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CONTRACTOR REPORT ARLCD-CR-83049

HIGH FRAGMENTATION STEEL PRODUCTION PROCESS

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Two heats of HF-1 steel which were purchased and metallurgically characterized in the previous phase of this project were used to determine the efforts of vendor and/or cooling method (used to produce the steel) on the production of the M549 projectile warhead metal parts. Parameters investigated included mult-parting, forging, rough-machining and nosing. The study included the design and development of tooling and forging and machining parameters in attempt at a cost-effective manufacturing process.

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SUMMARY

The overall objective of this project was to establish a data base for the manufacture of artillery projectiles from HF-1 steel utilizing mass production processes and equipment.

The M549 projectile was the test vehicle for this project and was manufactured utilizing HF-1 steel supplied by two steel vendors. Three different cooling techniques were utilized by the vendors in the production of the steel. These were the furnace, pit and box cooled methods.

A total of 1,562 pieces were processed during this project. This quantity of steel was divided among the two steel vendors and the three bar cooling techniques.

The process investigated and the acquisition of data during this project encompassed the following:

1. Mult Parting Techniques (Nick & Break and Sawing Processes) - Mult length and weight variations;

2. Forging - Process, tooling and gage design; temperatures and load requirements;

3. Rough Turn Machining - Speeds, feeds, tooling types, tooling life and pressures acquired for forgings in the spheroidized annealed versus unannealed conditions;

4. One Hit Nosing - Evaluated only to the extent of developing and confirming the forging process;

5. Metallurgical Evaluation - Conducted at all stages of the above listed processes.

The analysis of the data and metallurgical evaluation from mult parting through the rough machining processes indicated two main areas of concern. They were the undesirable effects of excessive conditioning of the billets as received from the steel mill and maintaining the proper forging temperature at the hot draw operation. These problem areas caused the majority of defects encountered during processing of the projectiles.

The most outstanding finding of this study was the determination that an air cooled forging can be machined without the need for a cost prohibiting spheroidize annealing process.

ACKNOWLEDGEMENTS

The performance of the various tasks involved with this project had required the cooperation and technical knowledge of many individuals employed by Chamberlain Manufacturing Corporation at the Scranton Army Ammunition Plant.

The authors wish to acknowledge the following personnel for their contributions and efforts involving both the performance of the project and the preparation of material contained in this report.

Mr. Herman Krankel, Engineering Manager -
Technical advice and supervision.

Mr. Herman Morckel, Senior Electrical/Hydraulic Engineer -
Instrumentation

Mr. Thomas McAndrew, Engineering Supervisor - Production Shop and Messrs. Joseph Griffin and Francis Bella, Senior Manufacturing Engineers -
Rough Turn Machining.

Mr. Timothy Murray, Draftsman -
Report - Illustrations.

Mr. John Zavacki, Technical Writer -
Report - Introduction, Background and Editing.

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INTRODUCTION

This report has been prepared by the Scranton Division of the Chamberlain Manufacturing Corporation as a Contract Data Requirement in accordance with Scope of Work - Project 5804189 under Modification 24 to Contract DAAA09-74-C-4009 and subsequent bi-lateral supplemental agreements thereto.

BACKGROUND

Project 5804189 is the second phase of the High Fragmentation Steel Production Process Manufacturing Methods and Technology Project. The overall objective of this project is to investigate the processes, techniques and tools for the manufacture of the M549 warhead from high fragmentation (HF-1) steel using mass production processes and equipment and establish a data base for this purpose.

The project was established to investigate the many problems encountered during the production process. A primary source of concern was the seemingly uneconomical methods of production. The project was designed to refine and optimize, if possible, the more critical and uneconomical processes by thoroughly investigating differences in the metallurgical characteristics in steel from different producers and different processes which might result in anamolies and to use the data to establish processing parameters for forging and machining operations.

The first phase of the project entailed the purchase and metallurgical characterization of two heats of HF-1 steel from different vendors. Performed by Chamberlain and funded under contract DAAA09-74-C-4009, Project 5794189 resulted in Contractor Report ARLCD-CR-81017, a thoroughly documented data base established by Chamberlain Metallurgical Engineer Colin MacCrindle.

Of primary interest in Phase I were the aforementioned anomalies found in HF-1. These included variations in heat-to heat chemistry, alloy segregation and material soundness. The project, therefore, involved purchasing steel from different vendors to investigate these variations. Another concern of this phase was the cooling method used by steel producers in the event of peak production situations such as mobilization. In such a situation, the usual method of "bung" or furnace cooling (by placing the steel in a furnace and gradually reducing the temperature) might not be feasible because of equipment priority allocations for other products. Alternate cooling methods were sought and the steel cooled using these methods, then compared and contrasted analytically with that produced by bung cooling.

The vendors chosen to produce the steel for Phase I were Republic Steel (Masland, Ohio facility) and Bethlehem Steel (Lackawanna, NY facility). Both vendors produced heats (production lots) of approximately 200 tons. Bethlehem cooled its product using the bung furnace method and chose box cooling (the placing of the billets into a metal box and allowing them to cool with no temperature control) as the alternate method. Republic, which had no furnace cooling equipment available at its facility, utilized pit cooling (in which the billets are simply placed in a pit where they remain for seventy-two hours).

All steel was identified by vendor, location of steel within the heat and cooling method. This identity was retained throughout Phase I and Phase II in order to determine not only metallurgical differences, but differences in forging results, machinability, etc., resultant from process, cooling method or location which might reduce the effectiveness of the forging and machining process or the quality of the finished product. Using the identification techniques described in Contractor

Report ARCLD-CR-81017, steel from each vendor, process and location was then evaluated for chemistry, cleanliness, macro and micro quality and surface quality.

The steel was also subjected to Jominy End Quench testing for hardenability, austenitized, quenched and tempered and mechanical property tests performed. The detailed results may be found in the previously mentioned report. Using the data accumulated during Phase I and the parameters established by the researcher, Phase II was then pursued with Chamberlain awarded the contract for its performance.

Phase II was designed to investigate production problems such as excessive machining of oversize mults (a result of forging eccentricity), high energy requirements of spheroidize anneal and machining difficulties enountered in the rough turning operation.

PROJECT DESCRIPTION

The objective of this project was to establish a data base for the manufacture of the M549 projectile from HF-1 steel. The scope of work stated that the project would be carried out according to the following tasks as outlined and described below:

Task A - Optimization of Forging Operation

1. Produce a quantity of mults by parting method of contractor's choice.

2. Forge this quantity of mults in an effort to establish the optimum forge tooling and process.

3. Use data from above to establish the minimum starting mult weight.

4. Upon evaluation of collected data, process a minimum of 100 mults through the forging operation to verify the established process and further refine it if necessary.

Task B - Evaluate Mult Parting Techniques

1. As a minimum the "Nick and Break" and "Cold Sawing" parting techniques shall be evaluated.

2. Steel from both heats and different cooling techniques shall be parted equally between the mult parting techniques.

3. Select a minimum of 5 mults from each heat, cooling and parting techniques for metallurgical and dimensional evaluation to determine the effects of mult parting techniques on the steel and the mult weight variation.

Task C - Evaluate the Need for Spheroidize Annealing of the Forgings

1. Process a representative sample of forgings produced in Task B through the following spheroidize anneal cycle:

1450°F ± 25°F for 2 hours. Cool to 1250°F.
1250°F ± 25°F for 4 hours. Air cool.

These groups shall be considered as the "control groups" against which other methods of imparting machinability shall be compared.

2. Investigate and determine the best alternate methods of imparting adequate machinability to forgings.

3. Perform a metallurgical analysis on the forgings produced per Item #1 above for comparison with metallurgical data obtained for the forgings produced per Item #2.

4. Rough machine a quantity of forgings as produced per Item #2 above in order to evaluate tool life and machining problems for comparison with the results obtained by rough machining a significant quantity of forgings from the control groups.

Task D - Evaluate Machine Tools for Rough Machining of Forgings

1. Investigate possible tool materials, geometries and equipment feeds and speeds to optimize the Rough Turn process.

2. Verify the optimum Rough Turn process as derived from #1 above, by processing through Rough Turn a statistically significant quantity of forgings from both the control and test groups from each heat.

Task E - Processing of Remaining Steel

1. Process a significant quantity of mults from each heat through mult parting.

2. Process all mults up to and including the optimization of Task D.

3. Maintain total identity of all steel processed such as heat, ingot, bar*, cooling technique and mult parting technique.

4. Weigh the mults produced in a statistically significant quantity.

5. Qualitatively analyze all forgings produced.

6. Perform an economic analysis of mult parting methods.

---

* The words bar and billet are used interchangeably throughout the report; both refer to the steel supplied by the vendor.

OPERATIONAL PROCEDURE

Steel Identity

HF-1 steel for this project, purchased under Phase I of MM&T Proj. 5794189 (ref. #1), was supplied by two (2) steel vendors, Republic Steel Corporation and Bethlehem Steel Corporation. The identity of the steel, as distinguished between the two (2) manufacturers and referenced frequently throughout this report, is presented below:

Manufacturer:	Republic	Bethlehem	Bethlehem
Mfg. Heat #:	8068860	517K4209	517K4209
Mfg. Process:	Double Conversion	Single Conversion	Single Conversion
Cooling Method:	Pit	Box	Bung
Chamberlain Heat #:	1	2A	2B

Steel Traceability

A general requirement for this project was to be able to identify whether HF-1 steel or the manufacturing process would be the cause of any problems that might occur during the manufacturing of this projectile.

To maintain steel traceability of all the projectiles produced during this project, each mult was numbered immediately upon completion of the mult parting process. The serialization of each mult provided the means of identifying the heat, billet, ingot and the position in the ingot from which it was derived. In all manufacturing processes, where the serial number of the specimen would be eradicated due to that particular process, such as forging, etc., the identity of each mult was noted at the beginning of that process and then the process piece was renumbered at the completion of that process. This manner of steel traceability was maintained from mult parting through completion of the nosing process. All inspection and necessary processing data was recorded and associated with each particular mult serial number.

All mults forged during this project were loaded into the furnace in numerical order and loaded with only one mult per furnace (the furnace has the capability of loading three rows). This procedure was deemed necessary in order to maintain identification of the mult as it exited from the furnace. Temperature and forging load readings were obtained and recorded during the following stages of the forging operation as listed below:

Temperatures: (All forging tasks.)

1. Mult at furnace exit (spot checks).
2. Mult just prior to preforming operation.
3. Preform Slug - just prior to piercing operation.
4. Pierce Bottle - just prior to drawing operation.
5. Forging - on coolout conveyor (spot checks).

Figure 1 exemplifies the stages of temperature recordings for items 2, 3 and 4 as stated above.

Forging Loads: (Task A & E)

1. Preform
2. Pierce
3. Draw

Figure 2 is an illustration depicting the various stages of forging for which load readings were acquired.

Utilization of Steel Processed

The identity and utilization of the mults parted during the various tasks of this project are listed below:

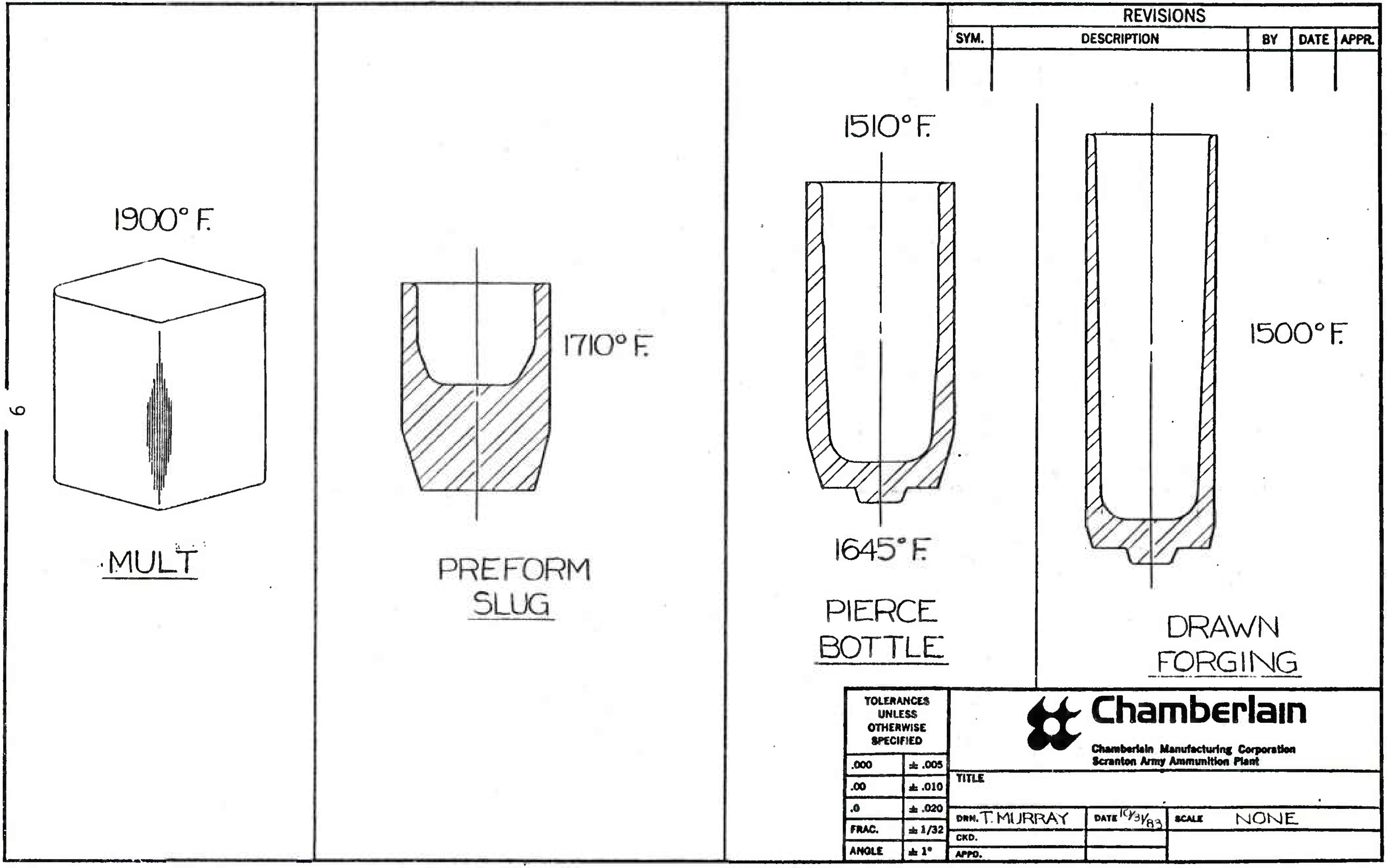


Figure 1. Various stages of forging operation for which temperatures were recorded.

* NOTE - Load values indicated are preliminary readings obtained at Task A. Refer to table 17 for accurate load values.

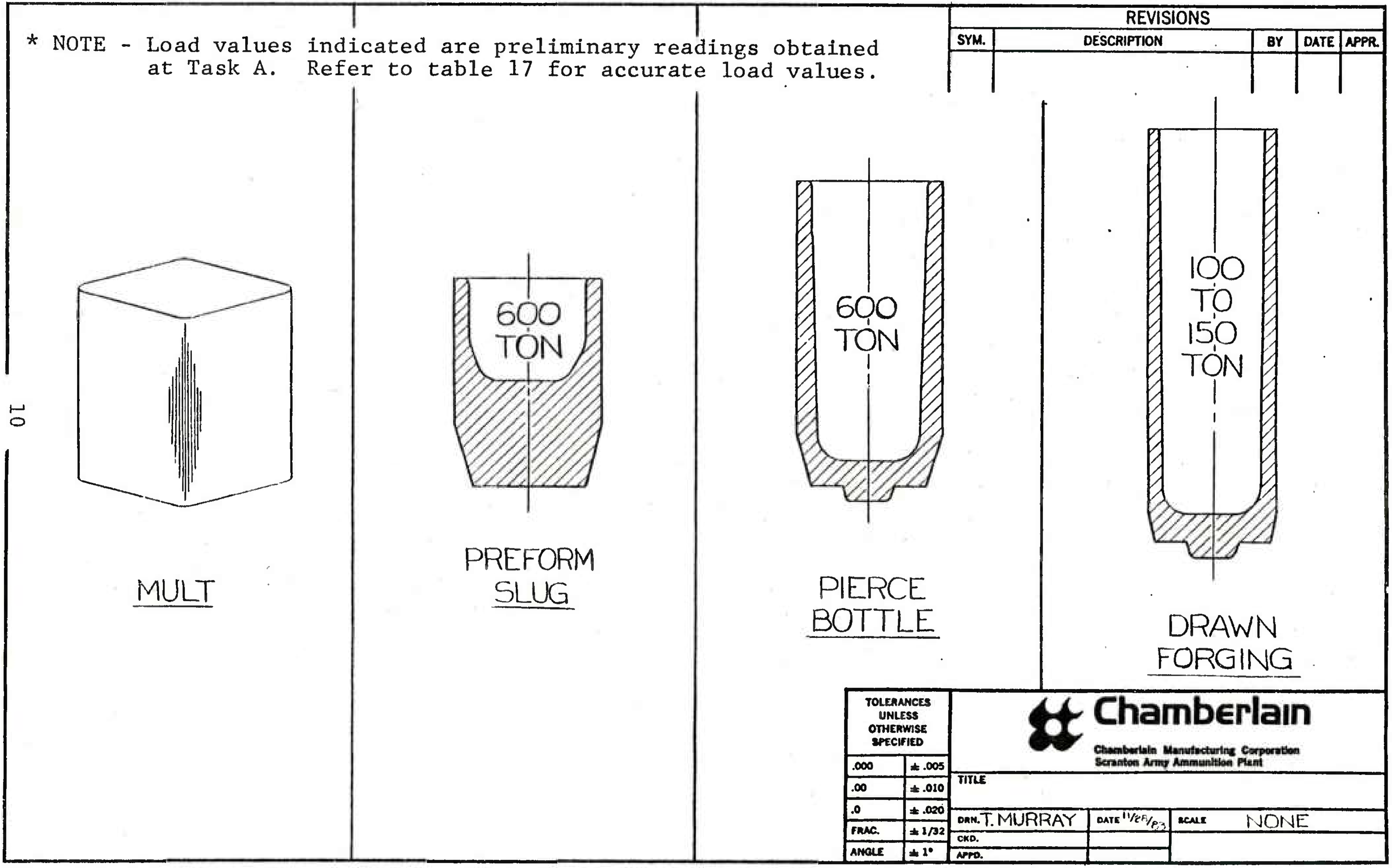


Figure 2. Various stages of the forging operation for which load readings were recorded.*

Task A

Vendor	Identity Heat #	Shell #'s
Republic	1	1 thru 23 & 40 thru 231
Bethlehem	2A	None
Bethlehem	2B	24 thru 39

Utilization

1. Optimization of the forging operation (Task A).

2. Evaluation of the need for a spheroidize annealing process (Task C).

3. Investigation of "rough turn" tooling material and designs and equipment feeds and speeds. (Prerequisite to Task D.)

4. Processing through "nosing operation" to evaluate the design dimensions of the "rough turned" shape (confirmation of Task A).

Task B

Vendor	Identity Heat #	Shell #'s
Republic	1	232 thru 295 & 424 thru 504
Bethlehem	2A	296 thru 338, 403 thru 423 & 505 thru 582
Bethlehem	2B	339 thru 402 & 583 thru 648

Utilization

1. Dimensional and metallurgical evaluation to determine the effects of the parting method on the steel (Task B).

2. Evaluation of the need for spheroidize anneal of forgings (Task C).

3. Optimization of rough machining process (Task D).

Task E

Vendor	Identity Heat #	Shell #'s
Republic	1	649 thru 996
Bethlehem	2A	997 thru 1277
Bethlehem	2B	1278 thru 1552

Utilization

1. Processing a suitable quantity of mults up to and including the optimization of Task D at or near normal production conditions to further evaluate the process with regard to Tasks A thru D.

OPTIMIZATION OF THE FORGING PROCESS (TASK A)

Process Development

The "Hot Forge Heat Treat" design process of any projectile begins with the review and analysis of the required finished part and the equipment available, or required, to produce that part. Since the M549 was the test vehicle for this project, the ordnance drawing of the finished projectile, figure 3, was reviewed and analyzed to determine what, if any, manufacturing problems might be encountered during production.

Areas of concern included:

1. The length of the ogive section of the projectile with its relatively thin finished wall section.

2. The sudden transition from the thin wall section of the ogive to the thicker wall section at the bore diameter, figure 4.

3. The possibility of the shell wall "buckling" at the base of the ogive during the "nosing" operation, figure 4.

A concession that had to be made, due to Item #1, was to add more material to the ogive as it decreases in diameter. Allowing that extra material enabled the rough turned piece to be made thicker in this area. This was necessary because the wall thickens as the nosing process takes place and the as-rough turned wall could have gotten too thin to support the load and "fold" up.

Continuing with the design of the "as nosed" shape, additional material was again added to the finished projectile configuration to provide material allowances for the "finish turn machining operation". The desired "as nosed" shape is

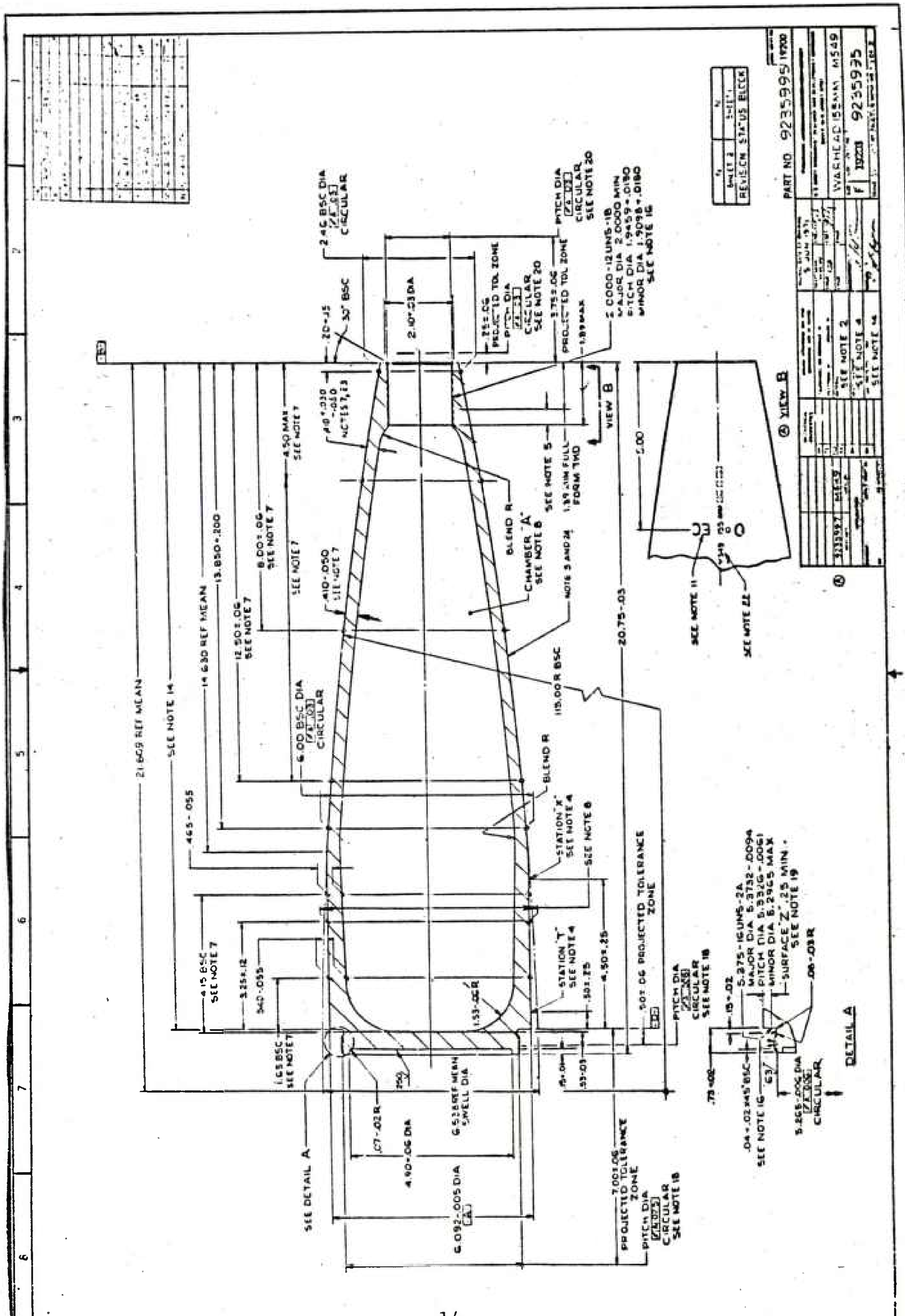


Figure 3. Ordnance drawing M-549

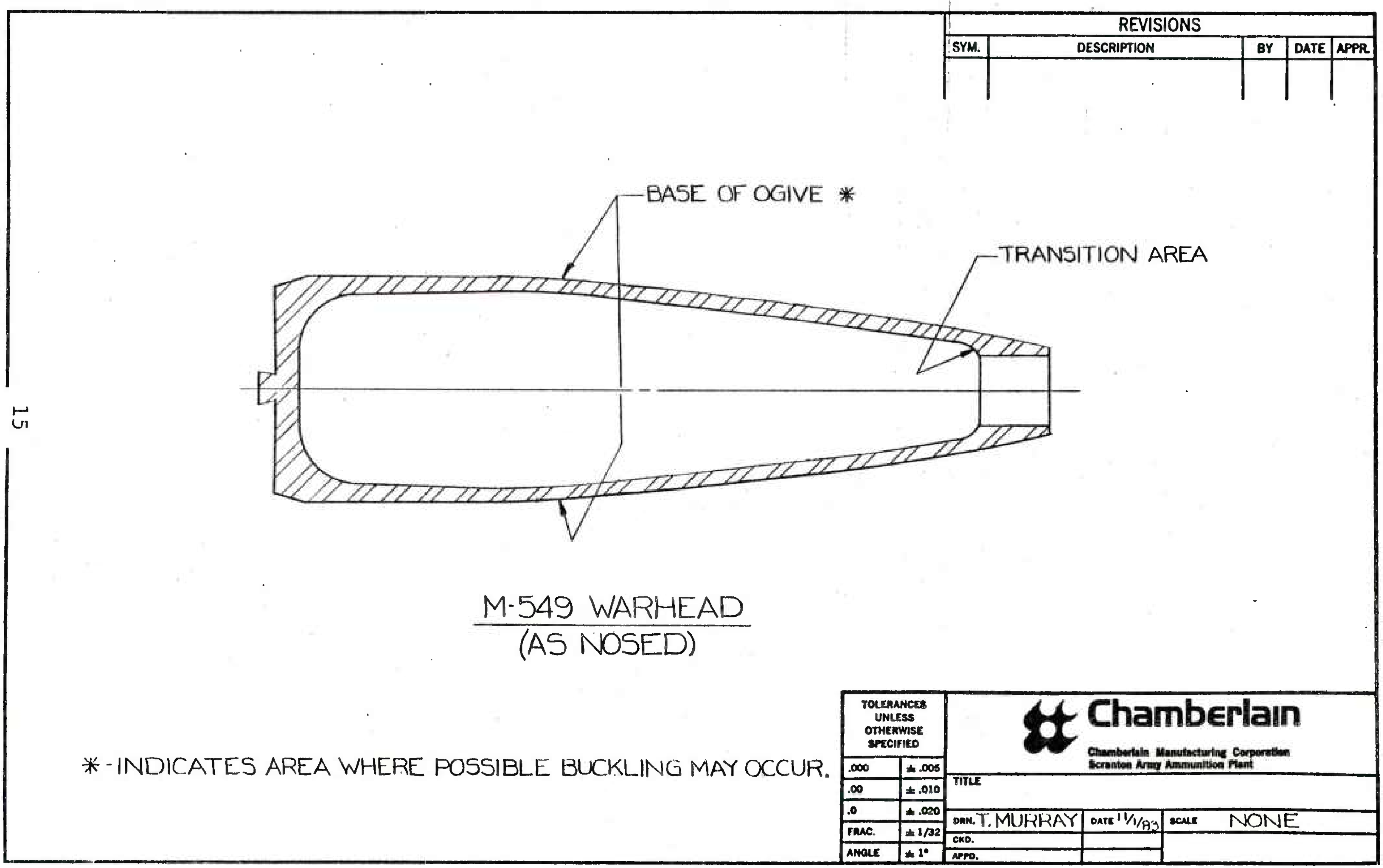


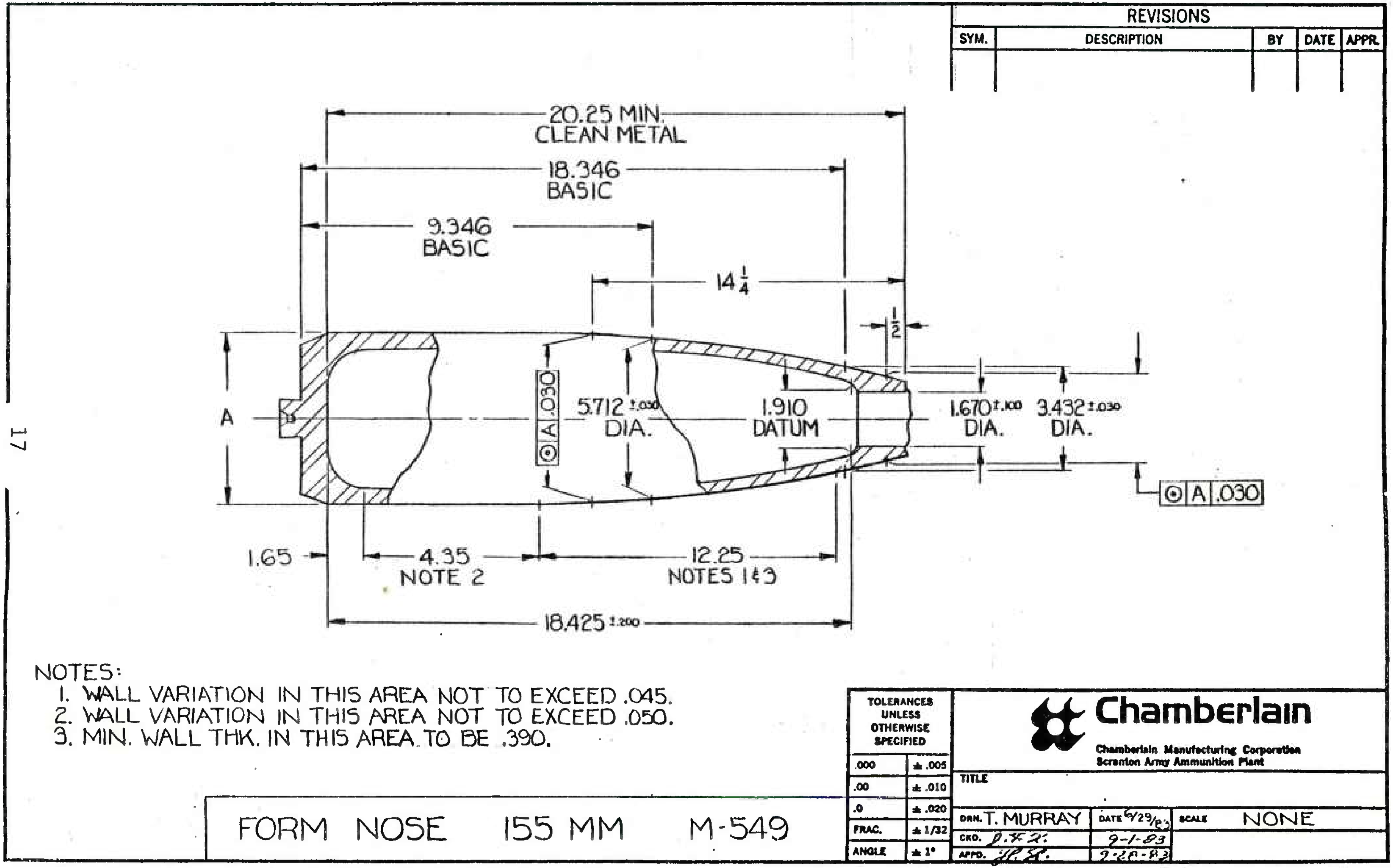
Figure 4. Sketch illustrating location of sharp transition and area where possible shell wall buckling may occur.

depicted in figure 5.

