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DEVELOPMENT OF IMPROVED METHODS, PROCESSES, AND
TECHNIQUES FOR PRODUCING STEEL EXTRUSIONS

L. M. Christensen

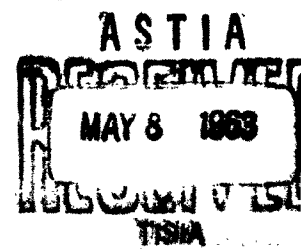
NORTHROP NORAIR
Contract AF33(600)-36713

Interim Engineering Report No. 15
1 January - 31 March 1963

An optimized extrusion and warm drawing process has been established
for PH15-7MO.

BASIC INDUSTRY BRANCH
MANUFACTURING TECHNOLOGY LABORATORY

Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio



**DEVELOPMENT OF IMPROVED METHODS,
PROCESSES, & TECHNIQUES FOR PRODUCING
STEEL EXTRUSIONS**

L. M. Christensen

An optimized extruding and warm drawing process has been established for PH15-7MO. The salient features of the process are:

- 1. A container temperature at the liner surface of approximately 900F is mandatory in order to consistently obtain crack free thin PH15-7MO steel extrusions.**
- 2. Selective subcooling of the point area to a martensitic type metallurgical structure is practical and results in a very substantial improvement in point durability.**
- 3. Multiple draw passes are possible without intermediate thermal treatment on PH15-7MO although work hardening does occur.**

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FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF33(600)-36713 from 1 January 1963 through 31 March 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This contract with Northrop Corporation, Norair Division, Hawthorne, California, was administered under the direction of Mr. T. S. Felker of the Basic Industry Branch (ASRCTB), Manufacturing Technology Laboratory, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

L. M. Christensen of Northrop Norair's Materials Sciences Laboratory was the engineer in charge. Major subcontractor was Allegheny Ludlum Steel Corporation, Watervliet, New York, with Mr. R. P. DeVries in charge of the subcontract engineering effort. Reporting to Mr. DeVries is Mr. J. H. Rice in charge of both extruding and warm drawing operations.

The primary objective of the Air Force Manufacturing Technology Program is to increase producibility, and improve the quality and efficiency of fabrication of aircraft, missiles, and components thereof. This report is being disseminated in order that methods and/or equipment developed may be used throughout industry, thereby reducing costs and giving "MORE AIR FORCE PER DOLLAR."

Your comments are solicited on the potential utilization of the information contained herein as applied to your present or future production programs. Suggestions concerning additional Manufacturing Technology development required on this or other subjects will be appreciated.

PUBLICATION REVIEW

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I INTRODUCTION

This report is the fifteenth in a series of interim engineering reports concerning a program for the development of an improved, commercially feasible extruding process, coupled with post extrusion cold and warm drawing, to produce ultra-thin airframe-quality steel extrusions that are comparable in quality to their aluminum alloy counterparts.

The reporting period covered in this document extends from 1 January 1963 through 31 March 1963

Included in this report is a summary and evaluation of warm drawing process technique development for PH15-7MO material. Details of an extended effort to fully optimize the process is delineated with an emphasis on "pointing" procedure and metallurgical control.

Further experience and conclusions relating to the sporadically encountered chevron type defect in both materials is summarized. A recent revision to the objectives and scope of the contract is also included.

A change in mode of preheating from induction to a resistance type furnace is described.

For the benefit of the reader, Appendix I contains summaries of the Interim Engineering Reports which have been previously published on this contract.

II CONTRACT SUMMARY

The following brief summary of the primary contract work statement elements is presented for continuity of this report:

Phase I Survey of the aircraft and extrusion industries to select shapes, alloys, and specifications for the extrusions to be developed in this program.

The three subcontractors chosen to participate in the development of experimental techniques to produce the simplest shape in two selected alloys were:

Allegheny Ludlum Steel Corp., Watervliet, N. Y.
Harvey Aluminum, Torrance, California
C. I. E. P. M., Paris, France

Phase II Development and Optimization of cold and warm draw techniques for the .06 thick Tee shape which was developed in Phase I.

Phase III Development of both extrusion and draw techniques for an actual advanced aircraft Weapons System structural shape in PH15-7MO steel alloy.

Phase IV Development of both extrusion and draw techniques for the same shape as Phase II except that the material shall be A-286.

Allegheny Ludlum Steel Corporation has been chosen as the subcontractor for the development activity of Phase II.

III CONCLUSIONS

1. A container temperature at the liner surface of approximately 900F is mandatory in order to consistently obtain crack free thin PH15-7MO steel extrusions.
2. Selective subcooling of the point area to a martensitic type metallurgical structure is practical and results in a very substantial improvement in point durability.
3. Multiple draw passes are possible without intermediate thermal treatment on PH15-7MO although work hardening does occur.
4. Uneven deformation during drawing such as repeated passes with edges unrestrained will induce edge cracking. It may be necessary to selectively and alternately deform specific areas.
5. Drawing at higher temperatures reduces the resultant work hardening. To retain maximum drawability, it may be advisable to vary the temperature of draw during a series of draw passes.
6. Because of the fact that essentially the same actual draw load is required for first or final pass it is quite feasible and obviously very desirable from a time standpoint, to make the original point small enough to accommodate the final pass.

IV OBJECTIVE

Extrusions for advanced design aerospace vehicles, often require a drawing operation following extrusion to obtain the required finished size. This is so for two reasons: first, sectional thickness and/or tolerances required are beyond that which can be obtained by the most advanced extrusion processes; secondly, tensile and yield strength of some alloys are improved by cold working of the metal prior to heat treatment. The varied designs to be encountered with the special aircraft shapes necessitate a directed study into the fundamentals of cold and warm drawing processes. To date, the process of metal-working has been an art, one of trial-and-error. A concerted effort will be made to reduce the variables to predictable facts. The entire scope of Phase II will be directed towards development of all precepts and facets of drawing operation as necessary to bring the extrudable product to an even thinner and closer tolerance article for use in airplanes, where weight and structural integrity are being utilized to a degree not before contemplated. These purposes will best be served by utilizing the typical advanced design extruded shape which formed the basis of development of advanced extruding techniques in Phase I. Using the Phase I "T" shape, complete details and precepts will be investigated and parameters established to yield the following specific target goals in addition to the basic configuration shown in Figure 1:

- a. Minimum length of 20 feet.
- b. Thickness of flange and section of $.040 \pm .003$.
- c. Radius between flange and section of $.060 \pm .010$.
- d. Surface finish of 63 rms or better.
- e. Straightness of .0063-inch/linear foot.
- f. Twist one quarter degree/linear foot, $2-1/2^\circ$ max.
- g. Angularity $\pm 1^\circ$ at any point of measurement.
- h. Flatness of .002-inch/inch cross-wise dimension.
- i. Aircraft and missile quality mechanical properties required in the as-drawn condition.

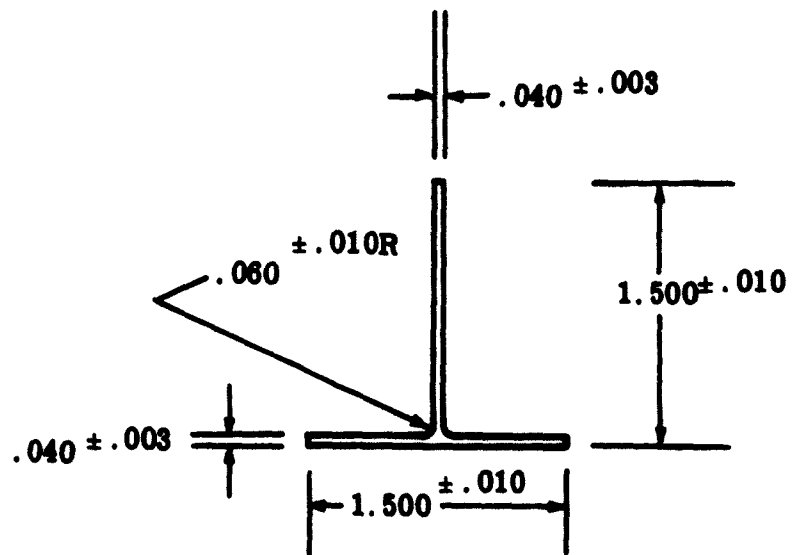


FIGURE 1 CONFIGURATION OF WARM DRAWN PHASE II TARGET
SHAPE TO BE PRODUCED IN H-11 AND Ph15-7Mo STEELS

V FACILITIES & EQUIPMENT

EXTRUDING EQUIPMENT AND FACILITIES

Extrusion Press:

Make - Lake Erie
Rating - 1778 tons
Ram Speed - 1250 inches per minute

The press is a modified Schoemann design with an air-water accumulator system, rated at 3150 psi. The press can deliver 1778 tons at the stem with 1500 tons coming from the main cylinder (980 square inches of cross sectional area), and 278 tons from the mandrel cylinder (146 square inches cross sectional area). The mandrel cylinder permits the movement of the mandrel independently of the main ram. The press also has a container shifting hydraulic system which permits the container to be opened from the die assembly; thereby allowing the hot saw to cut the extruded product at the exit end of the container. Die assemblies are loaded into a hydraulically operated die arm which moves on an axis perpendicular to the direction of extrusion. The arm is located between the container and the front platen of the press. This feature permits rapid changing of dies between pushes. (See Figures 2, 3, and 4.)

The press system was modified for this work by disengaging the mandrel cylinder which had a capacity of 278 tons (146 square inches in cross section area) and by adjusting the bottle pressure of the accumulator system to 1000 psi for 500 tons, and to 1500 psi for 750 tons. The press has a container shifting hydraulic mechanism that permits the opening and closing of the container against the die ring and utilizes the high pressure system of the press.

The closing speed of the press was decreased from 1205 inches/minute to about 900 inches/minute because the mandrel cylinder was disengaged. In normal operation, the mandrel cylinder pushes on the main cylinder when closing.

The container assembly consisted of a composite container liner. The 2.625 inch and 2.125 inch liners were shrunk inside the 5.625 inch liner. The liners were made from H-12 (Allegheny Ludlum Potomac) tool steel heat treated to 46 - 48 Rc. Only a length of sixteen inches of the container was used even though the overall length of the container is about 30 inches. This was done so that any stem breakage would occur within the container itself. See Figure 5.

Composition of Container Liners

Allegheny Ludlum Potomac (H-12) Hardness 46 - 48 Rc

C	.30 - .37
Mn	.20 - .40
Si	.75 - 1.00
P	.025 max
S	.025 max
Cr	4.75 - 5.25
Ni	.20 max
W	1.00 - 1.50
V	.20 - .25
Mo	1.30 - 1.60
Fe	REM.



FIGURE 2 ALLEGHENY LUDLUM, LAKE ERIE PRESS. ARROW INDICATES ACCUMULATOR SYSTEM.



FIGURE 3 ALLEGHENY LUDLUM, CLOSE-UP OF PRESS CONTAINER, BILLET LOADER, AND STEM NOTE PRESSMAN INTRODUCING GLASS PADS FOR DIE LUBRICATION.



FIGURE 4 ALLEGHENY LUDLUM, RAM ADVANCING ON BILLET.

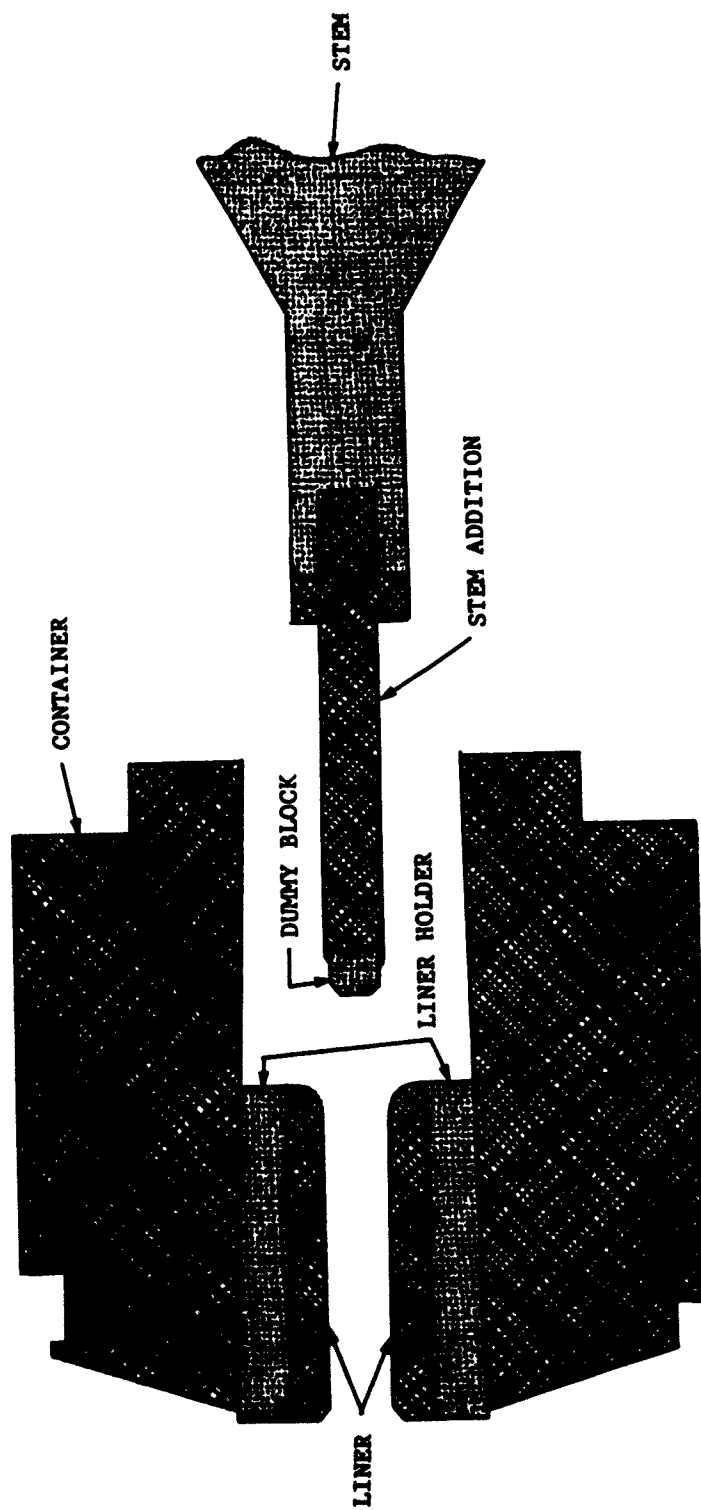


FIGURE 5 GENERAL ARRANGEMENT OF ALLEGHENY LUDLUM EXTRUSION PRESS

Stems

All stem material was produced from Allegheny Ludlum Seminole hard tool steel. This steel was selected because of its high compressive strength, and it is capable of being hardened to Rc 50 - 52 to sustain compressive loads of 35,000 psi. These stems are 15 inches in length and either 2.375 inches or 3.031 inches in diameter. The stems used proved quite successful in Phase I even though there were failures on Pushes 15 and 35. In both failures, the safe compressive load was exceeded.

