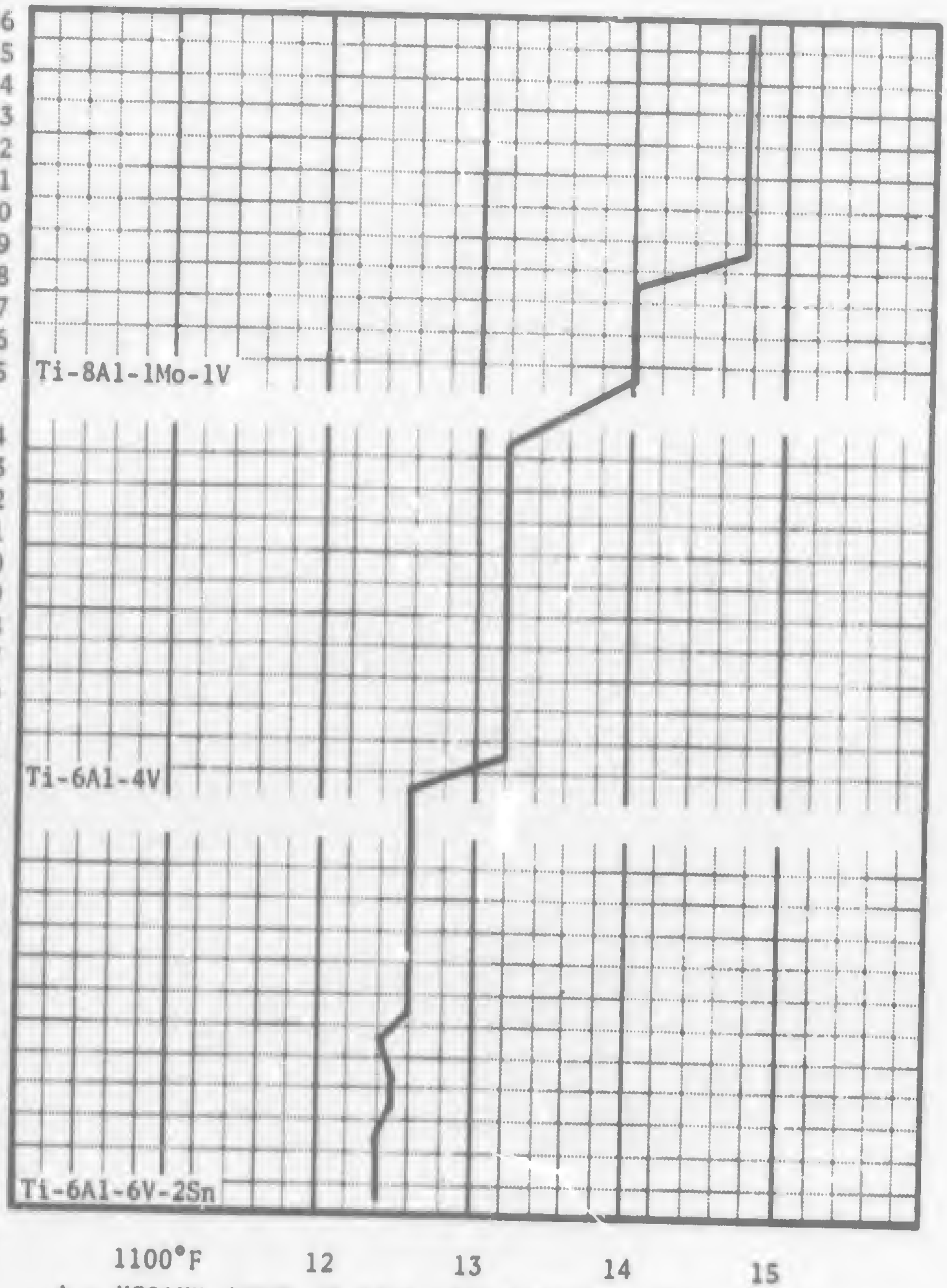