Unlike most shells, where the transition from the ogive to the bore diameter area of the shell is gradual, the M549 has a sharp and sudden transition. This condition, coupled with the thin to thick change in wall section, as per Item #2, might prove it difficult to obtain the desired internal profile at the bore diameter area during the nosing operation. Due to the sharp transition of the ogive into the bore area, a contoured crown was added to the open end outside diameter of the rough turned can. "Trial and error" is the most positive method available to determine the exact location of where the "crown" is to be placed in order to obtain the proper bore diameter and profile, In some cases, many trials and corrections must be made to the "rough turn can" in order to obtain the required configuration of the nosed shell. Based on past experience, a preliminary design of the rough turned shape is illustrated in figure 6.

The possibility of the shell wall buckling, at the base of the ogive, during the nosing process, is always a concern with thin walled projectiles such as the M549. Based on the designed dimensions of the as nosed and rough turned shapes, and a predicted nosing temperature of 816°C (1500°F), initial nosing load calculation revealed that the nosing force required to successfully nose the shell would be approximately 2.3 MN (259 tons). The force required to cause buckling at the base of the ogive was calculated to be approximately 2.5 MN (280 tons), indicating that buckling would not occur if the nosing temperature was maintained at 816°C (1500°F) or above.

Having analyzed the possible problem areas associated with this projectile and material, continuation of the design process proceeded with the development of the as-forged configuration. This entailed adding material allowances to



NOTES:
1. WALL VARIATION IN THIS AREA NOT TO EXCEED .045.
2. WALL VARIATION IN THIS AREA NOT TO EXCEED .050.
3. MIN. WALL THK. IN THIS AREA TO BE .390.

FORM NOSE 155 MM M-549

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	±.005
.00	±.010
.0	±.020
FRAC.	±1/32
ANGLE	±1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE

DRN. T. MURRAY	DATE 6/29/83	SCALE NONE
CKD. J.F.R.	9-1-83	
APPD. J.R.S.	9-28-83	

Figure 5. "As nosed" shape.

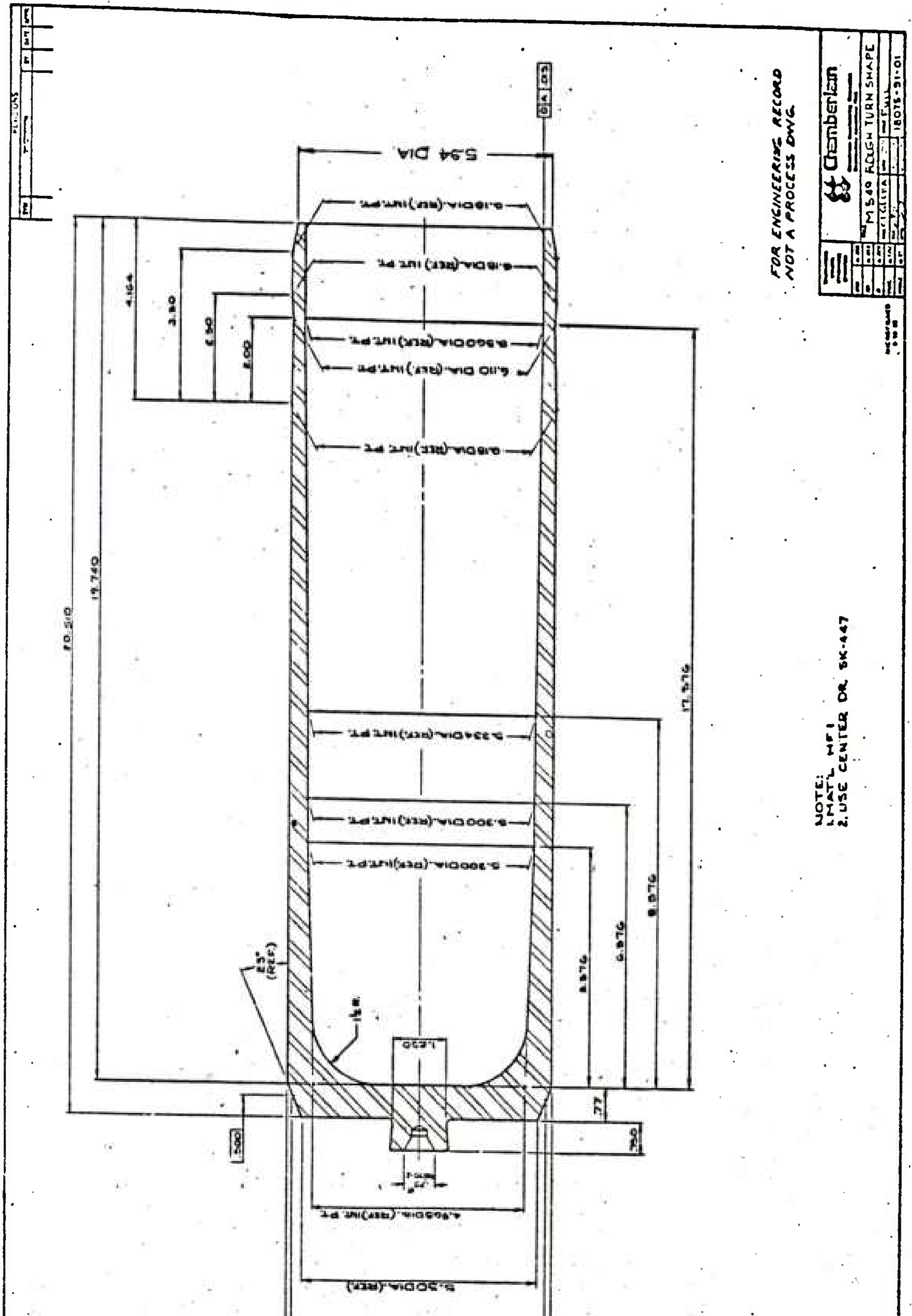


Figure 6. Rough turned shape.

the developed rough turn shape to provide material for forging eccentricity and rough turn machining. The desired as-forged configuration is presented in figure 7.

Based on the as-forged dimensions, normal forging tolerances were added along with allowances for mult variation and scale loss to determine the proper mult weight of 30.8 kg (68 lbs.). Allowing 0.91 kg (2 lbs.) for kerf loss (the amount of material lost due to the sawing operation) the required purchased (ordered) mult weight would be 31.75 kg (70 lbs.).

Once the mult weight of 30.8 kg (68 lbs.) was established, the mult length, preform slug and pierce bottle were developed to complete the design process of the M549 projectile. The sequence of production is illustrated in figures 8 and 9.

Tooling Development

Upon completion of the design process of the M549 projectile, the required forging and nosing tooling was then developed.

Acknowledging the shape and dimensions previously developed for the preform slug, pierce bottle, drawn forging and the desired as-nosed shape, the tooling was designed with dimensional allowances added to compensate for process temperature.

Figures A-1 thru A-10, listed in Appendix A, depict the forge and nosing tooling that were used to produce the M549 projectile during this project.

Once the tooling components were developed, the gages that were required to check the dimensions at various process operations were designed and constructed.

The gages constructed and/or utilized (per process operation)

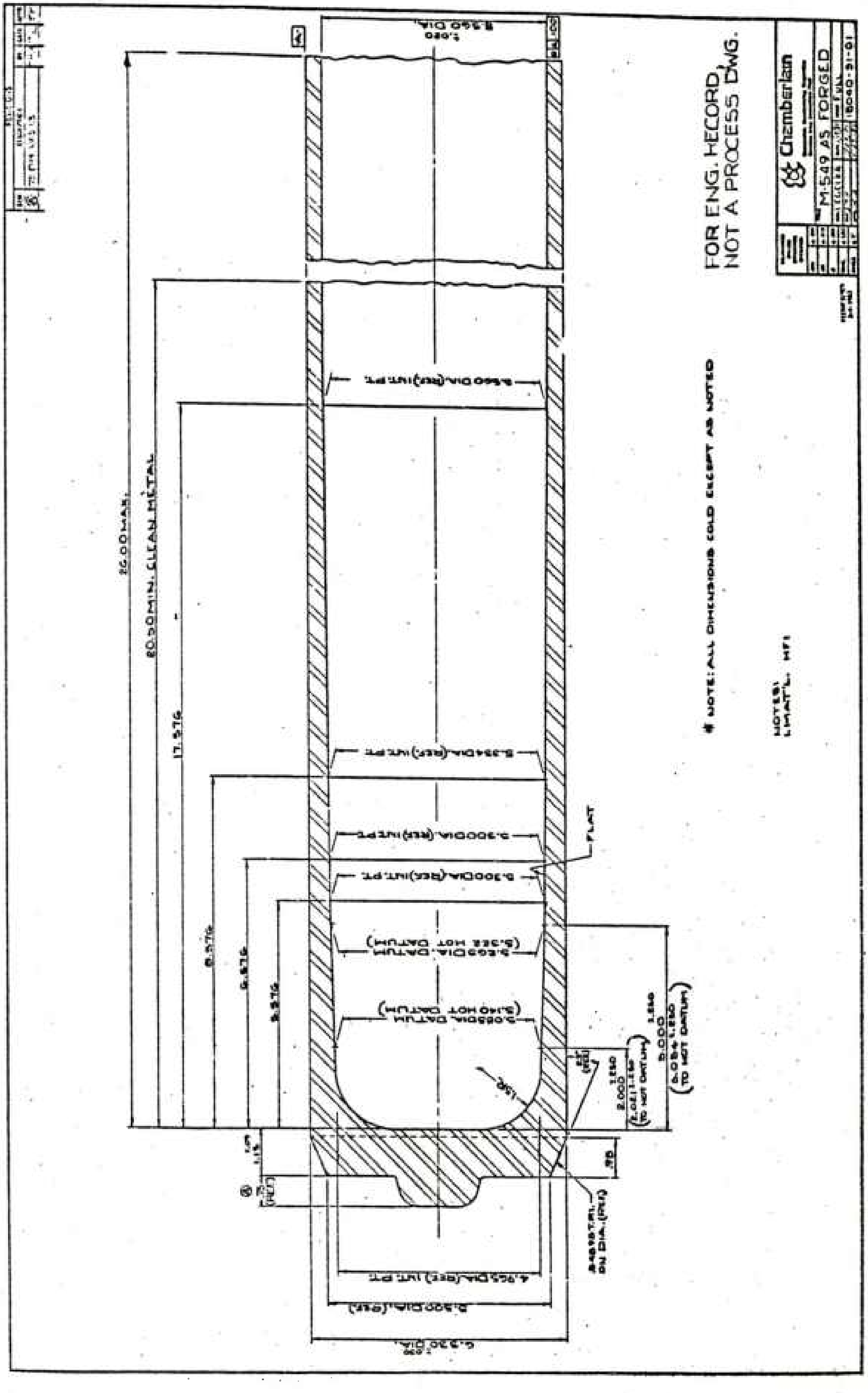


Figure 7. "As-forged" configuration.

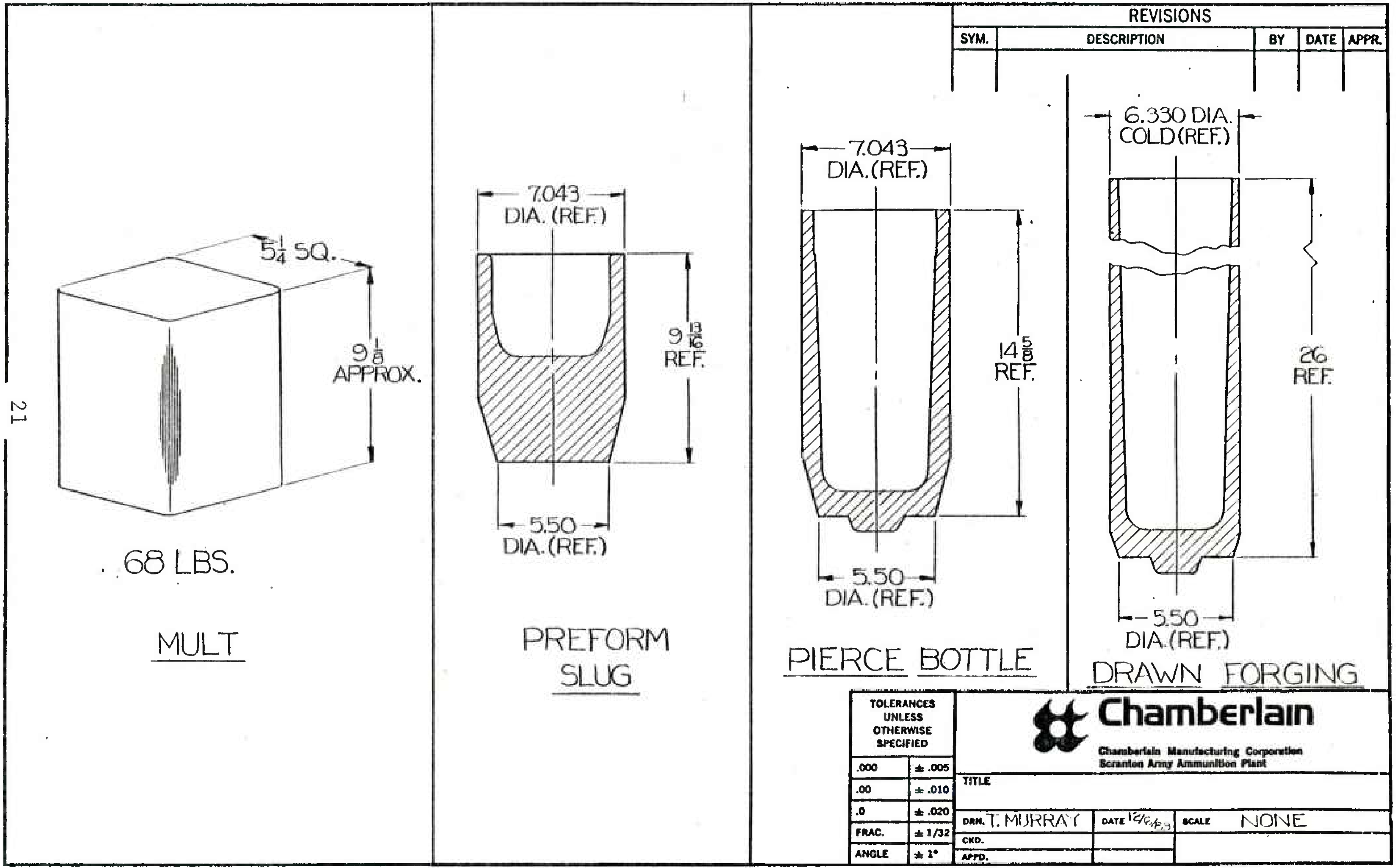


Figure 8. Forging sequence

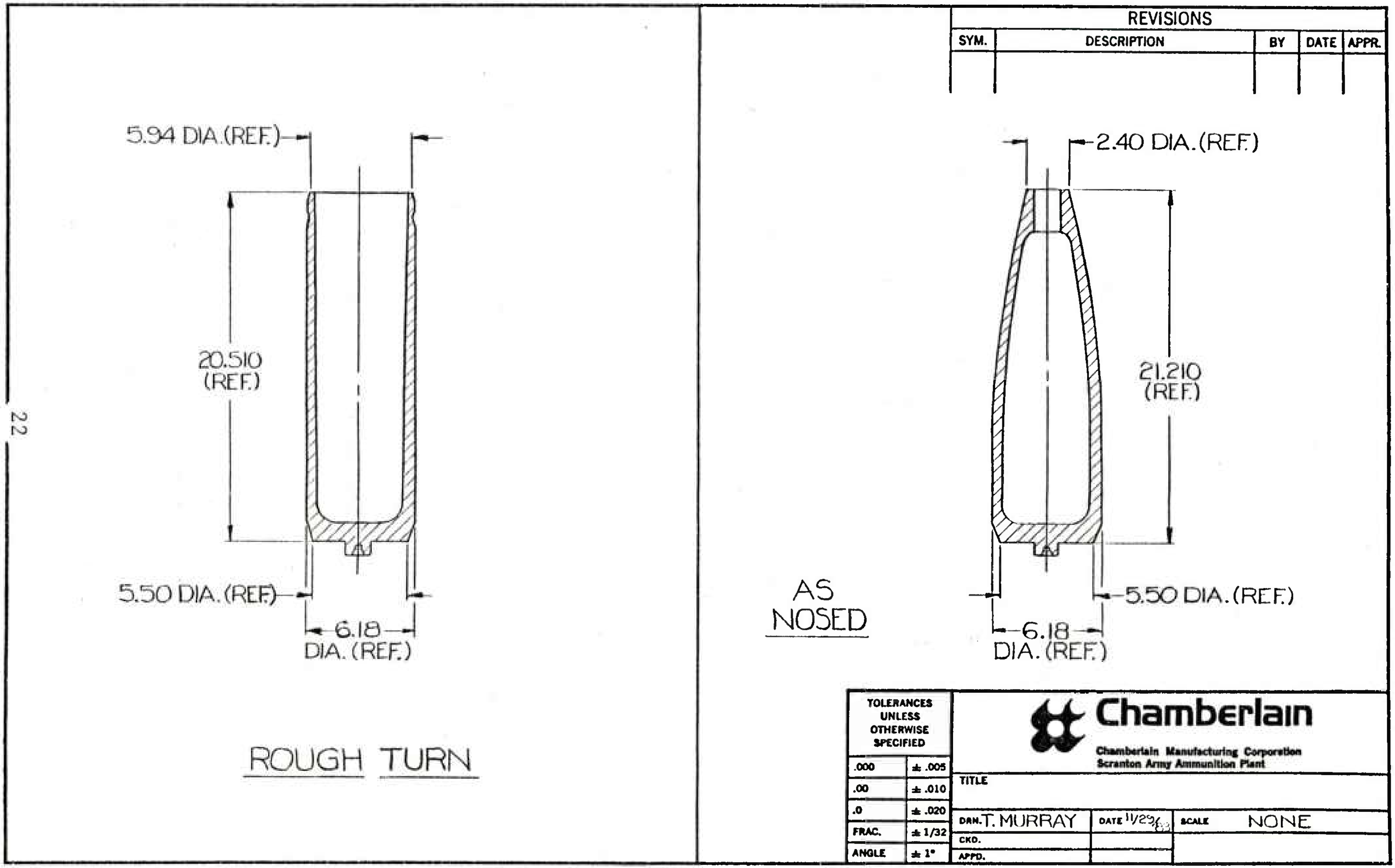


Figure 9. Rough Turn through Nosing sequence.

are listed below:

Forging (Hot) - Base thickness, cavity length, I.D. datum locations and eccentricity.
Forging (Cold) - Base thickness, cavity length, I.D. datum locations, eccentricity, I.D. and O.D. micrometers.
Rough Turn - Base thickness, overall length (3) O.D. snap gages & I.D. micrometers, wall thickness variation.
Nosing - Bore length, bore diameter, (2) O.D. datum diameter, wall thickness variation, cavity length.

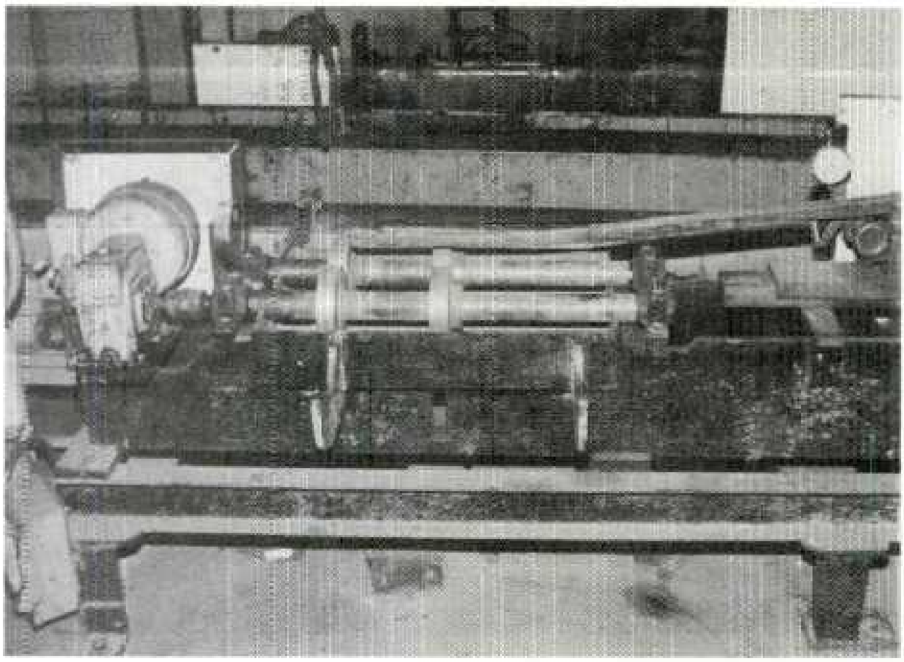
Some of the gages that were utilized during this project are presented in figures 10 thru 12, others are presented as sketches in figures B-1 thru B-5, Appendix B.

Testing Stages

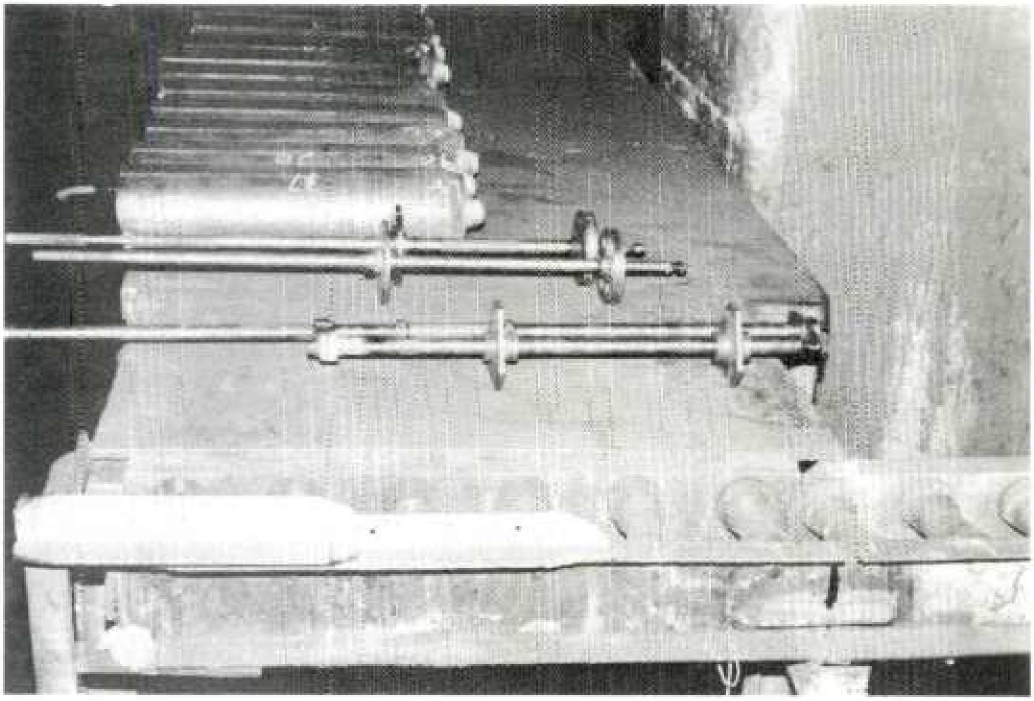
Parting Operation

All mults utilized for this task (231 pcs.) were parted by means of sawing on Metalcut XII and XIV cut-off saws equipped with 28" diameter x 50-tooth carbide tipped saw blades. Due to its flexibility over other forms of mult parting, the cut-off saw was used in order to obtain more accurate weight control of the mults during the initial testing stage (fig. 13).

Although design calculations established the weight of the mult to be 30.84 kg (68 lbs.), mult weight for this task was targeted at 32.2 kg (71 lbs.) in the sawing operation. The additional weight was added to allow for any unforseen problems that might occur during forging. This action is standard practice in the process development of any projectile.



A. Eccentricity gage (wall thickness variation).



B. I.D. datum gages (Top of Photo) Base Thickness Gage.

Figure 10. Photographs depicting some of the gages utilized for inspection of the forging.