Composition of Stems and Die Rings

Allegheny Ludlum Seminole Hard

Hardness Stems, 50 - 52 Rc
Rings, 45 - 50 Rc

C	.50 - .54
Mn	.20 - .40
Si	.75 - 1.00
P	.025 max
S	.025 - 1.50
W	.20 - .25
V	2.00 - 2.50
Fe	REM.

Dummy Blocks

Dummy blocks were produced from H-21 (Atlas A) material. This material was thought to be as acceptable as any available for an application which required strength at elevated temperatures.

Composition of Dummy Blocks

Allegheny Ludlum Atlas A (H-21)

Hardness 47 - 50 Rc

C	.28 - .30
Mn	.20 - .35
Si	.20 - .35
P	.025 max
S	.025 max
Cr	2.75 - 3.50
W	9.00 - 10.00
V	.40 - .50
Fe	REM.

Die Materials

In order to effect reproducible dimensionally homogenous Tee shaped products by the extrusion process, it is essential that the die material be one that will maintain stability at high temperature together with high pressure and the abrasive action that is bound to occur. The severe activity at the corners of the dies of the conventional hot-chamber variety had dictated that new materials be investigated for this program. Accordingly, several die materials were checked

with the following list being tried throughout the program.

- Allegheny Ludlum ALX and ALX-6 (Allegheny Cobalt Base Alloy)
- Ferrotic C dies containing titanium carbides infiltrated with steel.
- S-45 by Sintercast, containing titanium carbides infiltrated with stainless steel.
- Moly-sprayed H-21 die steel
- EDS Cobalt Base Alloy (Duplicast Die Co.)
- 10-W hot worked die steel (H-21) - Atlas A
- H-11 - 5% chrome hot worked

Of these materials the best results were shown in the ALX and ALX-6 dies. Their hot hardness was substantially better than any other materials tried. The ALX-6 has shown superior properties to all other listed.

From previous extruding efforts it was noted that the die closes upon usage for the first extrusion that goes through the aperture. Based upon the experience from this previous occasion, the die opening was deliberately made oversize to allow for this flow-in which appears to be uniform; consequently, the ALX-6 dies were opened up to .085 in width and a check of the extruded product shows that the dies did close to .071 and then remained at that figure for the succeeding pushes through the same dies.

Die Design

The best die design developed under this contract was a flat-faced die with .400 lead-in radius, .188 bearing lands, and with 25 inclined planes at the inside corners. A check of partly extruded billets has confirmed the fact that a good stream-lined flow is obtained throughout the normal length of the extrusion. See Figure 6 for detail of die configuration.

Earlier there was some question as to the best relative position of the orifice in the die as some activity was noted at the top of the Tee in each die which resulted in slight occasional tearing on the top edge of the product. It was estimated that a lowering of the orifice by about 1/16-inch would completely eliminate this problem.

The lower orifice was used during the current reporting period and has worked out quite satisfactorily.

Dies are cast by the "Shaw Process" at the Ferndale Plant of Allegheny Ludlum. Entrance radii and bearing reliefs are cast in, but the aperture in the bearing land area is solid and cut to size by Elox machining. The shape is then checked by an optical comparator.

Billet Heating

Results of a survey of tests showing actual billet heat loss indicated that heat loss was very slight in normal transfer times when using the radiation shield. Tests run at the same time without a radiation shield, indicated that temperature losses were excessive for most extruding operations.

The necessity for use of a radiation shield precluded use of the induction heater since it would not reliably heat a billet that was inside of a shield. Consequently another means of billet heating had to be provided.

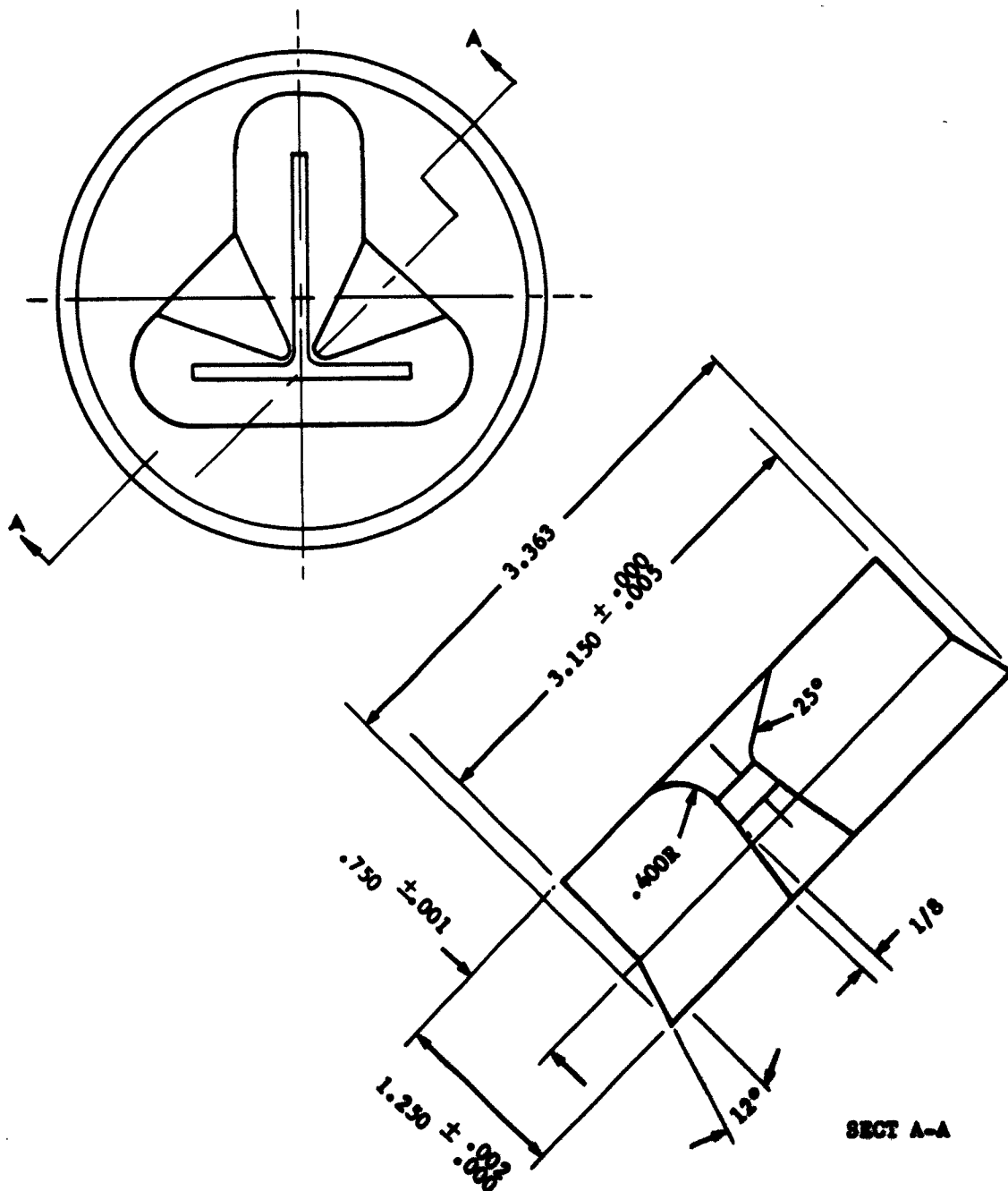


FIGURE 6 DIE DESIGN OF ALX-6 (COBALT BASE ALLOY) MATERIAL FOR PHASE II EXTRUDING

The heating problem was most efficiently solved by using an existing Hevi-duty electric furnace for heating the radiation shields. Immediately adjacent to it a Glo-bar electric furnace was installed to handle the 3 inch diameter billets. The procedure was to remove a shield from the Hevi-duty while the small billet was removed and rolled in glass on the apron of the furnace. At that point the glass covered billet was immediately inserted into the shield and the assembly transported by crane to the loader of the extrusion press. The small billet was then ejected by push rod from the shield directly into the liner and the shield moved away as the ram came forward to start the extrusion cycle.

The extruded products were deglassed in a sodium hydride bath operating at 700F. The pickle house also accommodates various acid tanks for bright finishing.

A 100 ton Sutton stretch straightener is available with a 360 degree de-twisting head and will accommodate forty to fifty-foot extrusions. (See Figure 7)

LUBRICATION

A very important development contributing to the success of this program was the selection of the proper glass and technique in applying the glass.

Die Lubrication

The fiber glass ALG-13 proved to be much superior in lubricating qualities and in handling than sintered powder glasses. The amount of glass used is best described by the physical volume of glass used. The pads were two inches thick and cut to three and one-half inches OD x two inches thick in the uncompressed form. One pad of glass provided sufficient lubrication and protection for an eight inch long billet.

Billet Glass

The PH15-7M0 was precoated with a glass coating of a finely crushed glass mixed with water. The combination was not colloidal. The glass designation was ALG-18, and is used for protection of the billet during heating only.

Container Lubrication

The billets were coated with a lubricating powder glass upon ejecting from the furnace. The practice was to place a layer of powdered glass - 20 mesh, over a .001" thick precut sheet of glass fiber. The sheet of fiber was ten inches wide by eighteen inches long and was placed on a table in front of the furnace door. The billet was ejected from the furnace and rolled through the glass before being placed in the radiation shield. This glass is designated ALG-12.

WARM DRAWING EQUIPMENT

In order to accomplish warm drawing it is necessary to accurately pre-heat the stock immediately before its being pulled through the draw die. Induction heating was originally chosen as the mode to accomplish this. A Lepel 100 KW induction unit was purchased and adapted to a regular production draw bench at Allegheny Ludlum Watervliet facility. The majority of the Phase II effort was conducted with induction heating but it did not function as efficiently or as reliably as had been anticipated.



FIGURE 7 ALLEGHENY LUDLUM, 100 TON HYDRAULIC STRAIGHTENER WITH ROTATING HEAD FOR DETWISTING AND 40 FOOT OPERATING BENCH

Consequently a new furnace utilizing resistance heating was fabricated at Allegheny. Figure 8 shows a three quarter view of furnace as it is installed in the bed of the draw bench, which has had the run in table removed to accommodate the heater. It is a resistance type muffled furnace composed of a stainless steel tube ten feet long and three inches in diameter and is heated by water cooled clamps attached to each end of the tube. Power is supplied by two 1500 AMP DC welding generators. Amperage is supplied at low voltage to reduce arcing. The heated tube is encased in K-33 insulating brick and magnesia blocks along its entire length and periphery. The refractory material is covered by a three sixteenth inch thick mild steel plate. Experience during this period has shown good reliability with a temperature variance from the radiant heat of approximately $\pm 50^{\circ}\text{F}$. A comparison of the two means of heating indicates the resistance furnace to be more reliable but less flexible than the induction mode of heating. Chief drawback to the present method is the fact that temperature at the draw die can be controlled primarily only by draw speed thus reducing the ability to vary combinations of speed and temperature.

Figure 9 is an overall view showing the entire draw bench with supporting equipment. This is a production bench with a 100,000 lb capacity. It has an undesirable feature of requiring manual hookup to the chain which has to be in motion at a predetermined rate of speed. This induces a degree of shock loading to the work piece as the drawing operation starts.

In operation of the furnace the temperature is monitored by a thermocouple imbedded in the resistance heated tube and recorded on a direct reading dial shown in Figure 9. The temperature is controlled by utilizing the control panel previously used with the induction heater. To check the temperature of the section to be drawn at the point of entrance to the draw die, pyrotel infra-red device is mounted as shown in Figure 9 and the temperature graph is plotted on a varian recorder. The varian instrument is located adjacent to the furnace temperature recorder.

As the preheated extrusion emerges from the resistance furnace it is drawn down by passing through the die assembly shown in Figure 10 which is in turn held in position by the die head shown in Figure 9.

Drawings of this die assembly were included in an earlier report, but a clearer interpretation of the assembly could be gained by including a photograph. The sections marked with a "C" denote tungsten carbide material, while sections marked with "S" or unmarked, are of H-11 tool steel. A cover plate is placed over the assembly of blocks to hold them firmly in place. The cover also adds rigidity to the case during drawing. Further reduction can be obtained by changing to thinner shims between the tungsten carbide inserts.