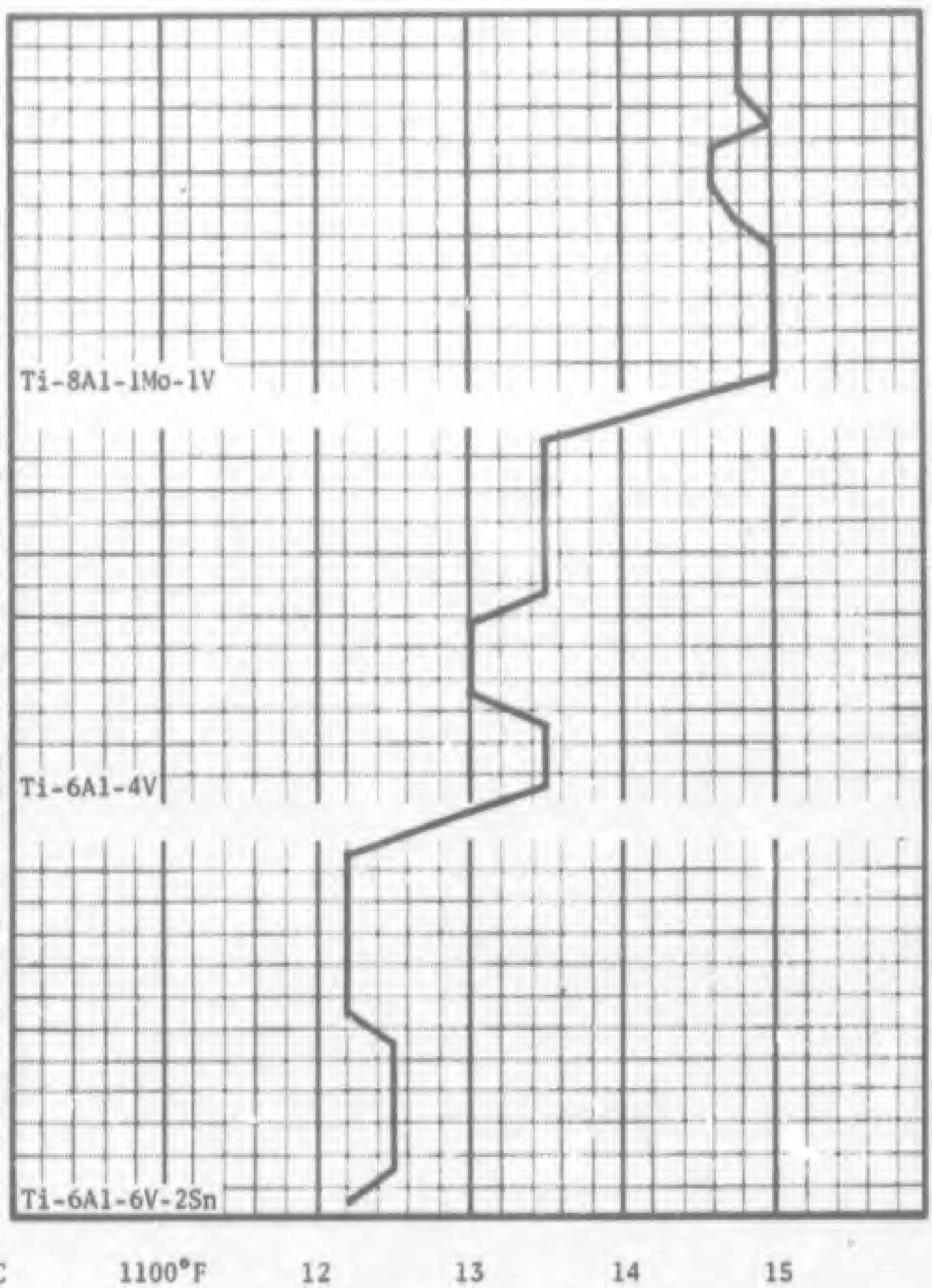
3	20	4
3	15	3
3	10	2
3	10	1