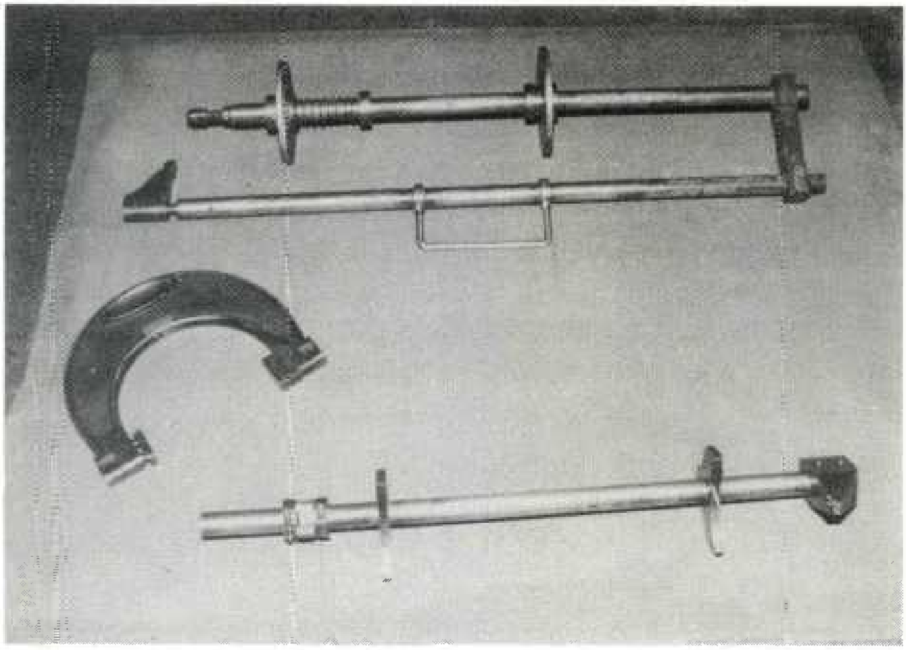


Figure 11. Photo depicting the "base thickness" gage (top), "O.D. snap" gage (middle) and "overall length" gage employed at the Rough Turn operation.

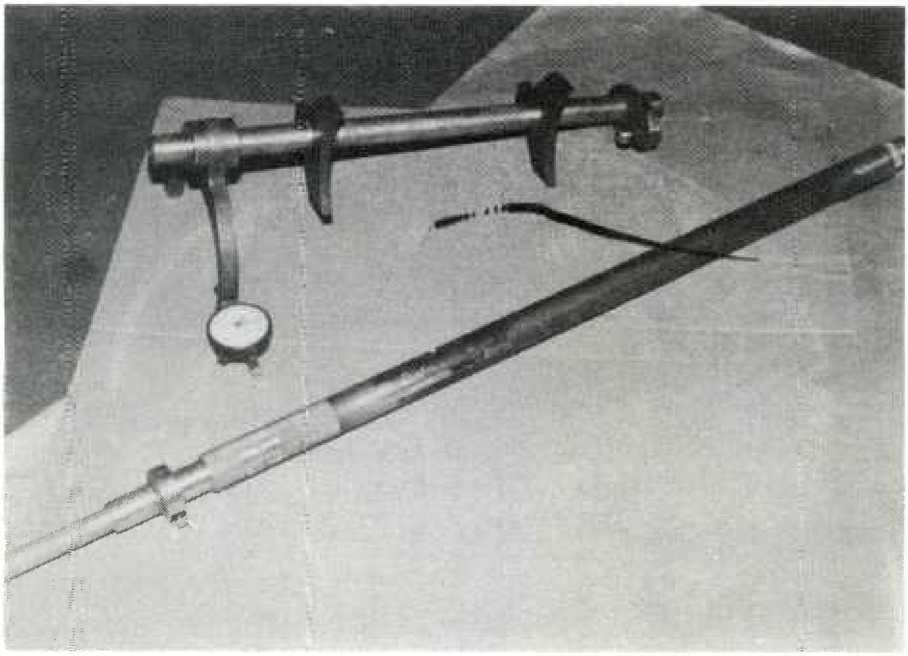


Figure 12. Photo depicting O.D. datum gage (top) and bore length gage utilized at the Nosing operation.

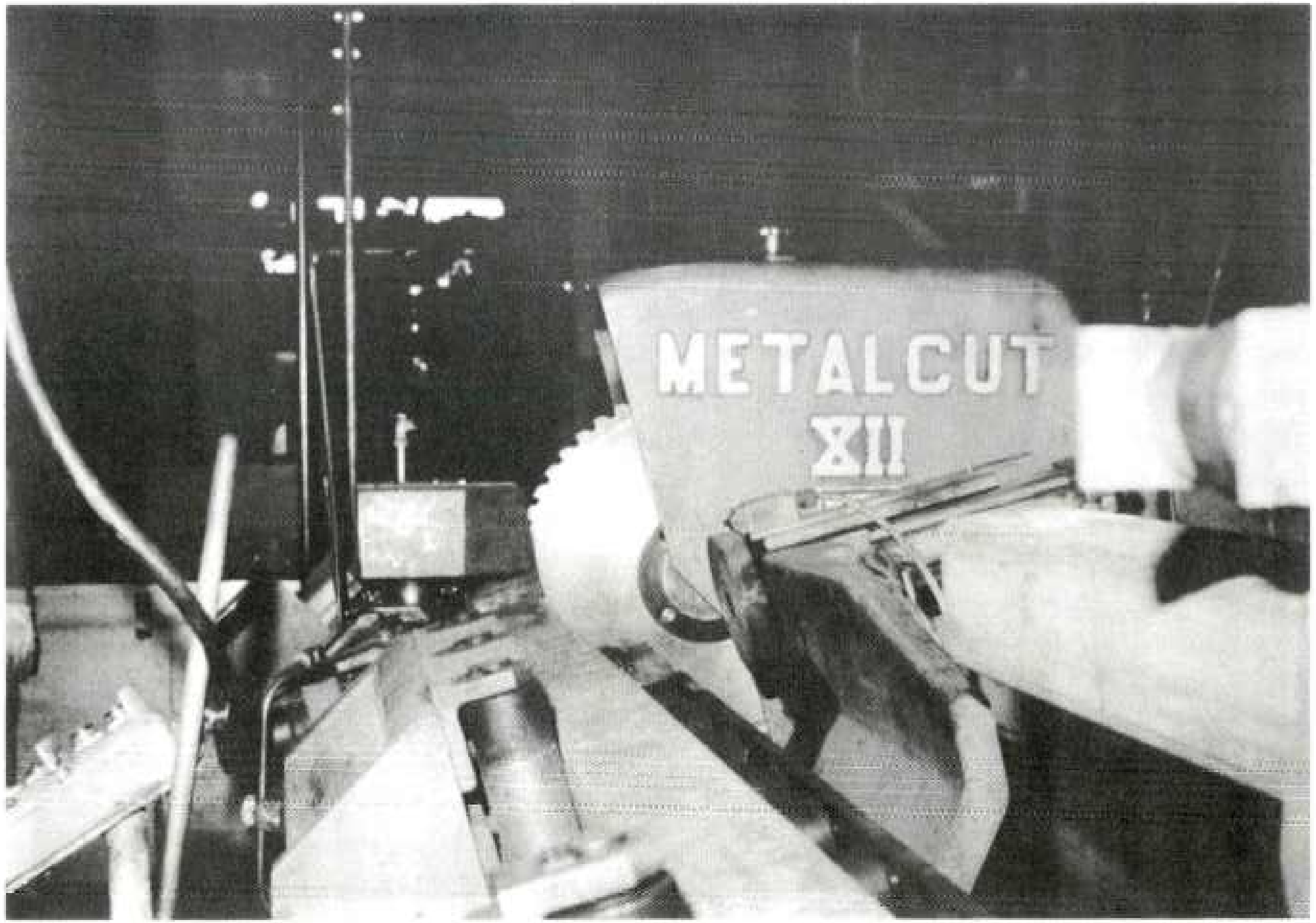


Figure 13. Photo depicting the Metalcut XII saw utilized for sawing the M-549 billets (HF-1 steel).

Due to the difference in the cross-sections and the conditioning of the steel as received from the two (2) steel vendors, a representative billet from each vendor was sawed, measured for length and weighed for a preliminary assessment of consistency. The billet supplied by Republic Steel Cc. yielded mults that averaged 231.77 mm (9-1/8") in length and 32.88 kg. (71.4 lbs.) in weight. The Bethlehem Steel Co. billet yielded mults that also averaged 231.77 mm (9-1/8") in length but 31.52 kg. (69.5 lbs.) in weight. The weight values are both within standard steel mill tolerances, but a weight tolerance on the plus side is preferable.

Forging Operation

Equipment

All mults processed during this project were heated to temperature in a Surface Combustion direct-fired rotary hearth furnace (figures 14 and 15), and forged on an Erie hydraulic press line consisting of a 7.11 MN (800 ton) capacity preform press, 7.11 MN (800 ton) piercing press and a 3.55 MN (400 ton) drawing press arranged in tandem (figures 16 thru 18). The following are the specifications of the three (3) presses:

Preform Press

Capacity: 7.117 MN (800 ton)
Stroke: 1.829 M (72 in.)
Ram Diameter: 0.711 M (28 in.)
Ram Area: 0.397 M^2 (615.75 in.^{2})
Ram Speed: 0.466 M/sec. 1100 IPM (Fast Advance)
0.059 M/sec. 140 IPM w/pump only.

Piercing Press

Capacity: 7.117 MN (800 ton)
Stroke: 1.829 M (72 in.)
Ram Diameter: 0.711 M (28 in.)
Ram Area: 0.397 M^2 (615.75 in.^{2})

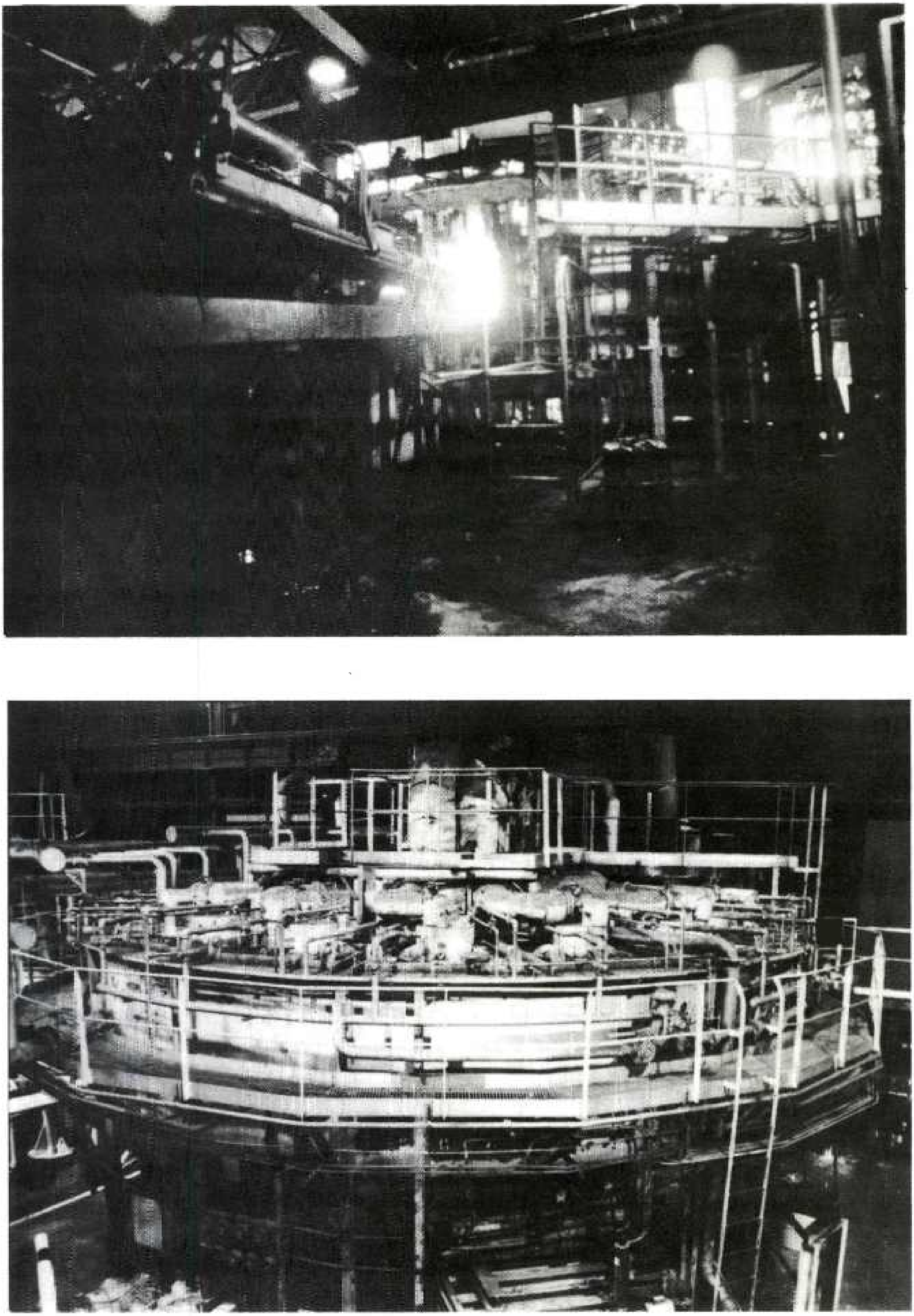


Figure 14. Photographs depicting discharge end (top) and rear view (bottom) of rotary hearth furnace.

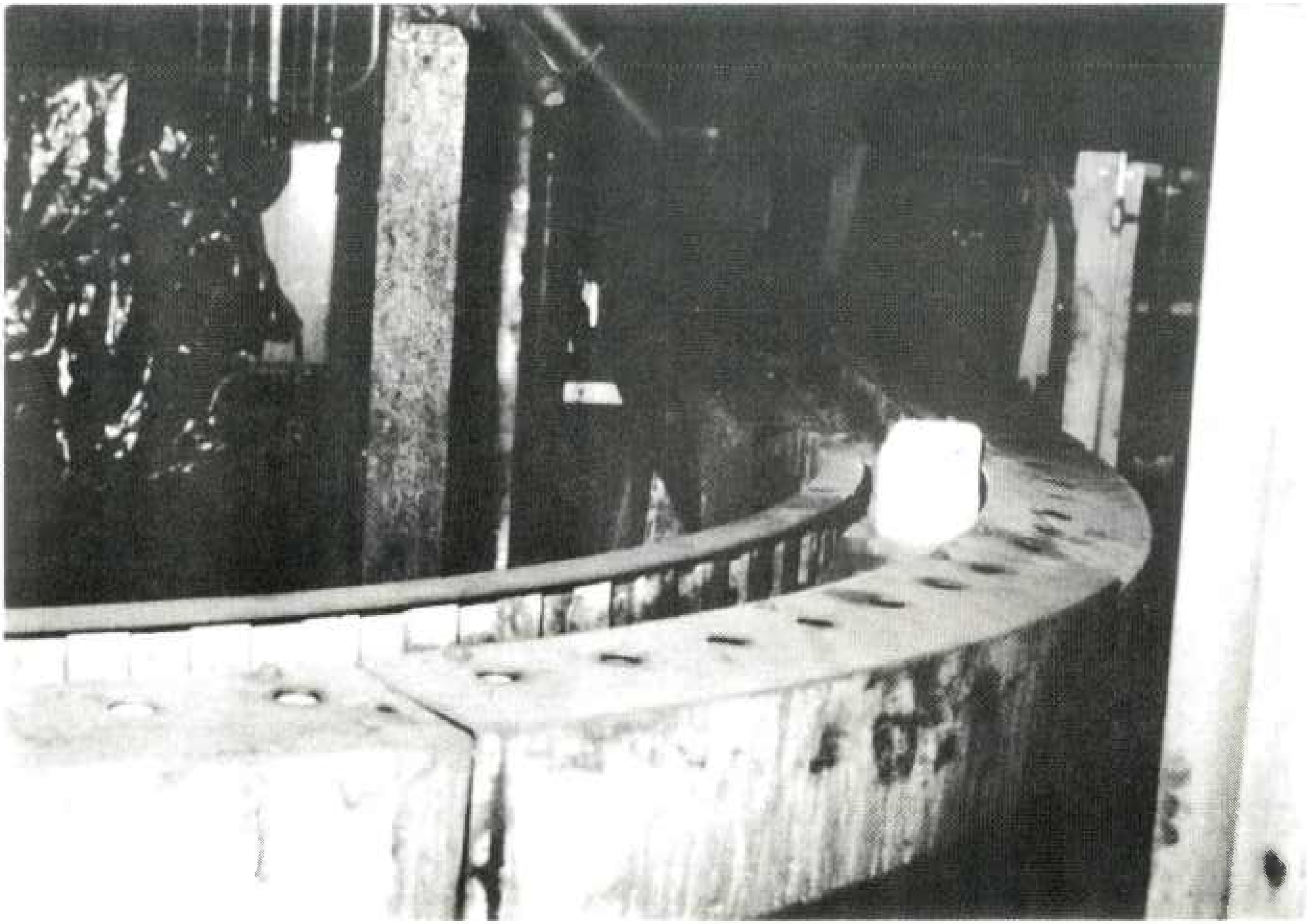


Figure 15. Photo depicting a heated mult on the furnace exit conveyor prior to entering the preform press.

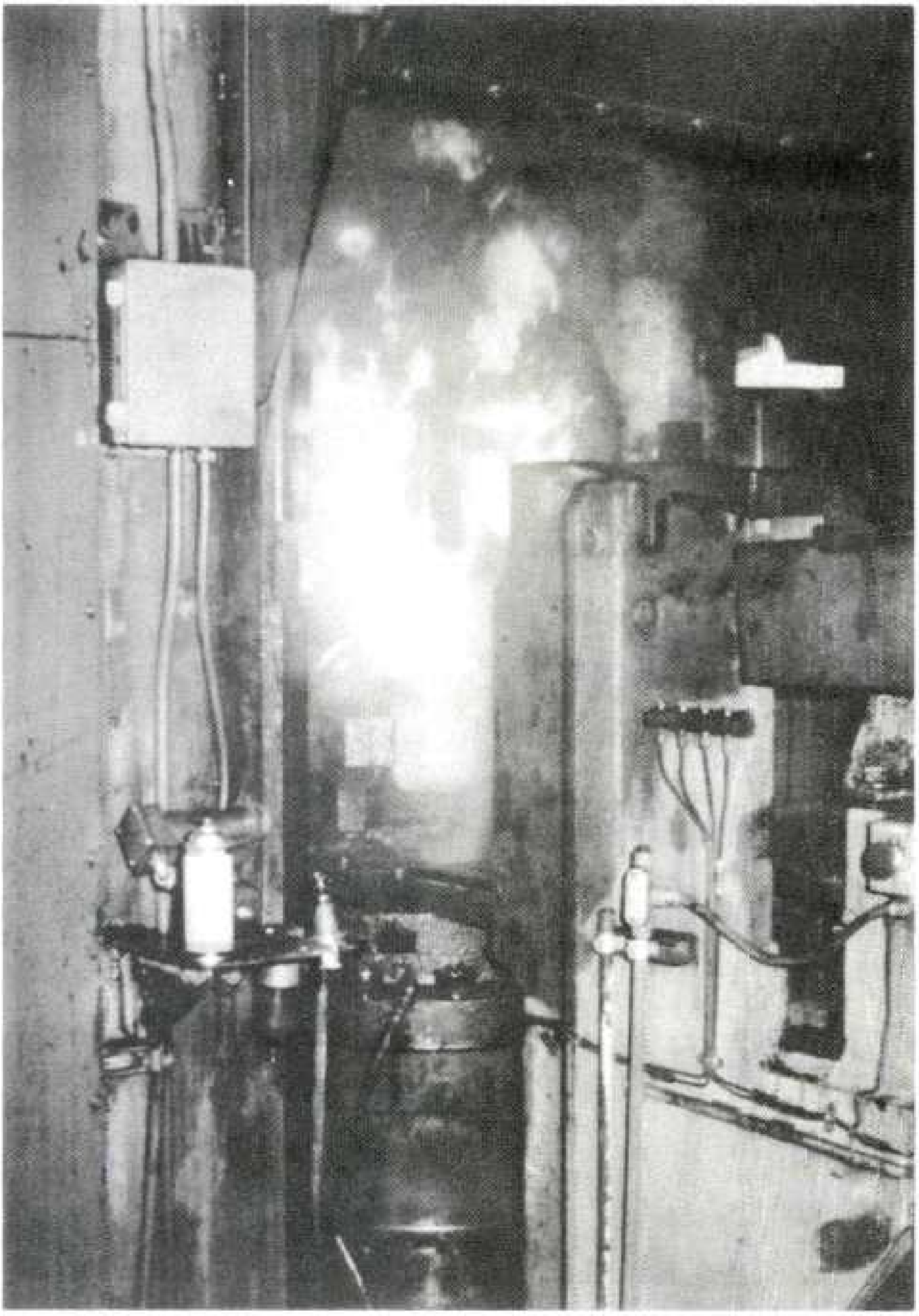


Figure 16. Photograph depicting the preformed "slug" as it exits the preform press die cavity.

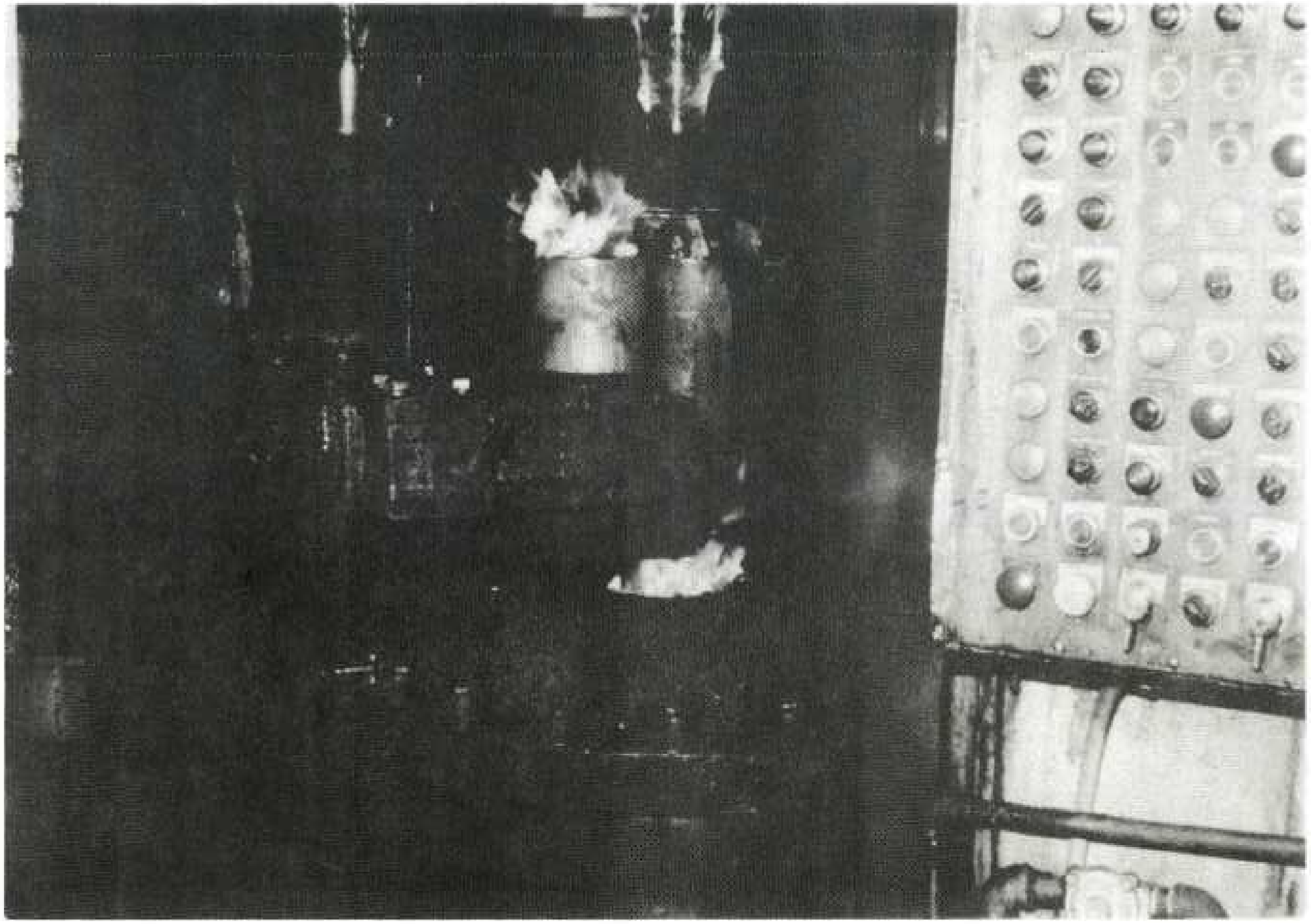


Figure 17. Photo revealing the pierce "bottle" (left) upon exit from the pierce press die cavity.

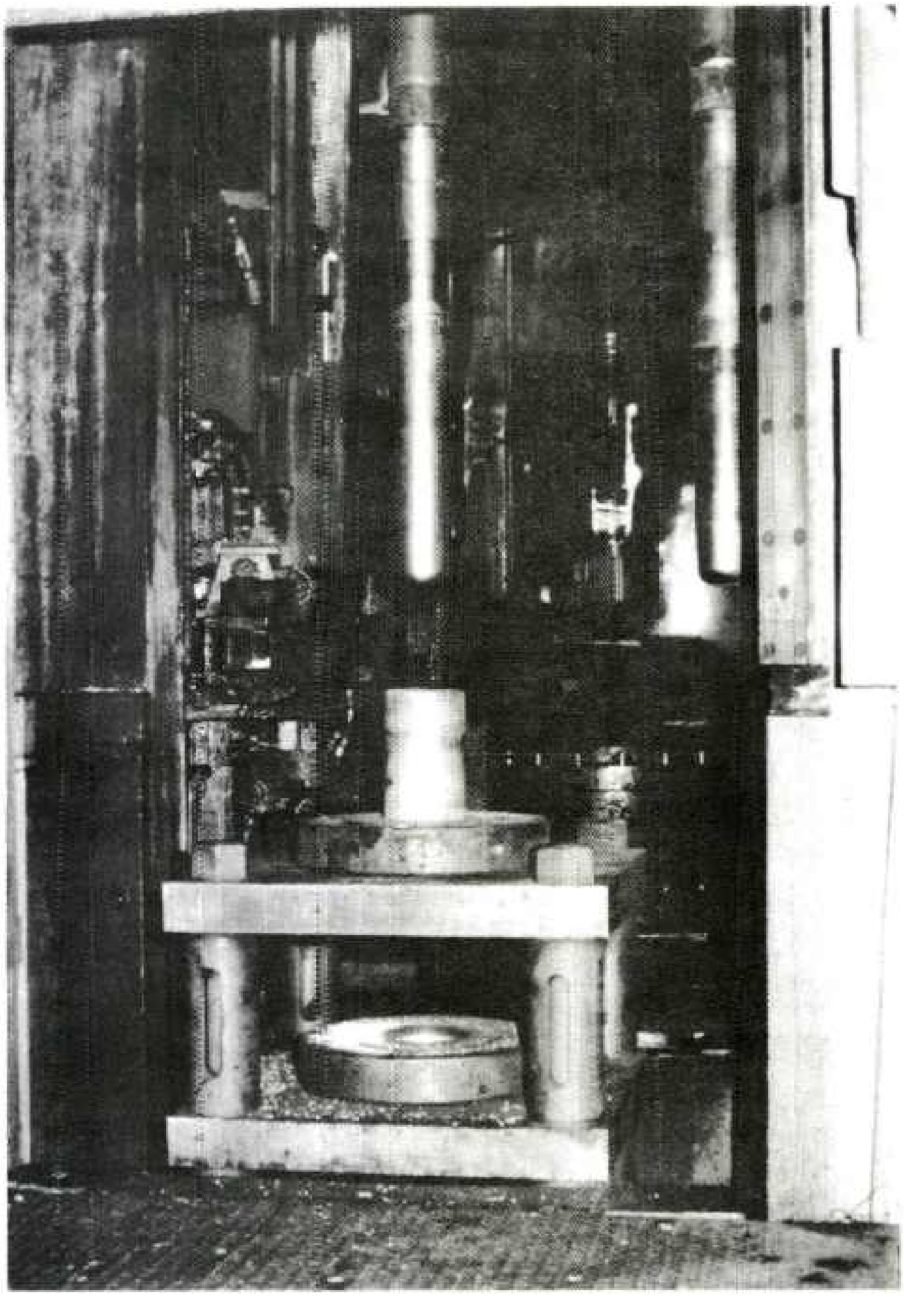


Figure 18. Photograph depicting the pierce "bottle" at the draw rings in preparation for the drawing operation.

Ram Speed: 0.466 M/sec. (1100 IPM) Fast Advance
0.254 M/sec. (600 IPM) w/ Accumulator
0.059 M/sec. (140 IPM) w/ pump only.