A source of trouble in the past has been the method of gripping the "point" area of the drawn length to provide the means of pulling the section through the draw die. In order to eliminate the slippage, the previously used gripper head shown in Figure 9 has been replaced by the positive acting Hufford jaw housing shown in Figure 11. It is mounted to the draw bench trolley which engages the chain drive by means of the manually engaged trolley hook.

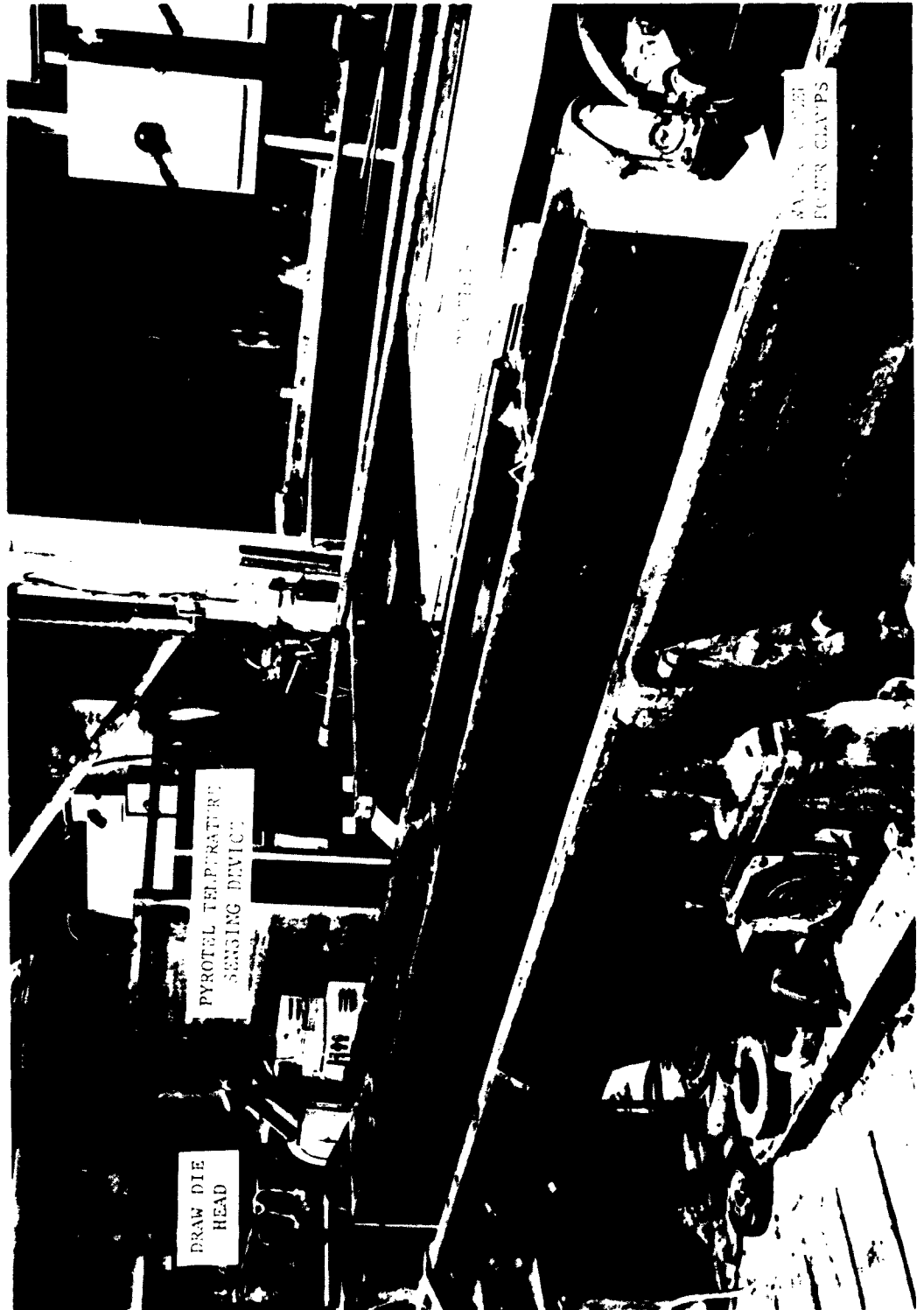


FIGURE 8 CLOSE-UP OF RESISTANCE PREHEAT FURNACE



FIGURE 9 WARM DRAWING FACILITY

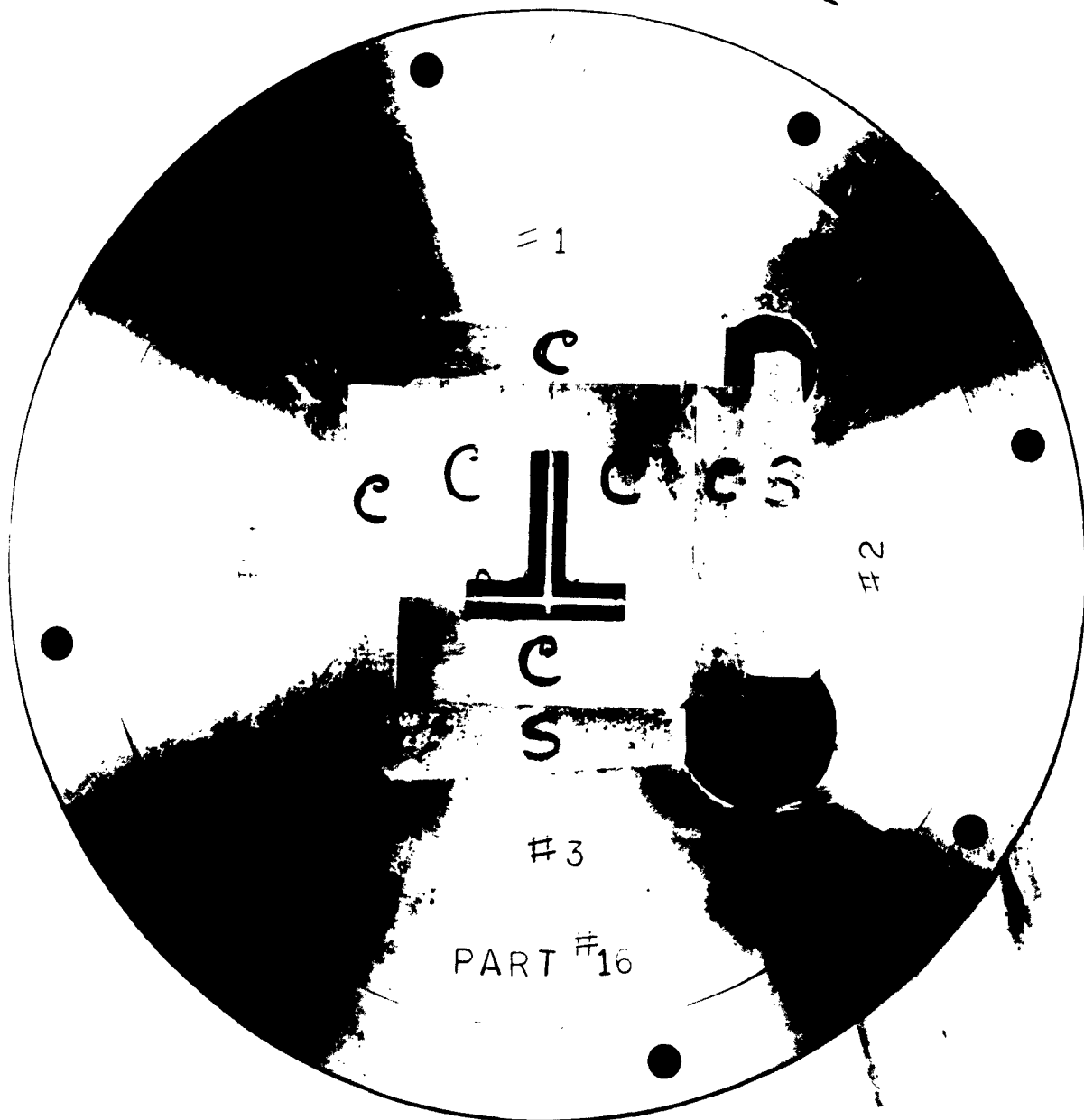


FIGURE 10 DIE ASSEMBLY FOR 0.060 INCH SECTION THICKNESS



FIGURE 11 HUFFORD JAW ASSEMBLY USED IN WARM DRAWING

VI EXTRUDING EFFORT

Previous experimentation in warm drawing with the induction heater had resulted in excessive breakage and had depleted the extruded stock available for drawing. A new extruding effort was scheduled for early January 1963 to replenish the supply but was delayed until the latter part of the month because of the fact that the extrusion dies had to be recast due to poor quality. Results were as follows:

21 JANUARY 1963 EXTRUDING EFFORT

The extruding technique established in previous efforts was considered to be optimized had been shown to repetitively produce an acceptable product in this difficult to extrude alloy PH15-7MO. It was therefore planned to simply reproduce using the same extruding parameters.

Extrusion Billet Analysis

In ordering PH15-7MO extrusion billet for the new effort, Allegheny Ludlum found that it could not be obtained from eastern seaboard sources within an acceptable length of time, so Norair undertook the procurement of same. A satisfactory commitment was obtained from a Los Angeles source, and a forged bar three and one-half inches in diameter was ordered under North American Aviation's material specification NAA LBO160-123. Also stipulated was the requirement that the ferrite content should not exceed 20%. Previously used material at Allegheny Ludlum was approximately 40% in ferrite and was believed to be detrimental in both processing and in obtaining satisfactory mechanical properties.

Vendor's test results, furnished with the incoming billet stock, certified that the material was capable of meeting physicals in the following condition:

Heat No.	Condition	Yield	Tensile	Elong % in Inches	% Red of Area
ARMCO 31436	TH-1050	195,000	196,000	16.2	40.0
	RH-950	222,000	223,500	11.1	37.0

The chemistry was as follows:

	% C	% Mn	% P	% S	% Si	% Ni	% Cr	% Mo	% Al
Actual	.057	.61	.015	.012	.35	7.26	14.95	2.24	1.09
Typical	.09	1.00	.04	.04	1.00	7.75	16.00	3.00	1.50
Max		Max	Max	Max	Max	6.50	14.00	2.00	.75

The ferrite content was listed as 10%.

The stock was then shipped to Norair's Materials Science Laboratory and the following report was issued:

Norair Material Sciences Laboratory Report

Evaluation

Subject bar was sectioned for metallurgical evaluation as billet material.

Conclusion

Material was found to have an acceptable microstructure, and the macrostructure is free from visible defects. Therefore, the material is acceptable as billet stock.

Results

1. The microstructure exhibited approximately 10% delta-ferrite.
2. Hardness values of three cross-sections indicate uniform heat treatment throughout the length of the bar.
3. A certified chemical analysis by Armco is typical for this material and deemed acceptable.
4. The macrostructure did not exhibit any unusual dis-continuities.

Examination of Material

A PH15-7MO billet, three and one-half inch round by seventy inch was received from Armco, heat #31436. Chemical analysis of the billet is reported on preceding page.

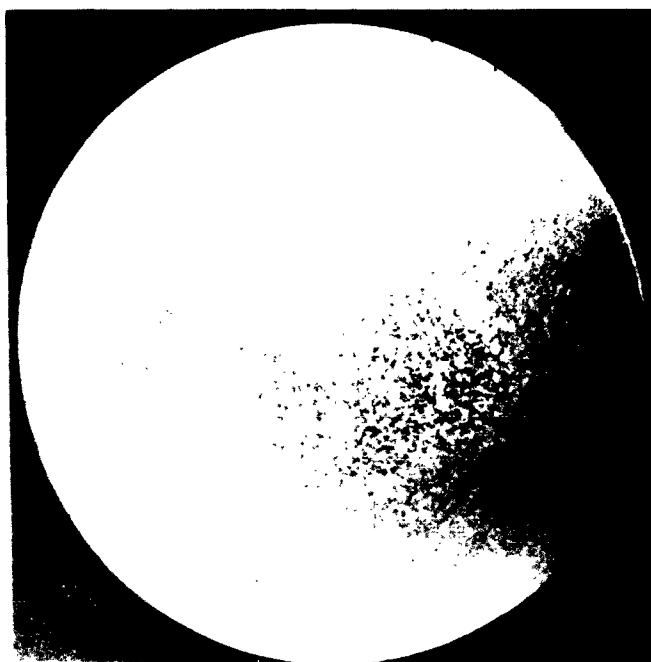
Three macro cross-sections were cut from the ends and center of the bar and identified. One end cross-section was marked No. 1 and the inside face of it was marked No. 2. The center cross-section was marked No. 5 and No. 6. The other end cross-section was marked No. 9 inside and No. 10 outside. The ends of the resulting billets are numbered in sequence i.e., 3, 4, 7, and 8.

No visible defects appeared after macro etching (Figure 12, 13, and 14).

Hardness values of each macro section were taken in the transverse direction. The results are shown in Figure 19. Hardness readings were taken at one quarter inch intervals along the diameter of each macro.

Micro specimens were cut from each macro cross-section. Micros were mounted in the longitudinal direction from the center and O.D. of each slab.