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

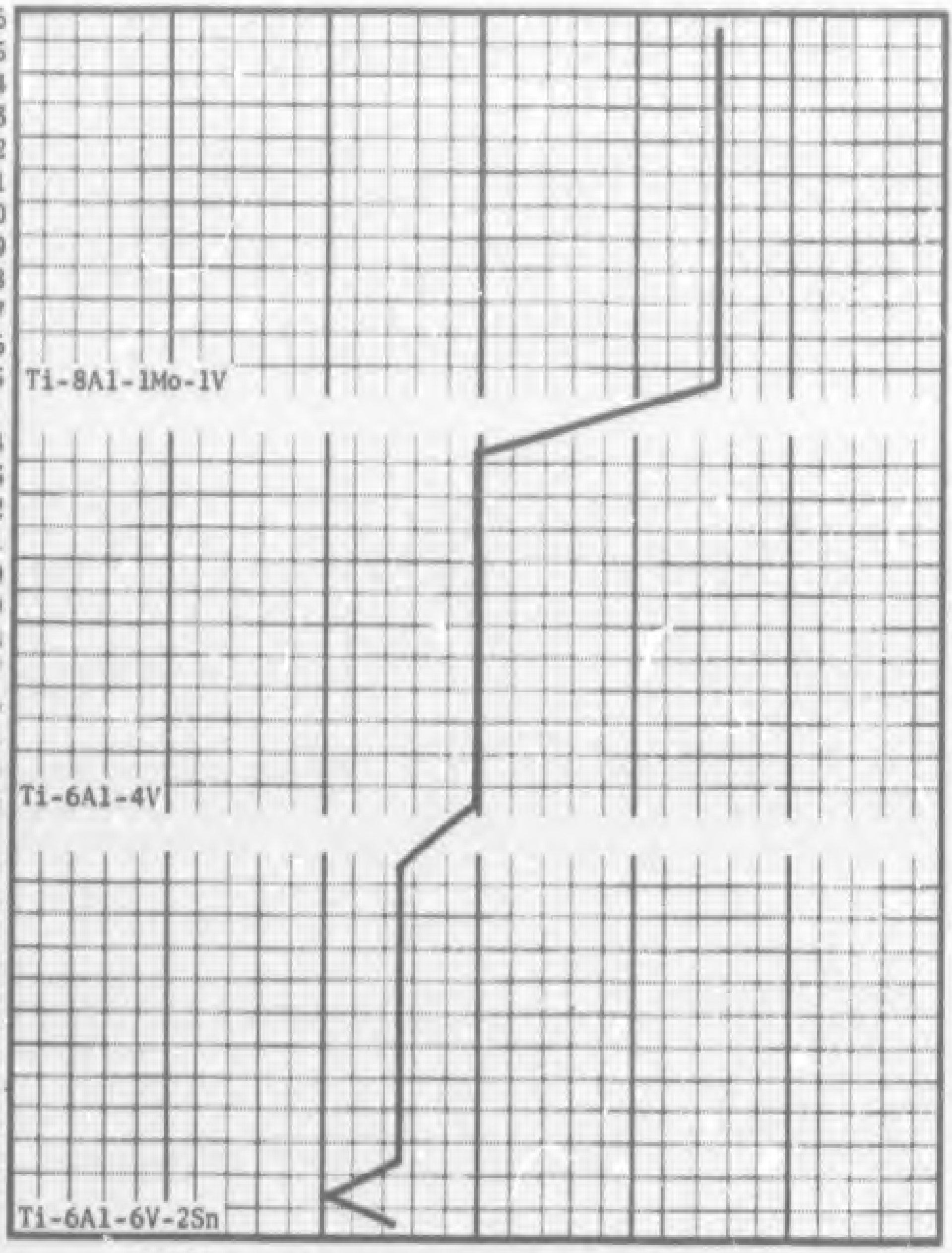
RDM 1496 ONE STEP .025 GAUGE
PART 6 CHANNEL

A	B	C
2	8	72
2	8	71
2	8	70
2	8	69
2	8	68
2	5	67
2	8	66
2	8	65
2	8	64
2	10	63
2	10	62
2	10	61
2	6	60
2	6	59
2	6	58
2	6	57
2	8	56
2	8	55
2	8	54
3	12	53
2	6	52
2	10	51
3	12	50
3	12	49
3	7	48
3	7	47
3	7	46
3	7	45
3	7	44
3	7	43
3	7	42
3	7	41
3	10	40
3	12	39
3	12	38
3	12	37



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1496 ONE STEP .070 GAUGE
PART 6 CHANNEL