Drawing Press

Capacity: 3.55 MN (400 ton)
Stroke: 3.048 M (120 in.)
Ram Diameter: 0.508 M (20 in.)
Ram Area: 0.202 M^2 (314.16 $in.^2$)
Ram Speed: 0.466 M/sec. (1100 IPM) w/ Accumulator

Testing

Initial forging of the M549 was conducted on April 14th, 15th and 16th, 1981. A total of 227 sawed mults were forged during this testing period. Initially, furnace temperature was set at a maximum of 1149°C (2100°F). This setting was used so as not to exceed the maximum mult temperature of 1149°C (2100°F) required by the M549 warhead government drawings. Using a furnace temperature setting of 1149°C (2100°F) yielded a mult temperature of 1093°C (2000°F) as it exited the furnace.

During the first day of testing, fourteen (14) pieces were processed through the forging operation. Review of inspection data revealed that the forgings were all within predicted design dimensions and the remaining pieces were forged on the following two (2) days.

Representative temperature readings, obtained with the use of a two color infrared pryometer, were recorded as follows: (ref. fig. 1)

1038°C (1900°F) - Prior to preforming.
932°C (1710°F) - Prior to piercing.
896°C (1645°F) - At base area prior to hot draw.
821°C (1510°F) - At open end area prior to hot draw.

Representative forge load values (ref. fig. 2) were obtained from existing load gages that are part of the press proper. These gages revealed a load of 5.338 MN (600 ton) at the pierce and from 0.889 MN (100 ton) to 1.334 MN (150 ton) at the hot draw operation as the forging progressed through the three (3) draw rings. The load values obtained were questionable due to suspected inaccuracies of the existing gages. It was then decided that pressure transducers and recording instrumentation would be obtained and installed on the press line so that reasonably accurate forging load data could be obtained during the performance of Task E.

Cooling

Upon completion of the hot draw operation, the forgings were cooled from approximately 816°C (1500°F) down to room temperature in still air on the cooling conveyor (fig. 19). During normal production conditions, the forgings are cooled to approximately 177°C (350°F) on the conveyor, dipped in a water tank and then removed from the line in preparation for the cavity shot blast operation.

When conducting initial forging tests on any projectile, it has been the standard procedure (at the Scranton AA Plant) to load the forgings in consecutive order on the cooling conveyor basket carriers. This method was used to insure that all forgings cooled in the same manner and to maintain test integrity. The water tank is normally used during production

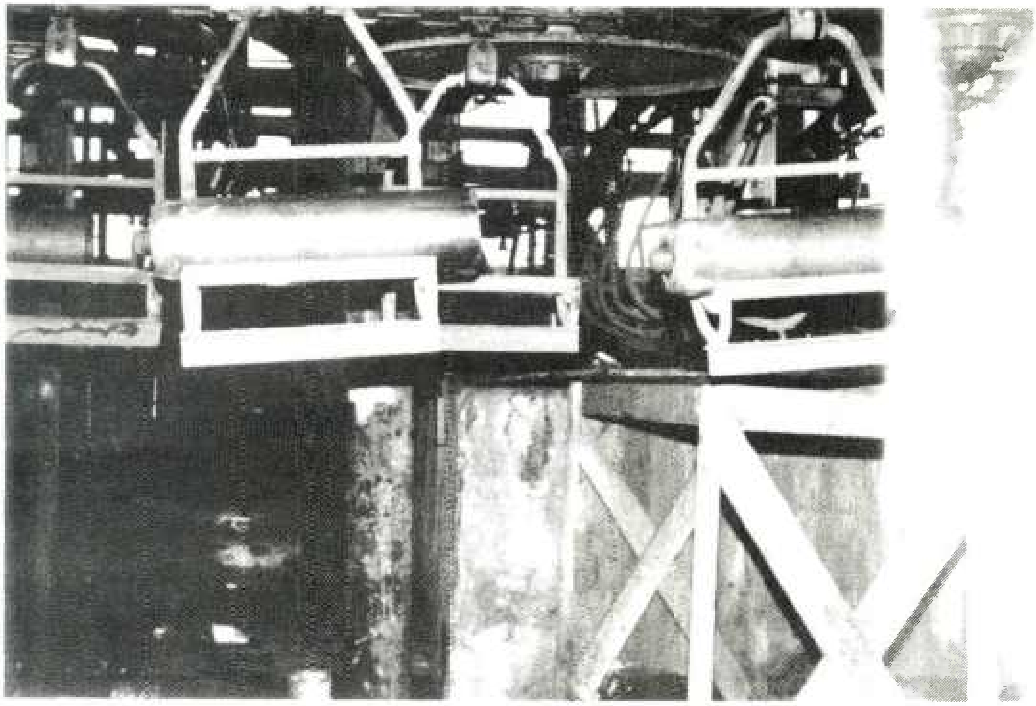


Figure 19. Photograph of M-549 shells on cooling conveyor.

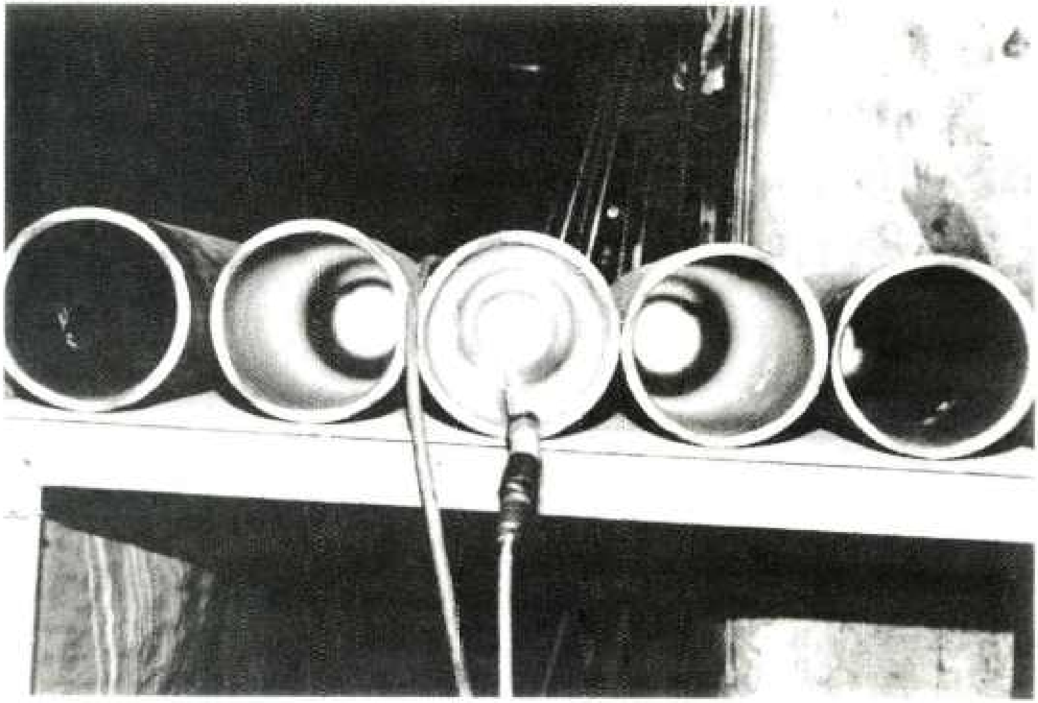


Figure 20. Photograph illustrating cavity condition of M-549 (HF-1)

only to insure that the shells are cool enough to handle when being unloaded from the conveyor.

It was anticipated that the difference in the way the forgings were cooled during this task (as compared to normal production methods) would be of no significance. Data and results obtained on this subject are presented in discussions of Task B in this report.

Inspection

All forgings produced met the standard inspection criteria of eccentricity, base thickness, datum diameters and length that were expected. Cavity conditions of the M549 forgings produced during this task, (fig. 20) were excellent. The forgings, both inside and out, exhibited more of a cold drawn appearance than that of hot forged. This is attributed to the reduced scaling which appeared to be characteristic of HF-1 during the performance of this task.

Metallurgical Evaluation of Forgings

Once the forgings were inspected, a representative forging was selected and evaluated for hardness. To evaluate the hardness, a full length section was cut from the forging. Hardness readings were obtained at one inch increments along the length of the section. The evaluation revealed a hardness of 32 Rockwell "C" at the base, progressing to a hardness of 39 Rc at the open end of the forging (see fig. 21).

The microstructure of the forging was evaluated by obtaining a half-inch section from an area approximately 76.2 mm (3 inches) from the base. It was then prepared and analyzed at 1000X magnification as presented in figure 22. Analysis of the sample showed the structure to be composed of

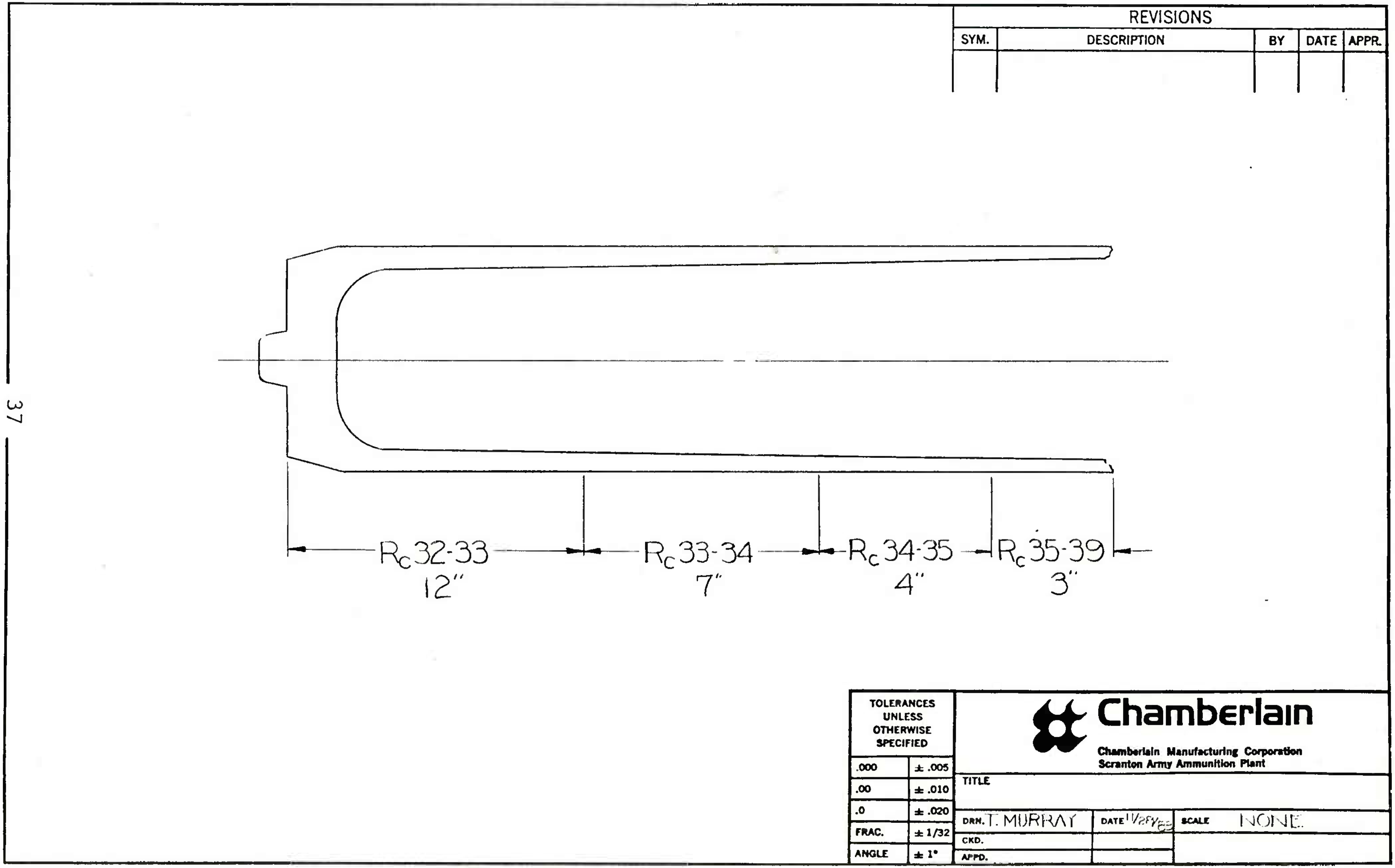


Figure 21. Illustration of hardness values for M-549 (HF-1) forging in the "as forged" condition.

Figure 22. Photomicrograph depicting the microstructure of a section from the M549 (HF-1) forging in the "as-forged" condition.

Mag. 1000X

approximately 90% fine pearlite and 10% coarse pearlite. There were no vivid white spots (which would indicate precipitated carbides) detected on the sample.

The hardness and microstructure evaluation indicate that the forging, as conventionally cooled, can be machined in this condition.

Spheroidize Anneal of Forgings

In preparation for Task C of this project, and also to aid in the optimization of the forging operation, 52 of the forgings produced from Heat #1 (Republic) steel, were processed through the spheroidize anneal cycle as outlined in the "Project Description" section of this report. The annealing process for this group of forgings was accomplished on a small batch basis utilizing Chamberlain's existing "tool room" furnaces. Total time to complete the required annealing cycle was 9-1/2 hours.

Hardness readings obtained from the spheroidize annealed forging revealed a Rockwell "B" hardness of 95 to 98 (Rc-18). Relating this to a conventionally cooled forging (as-forged condition) it would be roughly 53% as hard. (figure 23.)

A photomicrograph taken of a section of the annealed forging (figure 24) showed that the desired structure, consisting of spheroidal carbides in a ferrite matrix, was achieved.

This group of forgings was utilized as the control group for Heat #1 (Republic Steel) during the compilation of data for Tasks D and E.

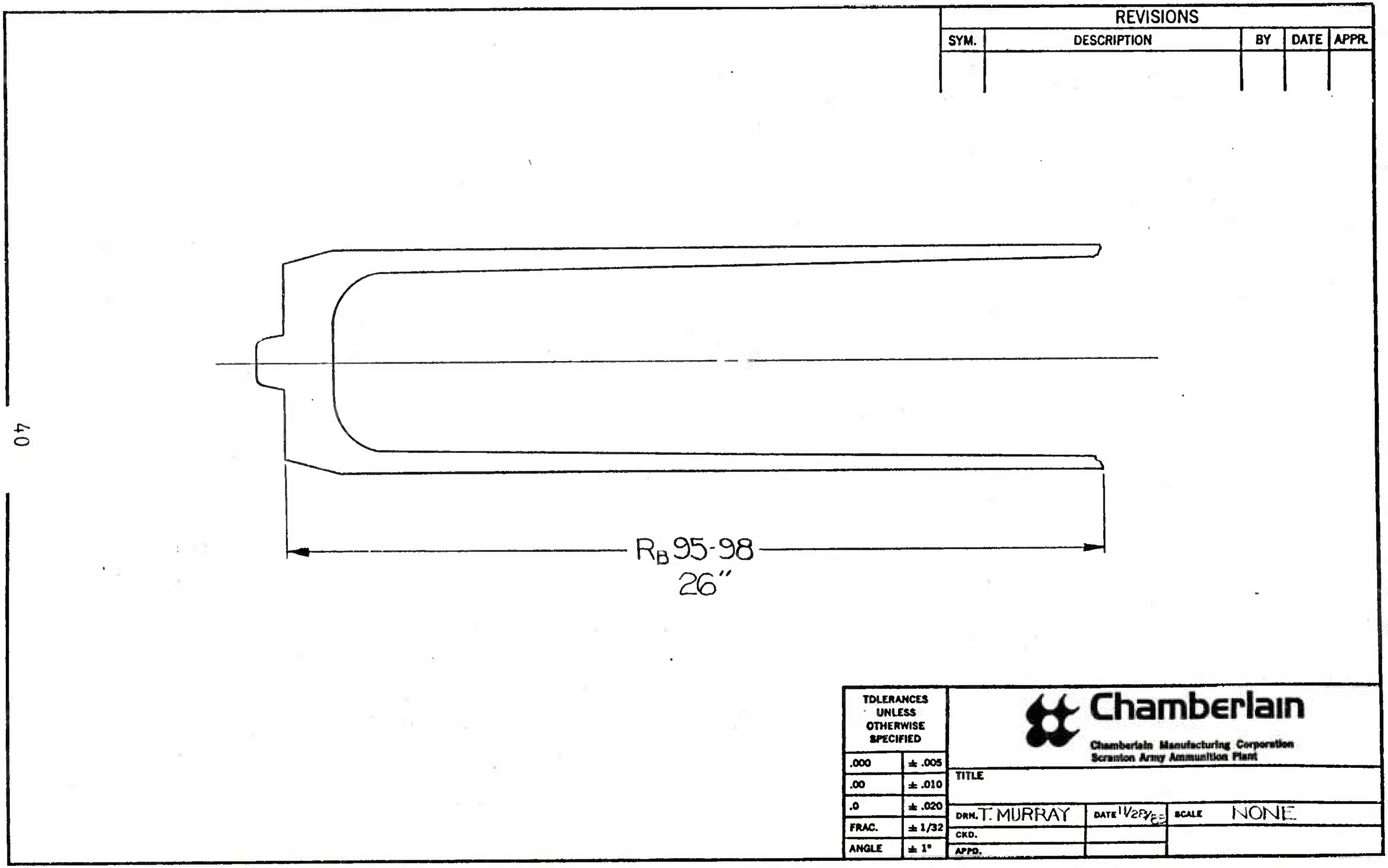


Figure 23. Illustration of hardness values for M-549 (HF-1) forging in the "spheroidized annealed" condition.

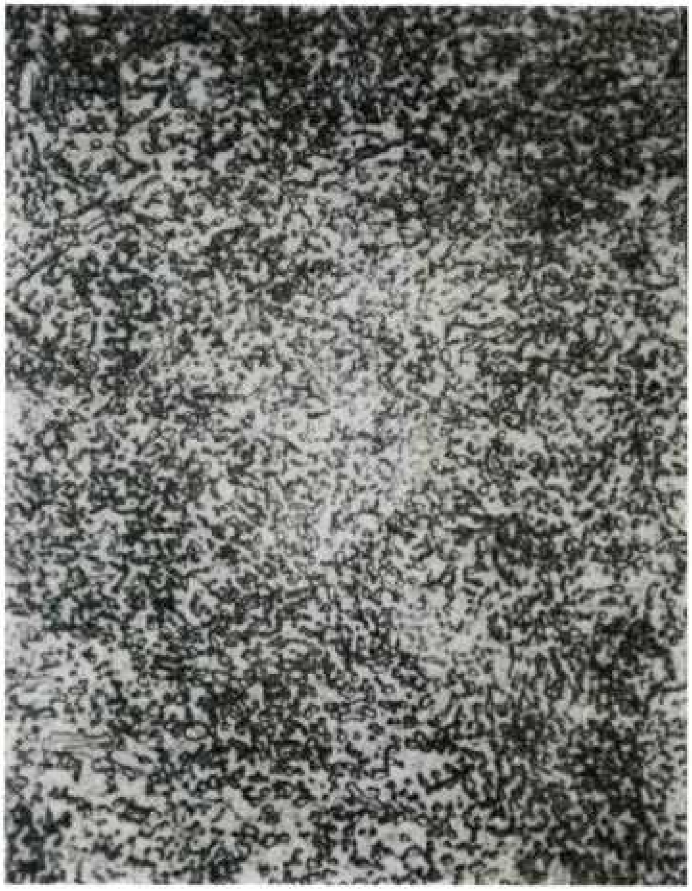


Figure 24. Photomicrograph illustrating the structure of a spheroidized annealed M-549 (HF-1) forging. Mag. 1000X.

Confirmation of the Forging Process

Center and Rough Turn Machining

All parts centered, rough turned and cut to length during this task were machined on a J & L N/C lathe chosen for its flexibility in making any changes that would be required.

A total of 80 forgings were rough turned during this task. All but two (2) of the forgings were machined in the as-forged condition.

No difficulty was encountered in machining these forgings using speeds and feeds compatible with the production rough turn equipment to be utilized in the performance of the remaining tasks of this project.

Nosing Operation

Although the nosing tests were not a requirement for this phase of the project, some parts had to be nosed to confirm that the desired as-nosed shape could be produced from the designed forging and rough turned shape.

Nosing tests were first conducted April 30, 1981 and were concluded August 13, 1981. The forgings utilized for the nosing tests were obtained from the group that was forged during Task A of this study.

Equipment

Nosing Press - (800 ton) capacity Bliss mechanical press with hydraulic cushion

Heat for Nosing - Westinghouse induction heating unit (originally designed for nosing the M107 projectile).

Heat Prior to Shell Lubrication - gas flame impingement.

Procedure

The rough turned can was first preheated to 93.3°C (200°F) and then sprayed with a water soluble graphite lubricant as presented in figure 25. After application of the lubricant, the rough turned can was inserted into the induction coil for a length of 76.2 mm (3 inches), heated for 12 seconds then inserted into the coil to a length of 342.9 mm (13-1/2 in.) and heated for a period of 18 seconds to attain an average nose-area temperature of 899°C (1650°F) to 927°C (1700°F) [figures 26 and 27]. This procedure was deemed necessary in order to properly heat the shell, since the M107 induction coil used was too short to properly heat the required length of the nosed portion of the M549 in one pass.

The part was then transferred to the Bliss mechanical press where the nosing operation was then performed. (figure 28.)

Temperatures of the part prior to nosing were obtained with the use of an infrared two-color pyrometer, while nosing loads were obtained from existing gages located on the press proper.

Testing

The forgings utilized to perform the nosing tests were obtained from the group that was produced during Task A of this study and were in the as-forged condition. Approximately fifty (50) nosed pieces and twelve (12) different rough turn can contour changes were needed to establish the proper bore length. The following thirty (30) shells were nosed in the refinement of the body dimensions of the as-nosed piece, and also, for the purpose of trying to alleviate wall thickness variations

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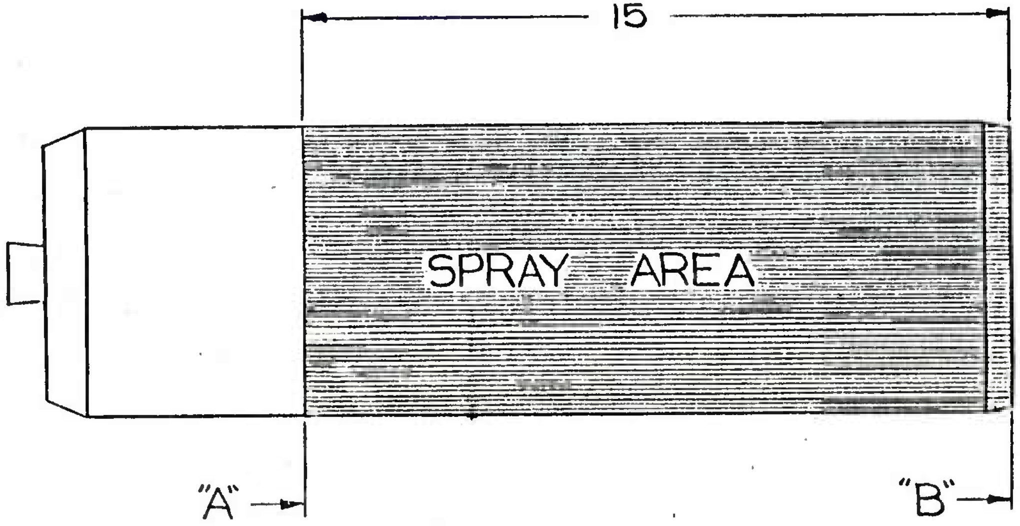


NOTES:
1. START SPRAYING AT "A" AND CONTINUE TO "B".
2. LUBRICANT: WATER SOLUBLE GRAPHITE.
3. SHELL MUST BE PREHEATED TO 200° F. PRIOR TO SPRAYING MIXTURE.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

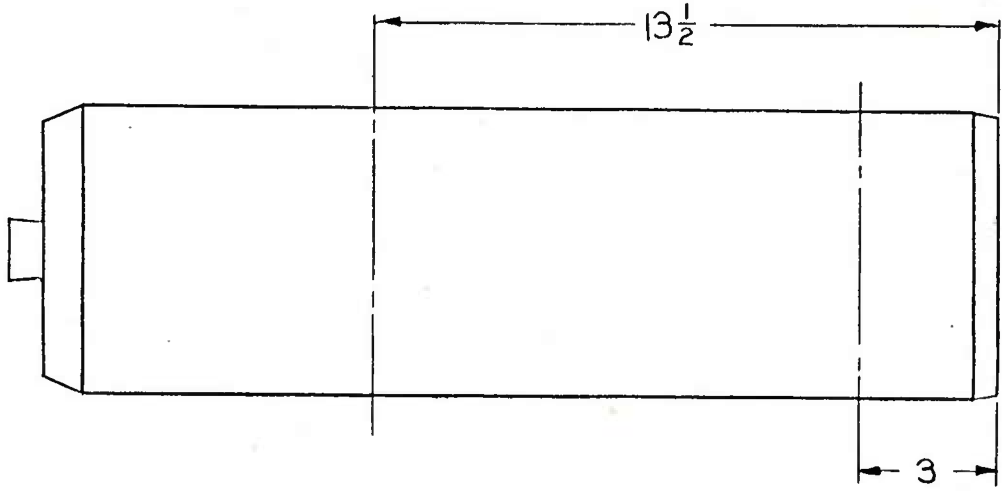
TITLE

GRAPHITE SPRAY 155 MM M-549

DRN. T. MURRAY	DATE 1/25/83	SCALE NONE
CKD.	9-1-83	
APPD.	9-28-83	

Figure 25 Application of graphite lubricant.

REVISIONS				
SYM.	DESCRIPTION	BY	DATE	APPR.



NOTE:
INSERT SHELL INTO INDUCTION COIL 3". HEAT SHELL FOR 12 SEC., THEN INSERT SHELL INTO INDUCTION COIL 13½" AND HEAT SHELL FOR 18 SECONDS. SHELL TEMP. TO BE 1650° F. UPON EXIT FROM COIL.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE
HEAT NOSE 155 MM M-549

DRN. T. MURRAY	DATE 1/25/83	SCALE NONE
CKD.	9-1-83	
APPD.	2-28-83	

Figure 26. Heating of Rough Turn Can for preparation of Nosing Operation.

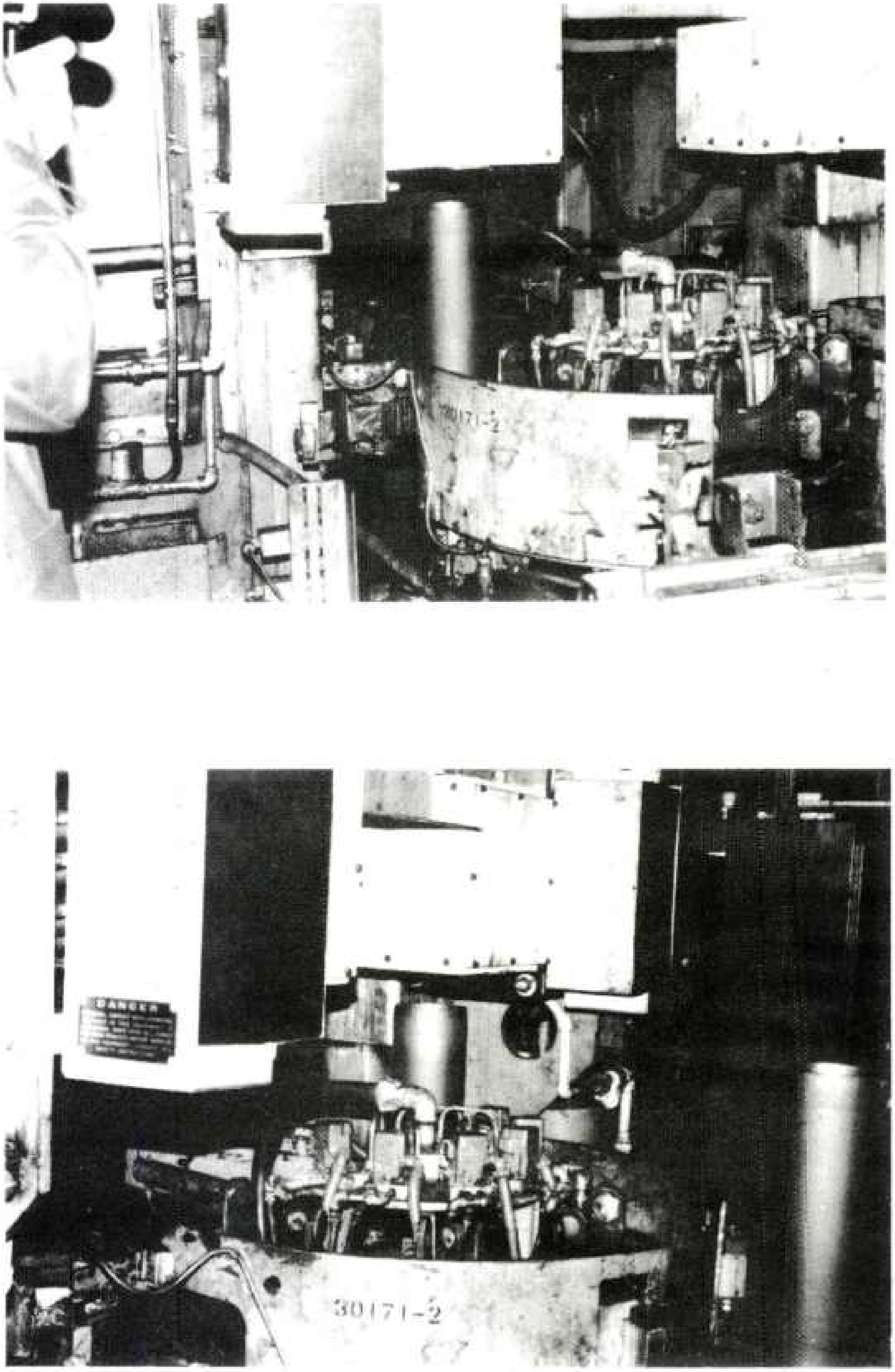


Figure 27. Photograph depicting the lubricated shell just prior to heating (top) and at the completion of the heating cycle (bottom).