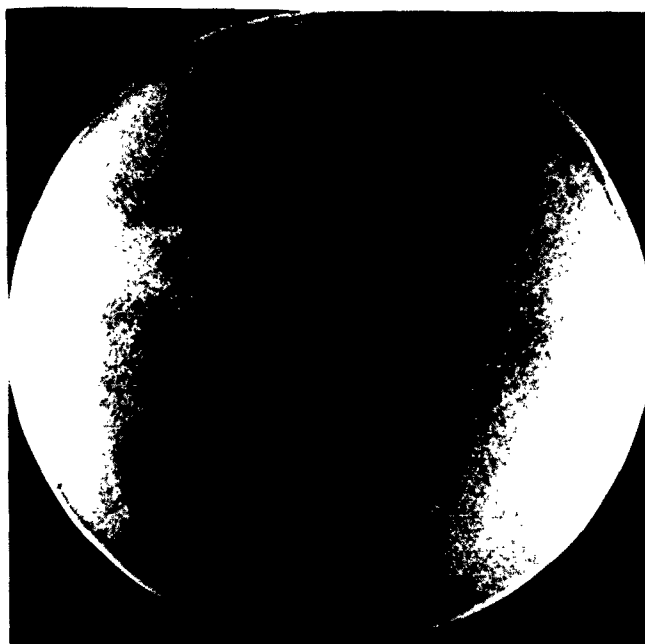
Metallographic examination of longitudinal micro specimens did not exhibit any discernible difference in microstructure. A comparison of microstructure between the O.D. and the center of the billet showed no difference (Figure 15, 16, and 17). Examination of the unetched micro specimens revealed an acceptable level of cleanliness (Figure 18).



MAG 1X

ETCHANT: HCl 38%
 H₂SO₄ 12%
 H₂O 50%

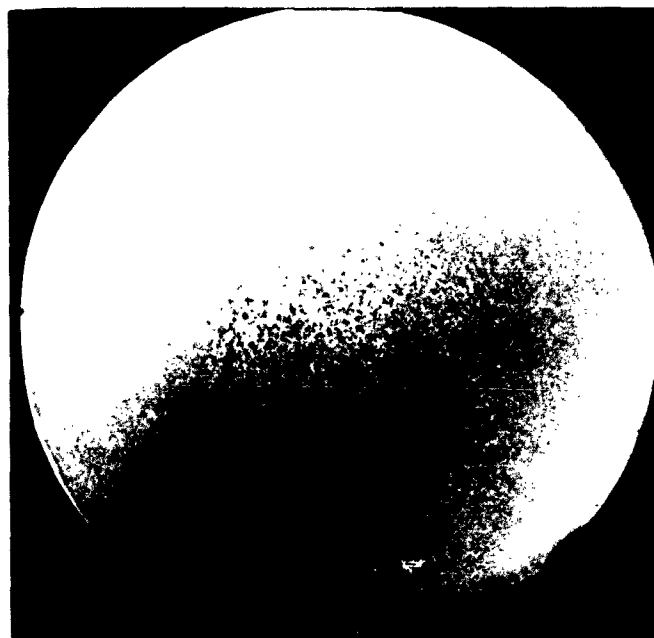
FIGURE 12 MACROGRAPH OF CROSS-SECTION OF SIDE #2



MAG 1X

ETCHANT:	HCl	38%
	H ₂ SO ₄	12%
	H ₂ O	50%

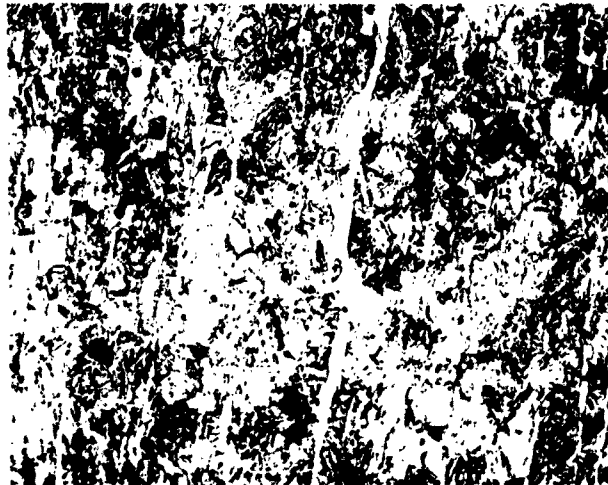
FIGURE 13 MACROGRAPH OF CROSS-SECTION OF SIDE #6



MAG 1X

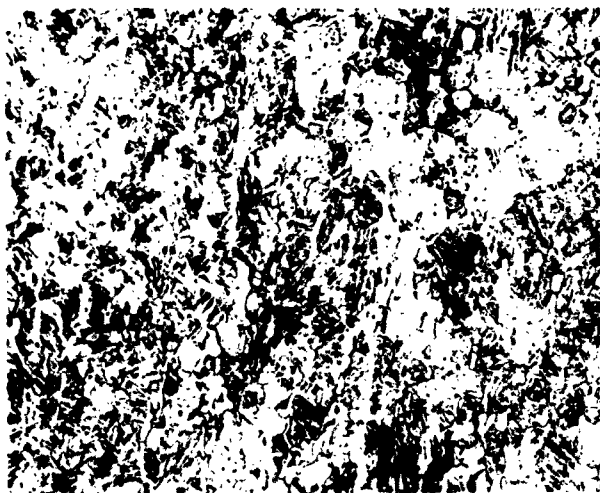
ETCHANT: HCl 38%
H₂SO₄ 12%
H₂O 50%

FIGURE 14 MACROGRAPH OF CROSS-SECTION OF SIDE #9



CENTER

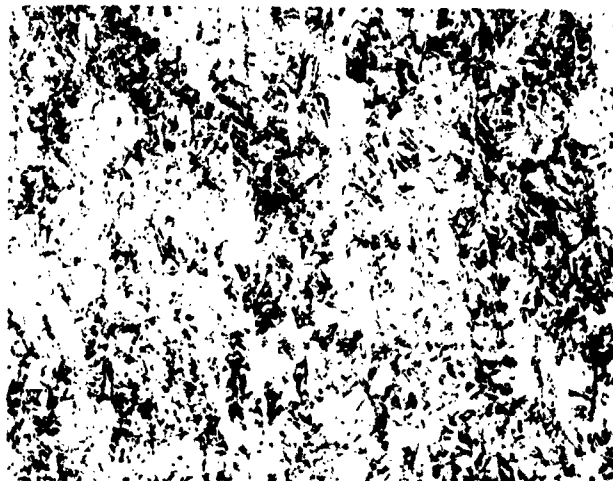
MAG. 100X ETCHANT: HNO_3 60% ELECTROLITIC
 CH_3COOH 40% ETCH



EDGE

MAG. 100X ETCHANT: HNO_3 60% ELECTROLITIC
 CH_3COOH 40% ETCH

FIGURE 15 MICRO-STRUCTURE OF THE CENTER AND EDGE REGIONS
 OF SIDE #2



CENTER

MAG. 100X

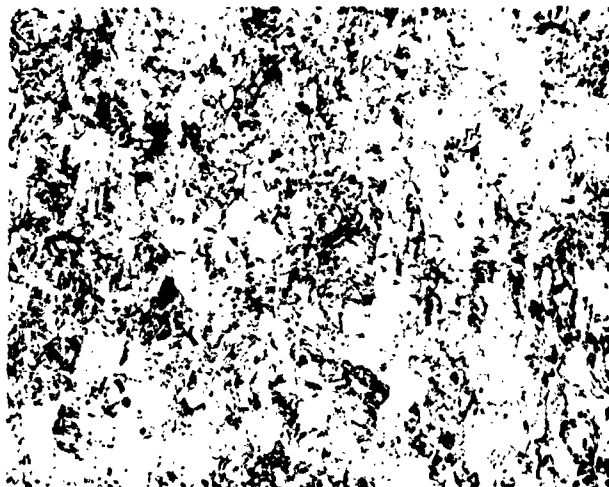
ETCHANT:

HNO_3

60% ELECTROLITIC

CH_3COOH

40% ETCH



EDGE

MAG. 100X

ETCHANT:

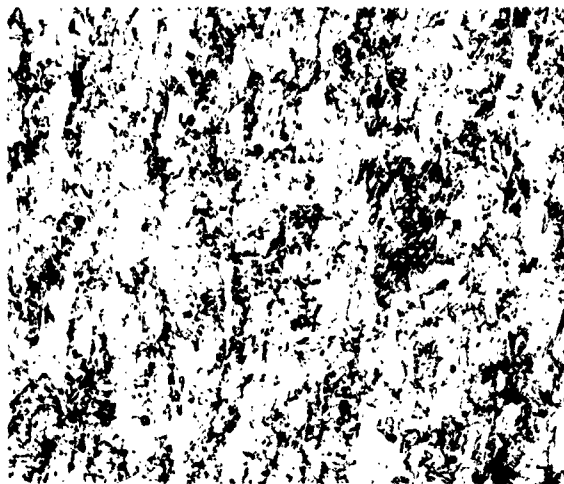
HNO_3

60% ELECTROLITIC

CH_3COOH

40% ETCH

FIGURE 16 MICRO-STRUCTURE OF THE CENTER AND EDGE
REGIONS OF SIDE #6

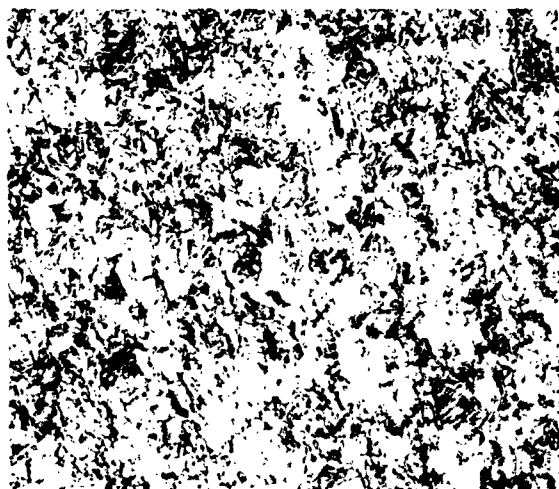


CENTER

MAG. 100X

ETCHANT: HNO_3
 CH_3COOH

60% ELECTROLITIC
40% ETCH



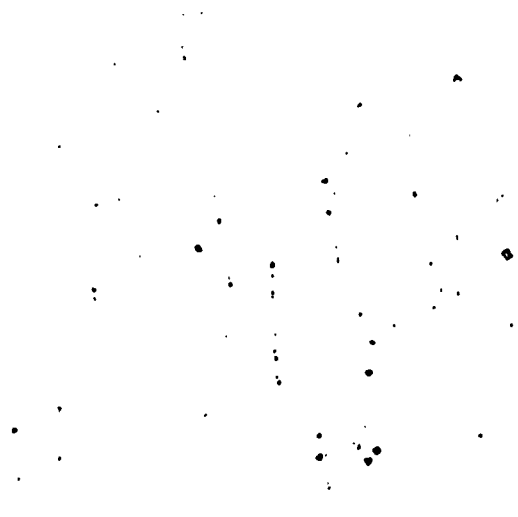
EDGE

MAG. 100X

ETCHANT: HNO_3
 CH_3COOH

60% ELECTROLITIC
40% ETCH

FIGURE 17 MICRO-STRUCTURE OF THE CENTER AND EDGE
REGIONS OF SIDE #9



MAG. 100X

UNETCHED

FIGURE 18 TYPICAL INCLUSION CONTENT OF BILLET MATERIAL

ROCKWELL C HARDNESS

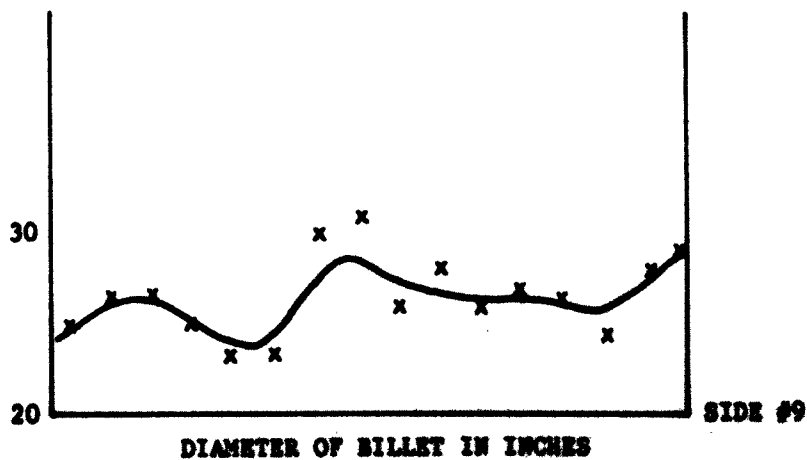
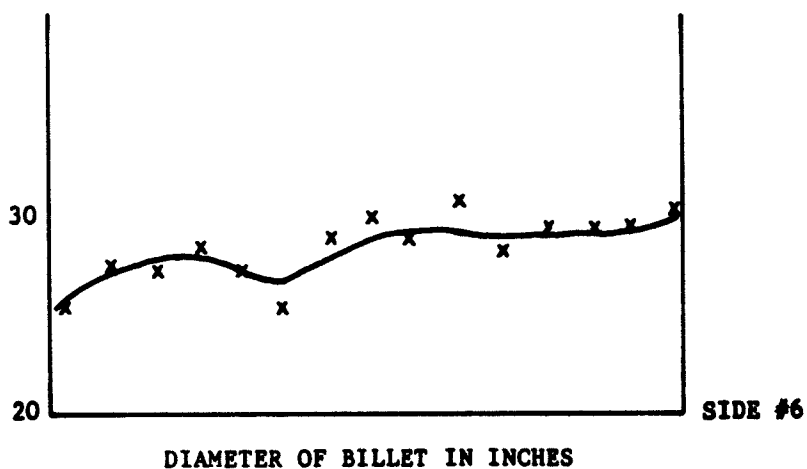
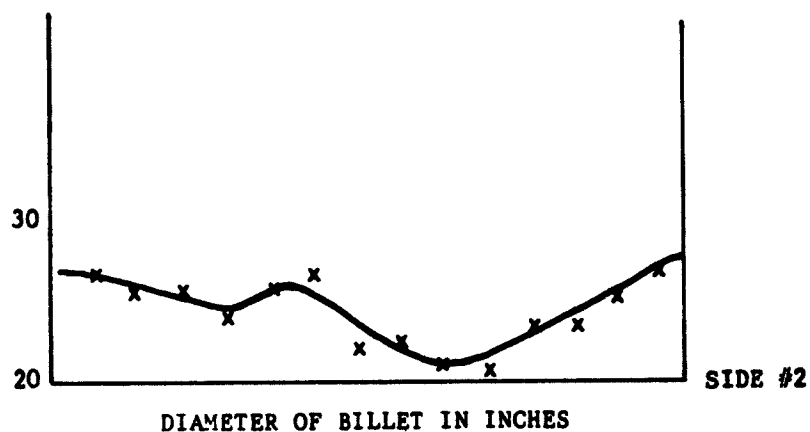


FIGURE 19 HARDNESS SURVEY OF SIDES OF MACRO SAMPLES CUT FROM EXTRUSION BILLETS

Extruding

On 21 January 1963 the extrusion of four billets was attempted but all four resulted in extrusions which were grossly torn and totally unsatisfactory. Rather than proceeding with the balance of the billet supply the extrusion effort was stopped to ascertain the reasons for the total failure.