A	B	C
2	10	36
2	10	35
2	10	34
2	10	33
2	10	32
2	10	31
2	10	30
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2	10	28
2	10	27
2	10	26
2	10	25
3	10	24
3	10	23
2	8	22
2	8	21
2	8	20
3	10	19
3	10	18
3	10	17
3	10	16
3	10	15
3	10	14
3	10	13
3	10	12
3	10	11
3	10	10
3	10	9
3	10	8
3	10	7
3	10	6
3	10	5
3	10	4
3	10	3
3	12	2
3	12	1

A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1510 TWO STEP .025 GAUGE
PART 6 CHANNEL

A	B	C
2	10	72
2	10	71
2	10	70
2	10	69
2	10	68
2	10	67
2	10	66
2	10	65
2	10	64
2	10	63
2	10	62
2	10	61
2	10	60
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2	10	58
2	10	57
2	10	56
2	10	55
2	10	54
2	10	53
2	10	52
2	10	51
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2	10	49
3	10	48
3	10	47
3	10	46
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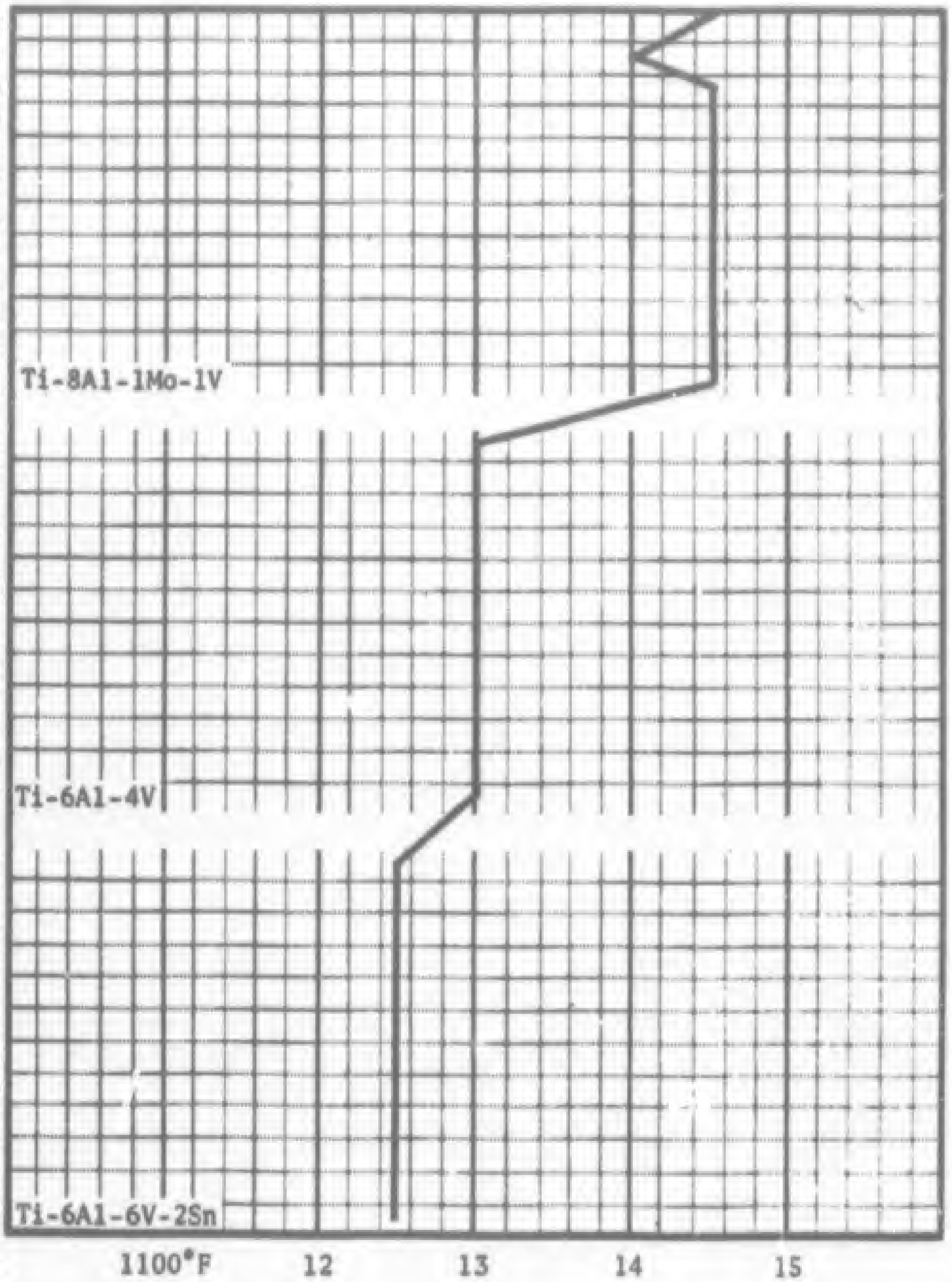
3	10	38
3	10	37