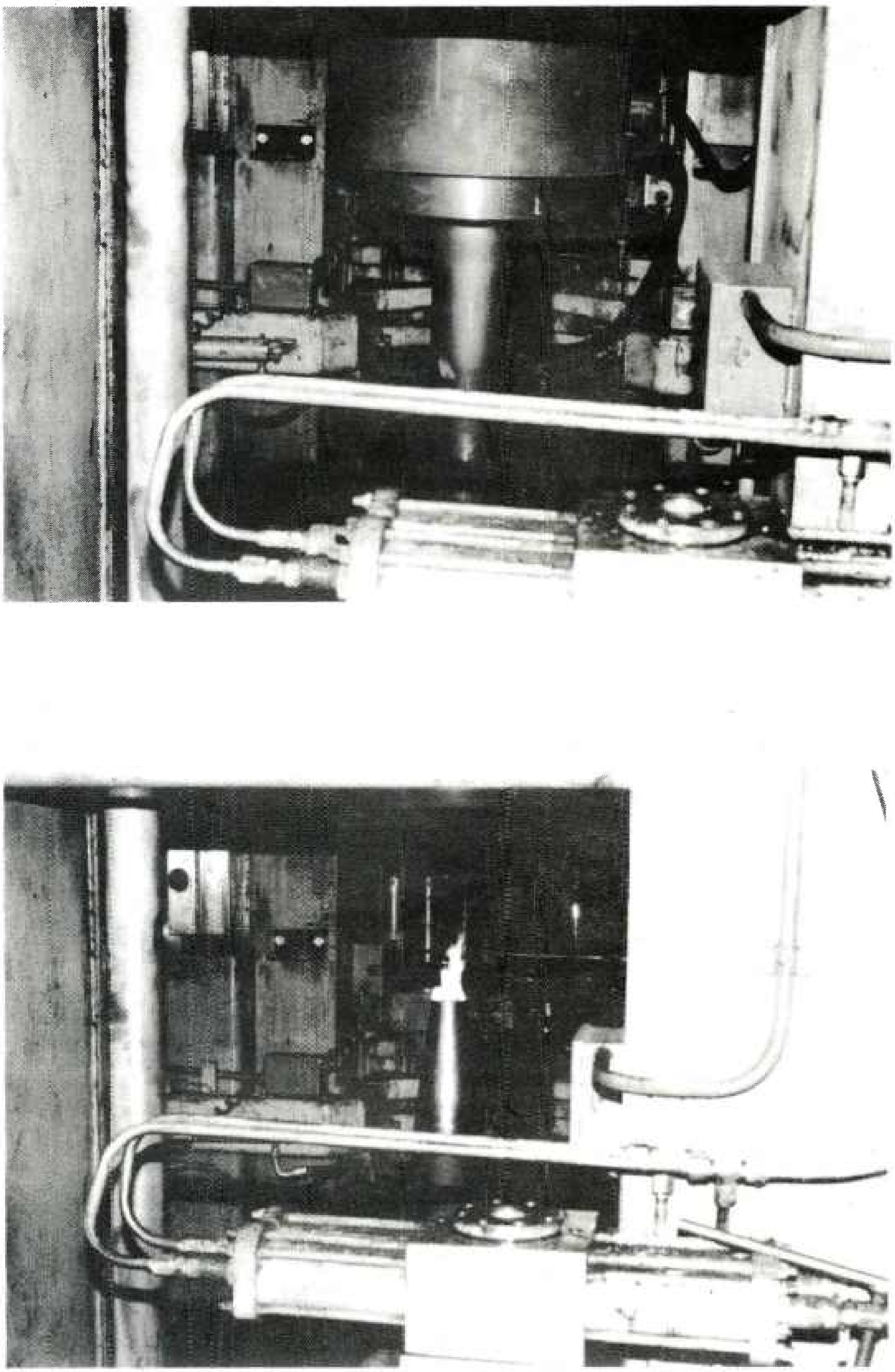


Figure 28. Photographs depicting the rough turned can at the die area prior to nosing (top) and the nosed shell at the completion of the operation (bottom).

that were occurring in the area to the rear of the bore (see fig. 29). The ordnance drawing of the M549 projectile (ref. fig. 3) specifies that the maximum variation in wall thickness shall not exceed 1.2 mm (0.050 in.). The wall thickness variation that was experienced while performing the nosing tests was found to be 2.5 mm (0.100 in.). During the process of refining the body dimensions, two (2) possibilities for the problem of wall variation were investigated.

The first possibility was that of uneven lubrication of the part prior to nosing due to non-uniformity of heat in the part prior to applying the lubricant. This possibility was eliminated by nosing a few parts that were not preheated prior to applying the lubricant. This procedure produced no improvement in the wall thickness variation.

The second possibility investigated was that of stresses being set up in the part during the forging operation. To determine if this condition was the cause of the problem, two (2) spheroidized annealed shells were rough turned and underwent the nosing operation. The results indicated no improvement in wall variation.

Since the proper body and bore length dimensions of the nosed piece were established, the wall variation problem was not pursued further and nosing optimization was left to be completed in a follow-up effort.

Nosing Temperatures

During the course of developing the required as-nosed shape, various nosing temperatures were tried along with various insertion lengths of the part into the induction heater coils. The temperatures that were investigated ranged from a low of 793°C (1460°F) to a high of 1010°C (1850°F). Dimensional

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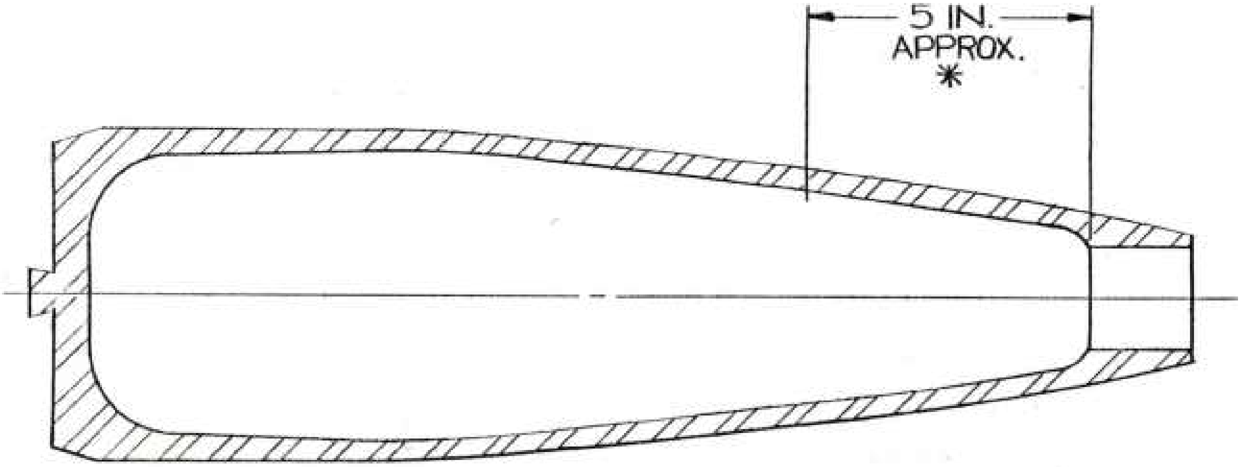


M-549 WARHEAD
(AS NOSED)

* - INDICATES AREA OF WALL THICKNESS VARIATION.

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE

DRN. T. MURRAY
DATE 11/1/83
SCALE NONE
CKD.
APPD.

Figure 29.Sketch illustrating the area to the rear of the bore where variations in wall thickness were occuring.

data showed that a temperature range of 898°C (1650°F) to 926°C (1700°F) produced the best results.

Nosing Loads

Once the final shape of the nosed piece and proper temperature range were established, nosing loads were obtained and recorded from existing load gages that were part of the press proper. The recorded loads ranged from 2.135 MN (240 tons) to 2.402 MN (270 tons). Figure 30 is a sketch depicting the average temperature and load range recorded for nosing the M549 (HF-1 steel).

Metallurgical Data

Although not required for this phase of the project, evaluation of the hardness and microstructure of the as-nosed shape was performed in preparation for Phase III of the MM&T HF-1 program.

Hardness readings were acquired from a "fork" section sawn from the as-nosed part. The results of the hardness test revealed a hardness of 24-30 Rc in the ogive and a hardness of 30-36 Rc in the transition zone as represented in figure 31.

An analysis of the microstructure revealed broken-up pearlite in the ogive and fine and coarse pearlite in the transition zone. This evaluation revealed that the as-nosed part had a stable metallurgical structure which should not require immediate heat treatment to prevent cracks from developing. This structure is illustrated in figure 32.

Figure 33 is a photomicrograph illustrating the structure at the base end of the heat transition zone of the nosed piece while figure 34 is a photomicrograph of the structure located at the nosed end of the heat transition zone

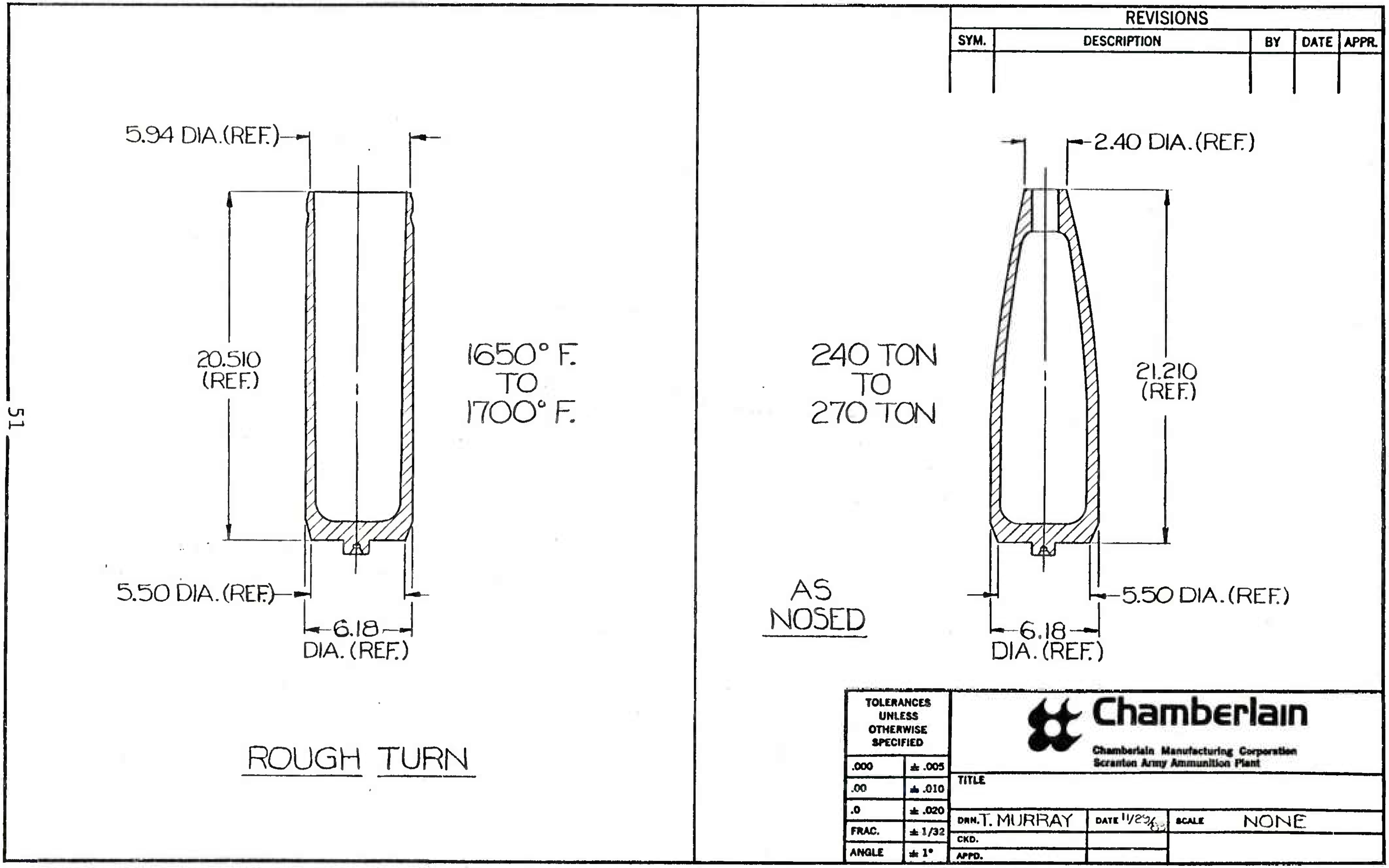


Figure 30. Sketch depicting average temperature and loads for nosing of M-549 (HF-1 steel).

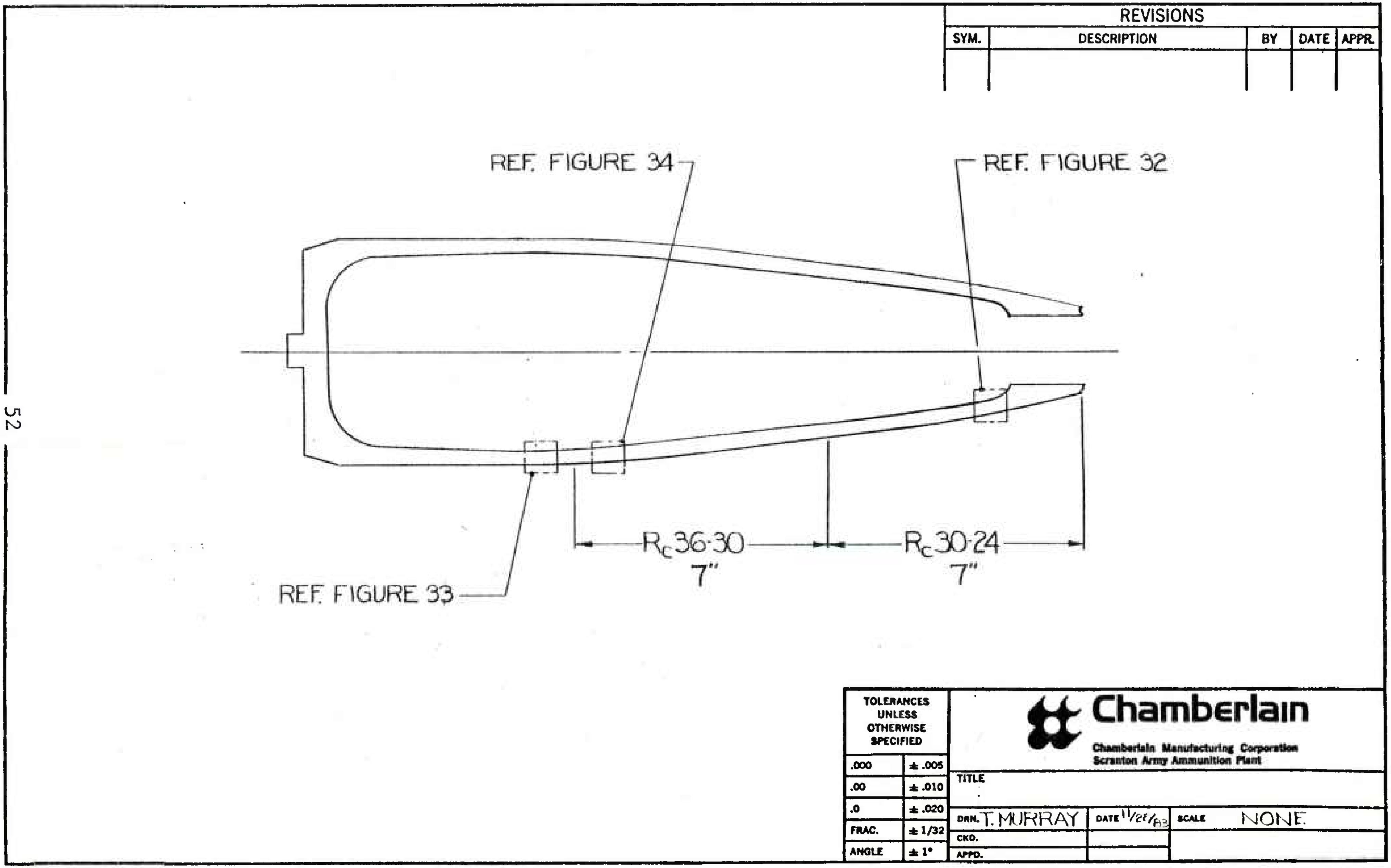


Figure 31. Sketch revealing hardness readings on cross section of as-nosed M549 part (HF-1).

M-549
Nosing

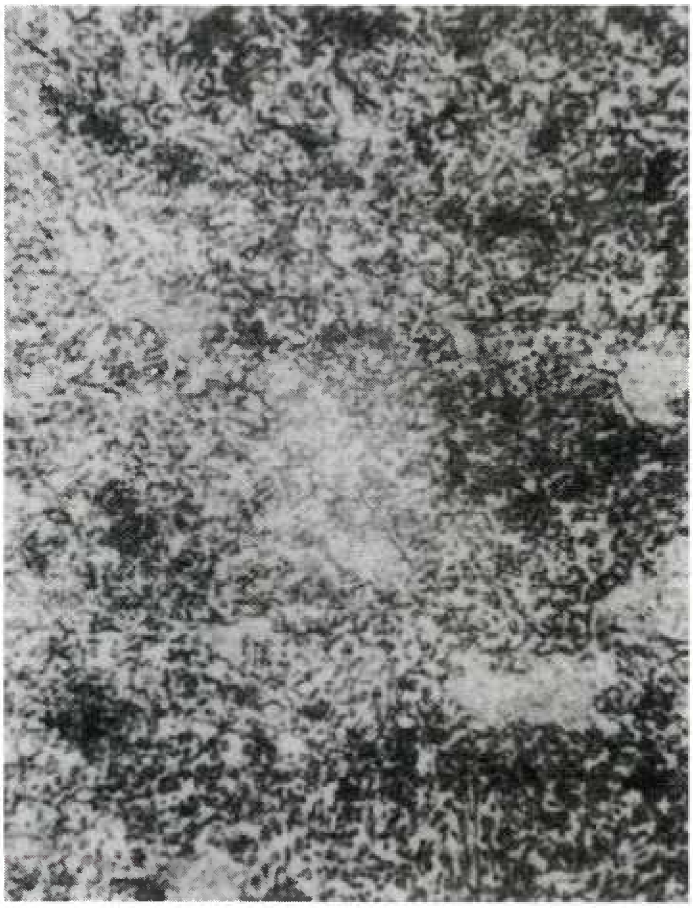


Figure 32. Photomicrograph of structure in nose area showing broken up pearlite. 1000X Nital.

M-549
Nosing

Figure 33. Photomicrograph of structure on base side of heat transition zone. 1000x Nital.

M-549
Nosing

Figure 34. Photomicrograph showing structure of nose side of heat transition zone after nosing. 1000x Nital

obtained after the nosing process was completed. Both were taken at 1000X magnification and mainly show a fine pearlite structure with no carbides visible.

From a visual standpoint, no evidence of cracking appeared in the pieces that were nosed during this study.

MULT PARTING EVALUATION (TASK B)

The objective of this portion of the project was to produce a quantity of mults from each heat and bar cooling technique, utilizing various mult parting methods, in order to determine the effects of mult parting on the HF-1 steel, and also to analyze the effects of the steel manufacturing process on the quality of billets produced with regard to variations in mult dimension and weight.

Upon evaluation of the forgings produced in Task A, it was determined that 0.907 kg (2 lbs.) could be removed from the weight of the mult by reducing the size of the boss (the protrusion on the base of the shell that is used for machining purposes) and the scale allowance (fig. 35 illustrates the reduction in boss size).

Targeted mult weight for this trial was 30.84 kg (68 lbs.).

Two (2) methods of mult parting were employed and evaluated. They were the "Nick and Break" and the "Cold Sawing" processes.

Nick and Break Process

The nick and break process is a conventional process whereby incremental lengths, as per required mult size, are first measured and marked on the top surface of the bar as received from the mill (fig. 36). Marking is then followed by the "Nicking" operation which consists of nicking the marked surface of the billet with a "gouging" or carbon arc electrode (figs. 37 and 38). This action creates a stress raiser at the nicked portion of the billet and is preparatory for the breaking operation. The nicked billet is then

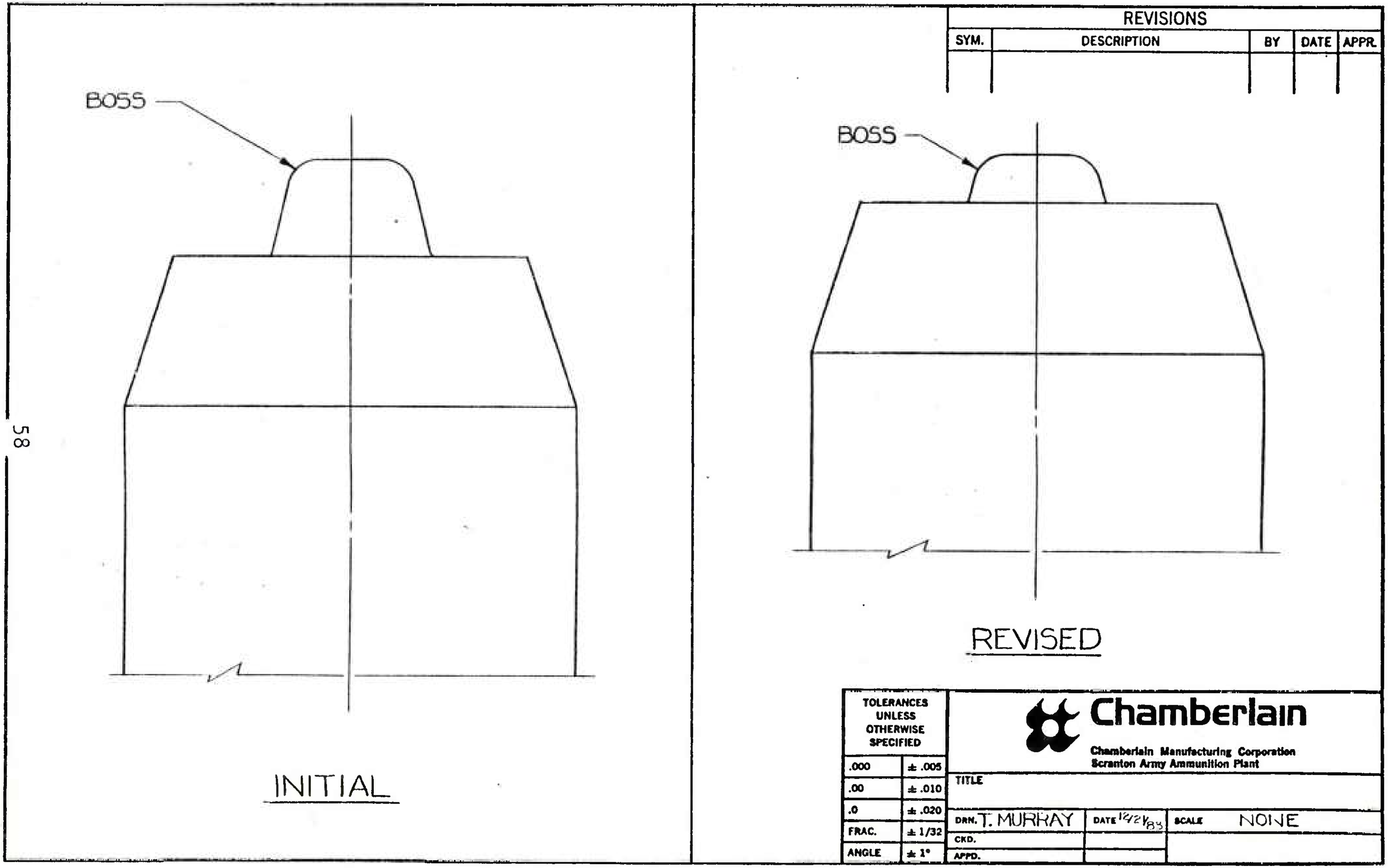
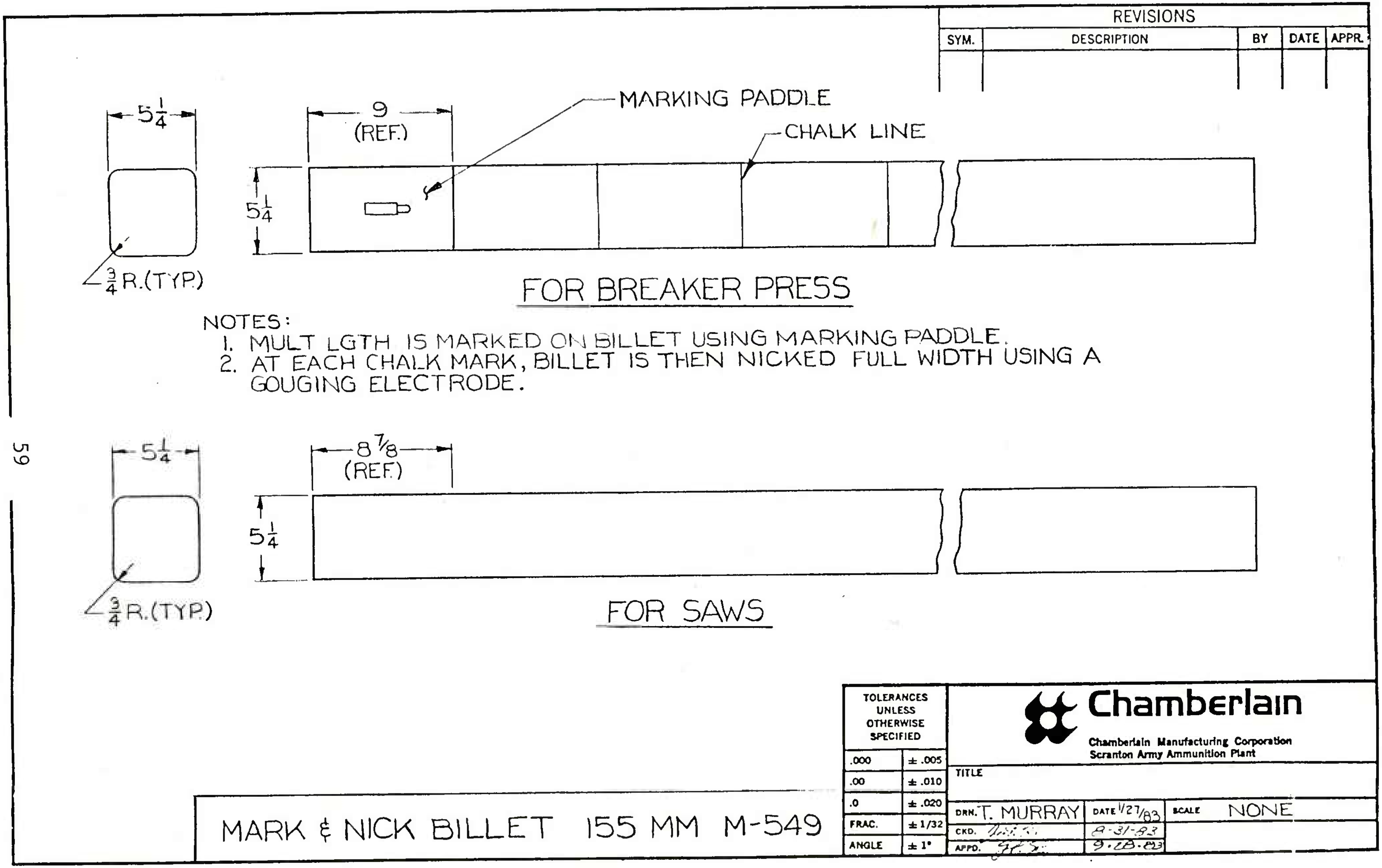


Figure 35. Illustration comparing the Initial and Revised Boss Designs.