Evaluation

A review of the factors involved showed three potentially contributory changes in parameters which were:

1. The container temperature was 500F instead of the previously used 900F. This change was due to a recent rebuilding of the press which boosted the available tonnage. In the reconstruction the means of preheating the container was changed from electrical resistance heat to gas fire and a 500F maximum limitation was imposed because of apprehension that a higher amount might warp the crosshead.
2. The PH15-7MO billet material was from a new heat and could conceivably be at fault because of a slight difference in chemistry.
3. The billets were held in the furnace at 2150F for an extended period of time and visually showed some evidence of deterioration of the glass slurry pre-coating.

A new extruding effort was then scheduled on a crash basis with the following steps being taken to attempt to insure a successful effort.

1. An insertable cal rod apparatus was fabricated to be used to preheat the inner surface of the liner to 900F. This was acceptable to the new press limitations, because there was no danger of internally induced heat being transmitted to the crosshead.
2. A new heat of billet material was procured from Armco which more nearly matched the chemistry of the previously successful heats.
3. A new supply of glass pre-coat for billets during heating was procured and scheduling was worked out to reduce the time of exposure to furnace temperature.

4 FEBRUARY 1963 EXTRUDING EFFORT

With the new insert type heater, new glass billet pre-coat and new billet material another extruding effort was attempted. There were available billets from the new heat and also four left over from the previously unsuccessful extruding. There had been no time to procure new dies so it was planned to use what new dies were still available and to reuse some from the last effort which exhibited little wear. Part of the used dies, however, were cracked.

Push 1

Material: PH15-7MO from latest Armco heat

Billet Temp: 2150F for 1.5 hours

Container Temp: Heated to 950F by insertion cal rod at time of withdrawal. Read 860F at time of upset.

Die Material: Used ALX-6 (cracked)

Die Lubricant: ALG-13

Transfer Time: 70 seconds

Upset Pressure: 1700 PSI

Run Pressure: 1100-1200 PSI

Result: LH side of base grossly cracked intermittently over half of the length. Cracks in extrusion appeared along same edge as the crack in the die and appears to be associated.

Push 2

Material: PH15-7MO from heat used unsuccessfully on 21 January.

Billet had been upset and re-turned.

Billet Temp: 2150F for 2.25 hours

Container Temp: Difficulty in reaching temperate because one element burned out. Was 850F at withdrawal and 800F at upset.

Die Material: New ALX-6

Die Lubricant: ALG-13

Transfer Time: 80 seconds

Upset Pressure: 1600 PSI

Run Pressure: 1100 PSI

Result: Perfect extrusion

Push 3

Material: PH15-7MO from latest Armco heat.

Billet Temp: 2150F for 3 hours (Noted some glass deterioration)

Container Temp: Partially burned out cal rod heater. Would not go above 775F so heated to 880F with portable gas flame. 850F at upset.

Die Material: New ALX-6

Die Lubricant: ALG-13

Transfer Time: 125 seconds

Upset Pressure: 1600 PSI

Run Pressure: 1100 PSI

Result: Perfect extrusion

Push 4

Material: PH15-7MO from heat used unsuccessfully on 21 January. Billet was not upset but was re-turned.

Billet Temp: 2150F for 4.5 hours

Container Temp: Heated by gas torch to 850F which read 775F at upset.

Die Material: New ALX-6

Die Lubricant: ALG-13

Transfer Time: 65 seconds

Result: Perfect extrusion

Push 5

Material: PH15-7MO from latest Armco heat.

Billet Temp: 2150F for 2 hours

Container Temp: Heated by gas torch to 925F and read 875F at upset.

Die Material: Used ALX-6

Die Lubricant: ALG-13

Transfer Time: 60 seconds

Result: Extrusion did not fill completely at any of the three extremities. Otherwise extrusion was without cracks. Extremities of the die were plugged with sheared metal. Appeared that container may have been too hot because of relation of gas flame impingement to thermocouple location.

Push 6

Material: PH15-7MO from latest Armco heat

Billet Temp: 2150F for 2.5 hours

Container Temp: Heated by gas torch to 850F and read 800F at upset.
Changed point of flame impingement.

Die Material: Used ALX-6

Die Lubricant: ALG-13

Transfer Time: 70 seconds

Result: Perfect extrusion

Evaluation

The extruding effort was successful from its prime standpoint of providing stock for warm drawing. About half of No. 1 extrusion is usable and the entire lengths of Nos. 2-6 are acceptable including No. 5 which had an incomplete fill.

The effort conclusively proved that it is necessary to have an elevated container temperature to extrude PH15-7MO without cracks. It also indicated that neither billet chemistry nor billet lube breakdown were the cause of the total failure of the 21 January exhibit.

This effort again clearly reaffirmed the fact that a repetitive process has been developed which will consistently produce crack free shapes in an alloy that industry wide experience has indicated as being crack prone.

VII WARM DRAWING

The scheduled conclusion of Phase II effort was very successful from the technological standpoint of achieving a final product which conformed to target specifications. However, the amount of final product yielded, particularly on PH15-7MO alloy, was so small that the process could hardly be considered optimized. It was demonstrated conclusively that the process is technically feasible and the potential benefits in quality of product and advancement of the state-of-the-art are substantial.

Surface quality and dimensional integrity of the .04 thick warm-drawn shape is excellent; the surface is consistently smoother than 63 rms and within $\pm .003$ tolerance. This means that it is now becoming feasible to use as-extruded and drawn condition of the multitude of ultra-thin PH15-7MO sections such as those which have been designed for the RS-70 weapons system. To date many of these sections have had to be laboriously and expensively machined from oversized extrusions or from bar. Since the vast majority of the advanced airframe structural shapes have members as thin as .030 to .050 thickness, the optimization of .040 thick shapes under this project promises a tremendous savings. The current technical status of this development is best summarized by stating that the feasibility is conclusively proven but not yet perfected to the point of assuring an adequate predictability.

ANALYSIS OF THE PROBLEM

In order to start the drawing operation, it is necessary to prepare the section by what is called "pointing". This means that the first six inches must have its thickness reduced sufficiently to allow it to pass unrestricted through the draw die so that it can be grasped on the far side of the draw die by gripper jaws. The trolley which holds the gripper jaws then is pulled down the bed and the deformation of drawing starts at the shoulder of the point where it contacts the bearing area of the draw die. In drawing a section of normal thickness of .25 of an inch, the few thousandths of an inch that are removed for the point is a small comparative percentage as opposed to a section which is only .05 thick, in which case a substantial percentage of cross-sectional area is lost. Which means that there is a significant loss in draw carrying capacity in the pointed area. The periphery of a thin section is nearly as great as that of a thick section, so that the draw load remains nearly the same. This is true because friction accounts for at least 90% of the draw load. With a marginal relationship, irregularities in the point area such as scratches, undercutting, or machining marks which are normally of no consequence, become critical and often result in point breakage.

Such difficulty was encountered in the development of the warm-drawing techniques with a starting quantity of twelve lengths of PH15-7MO. After processing them through the various experiments with repointing after each of the four draws the quantity remaining through the last .043 pass was two lengths of only three feet. Reasons for this high mortality were as follows, with points being experimentally prepared by various methods:

- a. Point failure due to excessive grinding in point preparation.
- b. Point failure due to undercutting at the liquid-air interface in the pickling solution.

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- a. Point failure due to excessive grinding in point preparation.
- b. Point failure due to undercutting at the liquid-air interface in the pickling solution.

- c. Point failure due to lack of straightness in machining points.
- d. Point failure due to excessive deformation in the fillet or edges of the extrusion.
- e. Arcing in the work coil due to liner failure with the consequent stoppage of drawing.
- f. Point failure due to overheating vagaries of the induction heater.
- g. Cracking during straightening.
- h. Slight misalignment of draw dies, causing a bending moment on point.

A review of these causes leads to the supposition that, with a subsequent order, many of them would be eliminated entirely and the balance would be substantially reduced. This however, is an opinion and needs to be substantiated by test to be able to say the process is predictably reproducible.

As stated above the major deficiency is the appreciable loss of load carrying capability in the point because of removal of material to allow passage through the draw die for hookup. It logically follows therefore, that if the point can be made to carry a greater stress than the cross section to be drawn, this would be of substantial benefit. Such an opportunity presents itself with this type of material due to its low temperature transformation characteristic of changing from an austenitic metallurgical structure, to that of a tough martensite type.

NORAIR MATERIAL SCIENCES LABORATORY EXPERIMENTATION

Rather than simply reiterating previous operations Norair devised the metallurgical approach of utilizing austenite in the drawn length, but to transform the point to a martensitic structure by subcooling.

Experimentation in the MSL was set up using both liquid nitrogen and alcohol and dry ice. In order to get a sharp demarcation in structure it was found necessary to provide a constant heat source immediately adjacent to the cold zone. Hardness traverses were then made to pinpoint the transition and to determine its degree of repeatability.

Also a problem in the previous warm drawing, was the length of time required to prepare the points by metal removal in Allegheny Ludlum's standard pickling solutions. To substantially accelerate this action Norair formulated and tried out a chemical machining solution which would remove stock at approximately a mil a minute. The previous pointing procedure was to remove only enough stock to accommodate the next draw die. However it was determined that the draw load is essentially the same on the first draw pass as it is on the last. Therefore, it is reasonable to assume that a point prepared to accommodate the final size should stand up through all the draw passes.

The next step then, was to adapt the process from laboratory conditions to the environment and facilities at Allegheny Ludlum. This was expected to require further experimentation and optimization.

POINT HARDENING

The first experiments at Allegheny Ludlum in point hardening was with liquid nitrogen. A two foot long piece was cut from No. 1 extrusion of the February 4th extruding effort and eight inches of it was immersed in liquid nitrogen which was contained in a twelve inch high by seven inch diameter thermos jar. A fiber cover was placed over the thermos jar with a cutout in the cover to accommodate the extrusion. Previous to insertion into the nitrogen, the extrusion to be sub-cooled, was imbedded through the bottom of an eight inch diameter open mouthed can. This was done by making a near to size cutout in the bottom of the can, inserting the required length of extrusion through it and pouring a one-fourth inch thick layer of thermosetting plastic around the bottom. To insure a water tight seal, the plastic called "Seal Peel" was poured against both the inside and the outside of the bottom of the can. This assembly of extrusion and can, was then placed above the jar containing liquid nitrogen and had eight inches of extrusion hanging down in the nitrogen. Into the can was placed water to a three-fourth level and an immersion heater inserted, to control the water temperature at 150F. Nitrogen and water was replenished when required during the eight hour period of exposure. The part was inspected for hardness with the following readings being obtained:

<u>TABLE I</u>		
Sample A subcooled in liquid nitrogen for 8 hours.		
7.0	33	67
6.5	33	67
6.0	33	67
5.5	33	67
5.0	33	68
4.5	33	68
4.0	33	68
3.5	34	68.5
3.0	35	68
2.5	34	68
2.0	33	68
1.5	33	67
1.0	34	67.5
.5 in	33	67
Bottom	34	67.5
Location	Rc	Ra

A consistent hardness was obtained, but it was not sufficiently different from the area of extrusion in the hot water, so the adequacy of the previously annealing was rechecked. The extrusion had been annealed for one-half hour at 1950F followed by water quench and then stretch straightened. This operation had caused work hardening to the point where it negated the effect of solution anneal.

Two new forty-five inch lengths, designated sample No. 1 and No. 2 were then cut from extrusion No. 1 of the January 21 extruding effort. The parts were annealed one-half hour at 1950F AC in furnace No. 4 in the production annealing department. This furnace is shown in Figure 20. Hardness was checked following the thermal treatment and was found to be Ra 48 after pickling.