A = "SOAK" (TIME IN MINS. TO HEAT UP BLANK)
B = NO. OF MINS. IN CLOSED POSITION.
C = PART IDENTIFICATION NUMBER.

RDM 1510 TWO STEP .070 GAUGE
PART 6 CHANNEL

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(CONT'D)

Grumman's one-step hot forming of the complex-compound shaped parts were major achievements in titanium forming. This vertical draw forming operation is described in detail in Section IX. Grumman also developed a horizontal draw forming technique that makes it possible to form curved "hat" and channel sections with deep chordal heights. This technique eliminates costly preform operations such as brake forming, stretching, drop hammering, and rubber forming.

Based on generally lower tool fabrication costs, time-savings, and opportunities for greater latitude in the design of aircraft parts, Grumman believes that the one-step forming process is preferable for all six parts.

This final report also documents: 1) The metallurgical tests performed on all three alloys--8 Al-1Mo-1V, 6Al-6V-2Sn, and 6Al-4V; 2) Grumman's method of determining the time-temperature parameters and minimum bend radii values of the three alloys tested; and 3) The feasibility of simultaneous forming and aging of production parts from solution-treated 6Al-4V alloy using short-time aging cycles.

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1. ORIGINATING ACTIVITY (Corporate author) Grumman Aircraft Engineering Corporation Bethpage, Long Island, New York	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b GROUP

3. REPORT TITLE Optimum Forming Processes and Equipment Necessary to Produce High Quality, Close Tolerance Titanium Alloy Parts

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Technical Report -1 June 1966 through 30 May 1968

5. AUTHOR(S) (Last name, first name, initial)
Newman, Joseph S.
Caramanica, John S.

6. REPORT DATE September 1968	7a. TOTAL NO. OF PAGES 340	7b NO. OF REFS
8a. CONTRACT OR GRANT NO. AF 33(615)-5083	9a. ORIGINATOR'S REPORT NUMBER(S) AFML-TR-68-~~257~~ → 259	
b. PROJECT NO. 9-770		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		

10. AVAILABILITY/LIMITATION NOTICES
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U.S. Air Force - Air Force Systems Command Systems Engineering Group (RTD) Wright-Patterson AFB, Ohio

13. ABSTRACT
This Final Report summarizes the accomplishments of Grumman Aircraft Engineering Corporation under Contract AF 33(615)-5083 during the two-year period from 1 June 1966 to 30 May 1968.
This Air Force Contract required Grumman to develop and establish optimum forming processes and equipment for the production of high quality, close tolerance titanium alloy parts of varied and complex configurations. Six parts representative of present and future structural titanium requirements (tail cone frame, door channel, annular ring, zee, frame and channel) were selected for study. These six parts are typical of varied configurations which impose complex forming problems. Since forming difficulties vary with material thicknesses, Grumman used .025" and .070" material for each of the three alloys selected. Tooling for the one-step and two-step forming methods was made to handle both material thicknesses. All parts produced by the one-step forming process, after determining the optimized forming parameters for each, were within $\pm$.005 conformity to contour and $\pm$ 1/4° angular tolerance. Similar dimensional tolerances were also achieved with the two-step process, however, there was poorer definition in joggled areas as well as other areas of sharp changing contours.
For this program, Grumman's two USI hot draw forming and sizing presses were used to evaluate the one-step form method as well as the two-step cold preform hot sizing method. When utilized in accordance with various tooling concepts, the unique features of these two presses resulted in lower manufacturing costs, better quality, reduced flow time, and production of more intricately shaped parts.

DD FORM 1 JAN 64 1473

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Titanium Alloys Hot Forming Forming Lubricants Tooling Material for Hot Forming Hot Platen Presses Die Cushion Systems Hot Die Handling and Alignment						

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