NOTES:
1. MULT LGTH IS MARKED ON BILLET USING MARKING PADDLE.
2. AT EACH CHALK MARK, BILLET IS THEN NICKED FULL WIDTH USING A GOUGING ELECTRODE.

Figure 36. Operation - Mark and Nick Billet

Figure 37. Photograph illustrating the nicking of a billet.

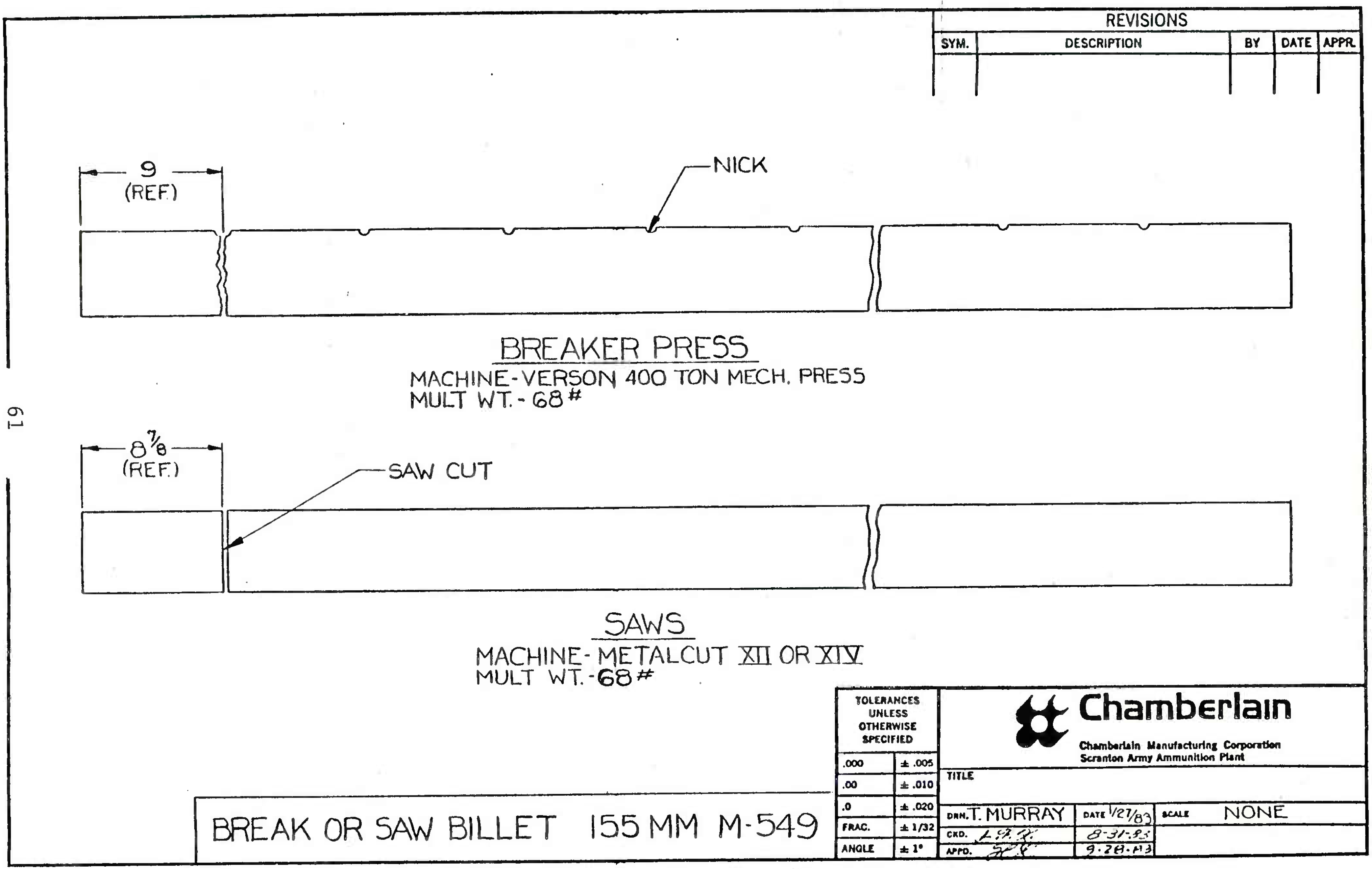


Figure 38. Operation - Break or Saw Billet

fed by conveyor to a Verson mechanical press, rated at 400 tons, where the breaking operation is then performed (fig. 39).

The number of mults parted per heat No. is as follows:

Heat #1 (Republic) - 75
Heat #2A (Bethlehem) - 78
Heat #2B (Bethlehem) - 68

An experiment to evaluate the best method for obtaining the squarest and cleanest ends of the broken mult was tried on the first billet processed. The experiment consisted of nicking the first half of the billet with a three inch nick on the center and top face of the billet and the remaining half of the billet with a nick completely across the top of the billet face (fig. 40).

For some steels, the three inch long nick produces a high degree of squareness on the mult ends. However, with HF-1 steel the results indicated that the mults with the nick completely across the top face had the cleanest and squarest ends (figs. 41 and 42). The remainder of the test billets were processed in this manner.

Upon completion of the "Nick and Break" operation, five (5) mults from each heat (Heat Nos. 1, 2A and 2B) were selected at random from the bars that were nicked and broken and dimensionally analyzed. The dimensional and weight data is presented in Tables 1 through 3. As revealed by the data presented, average length of the mults ranged from 225.4 mm (8-7/8 in.) to approximately 241.3 mm (9-1/2 in.) with the majority of lengths being 231.7 mm (9-1/8 in.) to 234.9 mm (9-1/4 in.) for the three heats of steel involved.

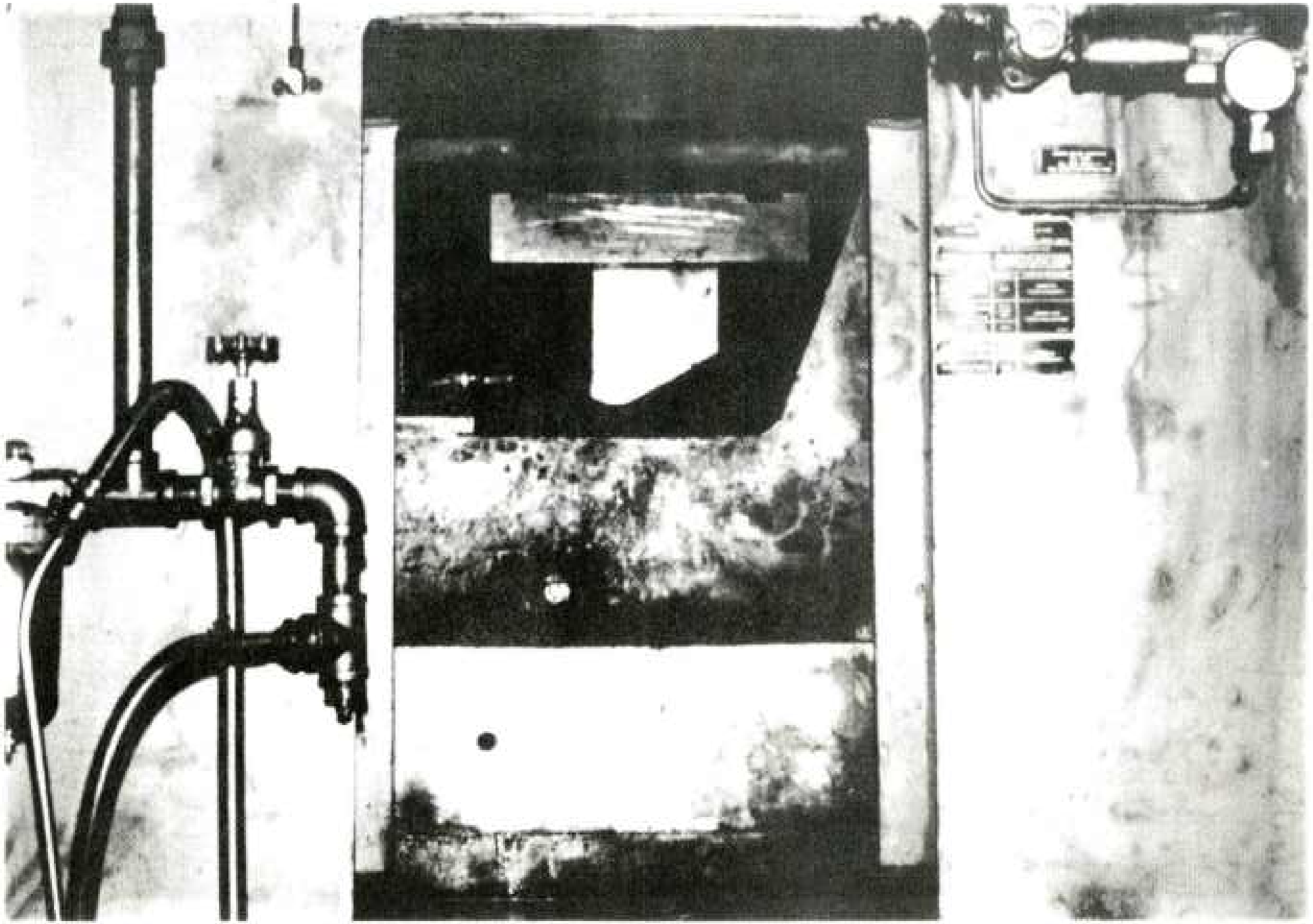


Figure 39. Photo depicting the tooling punch utilized on the breaker press during the "breaking" operation.

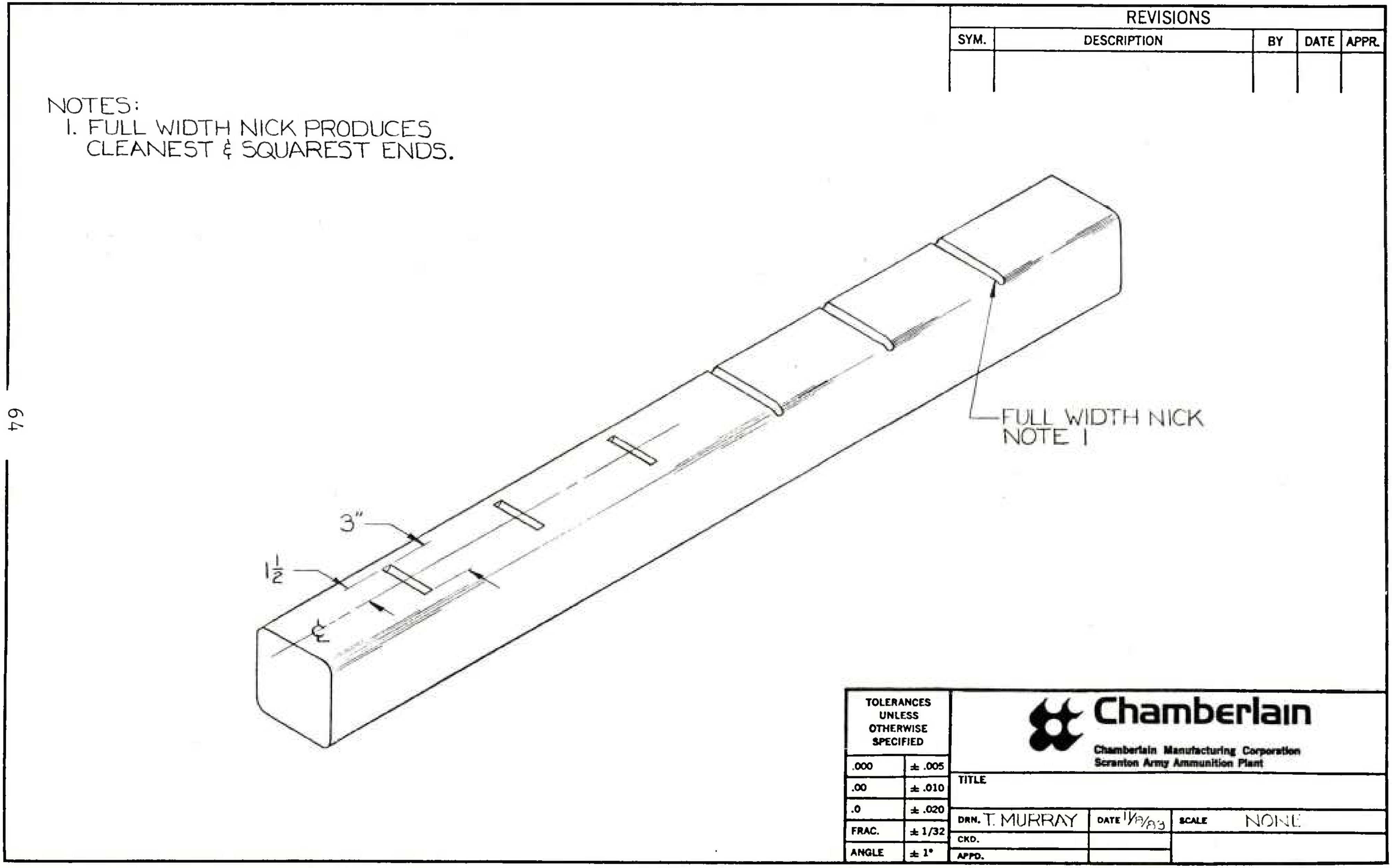


Figure 40. Sketch illustrating experimental nicking procedure.

Figure 41. Photograph illustrating clean ends of mult (HF-1 steel).

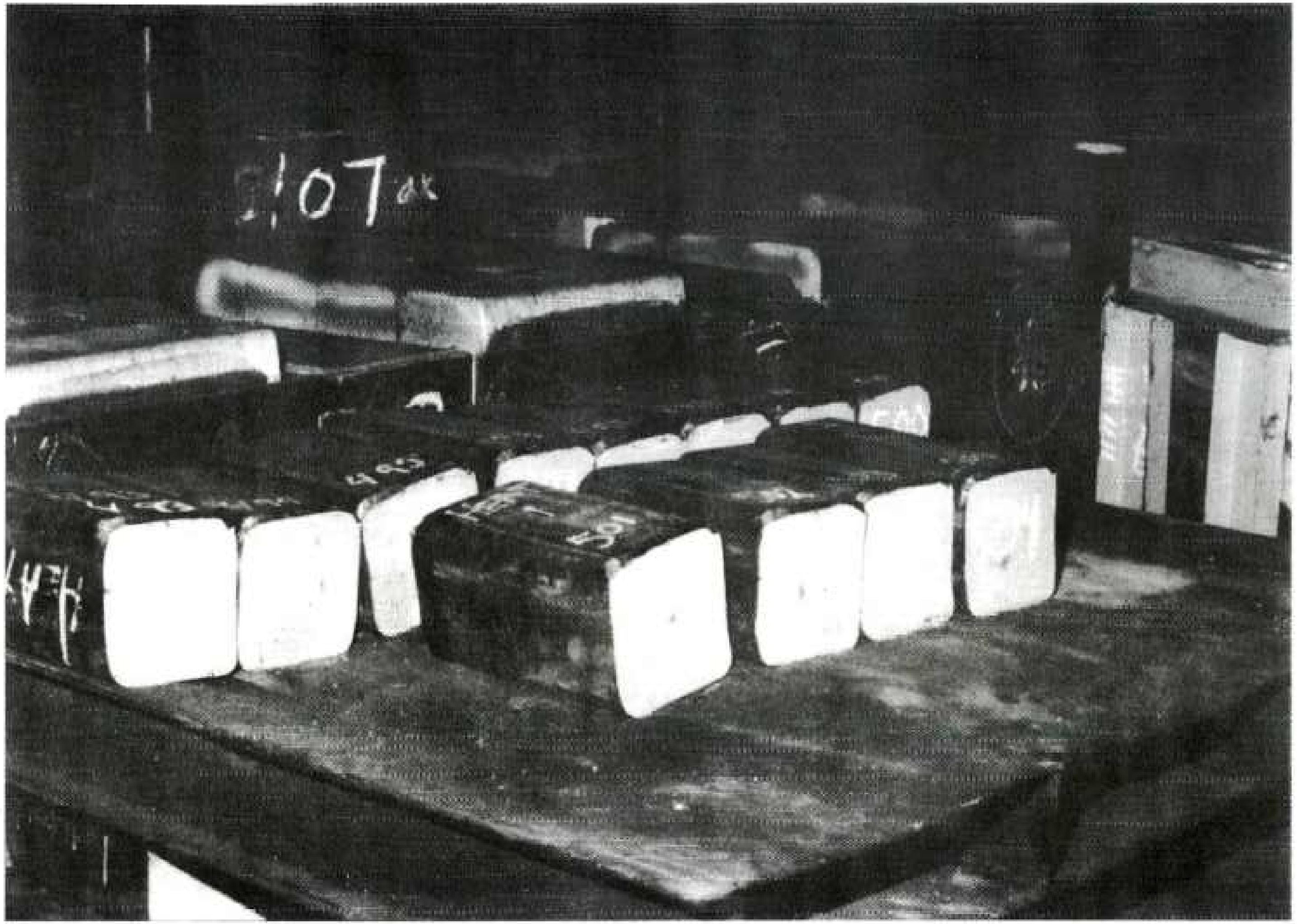
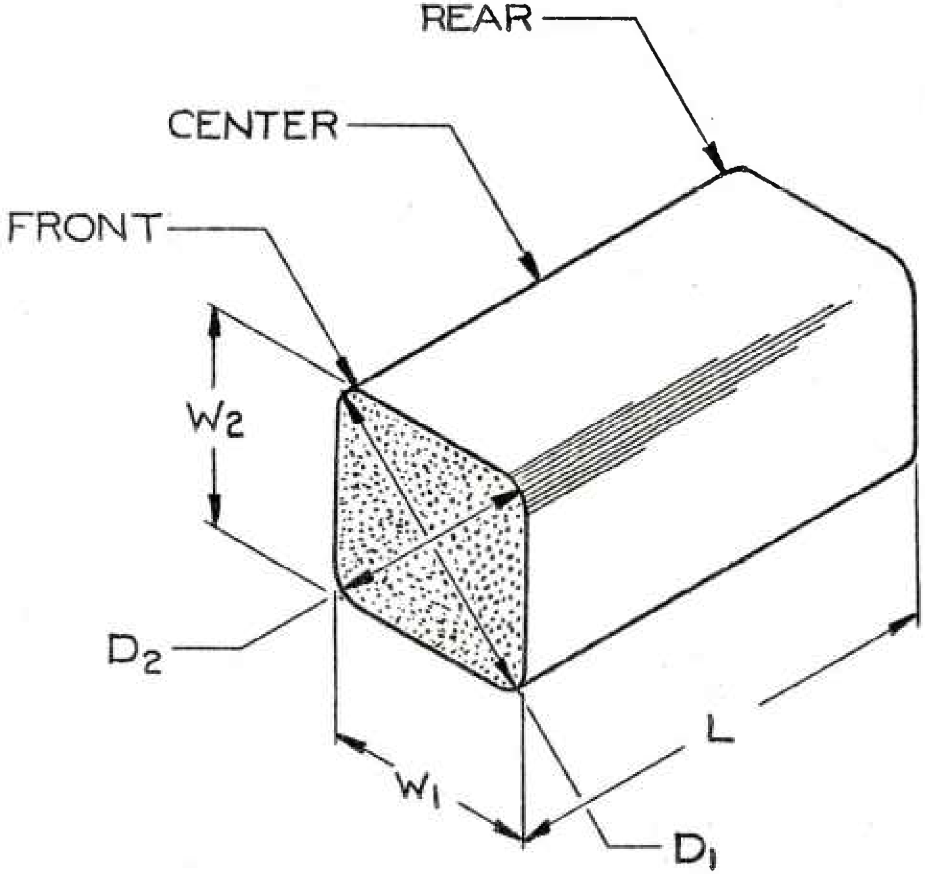


Figure 42. Photograph illustrating squareness of mult ends (HF-1 steel).

Table 1. Dimensions and Weights of Parted Mults



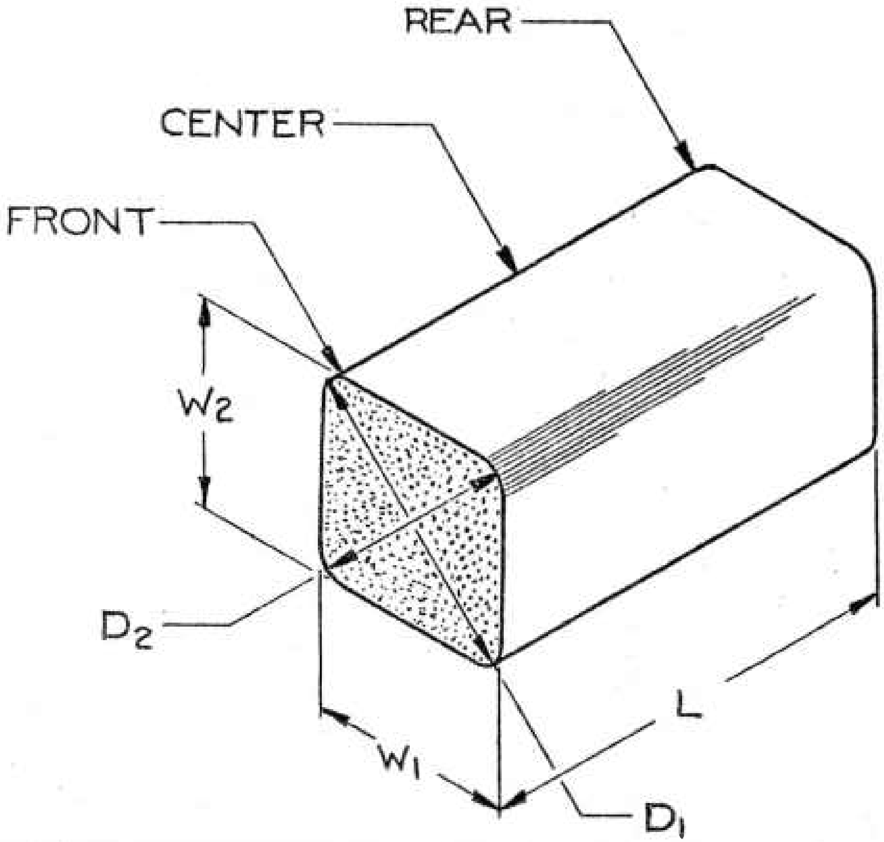
Heat No. 1

Manufacturer: Republic

Parting Process: Nick & Break

BAR #/MULT#	FRONT (IN.)				CENTER (IN.)				REAR (IN.)				L (INCH)	WEIGHT (LB-OZ.)
	W1	W2	D1	D2	W1	W2	D1	D2	W1	W2	D1	D2		
19-AC/485	5.286	5.314	6.776	6.777	5.288	5.317	6.745	6.776	5.288	5.323	6.740	6.778	9-1/16	69-12
29-BC/492	5.297	5.302	6.778	6.763	5.305	5.300	6.779	6.762	5.297	5.308	6.779	6.759	9-1/8	69-0
15-BB/448	5.322	5.320	6.780	6.803	5.331	5.319	6.782	6.804	5.331	5.320	6.782	6.802	9-1/4	70-0
21-BC/427	5.312	5.313	6.800	6.763	5.312	5.315	6.797	6.766	5.314	5.314	6.797	6.766	9-1/4	70-8
21-BC/434	5.315	5.321	6.765	6.795	5.316	5.320	6.765	6.800	5.316	5.315	6.770	6.800	9-1/2	72-4

Table 2. Dimensions and Weights of Parted Mults



Heat No.: 2A

Manufacturer: Bethlehem

Parting Process: Nick & Break

BAR #/MULT#	FRONT (IN.)				CENTER (IN.)				REAR (IN.)				L	WEIGHT
	W1	W2	D1	D2	W1	W2	D1	D2	W1	W2	D1	D2	(INCH)	(LB-OZ.)
10-H/553	5.165	5.210	6.875	6.700	5.140	5.230	6.880	6.695	5.145	5.233	6.875	6.705	9-1/16	67-8
20-C/509	5.205	5.252	6.804	6.700	5.205	5.249	6.804	6.702	5.203	5.250	6.806	6.695	9-1/8	68-4
1-C/522	5.040	5.103	6.700	6.878	5.150	5.106	6.700	6.876	5.148	5.109	6.696	6.874	9-1/4	67-4
10-B/577	5.100	5.190	6.860	6.695	5.106	5.200	6.855	6.692	5.109	5.200	6.865	6.690	9-1/8	67-4
10-B/561	5.512	5.175	6.705	6.841	5.210	5.200	6.700	6.850	*	*	*	*	8-7/8	65-0

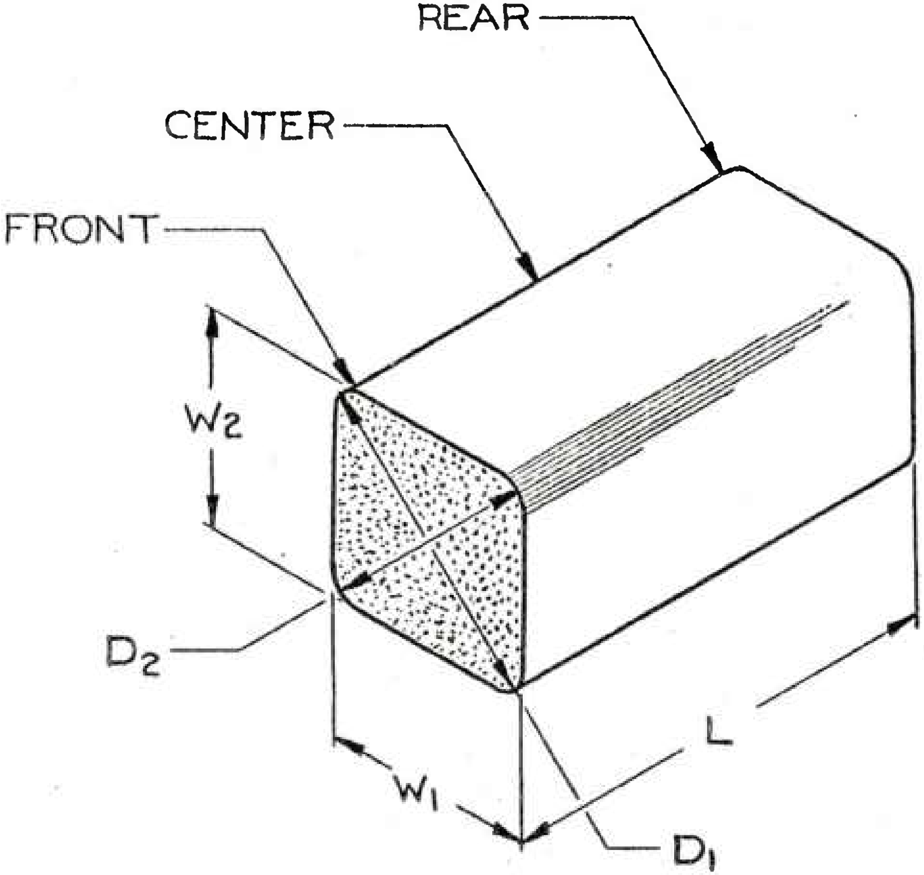
*UNDERSIZE - COULD NOT GET READINGS.

Table 3. Dimensions and Weights of Parted Mults

Heat No.: 2B

Manufacturer: Bethlehem

Parting Process: Nick & Break



BAR #/MULT#	FRONT (IN.)				CENTER (IN.)				REAR (IN.)				L	WEIGHT
	W1	W2	D1	D2	W1	W2	D1	D2	W1	W2	D1	D2	(INCH)	(LB-OZ.)
2-II/607	5.214	5.242	6.884	6.700	5.212	5.248	6.850	6.700	5.45	5.250	6.855	6.695	9-1/8	68-4
2-II/622	5.272	5.230	6.705	6.885	5.247	5.221	6.703	6.887	5.250	5.220	6.711	6.880	9	67-8
11-II/591	5.075	5.247	6.704	6.870	5.073	5.245	6.700	6.869	5.053	5.271	6.695	6.882	9-1/4	68-6
5-I/638	5.237	5.207	6.661	6.804	5.237	5.209	6.678	6.806	5.238	5.206	6.707	6.814	9-1/8	67-6
5-I/647	5.185	5.075	6.800	6.710	5.185	5.102	6.800	6.711	5.187	5.154	6.797	6.715	9-1/4	68-0

As indicated in Table 1, the length of mult No. 434 was recorded to be 241.3 mm (9-1/2 in.). This is 6.4 mm (1/4 in.) over the desired maximum length of 234.9 mm (9-1/4 in.). A condition of this sort is not easily controlled during production since the reproducibility of accurate marking and nicking of the billet is highly dependent upon the skill of the operator. Improper placement of the billet relative to the billet stop on the breaker press is also a problem that occurs, but gradually lessens with improved skill of the press operator.