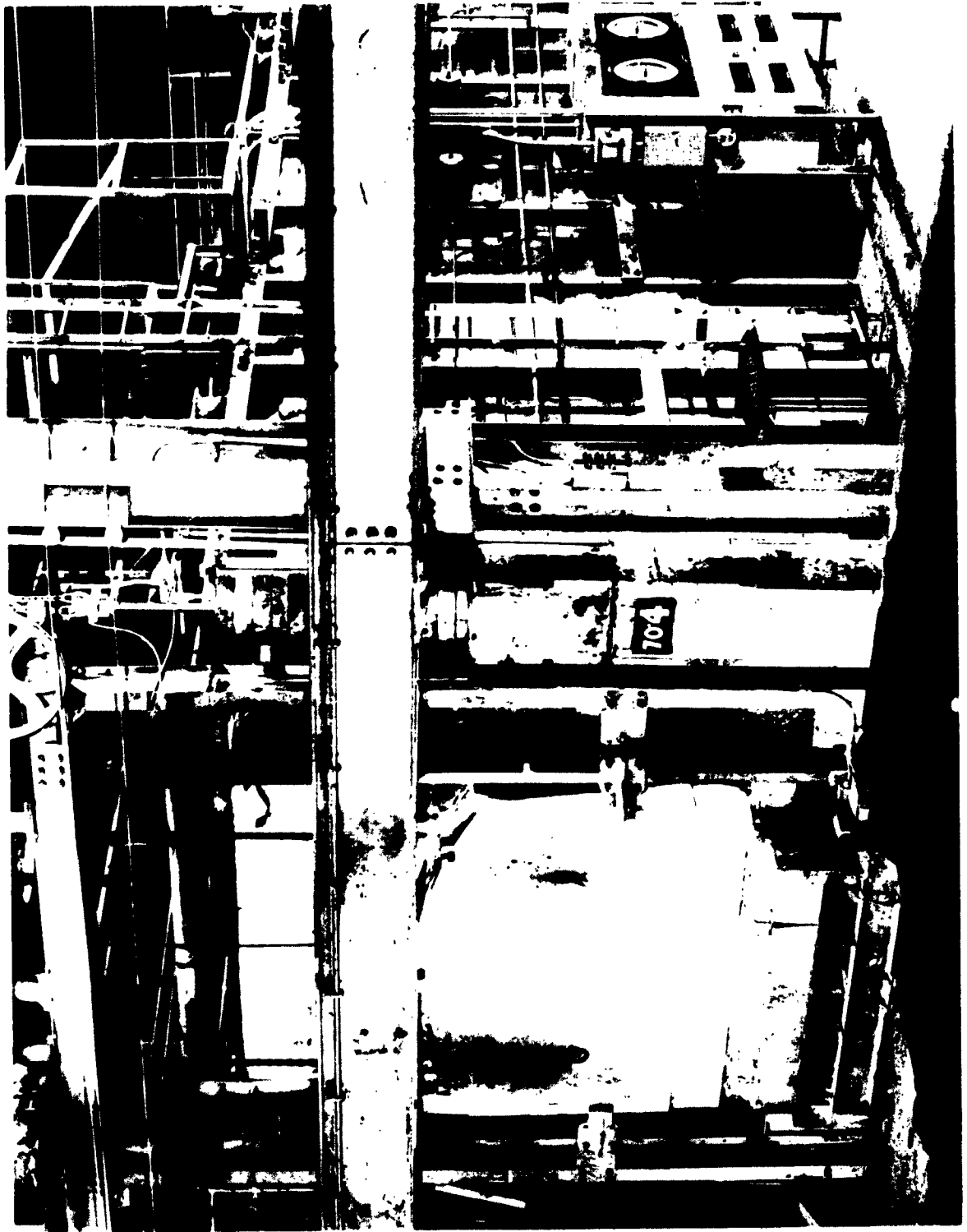


FIGURE 20 OILED FIRED HEAT TREATING FURNACE #4 USED TO ANNEAL
"T" SHAPES AT 1950F

Samples No. 1 and 2 were then subcooled in liquid N₂ with a hot water zone at 150F immediately, and a hardness traverse showed the following results in Table II.

TABLE II				
Hardness of samples No. 1 and 2 after anneal at 1950F one-half hour AC (hardness 48 Ra) and subcooled in liquid nitrogen.				
9.0	48	150F water	50	150F water
8.5	45	150F water	48	150F water
8.0	46	150F water	46	150F water
7.5	48	Bottom of water	47	Bottom of water
7.0	55	Bottom of can	63	Bottom of can
6.5	70		77	
6.0	67		73	
5.5	70		71	
5.0	69		75	
4.5	62		64	
4.0	54		60	
3.5	53		53	
3.0	52		54	
2.5	52		54	
2.0	53		53	
1.5	53		54	
1.0	54		52	
.5 in	53		53	
Bottom		Liquid N ₂		Liquid N ₂
Location	Ra	Sample No. 1	Ra	Sample No. 2

An analysis of hardening data on the above samples consistency, showed an uneven hardening pattern in the subcooled portion. It must be deduced that the upper area which was in and out of the liquid nitrogen due to boil off did harden up to desired levels. However the portion which was always within the liquid N₂ hardened only slightly.

To corroborate the observations sample No. 1 was then placed as is, from the liquid nitrogen, into alcohol and dry ice for an eight hour period. No provisions were made for a hot water zone because the immediate problem was to obtain consistency in the subcooled zone. Results are shown on Table III.

TABLE III		
Nitrogen subcooled sample No. 1 re-subcooled for eight hours in alcohol and dry ice.		
9.0	68.5	
8.5	68.5	
8.0	66	
7.5	67	
7.0	66	Air
6.5	69	Top of dry ice
6.0	68.5	
5.5	68.5	
5.0	70	
4.5	68	
4.0	69	
3.5	68.5	
3.0	69	
2.5	68	
2.0	67.5	
1.5	68	
1.0	68.5	
.5 in		
Bottom		Dry Ice
Location	Ra	Sample No. 1

With the consistency of a satisfactory hardness level shown in Table III, the remaining question was the effect of combining dry ice treatment with the hot water zone heating. Two samples No. F and G were prepared from the torn area of extrusion No. 1 and re-annealed. It appeared that there might be importance in elapsed time after heat treat so part F was subcooled 2 days after 1950F one-half hour AC while part G was subcooled one and one-half hours after the same annealing treatment. Both parts were subcooled 8 hours in alcohol and dry ice with the hot water zone heating being provided as previously described.

The results as shown in Table IV were most satisfactory. A consistently hardened area was exhibited throughout the subcooled zone and a sharp demarcation to soft structure was obtained at identical spots on both samples.

With the point hardening thus worked out the process was utilized in preparation of two, four foot pieces for experimental warm drawing and also in preparation of full length sections for pilot production drawing. Figure 21 shows five, full length sections being simultaneously metallurgically transformed. The setup is identical to that used in preparation of experimental samples except for size of containers used. The large lower receptacle contains the dry ice and alcohol solution and suspended an inch and a half above that level is the container holding the heated (150F) water. The water is heated by means of two immersion heaters shown protruding from each side of the top of the upper container. The five extrusions are suspended from a rafter and imbedded through the bottom of the hot water can. A thermosetting plastic poured over the base and around the protruding extrusions prevents water leakage. Below the water receptacle the extrusions are suspended to a proper depth into the alcohol and dry ice.

TABLE IV

Hardness of samples F and G after subcool in alcohol and dry ice with an adjacent heated water zone.

Location	Ra Sample No. F (2 days from anneal to subcool)	Ra Sample No. G (1½ hours from anneal to subcool)
12.0	53.5	52
11.5	55.5	53
11.0	54	53.5
10.5	56	54
10.0	54.5	53
9.5	55	52
9.0	53.5	52.5
8.5	55.5	53.5
8.0	53	53
7.5	64	63
7.0	67	66
6.5	68.5	69
6.0	68.5 Top of Dry Ice	67 Top of Dry Ice
5.5	70	68
5.0	70.5	68.5
4.5	72	69.5
4.0	67.5	69
3.5	68.5	67.5
3.0	69	69
2.5	69	70
2.0	70	70
1.5	68.5	70
1.0	69.5	68.5
.5 in		
Bottom	Dry Ice	Dry Ice



FIGURE 21 POINT HARDENING SET-UP USING DRY ICE AND HEATED WATER

CHEMICAL MACHINING

Previous warm drawing effort utilized shapes which were pointed by etching the excess metal away by use of Allegheny's standard shop process pickling solution. Because of the excessive trouble with point breakage, the practice was to etch down the point only enough to accommodate the next size draw pass.

In an effort to substantially reduce the time spent in pointing, the problem was approached from two standpoints. The first was the derivation of a new formula to vastly accelerate the speed of chemical machining. The new solution which was devised, succeeded in removing metal at the rate of approximately a mil a minute. Secondly, to further reduce the pointing time it was considered feasible to prepare the point originally to accommodate all the subsequent draw passes. This is possible because of the fact that the draw load for the first and last passes are essentially the same.

Using this approach, the Norair Materials Sciences Laboratory devised the following procedure:

- A. Anneal and harden point to a martensitic structure as delineated in previous section.
- B. Determine hardness transition zone.
- C. Chemically machine point as follows:
 1. A bath of the following composition heated to 140F.
 - 37% water
 - 31% H_3PO_4
 - 15% HCl
 - 17% HNO_3
 - .2% Nacconal (wetting agent)
 - 4 grams of iron dissolved in HCl per liter of solution
 2. Determine the rate of chemical machining of bath under temperature conditions which will be encountered.
 3. Select desired profile thickness.
 4. Compute the rate of descent into the bath to obtain the desired profile based on milling rate.
 5. Provide a variable speed motor and gear arrangement capable of lowering the extrusion into the bath at the desired rate.
 6. Water wash tanks to remove the milling solution.

Some difficulty was experienced in adapting the above procedure to the conditions and environment at Allegheny Ludlum. See Figure 22 showing setup of apparatus for point preparation. The size of the beaker holding the acid solution is critical in respect to the cross section of surface exposed. A small size will cause overheating and an action that is too violent. The temperature of the extrusion as it enters the solution will have a profound effect on resultant action and may have to be warmed up to avoid a delay in metal attack.



FIGURE 22 CHEMICAL MACHINING OF POINTS

Detail of the point configuration produced by chemical machining is shown in Figure 23. The operation is most accurately performed by immersing the seven inches of desired point length into the solution and immediately start a pre-determined constant rate of descent for the two inch shoulder length, depending on the amount of material to be removed. The reason for further immersion, rather than withdrawal from the solution, would be because the latter would not give a straight shoulder. This would be caused by continuing action of adhering solution above the level of the bath.

THERMAL TREATMENT STUDY

In the course of development of point subcooling techniques with liquid nitrogen, and alcohol and dry ice it became necessary to anneal certain experimental lengths several times. This was caused by uneven hardening in nitrogen and the necessity of re-annealing before re-processing. It became apparent that multiple treatments caused a change to occur which prevented resoftening. This was a source of concern because of the definite possibility of having to incorporate in process thermal treatments between draw passes.

Initial reasons for multiple treatments was that of stretch straightening. The six extrusions from the 4 February extruding exhibit were first annealed at 1950F for one-half hour followed by water quench and then pickled. They were then stretch straightened in the normal procedure on the 100 ton Sutton straightening press. A later hardness survey disclosed they were at a Rockwell of 68 Ra or 33 Rc and it was necessary to re-anneal to obtain the desired softness. This was done successfully, but a third annealing treatment after unsatisfactory point hardening, was sometimes unsuccessful.

An example of this was Sample No. 2 which was a four foot length cut from extrusion No. 1 of 21 January effort. History was as follows:

1. 1950F 1/2 hour AC, straightened and pickled. Hardness 46-50 Ra H.T. in oil fire furnace No. 4.
2. Subcooled in liquid N₂ on one end.
3. Re-annealed 1950F one-half hour AC in gas fire lab furnace. Hardness after sandblast Ra 57-60.
4. Re-annealed again in gas fire lab furnace 1950F one-half hour AC. Hardness still Ra 57-60.

Since two different furnaces were involved in the above, further tests were run using the above material, and new stock with the same results.

In order to more authoritatively ascertain conditions and results a controlled test was then performed with attached thermocouples and variable time at temperature. Four, new one foot specimens were cut from extrusion No. 1 of 4 February effort, and were designated K, L, M, and N. Results were as shown in Table V.

Sample M after annealing as shown, and a subsequent hardness check, was put into water quench tank at 42F for 30 minutes then rechecked the following day. Because of the substantial hardening that occurred with Sample M, Sample L was put in quench tank, but it remained at the same hardness level.