Due to the fact that weight and length dimensions are not easily controlled using the nick and break process, and since the ends of the mults are not perfectly square, no definite conclusion could be made from this data concerning the effects of the steel manufacturing process on mult weight variation. A more thorough investigation concerning weight variation is presented below.

Sawing of Mults

The sawing of mults was performed on a Metalcut XII and XIV cutoff saw utilizing 28" diameter x 50 tooth carbide tipped circular saw blades.

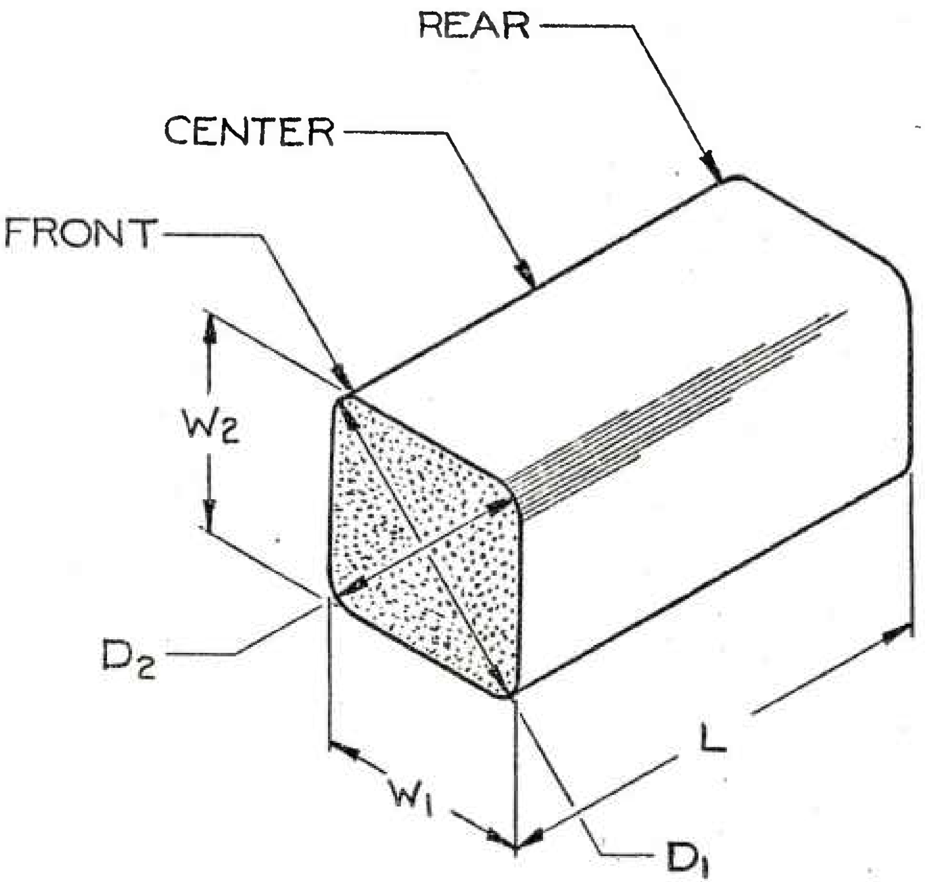
Initial speed and feed rates used for cutting the HF-1 steel were approximately 420 SFPM and 13 in./min. respectively. Target mult weight for the sawed billets during this task was 30.84 ± .45 kg (68 ± 1 lb.). Approximately 65 mults were sawed from each heat and cooling technique. Five mults from each heat were then selected and dimensionally analyzed. The dimensional and weight data obtained is presented in Tables 4 through 6. Listed in Appendix C are tracings of the profile of the billet cross section for the respective mults. The profiles are presented to show the difficulties that can

Table 4. Dimensions and Weights of Parted Mults

Heat No.: 1

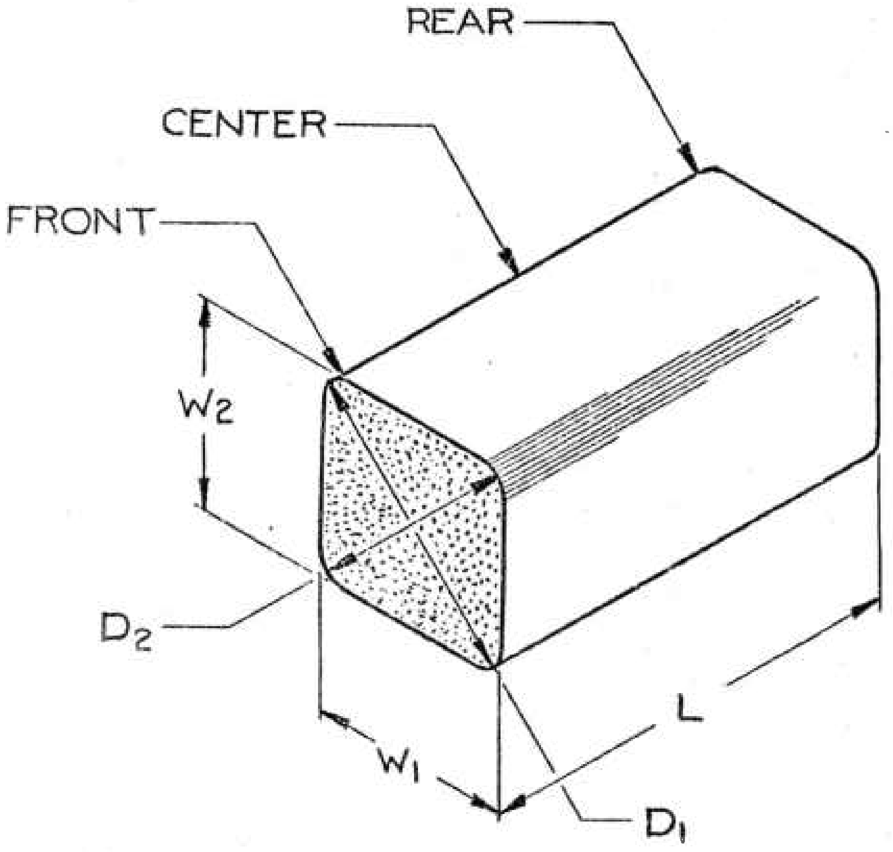
Manufacturer: Republic

Parting Process: Saw



BAR #/MULT#	FRONT (IN.)				CENTER (IN.)				REAR (IN.)				L	WEIGHT
	W1	W2	D1	D2	W1	W2	D1	D2	W1	W2	D1	D2	(INCH)	(LB-OZ.)
25-BC/278	5.330	5.305	6.772	6.772	5.327	5.302	6.180	6.771	5.322	5.302	6.775	6.805	8-7/8	68-14
20-BA/269	5.312	5.325	6.805	6.780	5.325	5.325	6.805	6.778	5.310	5.324	6.804	6.781	9-1/16	70-2
20-BA/264	5.308	5.325	6.776	6.803	5.308	5.325	6.780	6.804	5.308	5.326	6.778	6.803	8-7/8	68-14
16-AB/254	5.311	5.261	6.785	6.780	5.315	5.263	6.779	6.778	5.314	5.268	6.785	6.782	8-15/16	68-12
16-AB/240	5.285	5.266	6.769	6.775	5.297	5.297	6.765	6.773	5.293	5.266	6.764	6.771	8-7/8	68-0

Table 5. Dimensions and Weights of Parted Mults



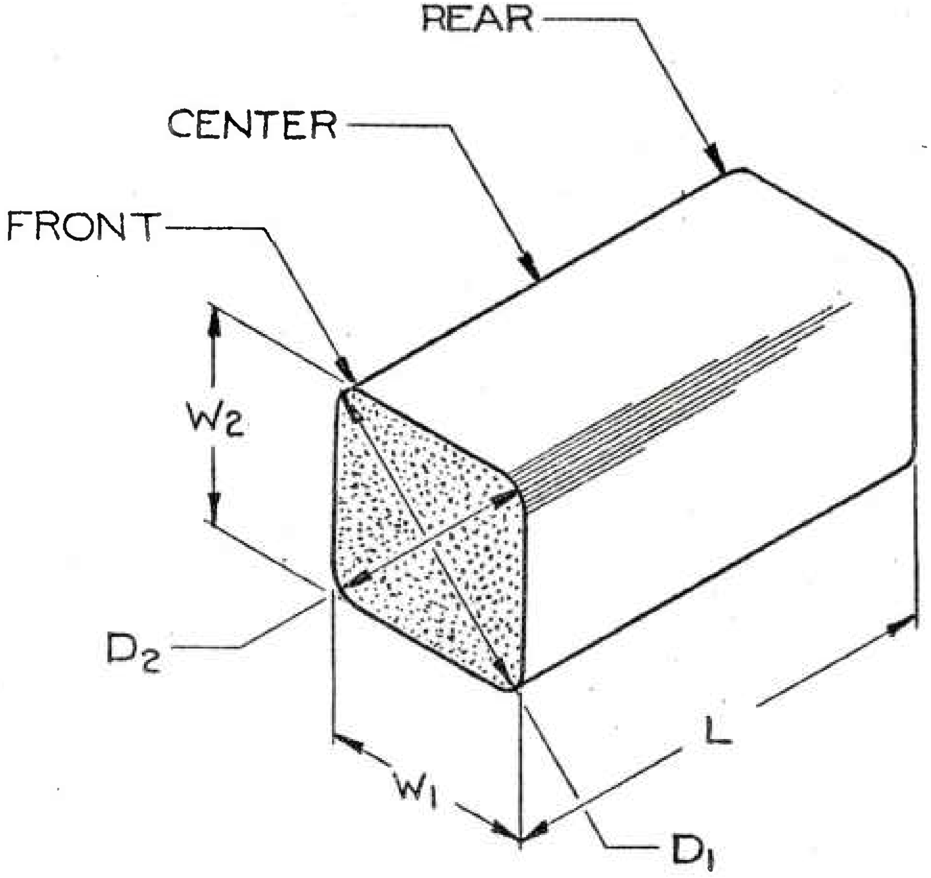
Heat No.: 2A

Manufacturer: Bethlehem

Parting Process: Saw

BAR #/MULT#	FRONT (IN.)				CENTER (IN.)				REAR (IN.)				L	WEIGHT
	W1	W2	D1	D2	W1	W2	D1	D2	W1	W2	D1	D2	(INCH)	(LB-OZ.)
10-I/304	5.212	5.188	6.850	6.695	5.212	5.223	6.855	6.708	5.215	5.196	6.848	6.691	8-7/8	66-6
10-I/317	5.044	5.030	6.786	6.694	4.943	5.015	6.775	6.690	4.815	4.919	6.780	6.675	9-5/32	65-10
1-H/414	5.111	5.165	6.700	6.698	5.128	5.141	6.700	6.698	5.113	5.141	6.701	6.700	9-3/16	67-12
10-C/322	5.148	5.102	6.863	6.690	5.137	5.116	6.863	6.695	5.127	5.078	6.859	6.697	8-7/8	65-4
10-C/337	5.188	5.214	6.860	6.690	5.219	5.217	6.865	6.695	5.185	5.215	6.868	6.696	9-1/8	68-4

Table 6. Dimensions and Weights of Parted Mults



Heat No.: 2B

Manufacturer: Bethlehem

Parting Process: Saw

BAR #/MULT#	FRONT (IN.)				CENTER (IN.)				REAR (IN.)				L	WEIGHT
	W1	W2	D1	D2	W1	W2	D1	D2	W1	W2	D1	D2	(INCH)	(LB-OZ.)
11-C/382	5.628	5.217	6.903	6.672	5.242	5.215	6.891	6.688	5.267	5.210	6.871	6.770	9-1/8	68-14
11-C/389	5.262	5.046	6.880	6.688	5.239	5.046	6.875	6.695	5.235	5.079	6.882	6.688	9-3/16	68-2
2-B/350	5.265	5.222	6.860	6.701	5.240	5.248	6.858	6.702	5.241	5.222	6.873	6.693	9	68-2
2-I/378	5.237	5.226	6.700	6.780	5.237	5.235	6.698	6.782	5.156	5.231	6.706	6.778	9-1/8	68-11
2-B/340	5.235	5.221	6.885	6.686	5.235	5.220	6.888	6.690	5.237	5.217	6.870	6.697	9	68-0

be encountered in trying to maintain weight tolerances when sawing mults, on a production basis, from billets having irregular cross sections and poor surface quality.

Table 4 (Heat No. 1) shows that the targeted weight of 30.84 kg (68 lbs.) was easily maintained at an average length of 225.4 mm (8-7/8 in.) on Republic steel.

As indicated in the table, mult number 269 was cut to a length of 230.18 mm (9-1/16 in.) and yielded a weight of 31.8 kg (70 lbs.-2 oz.). It was intentionally cut to this length for the purpose of establishing a mult length tolerance range (with regards to weight) for the billets that were to be sawed from Heat No. 1 during the performance of Task E of this project.

The mult profiles (Appendix C) for this heat exhibit a fairly constant cross section, indicating that there should be no difficulty in maintaining the desired weight to length range when sawing billets from this heat on a production basis.

However, in viewing the profiles of the mults for Heat Nos. 2A and 2B, erratic cross sections and severe finish grinding of billet defects at the steel mill is evident. It proved difficult to maintain the targeted mult weight while sawing mults from these two (2) heats. Depending on the severity of the grinding, length adjustments had to be continually made in order to attain a mean weight of 30.84 kg (68 lbs.).

Although only five mults from each heat were dimensionally analyzed and weighed, it is evident that the quality of the billets in Heat Nos. 2A and 2B is far inferior to the quality of the billets contained in Heat No. 1.

Past experience has indicated that poor quality of the billet surface along with irregular billet cross sections has a direct effect on the quality of the forgings produced.

Metallurgical Evaluation of Parted Mults

Several mults that were processed by the nick and break operation had the nicked area metallographically evaluated. Paragraphs A, B and C detail the hardness zones. Figures D-1 through D-10 of Appendix D are photomicrographs of nicked areas from other bars which were nicked and broken.

A. A sample, figure 43, of Bethlehem Steel which was cooled in a "bung" furnace was evaluated. The nicked area is from bar 10H.

Structure	Hardness Rc
Retained austenite 0.008 inches thick	46
Area of coarse untempered martensite, retained austenite and	61
fine untempered martensite 0.011 inches thick	35
Fine untempered and tempered martensite	65

The term "untempered martensite" is used even though the platelets etch dark. It is felt that the untempered martensite is tempered in the use of a thermal setting mounting material which cures at 150°C (302°F).[4]

Refer to Appendix E for the evaluation of retained austenite.

Nick & Break
M-549
Bethlehem Steel

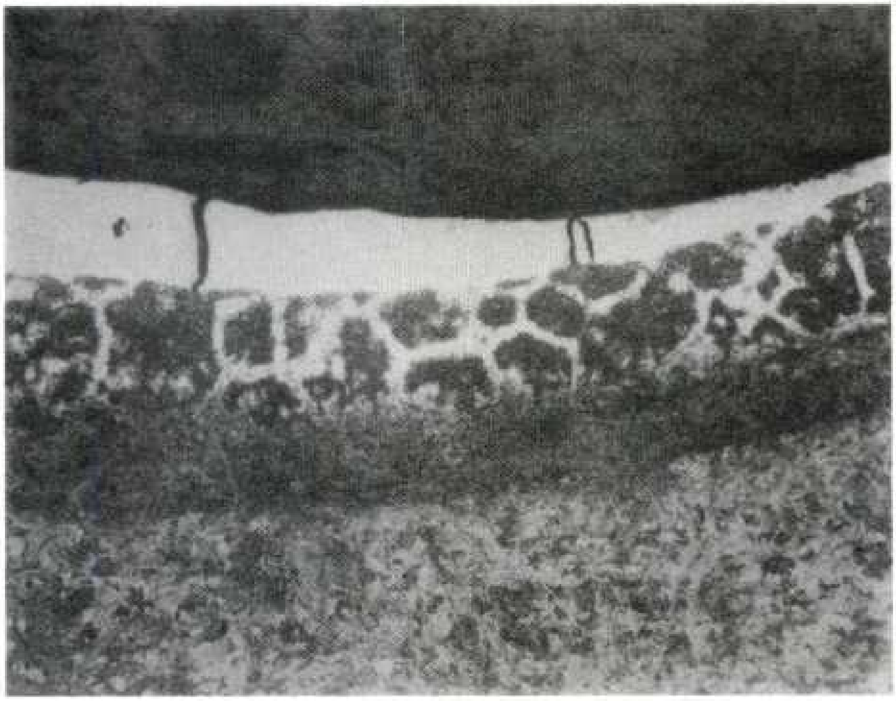


Figure 43. Photomicrograph of nicked area from bar 10H. 63X Nital Etchant.

B. A sample, figure 44, of Bethlehem Steel which was box cooled was evaluated. The nicked area is from bar 11H.

Structure	Hardness Rc
Area of retained austenite. None	---
Area of coarse untempered mertensite and retained austenite. 0.013 inches thick	63
Fine untempered martensite. 0.009 inches thick	59
Fine untempered and tempered martensite	46

Nick & Break
M-549
Bethlehem Steel

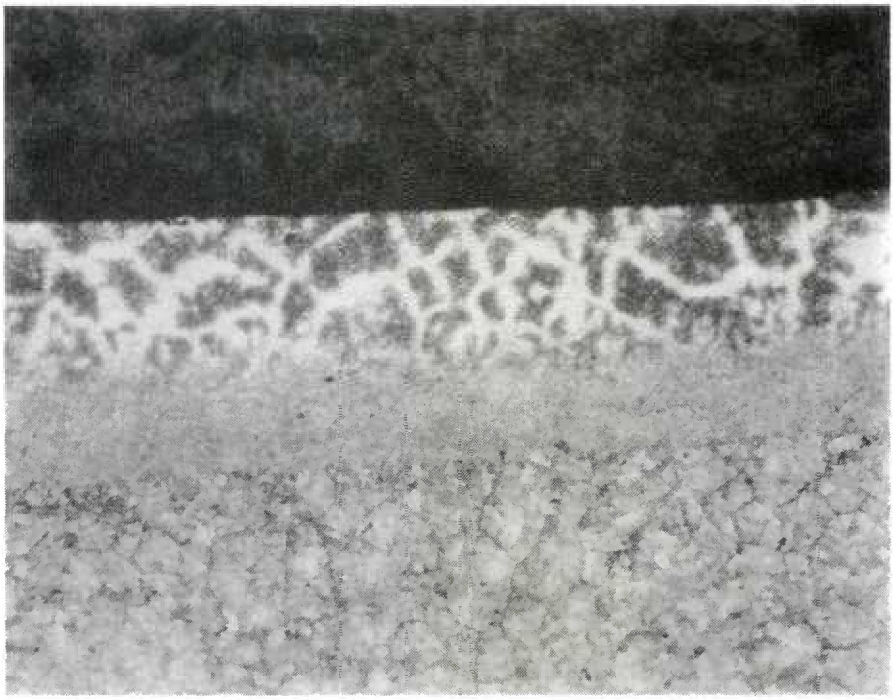


Figure 44. Photomicrograph of nicked area from bar 11H. 63X Nital Etchant.

C. A sample, figure 45, of Republic Steel which was pit cooled was evaluated. The nicked area is from bar 19 AC.

Structure	Hardness Rc
Retained austenite 0.004 inches thick	47
Untempered martensite and retained austenite.	53 34
Fine untempered and tempered martensite	65

Nick & Break
M-549
Republic Steel

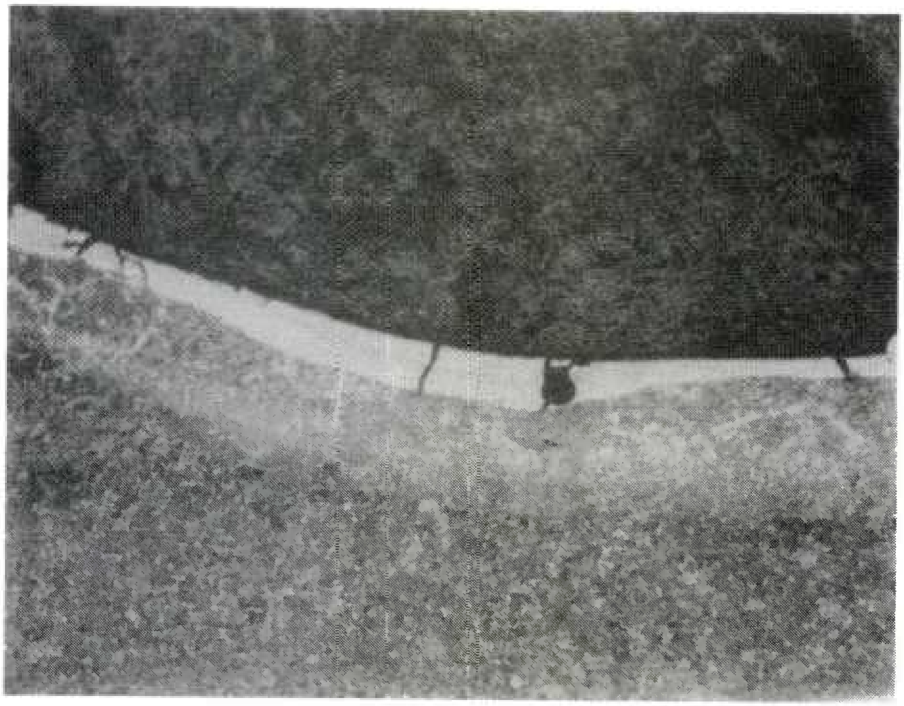


Figure 45. Photomicrograph of nicked area from bar 19AC. 63X Nital Etchant.

It was noted in all samples that blow holes and some cracks perpendicular to untempered martensite layers were present. Several forgings were checked with die penetrant resulting in no detectable indications. Also, no indications were visible during the rough turn operation.

Several samples of a sawed section were evaluated and more are illustrated in report ARLCD-CR-81017. All show a clean section with no structure degradation, no cracking and all have the mill scale intact. Figure 46 illustrates one of these sections.

Even though no abnormal defects were detected during forging or rough turn, which were attributable to the nick and break process, its use should be discouraged because of the cracks that are visible in the heat affected zone. These cracks are severe stress raisers and could propagate major defects.

Forging Operation

The mults parted during this task were forged on June 30, July 1 and July 2, 1982. Furnace temperature was initially set at 1121°C (2050°F), but was gradually increased to 1176°C (2150°F) with average process temperatures being recorded as follows:

Prior to Preform - 1065°C (1950°F)
Prior to Pierce - 943°C (1730°F)
Prior to Draw at Base - 893°C (1640°F)
Prior to Draw at Open End - 843°C (1550°F)

Table 7 is an inspection scrap report indicating the reasons the particular shells were scrapped. The majority of defects listed are temperature related due to material

Sawed Mult
M549

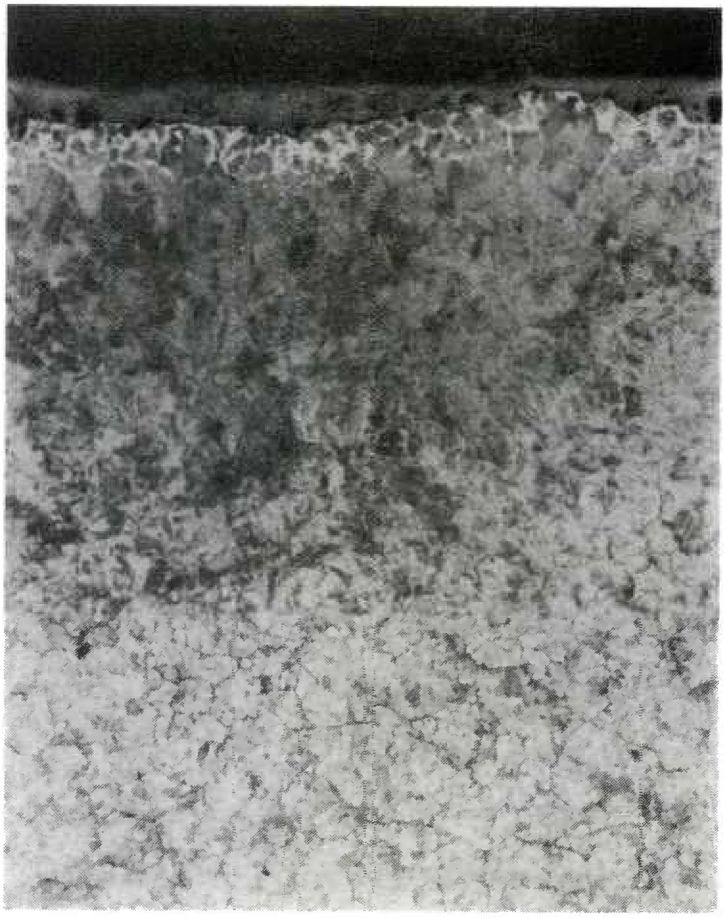


Figure 46. Photomicrograph of sawed mult showing no deleterious effect. 63X Nital Etchant.

Table 7. SCRAP SHELL REPORT - TASK B

Heat No.	Shell I.D. Number	Parting Process	Defect
1	259	Saw	Preform Slug
1	260	Saw	Short (Reheated Mult)
1	262	Saw	Stuck on Mandrel
1	291	Saw	Bottle *
1	292	Saw	Stuck on Mandrel
2A	318	Saw	Short (Under 65 lbs.) Reheated Mult, Hot Sheared End
2A	320	Saw	Short
2B	339	Saw	Short
2B	344	Saw	Bottle *
2B	348	Saw	Bottle *
2B	352	Saw	Pulled Apart in Rings
2B	353	Saw	Bottle *
2B	354	Saw	Bottle *
2B	357	Saw	Pulled Apart in Rings
2B	359	Saw	Bottle *
2B	384	Saw	Short
2B	386	Saw	Short (H.B.) - Press not bottomed
2B	387	Saw	Short (H.B.)
2B	391	Saw	Preform Slug
2B	392	Saw	Bottle *
2B	397	Saw	Bottle *
2B	400	Saw	Short (H.B.)
2B	403	Saw	Short (H.B.)
2B	406	Saw	Short (Max.)
2B	415	Saw	Short (H.B.)
1	446	Nick & Break	Stuck on Mandrel
1	503	Nick & Break	Cracked Open End
2A	558	Nick & Break	Water Quenched (Gage Stuck)
2B	620	Nick & Break	Pulled Apart in Rings
2B	623	Nick & Break	Short

Table 7. (cont'd.)

HB = Heavy Base

* "Bottle" is the terminology utilized to describe the forging product that has been processed through the piercing operation, but not through the drawing operation due to improper temperature for complete processing (ref. fig. 8).

handling delays during the forging operation and not to any one particular heat of steel. The type of handling delay encountered during this test was due to a malfunction with the preform loading arrangement causing some of the mults to hang-up on the preform loader. This delay in loading some of the mults into the die cavity naturally caused a decrease in the temperature of the mult involved. Depending on the temperature of the mult, some were processed completely through the draw operation, resulting in the back end of the shell being pulled apart while progressing through the draw rings, while others were cooler and could not be completely forged properly, due to forging load requirements exceeding the load capacities of the presses. No forging load readings were obtained for this group of shells.

Since this group of forgings consisted of mults parted by both the Sawing and Nick and Break operations, particular attention was given to the cavity conditions of these forgings. Table 8 is a listing of the cavity defects found during the inspection of this group of forgings. The majority of cavity defects for the sawed mults were caused by scale. The forgings parted by the Nick and Break operation were rejected due to laminations in the base and wall of the cavity, a reject condition which is normal for mults parted in this manner regardless of the type of steel being used.

Table 9 lists a comparison of forging eccentricity values between the mults produced by both the Sawing and Nick and Break operations, and also by heat number. As revealed by the table, no discernable difference in eccentricity values is noted between the variables involved, indicating that the method of mult parting did not affect the eccentricity of the forgings produced in this task.