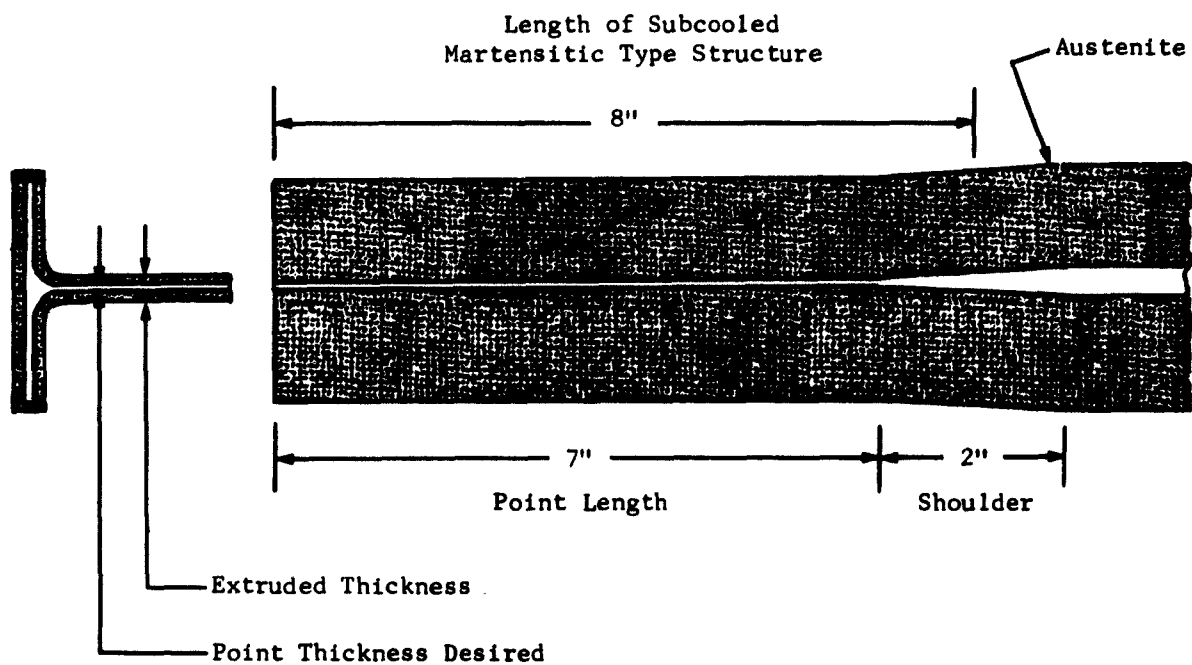


FIGURE 23 CONFIGURATION OF POINTS PRODUCED BY CHEMICAL MACHINING

<u>TABLE V</u> Hardness survey of samples exposed to variable time at temperature					
Sample No.	Attached Thermocouple Reading	Time at Temperature	Hardness before anneal	Hardness after anneal	Recheck of hardness the following day
N	1982F 1930F	1½ hour water quench	66-68 Ra	64-65 Ra	64-65 Ra
M	1979F 1931F	1½ hour air quench	66-68 Ra	54-55½ Ra	66-68 Ra
L	1983F 1970F	1 hour air quench	67-68 Ra	53-54 Ra	51½-56 Ra
K	1972F	30 min. air quench	68-68½ Ra	54-55 Ra	54-55 Ra

Metallurgical aspects of the hardening mechanism were, of course, more important than hardness reading, so micro samples were cut from pertinent specimen and mounts prepared. Micro hardness traverses were taken on all micro specimen and the results correlated very well with the above listed hardness results. The micros were reviewed by Allegheny Ludlum metallurgists. The consensus of opinion was that decarburization is resulting from accumulative exposure to furnace atmosphere. It is believed that the loss of carbon raises the M_s , with transformation to martensite being eminent.

The micro of Sample K which was exposed to only one-half hour at 1950F showed what appeared to be a thin layer of martensite around austenite. The other samples which had been exposed to one and one-half or more hours were heavily martensitic.

Photos of the micros from the thermal treatment study and from each draw pass will be published in the next interim engineering report.

PRE-DRAW METALLURGICAL INVESTIGATION ON WARM ROLLED SPECIMEN

These tests were conducted at Northrop Norair in order to obtain preliminary data on the strength of the extrusion at drawing temperature, and some of the effects of drawing. Specimen material for this test was obtained from an 0.060 inch sheet of PH15-7MO. In order to simulate extrusion microstructure the specimens were heated to 2200F for two hours using argon for a protective atmosphere. After air cooling the specimens were heated to 1950F for one-half hour and water quenched. Again argon was used as a protective atmosphere.

Specimens were then either cold or warm rolled to simulate the reduction in area experienced during drawing operations as follows:

10% reduction in area	30% reduction in area
Room temperature	_____
600F	600F
800F	800F
1000F	1000F
1200F	1200F

The rolled material was then subjected to various tests in order to evaluate its microstructure, hardness, magnetic properties (a relative measurement of austenite) and tensile strength at rolling temperature.

Magnetic data was obtained from an instrument which only yielded relative values. Thus the specimen rolled at 600F contained more transformation product than the specimen rolled at 800F, however it was less than the specimen rolled at room temperature. When plotted (Figure 24) it is seen that the lower the rolling temperature the more transformation product formed. The differences were greater between rolling temperatures than between amounts of deformation at the

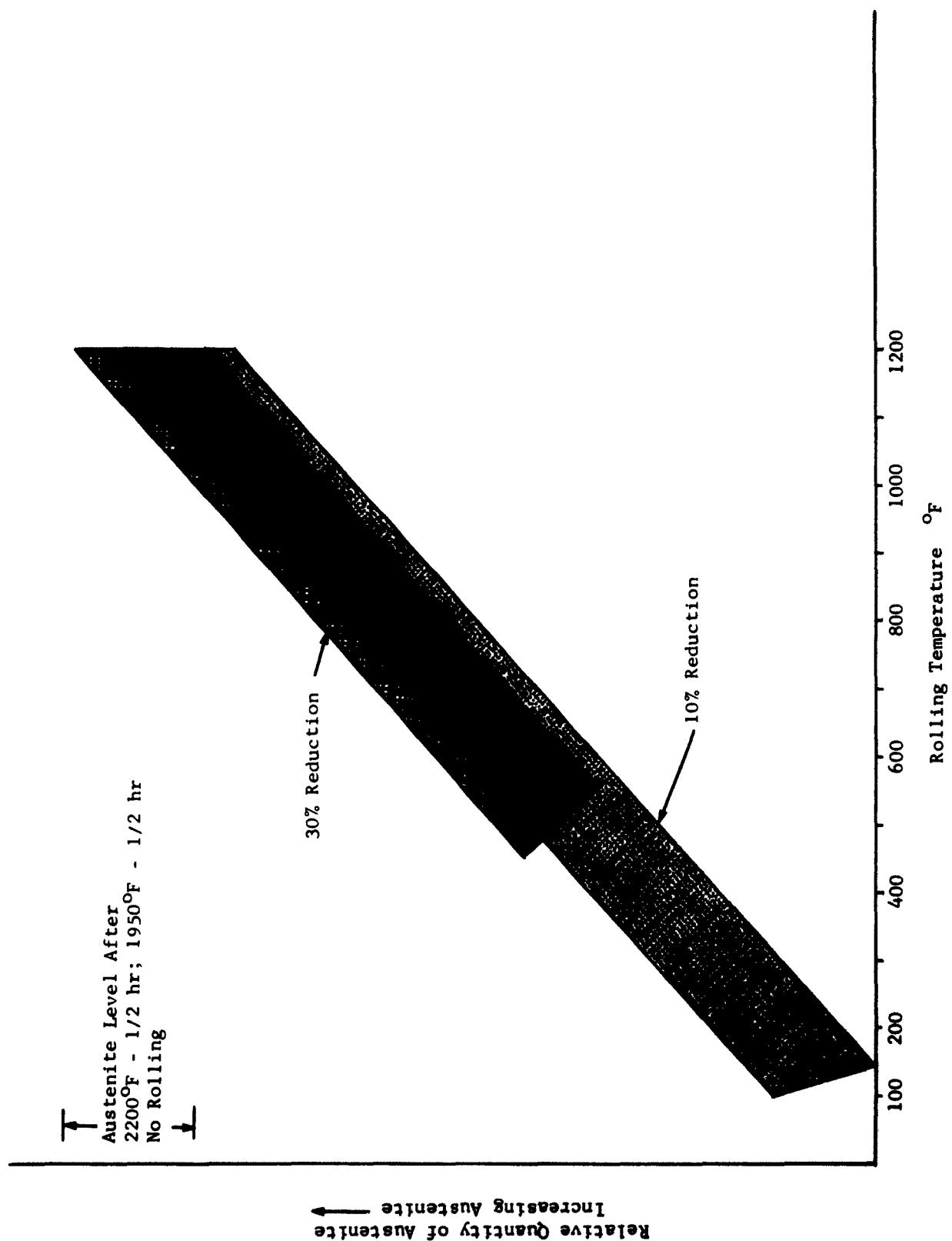


FIGURE 24 MAGNETIC DETERMINATION OF CHANGE IN AUSTENITE CONTENT DUE TO ROLLING

same temperature. The amounts of transformation product formed is related to the degree of strengthening, which occurs upon drawing. Finally a 30% reduction transforms more austenite than a 10% reduction, which indicates that the steel coming out of the die is stronger than the steel entering the draw die even after the first reduction.

In order to evaluate the tensile properties of the steel as it leaves the draw die, tensile tests were conducted at the rolling temperatures. Thus both rolling and test evaluation were at a given temperature.

As the draw load is quite dependent on surface area and the amount of friction, varying draw temperature does not greatly effect the draw load. Therefore preventing fracture of the drawn part is a matter of controlling the drawing temperature so as to retain sufficient strength in the material at temperature to carry the draw load stress.

Test results from the rolled samples are tabulated in Table VI. Data shows that the yield strength and ultimate strength changed as follows:

1. Steady decrease in strength from 600F to 1000F.
2. Rapid decrease in strength above 1000F.
3. Specimens with 30% reduction were stronger than those with 10% reduction at a given temperature.

Percent elongation values were slightly effected by temperature up to 1000F. However, 30% reductions did decrease the elongation values. Note that this data parallels the magnetic data.

Based on the above data the draw temperature should be 600F. However, when lubricant effects and past experience were added, a draw temperature of 800F was selected. Later it was necessary to modify the temperatures to 800F for initial stages, and 1000F for final stages.

These draw temperatures proved successful in producing drawn parts without failure due to excessive draw loads.

POINT STRENGTH

A strong tough point is desirable for the drawing operation. Data in Table VII indicates the strongest point would be formed by ageing at 950F. Unfortunately this point would be somewhat brittle. Since the point must withstand shock loads, the tougher non-aged heat treat point was selected.

EXPERIMENTAL DRAWING

With the point preparation optimized by metallurgical transformation hardening and chemical machining of the point profile, the next step was to use these techniques in the warm drawing operation. Because of the possibility of encountering in-process thermal treatment difficulty, a dual approach basis was planned for experimental warm drawing.

TABLE VI Mechanical Properties						
Rolling* & Test Temperature F	Yield Strength		Ultimate Strength		% Elongation	
	10% Reduction	30% Reduction	10% Reduction	30% Reduction	10% Reduction	30% Reduction
	PSI	PSI	PSI	PSI	%	%
Room Temperature	52,000 49,800		156,000 155,000		16 19	
600	73,200 74,500	102,000 98,300	87,900 90,000	110,000 109,000	19 16	7 5
800	65,800 69,800	97,800 94,800	86,000 88,200	106,000 104,000	17 18	5 5
1000	66,800 70,900	93,700 93,900	84,200 85,900	103,000 101,000	15 15	7 6
1200	53,900	65,600	63,300	71,600	14	14
* Heat Treatment Prior to Rolling: 1. 2200F - 2 hours - Argon - Air Cool 2. 1950F - one-half hour - Argon - Water Quench						

<u>TABLE VII</u> Point Strength				
Condition*	Yield Strength PSI	Ultimate Strength PSI	% Elongation %	Charpy Impact (Sheet Specimen) Ft-Lbs
No Age	118,000 118,000	183,000 182,000	13 13	7.2
Aged 950F	197,000	228,000	14	4.1 4.1
* Heat Treatment: 1. 2200F - 2 hours - Argon - Air Cool 2. 1950F - one-half hour - Argon - Water Quench 3. - 100F - 8 hours 4. Either no age or aged at 950F - 1½ hours				

Two, four foot long specimens which were designated No. J and No. O were prepared according to the pointing procedure covered in previous sections. Sample No. O was cut from fresh stock (Extrusion No. 6) and was hardened by subcooling in alcohol and dry ice and then chemically machined down in the point area sufficiently to accommodate all the draw passes. Sample No. J was cut from extrusion No. 1. It did not receive the subcool hardening treatment and the point was chemically machined down only enough to accommodate the first pass.

The approach was to keep Part No. O in the austenitized condition throughout the series of draw operations, and to draw Part No. J through in the tempered Martensite condition. Micro specimens were cut from each before the first draw and another specimen was to be cut after each draw pass. These micros will be shown in the next interim Engineering Report. Part No. J was tempered at 1200F for four hours and Part No. O was austenitized at 1950F for thirty minutes followed by air quench.

Dimensional Inspection

Dimensional inspection before the first breakdown pass was as follows:

<u>Part No. J</u>				
	Base Thickness	Vertical Thickness	Base Width	Vertical Height
Front	.076/.078	.070	1.485	1.502
Middle	.074/.077	.069	1.490	1.497
Back	.074/.077	.070	1.485	1.493
<u>Part No. O</u>				
Front	.067/.070	.069	1.505	1.517
Middle	.068/.071	.073	1.522	1.528
Back	.071	.073	1.522	1.528

Draw Furnace Calibration

The resistance heated furnace which recently replaced the Lepel induction unit had not previously been used in drawing the steel sections. Consequently it was necessary to calibrate the furnace to this particular shape. The furnace is equipped with a thermocouple in the heated tube, and a direct reading indicator is attached, but the important aspect of preheat, is the temperature on the workpiece immediately adjacent to the entrance side of the draw die. That temperature is measured by pyrotel infra-red sensing unit which is hooked up to a varian tape type recorder. It was necessary to insert a thermocoupled extrusion into the furnace, preheat, move the thermocouple area into the draw die, and record that temperature. This had to be done at various anticipated amounts of heat so that a direct conversion could be made from the varian tape. It was then necessary to make dummy runs through the furnace to establish the best positioning of the work piece during preheat, and the amount of preheat time that would give the proper level and the most uniform distribution of that heat.

Draw Load Measurement

It is highly desirable to measure the amount of draw load required to pull each extrusion through each size draw die, and to record the variation of that load from one end of the extrusion to the other. Fairly reliable draw load

measurements were obtained in previous draw efforts with a strain gage equipped tensile type adapter between the gripper jaw housing and the trolley. Since that time the old gripper setup has been replaced by a Hufford jaw housing. A great deal of difficulty with slippage had been previously encountered so the Hufford stretch press gripper housing, which provides positive reliable action, was substituted. The Hufford housing was sufficiently heavier than its predecessor, that excessive bending loads were induced on the tensile bar. Attempts to calibrate the unit were consequently unsuccessful. After several tries on and off the bench, this approach gave way to attachment of strain gages to the hook. This was also unsuccessful, probably because of the hooks massive cross section.

Warm Drawing

Parts No. J and No. O were set up to be drawn at 700F in accordance with evaluation of the previous warm rolling metallurgical investigation on sheet strips. On the first pass of .65 Part No. J, the martensitic sample broke during drawing, about a third of the way back. This left such a short length, that it was deemed advisable to proceed with just the one experimental length. An examination of No. J disclosed evidence that the break emminated from a pre-existant crack which was not noticed in pre-conditioning. The experiment then continued with just the austenitized and point hardened sample No. O.

Results were excellent with Part No. O going through all five draw passes without intermediate thermal treatment or breakage. After each pass, micro samples were cut and hardness readings taken. After the third pass, the hardness went up to Rc 31. This was high enough to cause concern, so the draw temperature for the fourth and fifth passes was raised from 700F to 1000F. Further checks indicated that the hardness was slightly reduced after the fourth and fifth draws.

Results were as follows:

Draw Pass No.	Draw Die Size	Sample No. O		Sample No. J	
		Preheat Temp.	Hardness	Preheat Temp.	Hardness
Before Drawing			Ra 51-55		Ra 54-55
1	.065	700F	Rc 19	700F	
2	.058	700F	Rc 24		
3	.052	700F	Rc 31		
4	.047	1000F	Rc 27		
5	.042	1000F	Rc 28-29		

PILOT PRODUCTION DRAWING

The experimental drawing on Part No. O with the martensitic point and austenite drawn length was very successful. Completely eliminated so far was the previous nemesis of point breakage. There was, however, one potential source of trouble observed during the warm drawing of Part No. O, there was an apparent tendency to develop or propogate cracks on the edges. These cracks did not cause failure but at one point it was necessary to stop and condition out the small edge cracks. The draw dies used were made so that the ends of the drawn shape were not restricted. It was hypothesized that this may have contributed to the edge crack

condition. It was therefore planned, to interpose edge restricted and unrestricted dies during the drawing sequence, for the pilot production effort.

The pilot production quantity consisting of five extrusions, Nos. two thru six from 4 February extruding date were all prepared for drawings by using the same technical approach which worked successfully on experimental sample No. 0. Extrusions No. two and five were fifteen to sixteen feet in length before drawing, while No. six was only eight feet long as sample lengths had been cut off for experimentation. All five extrusions had the point area hardened to a martensitic type metallurgical structure by simultaneously subcooling in dry ice and alcohol (see Figure 21). The points were chemically machined to accommodate all draw passes which meant reducing the sectional thickness in the point area from an "as extruded" thickness of approximately .070 down to .043. All parts had been annealed at 1950F for one-half hour and air quenched, so the drawing length in the austenitic condition had a hardness of Ra 55 while the martensitic points had a hardness of Ra 68-70. Tests are now being performed to ascertain the actual differences in tensile and yield strength as reflected by the increased hardness and these results, with an analytical approach to allowable thickness versus draw loads will be included in the next report.

With the results and procedure devised in the experiment drawing of the metallurgical investigation using sheet strip rolled and tested at drawing temperatures, the following draw sequence and procedure was formulated for processing the pilot production quantity:

- Pass No. 1 - .065 S12E with free edges, draw temperature of 700F. Hold part in hot zone of furnace for two minutes. Hook up and draw at ten ft/min. Check hardness on each piece.
- Pass No. 2 - .058 S12E with free edges, draw temperature of 750F. Hold part in hot zone for two minutes. Hook up and draw at ten ft/min. Cut samples for hardness check.
- Pass No. 3 - .060 die size with restricted edges. Draw temperature of 750F. Hold in hot zone for two minutes. Hook up and draw at ten ft/min.
- Pass No. 4 - .052 die size with free edge, draw temperature of 1000F. Hold in hot zone for one minute. Hook up and draw at eight ft/min.
- Pass No. 5 - .054 die size with restricted edges. Draw temperature of 1000F. Hold in hot zone for one minute. Hook up and draw at eight ft/min. Cut samples for hardness.
- Pass No. 6 - .047 die size with free edges. Draw temperature of 1000F. Hold one minute in hot zone. Hook up and draw eight ft/min. Cut samples for hardness.
- Pass No. 7 - .048 die size with restricted edges. Draw temperature of 1000F. Hold in hot zone for one minute. Hook up and draw at eight ft/min.
- Pass No. 8 - .042 die size with free edges. Draw temperature of 1000F. Hold in hot zone for one minute. Hook up and draw at six ft/min. Cut samples for hardness.

Pass No. 9 - .043 die size with restricted edges. Draw temperature of 1000F. Hold one minute in hot zone. Hook up and draw at six ft/min. Cut samples for hardness.

After chemically machining the points, they were fitted to the draw die and a certain amount of hand work was necessary due to non-uniformity of thickness in the extrusions. The draw bench was setup according to the above procedure, and all five specimens were successfully drawn through the first two passes. There was no breakage of either points or drawn length. They were then put through the third draw die and still no breakage, however, they had become excessively warped from the repetitive drawing operations. The limiting factor with regard to straightness during drawing is not so much getting the shape through the draw die as it is getting it through the preheat furnace. The heated element in the furnace is a three inch diameter stainless tube and since the extrusions are fifteen to twenty feet long an appreciable amount of bow precludes this possibility.

It was then necessary to stretch straighten before proceeding with any more drawing. It was inadvisable to attempt to straighten cold on the 100 ton Sutton stretch straightener because of the hardness which had been induced by the stretching operation. It was also inadvisable to try to anneal for cold straightening at such a relatively early stage, because of the deleterious effect observed in the preliminary thermal treatment study. Because of this the parts had to be straightened on Alleghenys resistance heated straightener. It is a 7500 amp resistance heater of which the chain driven right hand end is capable of straightening with power continuously on. The drawn shape is gripped at each end by revolving gears. This is obviously a very undesirable setup because of the possibility of damage by the gear teeth.

As the reporting period ended the parts were straightened on this apparatus at 1000F and extensive damage was inflicted on both ends of all sections. It will therefore be necessary to halt further drawing until the parts can be cut off, re-hardened by subcooling, and re-pointed.

VIII EVALUATION OF PHASE II EFFORT

Previous Phase II efforts to warm draw PH15-7MO with a starting quantity of thirteen specimens of eight to ten foot lengths, resulted in a technically successful completion of the target shape. However only two pieces of a length of two feet each were drawn through the final die size. The very predominant reason for this loss of drawing stock was because of point breakage. The points repeatedly broke off during drawing and had to be repointed thus using up a foot or so of stock. As nearly as can be determined fifty-two points broke off during the previous warm drawing effort.

By comparison, in the current effort, twenty-one draw passes have been made to date and not one point has broken. This remarkable improvement must be attributed to a Norair devised technical approach consisting of the following precepts:

1. Preferential strengthening of the point area by metallurgically transforming it to martensite by subcooling.
2. Easy to deform austenitic structure of the portion to be drawn.
3. More dependable gripping action by the Hufford jaws.
4. Pre-selection of proper draw temperatures consistent with elongation and tensile strength as determined by preliminary metallurgical tests.

The most important remaining problem now, appears to be obtaining an improved method of warm straightening. It will not be a serious deterrent however to the completion of Phase II other than loss of time. For Phase III however its importance will be amplified.

IX PROGRAM FOR THE NEXT QUARTER

The following is expected to be accomplished during the next reporting period:

1. The five pilot production sections will be re-pointed and the drawing sequence resumed to what has every indication of a successful conclusion.
2. Further investigation will be made of the micrographs which were taken from specimens involved in the thermal treatment study, and from the micros obtained following each draw pass. The metal-lurgical vagaries will be clarified and published.
3. Current test will be completed on actual strength of point area versus drawn length, and will be presented analytically with allowable draw loads, frictional forces, and magnitude of stresses.
4. Mechanical tests will be made on fully drawn pilot production specimen, heat-treated to maximum strength levels.
5. ASD approval will be requested for consideration of completion of the Phase II extruding and warm drawing technique development effort.
6. Phase III development of extruding and warm drawing techniques for an advanced design aerospace vehicle structural shape of PH15-7MO, will be instituted.

APPENDIX I
SUMMARY OF PREVIOUS
INTERIM REPORTS

APPENDIX I

Summary of previous Interim Reports published under Contract AF33(600)-36713.

Interim Engineering Report No. 1, NAI-58-656, included a full discussion on the surveys of both the airframe and the steel extruding industries. Also included was the basis for selecting the Phase I shape, the target specifications, and the initial three participating subcontractors.

Interim Engineering Report No. 2, NAI-58-876, included a full discussion of Allegheny Ludlum's equipment, extruding precepts, and facilities, as well as reporting the first half of their experimental extruding effort. It covered only the preliminary large diameter container pushes at Harvey Aluminum because at the close of the report period their small diameter container had not been completely fabricated. Interim Report No. 2 did not include any technical data from C. I. E. P. M. because Sejournet's extruding effort did not begin until after the issuance of that report.

Interim Engineering Report No. 3, NOR-59-246, included a detailed description of the last half of Allegheny Ludlum's effort since the first portion was covered in Report No. 2. The extruding effort by C. I. E. P. M. (Sejournet) was included in its entirety with extensive inspection data obtained from their several extrusions. No coverage was given to Harvey Aluminum's effort because Harvey was late in submitting their report.

Interim Engineering Report No. 4, NAI-59-354, included a complete tabulation of detailed inspection and evaluation of samples submitted from each of the three participants. Such items were listed as dimensional variation, surface roughness, and inclusion count. Also included was the complete presentation of the entire Phase I effort for Harvey Aluminum. A discussion and summation of the scheduled Phase I effort was presented together with details of an extended development effort for Phase I with Allegheny Ludlum as subcontractor.

Interim Engineering Report No. 5, NOR-59-504, included details of the design and utilization of a radiation shield for heating and handling of billets. Also included was information and technical substantiation for a high-heat container liner which was conceived and fabricated primarily for extruding A-286 material. The report presented details of an extruding effort with the high-heat liner which was foreshortened due to premature container and stem failure. Efforts to replace these failed major components was underway when the steel strike halted all activity.

Interim Engineering Report No. 6, NOR-60-106 includes activities starting from the end of the steel strike on 7 November 1959. After resumption of work schedules, some time was consumed in reactivating the plant and facilities during which a new liner and new stems were being finished. Extruding of A-286 was again attempted with the high heat liner and again resulted in gross failure of tooling. Subsequently, PH15-7MO was substituted for A-286.

APPENDIX I (Cont'd)

Another extruding effort was made with H-11 and the new PH15-7MO using a container liner at the more conventional 900F temperature. It was anticipated that extruding of A-286 will possibly be resumed at a later stage in the program.

Interim Engineering Report No. 7, NOR-60-253, completely summarized Phase I effort. A major extruding effort was planned and effected using H-11 and PH15-7MO. A new stable die material was used extensively which, in the previous period, had indicated promise. A new higher melting point glass was used with billets that received a longer soak period at temperature. Results were deemed to be an unprecedented success in efforts to produce super thin (.06) thicknesses of aircraft type shapes in difficult-to-form alloys.

Interim Engineering Report No. 8, NOR-61-199, includes mechanical property test results showing low longitudinal tensile values in the leg section in the evaluation of Phase I extrusions in both H-11 and PH15-7MO materials. It includes extensive metallurgical studies by both Northrop and Armco Steel Corporation which suggest that the low properties resulted from diffusion of the nickel lubricant material into the surface of the extrusions. It also covers program planning for Phase II to resolve this problem as well as further improvement of extruding techniques. Also included is planning for cold and warm drawing to yield sections of .04 wall thickness.

Interim Engineering Report No. 9, NOR-61-245, shows results of Phase II extruding effort to improve the producibility of the process, eliminate low mechanical properties, and provide extruded stock for cold and warm drawing experimentation. Details of the extruding effort with some clad and some unclad billets in both H-11 and PH15-7MO is covered.

Interim Engineering Report No. 10, NOR-62-19, comprises full details of final extruding effort to provide stock for Phase II drawing experimentation. The effort showed good reproducibility and proved the feasibility of eliminating the nickel plate previously used. It also delineates the details and difficulties of setting up and preliminary calibration of the induction heating apparatus for warm drawing.

Interim Engineering Report No. 11, NOR-62-77, provides a full description of the warm drawing facility and equipment used for developing techniques for very thin H-11 and PH15-7MO airframe shapes. Precise dimensional data is presented in graphic form on extruded stock to be drawn. Some of the difficulties encountered in pointing and gripping are given with the remedial action which was required. The extensive problems connected with obtaining a uniform preheat with the induction heater are covered and the resultant corrective action of using constant power and constant speed.

Interim Engineering Report No. 12, NOR-62-170, summarizes details of development of process techniques for warm drawing H-11 from an as extruded thickness of .065 through four reductions to a thickness of .040. Also discussed are details of a chevron type defect which developed sporadically during the reducing passes. The report contains dimensional inspection results of the fully drawn sections.

APPENDIX I (Cont'd)

Interim Engineering Report No. 13, NOR-62-216, contains similar data to Report No. 12 except that the experimental material involved is PH15-7MO instead of the H-11 contained in Report No. 12. Results of processing technique development of PH15-7MO is given in detail, summarized and evaluated. Further discussion of the chevron type defect which has been encountered with both types of material is also included.

Interim Engineering Report No. 14, NOR-63-9, gives a detailed breakdown of a new technical approach to preparation of stock for warm drawing. It is intended to fully optimize the process by putting an emphasis on metallurgical control and pointing technique. Also described is a change in mode of pre-heating for warm drawing from induction to a resistance type furnace. Details are given of a recent revision to the objectives and scope of the contract.

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