During normal production operations the forgings are

Table 8. CAVITY DEFECTS - TASK B FORGINGS

Heat No.	Parting Method	Defect Condition Scale Holes Base & Wall	Defect Condition Laminations Base & Wall	Defect Condition Cold Tears Open End	Total Forged Pieces	% Defective Cavities
1	Saw	1	---	---	59	1.69
1	Break	1	3	---	76	5.26
2A	Saw	3	---	---	59	5.08
2A	Break	---	---	---	73	0
2B	Saw	---	---	1	59	1.69
2B	Break	1	3	---	61	6.56

Table 9. Eccentricity Values (Inch) of Sawed vs Nick & Break Mults (Task B).

Heat No.	Position	Sawed			Nick & Break		
		Min.	Max.	Avg.	Min.	Max.	Avg.
1	Base	0.020	0.070	0.040	0.010	0.100	0.045
	Center	0.020	0.060	0.040	0.020	0.080	0.040
	Open End	0.020	0.060	0.040	0.030	0.070	0.040
2A	Base	0.010	0.050	0.045	0.030	0.070	0.045
	Center	0.020	0.040	0.040	0.030	0.050	0.040
	Open End	0.020	0.050	0.040	0.020	0.060	0.040
2B	Base	0.015	0.050	0.030	0.030	0.070	0.045
	Center	0.020	0.050	0.035	0.030	0.050	0.035
	Open End	0.020	0.040	0.030	0.030	0.060	0.040

25.4 mm Per Inch

NOTE: Eccentricity values presented in the table above are based on the following sample size:

Heat No.	Sawed	Nick & Break
1	9	13
2A	7	15
2B	4	6

cooled to about 177°C (350°F) on the cooling conveyor, dipped in a water tank and removed from the line in preparation for the shot blast operation. However, as previously mentioned, the forgings produced for Task A were cooled to room temperature on the cooling conveyor. This procedure was used to maintain integrity of the HF-1 forgings, and is standard practice when conducting tests of this nature. However, there was a concern as to whether or not the use of the dip tank would have an effect on the HF-1 steel. To resolve this concern, temperature readings were taken at various time intervals on the cooling conveyor while producing forgings during Task B, (Table 10). The data shows that the average temperature of the forging just prior to entering the dip tank was approximately 104.4°C (220°F) while the temperature of the forging as it exited the dip tank was recorded at 51.6°C (125°F).

The recorded temperatures indicate that the temperature at the entrance to the water tank is well below the HF-1 steel M's temperature, indicating that the rate of cooling was slow enough to produce pearlite. This then should have no deleterious effect.

Figure 47 depicts a structure obtained by slow cooling on the conveyor without using the dip tank. It is a fine pearlite with some small areas of coarse pearlite.

Figure 48 depicts a structure obtained by slow cooling on the conveyor followed by dipping in the water tank. This also produced a structure of fine pearlite very similar to that structure produced in the previous figure.

Neither has an untempered martensite or grain boundary precipitates. Therefore, both are acceptable indicating the suitability of the dip tank at Chamberlain Manufacturing Corporation.

Table 10. Temperature changes occurring from entrance on cooling conveyor to quench tank exit.

NOTE: All temperatures shown are in °F.

	Cooling Conveyor		Before Quench		After Quench	
Shell No.	Temp. F1	Time T1	Temp. F2	Time T2	Temp. F3	Time T3
526	1200	9:15	215	10:30	125	10:31
527	1230	9:15	215	10:31	125	10:32
528	1240	9:16	200	10:34	125	10:35
529	1220	9:16	210	10:34	130	10:35
530	1190	9:17	200	10:34	125	10:35
531	1190	9:18	190	10:36	130	10:38
532	1220	9:19	220	10:36	125	10:38
533	1260	9:20	---	-----	---	-----
534	1180	9:20	230	10:38	130	10:39
535	1190	9:21	---	-----	---	-----
536	1220	9:23	225	10:39	125	10:40
537	1200	9:23	---	-----	---	-----
538	1190	9:24	225	10:41	125	10:42
539	1200	9:25	210	10:41	125	10:42
540	1210	9:25	250	10:41	130	10:42
541	1210	9:26	225	10:42	125	10:43
542	1160	9:26	235	10:42	125	10:43
543	1160	9:27	220	10:43	125	10:44

Average temperature at cooling conveyor - 1204° (T1)

Average temperature at quench tank entrance - 218° (T2)

Average temperature at quench tank exit - 126° (T3)

Average elapsed time from conveyor to tank - 1 hr. 18 mins.

M549
"Dip Tank" Evaluation

Figure 47. Photomicrograph of forged structure of a shell that was cooled on conveyor. 500X Picral.

M549
"Dip Tank" Evaluation

Figure 48. Photomicrograph of forged structure of a shell that was final cooled in dip tank. 500X Picral.

EVALUATION OF: THE NEED FOR SPHEROIDIZE ANNEALED FORGINGS (TASK C) AND THE MACHINE TOOLS FOR ROUGH MACHINING OF FORGINGS (TASK D)

Since the project description for Tasks C and D are interrelated, the work performed and the results obtained for both tasks are presented under this section of the report.

Prior to the commencement of this project, a preliminary study concerning the effects of machining HF-1 forgings for the M795 warhead was conducted. The results of this study, also confirmed by metallurgical analysis of forgings produced during Task A, verified that the method of cooling the forgings, now employed at the Scranton AA Plant, would produce a machinable forging processed from HF-1 steel. Upon recommendation from Chamberlain Manufacturing Corporation and with Government concurrence, it was decided that the shells produced by this method of cooling would be considered as the "alternate method" of imparting adequate machinability to the forgings. This group of forgings labeled as-forged was utilized for comparison of rough turn tooling data against the control group (those forgings that were processed through the spheroidize anneal process).

Metallurgical evaluation and hardness readings for both the as-forged and the spheroidized annealed forgings are presented in Tasks A and E of this report.

Per Task A, hardness values obtained for the annealed shells produced from Heat No. 1 ranged from 95 to 98 Rb. The values obtained during this task for the annealed shells of Heat Nos. 2A and 2B were also in the range of 95 to 98 Rb (210-228 BHN).

Hardness values were also obtained at the rough turn operation for Heat Nos. 1, 2A and 2B in the as-forged condition. The hardness readings obtained are presented in Table 11. As can be seen in the table, the hardness values obtained for the shells are greater at the open end than at the boattail section of the shell. The reason for this is the slightly thinner shell wall at the open end when compared to the wall thickness at the boattail section, thus the rate of cooling at the open end is more rapid than at the boattail, resulting in a slight increase in hardness at this area. The table also shows that the average hardness values are similar for all three heats of steel.

Investigation of Rough Turn Tooling

As previously mentioned, an investigation concerning various tooling data on rough turn machining was undertaken prior to the performance of Task A of this project.

The investigation was performed utilizing a J & L numerically controlled No. 4512 "Shaft" lathe (figs. 49 and 50). It was chosen for this test due to its flexibility in obtaining various speed ranges easily and quickly without the need to change gears, as is required for production tracer lathes.

The tests were conducted utilizing three different surface speeds comparable to the speeds that could be obtained on the production tracer lathes that would be employed during the performance of Tasks D and E. During the investigation, it was not known whether the rough turning operation would be conducted on the 155 mm (6 in.) or 175 mm (7 in.) production line tracer lathe; therefore, the surface speeds chosen for this test were 340 and 427 SFPM which could be attained on the 155 mm lathes, and 267 SFPM, usable on the 175 mm production lathe.

Table 11. Hardness values obtained at the rough turn operation for Heat Nos. 1,2A & 2B in the "as-forged" condition.

Heat No.	Shell No.	Open End BHN (R_c)	Boattail BHN (R_c)
1	753	297 (31.5)	272 (28.1)
1	853	283 (29.6)	297 (31.5)
1	874	383 (41.3)	383 (41.3)
1	911	312 (33.2)	297 (31.5)
1	940	364 (39.2)	346 (37.2)
1	948	346 (37.2)	297 (31.5)
Average		331 (35.3)	315 (33.6)
2A	405	346 (37.2)	312 (33.2)
2A	508	382 (41.2)	312 (33.2)
2A	512	346 (37.2)	308 (32.8)
2A	525	329 (35.2)	312 (33.2)
2A	533	382 (41.2)	346 (37.2)
2A	544	346 (38.2)	312 (33.2)
Average		355 (38.2)	323 (34.5)
2B	1360	329 (35.2)	312 (33.2)
2B	1397	364 (39.2)	346 (27.3)
2B	1436	315 (33.6)	310 (33.0)
2B	1454	329 (35.2)	300 (31.9)
2B	1469	312 (33.2)	297 (31.5)
2B	1506	346 (37.2)	312 (33.2)
Average		333 (35.6)	313 (33.3)
All Heats Combined	Min.	283 (29.6)	272 (28.1)
	Max.	383 (41.3)	383 (41.3)
	Avg.	340 (36.5)	315 (33.6)

Figure 49. Machining of the M-549 projectile (HF-1 steel) on a J & L numerically controlled lathe.

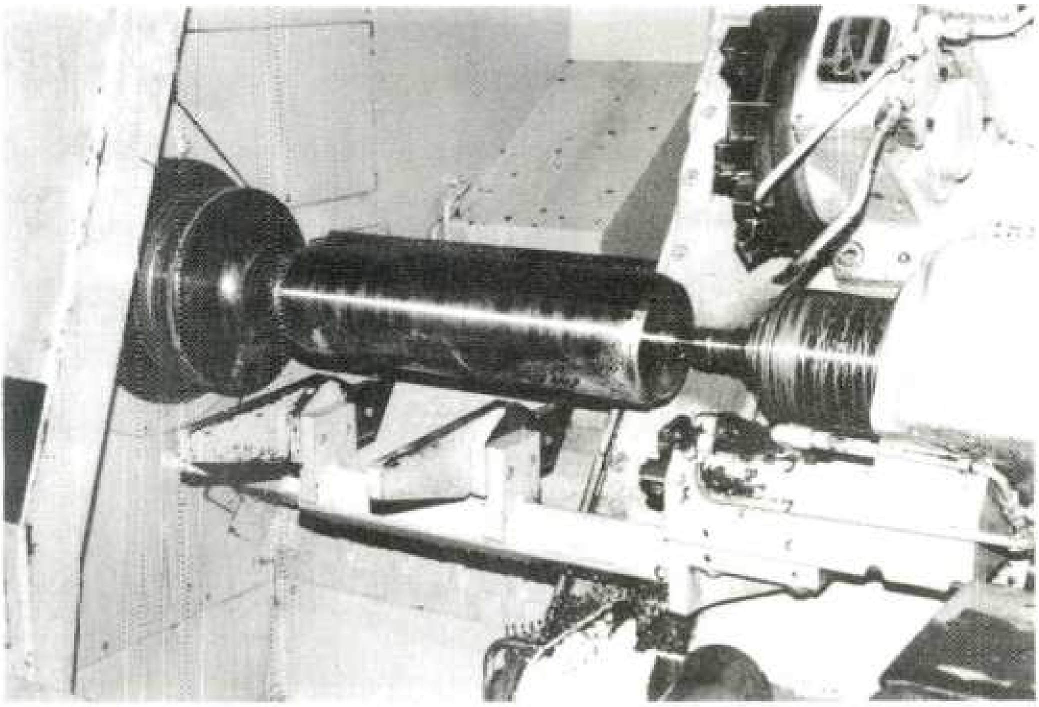


Figure 50. Completion of the machining operation of the M-549 performed on a J & L numerically controlled lathe.

A variety of insert types and grades were used in combination with several speeds, feeds and depths of cut. The condition of the insert with regards to wear land, cratering, deformation and chipping were monitored and recorded. The depths of cut utilized for this test were:

1. 3.56 mm (0.140 in.) which approximates the maximum depth of cut that could be encountered during the rough turning operation. This was monitored for the purpose of determining the amount of material that could be cut prior to insert failure (caused by either chipping or breaking), and

2. 1.52 mm (0.060 in.), which approximates the minimum depth of cut which could be encountered for this projectile during the rough turn operation and used for determining the wear land rates of the various grades of inserts tested.

Several feed rates were also monitored, but the one employed most often was 0.76 mm/rev. (0.030 in./rev.), which produces the desired rough turned finish required for the nosing operation.

The tests were conducted on both the turning and facing operations, with the resulting data being displayed in Tables 12 and 13.

For reference, a manufacturer's "Grade Comparison Chart" indicating the class, application, grade and manufacturer's designation of various inserts is included in Appendix F.

Analysis of the data acquired from this test prompted the following conclusions:

1. Inserts used in tool holders with 0° lead angle broke or chipped constantly.

Table 12 HF-1 Rough Turn tooling test results for the turning operation performed on shells in the "as forged" condition.

Insert Style	Insert Grade	Length of Cut (in.)	Depth of Cut (in.)	Speed (SFPM)	Feed (in./rev.)	Wear Land (in.)	Insert Condition		
							Crater	Deformation	Chipping
SNMG[c] 644	NT-56	6	0.140	267	0.030	0.005	None	None	None
	570	6	0.140	267	0.030	0.002	"	"	"
	"	6	0.140	267	0.030	0.003	"	"	"
	"	18	0.140	267	0.030	-----	"	"	Broke
	"	12	0.140	427	0.030	0.010	"	"	Slight
SNMA[b] 644	570	18	0.140	267	0.030	-----	None	None	None
	516	9	0.140	427	0.030	0.044	Slight	Slight	"
	516	30	0.060	427	0.030	0.060	Slight	Slight	"
	315	120	0.060	340	0.030	0.004	None	None	Chipped
SNMA[c] 648	9720	36	0.140	427	0.030	0.016	0.060 Wide thru coat	Slight	None
		150	0.060	427	0.030	0.016	0.060 Wide thru coat	Slight	None
SNMA[b] 648	9720	24	0.140	340	0.030	0.022	0.040 Wide thru coat	Slight	None
		150	0.060	340	0.030	0.022	0.040 Wide thru coat	Slight	None

Table 12 (cont'd.)

Insert Style	Insert Grade	Length of Cut (in.)	Depth of Cut (in.)	Speed (SFPM)	Feed (in./rev.)	Wear Land (in.)	Insert Condition Crater	Deformation	Chipping
SNMA [c] 648	NT-2	72	0.140	267	0.030	0.004	Slight	None	None
		420	0.060	267	0.030	0.004	Slight	None	None
	NT-2	60	0.140	340	0.030	0.004	None	None	None
		300	0.060	340	0.030	0.004	None	None	None
SNMA [b] 644	515	120	0.140	340	0.040	0.006	None	None	None
		120	0.060	427	0.048	0.006	None	None	None
	515	90	0.060	340	0.030	0.012	None	None	None
RNMA [a] 64	KC-250	90	0.060	340	0.040	0.018 thru coat	0.022 Wide	None	None
	SP-289								
		6	0.060	427	0.036	-----	-----	None	None
		6	0.060	427	0.030	-----	-----	None	None
SNG [b] 643	HC-2	30	0.060	644	0.018	None	None	None	Very Slight
	AL_2O_3	60	0.060	805	0.018	"	"	"	"
TNMA [a] 548	FT-62	6	0.140	427	0.030	0.012	0.060 Wide	Slight	Slight

Table 12. (cont'd.)

Insert Style	Insert Grade	Length of Cut (in.)	Depth of Cut (in.)	Speed (SFPM)	Feed (in./rev.)	Wear Land (in.)		Insert Condition	
							Crater	Deformation	Chipping
TNMA [a] 544	K21	6	0.140	427	0.030	0.015	0.060 Wide	Large	Shattered
TNMG [a] 544	KC-910	6	0.140	427	0.030	N/A	N/A	N/A	Broke
	KC-910	6	0.140	267	0.030	N/A	N/A	N/A	Broke
	KC-850	6	0.140	427	0.030	N/A	N/A	N/A	Broke
	P-2	6	0.140	267	0.030	0.008	None	None	Coatings Chipped
TNMG [a] 544	P-2	6	0.140	267	0.030	N/A	N/A	N/A	Broke
	KC-850	5	0.140	267	0.030	0.006	None	None	None

a. Tool holder w/ 0° lead utilized (carboloy).

b. Tool holder w/ 15° lead utilized (carboloy).

c. Tool holder w/ 45° lead utilized (carboloy).

d. Information on toolholders and inserts is listed in appendix.

Table 13. HF-1 Rough Turn tooling test results for the facing operation performed on shells in the "as forged" condition.

Insert Style	Insert Grade	Length of Cut (in.)	Depth of Cut (in.)	Speed (SFPM)	Feed (in./rev.)	Wear Land (in.)	Insert Condition Crater	Insert Condition Deformation	Insert Condition Chipping
SNMG[b] 644	570	4	0.250	267	0.010	-----	-----	-----	Broken
	VN-5	2	0.250	267	0.010	-----	-----	-----	"
SNMG[b] 648	NT-2	10	0.250	267	0.015	0.002	-----	-----	Chipped
	NT-2	24	0.200	420	0.015	0.003	None	-----	"
SNMA[b] 648	315	20	0.200	267 427	0.015	0.006	-----	-----	Slight Chipped
	315	40	0.200	427	0.015	0.008	-----	-----	-----
CNMG[a]	HN+	2	.0250	267	0.010	-----	-----	-----	Broke
	HN+	2	0.200	267	0.015	-----	-----	-----	"

a. Toolholder w/ 0° lead utilized.

b. Toolholder w/ 15° lead utilized.

2. Steel grade inserts deformed with breakage occurring shortly thereafter.

3. Inserts with chip breakers are not required for cutting HF-1 steel, but when utilized, the inserts broke, chipped and wore out at a faster rate than inserts having no chip breaker.

4. Cast iron grade titanium carbide coated inserts performed better than steel grade inserts with the same coating.

5. For the turning operation, inserts with a 1/8" nose radius outperformed the inserts that had a 1/16" nose radius. Inserts having a 3/8" radius wore out at a faster rate than one with a 1/8" radius.

6. For the facing operation, inserts with a 1/16" nose radius performed better than one with a 1/8" radius.

7. A feed rate greater than 0.035 in./rev. caused the chips to bunch up and also generated heat checking in the tools.

Evaluation of Rough Turn Tooling

The center drilling operation was performed on a Sundstrand Model 8A "special" lathe temporarily tooled to center drill the boss and cut off the excess material (ring) on the open end of the M549 projectile for this project.

Although not a required evaluation for this project, it was noted that approximately 30 to 35 shells per drill bit were produced on the center drill that was utilized (1" dia.std.) for this operation. Naturally this figure will change depending on the type of production equipment employed to perform this operation on a production basis.

The center drilling operation, as accomplished during this test, is illustrated in figures 51 and 52.

Since production of the 155 mm M107 projectile was on-going during the scheduled performance of this test, it was decided that machinability studies would be conducted on one of the lathes incorporated in the 175 mm production line.

The rough turn operation was performed on a Detroit Broach multislide hydraulic tracer lathe, model No. B1458-42, equipped with a 150 HP main drive motor, four traverse and two plunge slides. Three traverse slides were utilized for turning the body while the two plunge slides were employed for the facing and parting operations. Figure 53 illustrates the tooling set-up used for performing the turning operation. The parting and facing tool blocks (and slides) are situated to the rear of the shell and cannot be readily viewed in the above mentioned figure. However, a view from the top of the machine mandrel displaying the parting and facing tools, is presented in figure 54.

Instrumentation

During the performance of this task, tool pressures, in the tangential direction, were measured and recorded for the three tools involved with the turning operation. To acquire the tooling loads, a strain gage was epoxied to a specially designed fixture. The fixture was inserted between the bottom of the tool holder and the top of the tooling block "pocket", (fig. 55). The conditioned outputs from the strain gage fixture for tools Nos. 1, 2 and 3 were connected to channels 1, 2 and 3, respectively, on a 6-channel strip recorder (fig. 56). (The recorder shown was also utilized for obtaining forging load and stroke data during the performance of Task E of this project.)

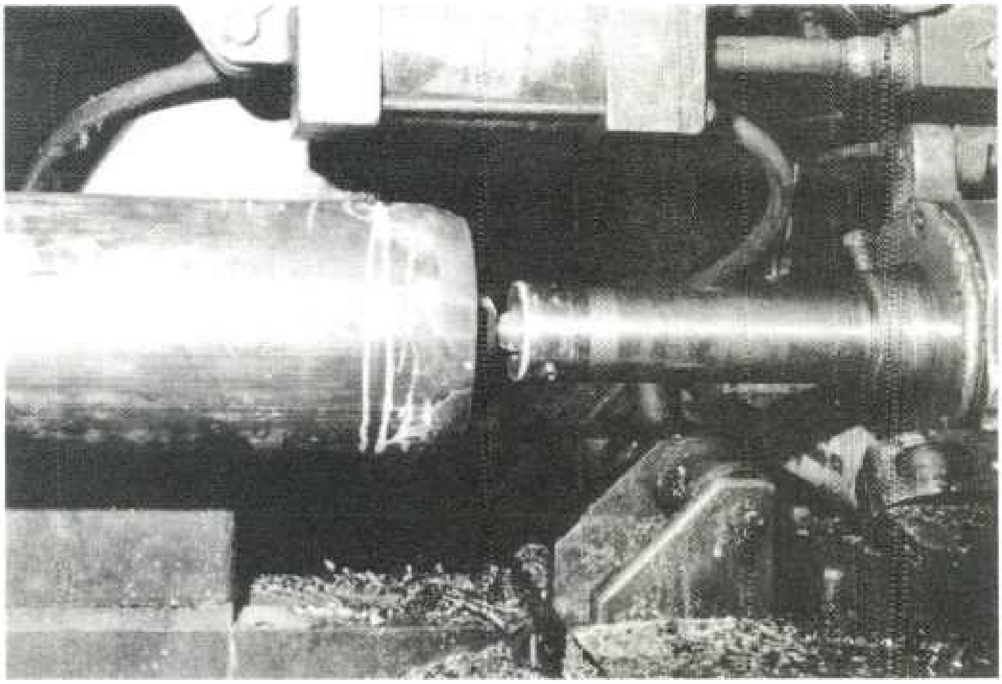


Figure 51. Center drilling of "boss" on the M-549 shell.

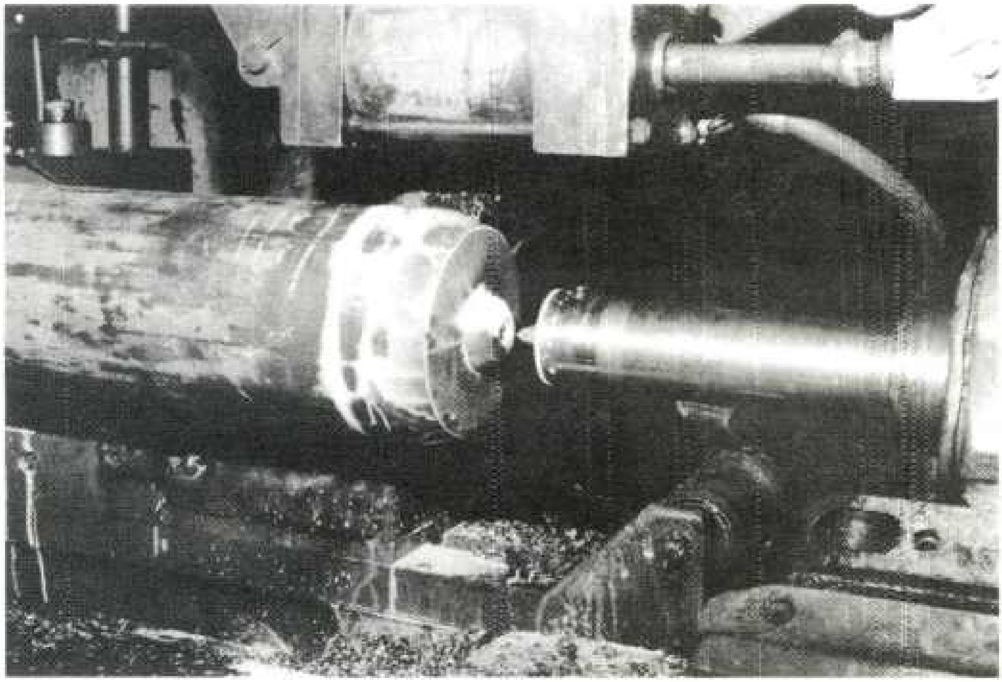


Figure 52. Completion of the center drilling operation.

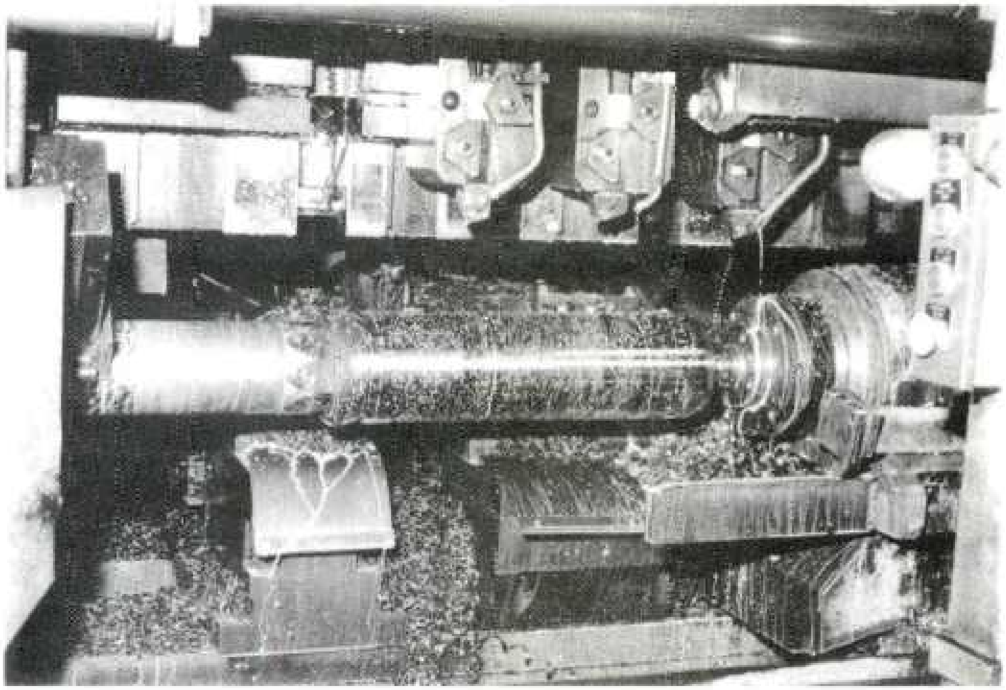


Figure 53. Tooling set-up on Detroit Broach tracer lathe illustrating the tooling utilized for the turning operation. (Note 3 tooling blocks at top of photo.)

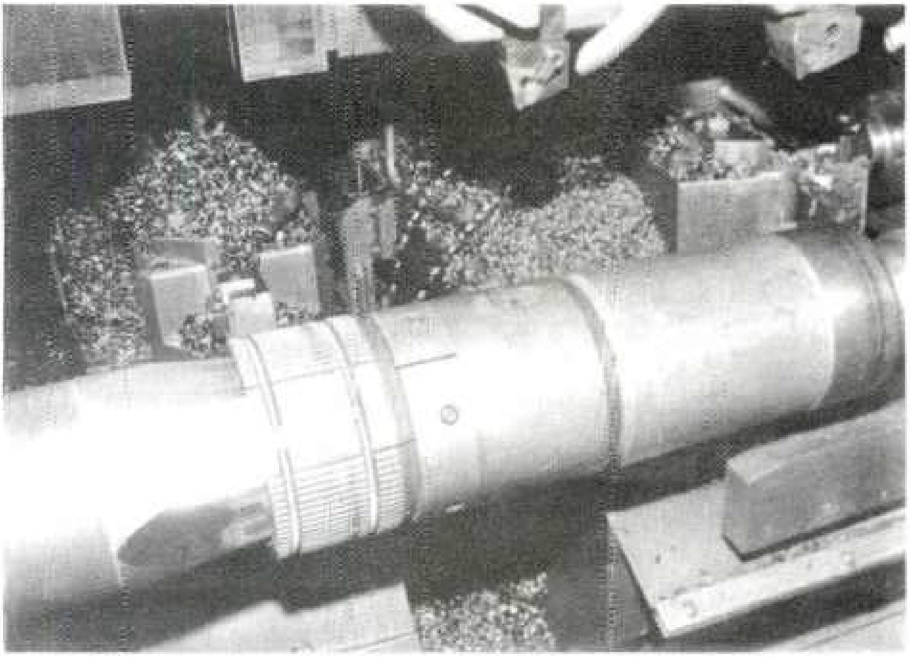


Figure 54. View overlooking top of machine mandrel displaying parting (left) and facing tools (right).

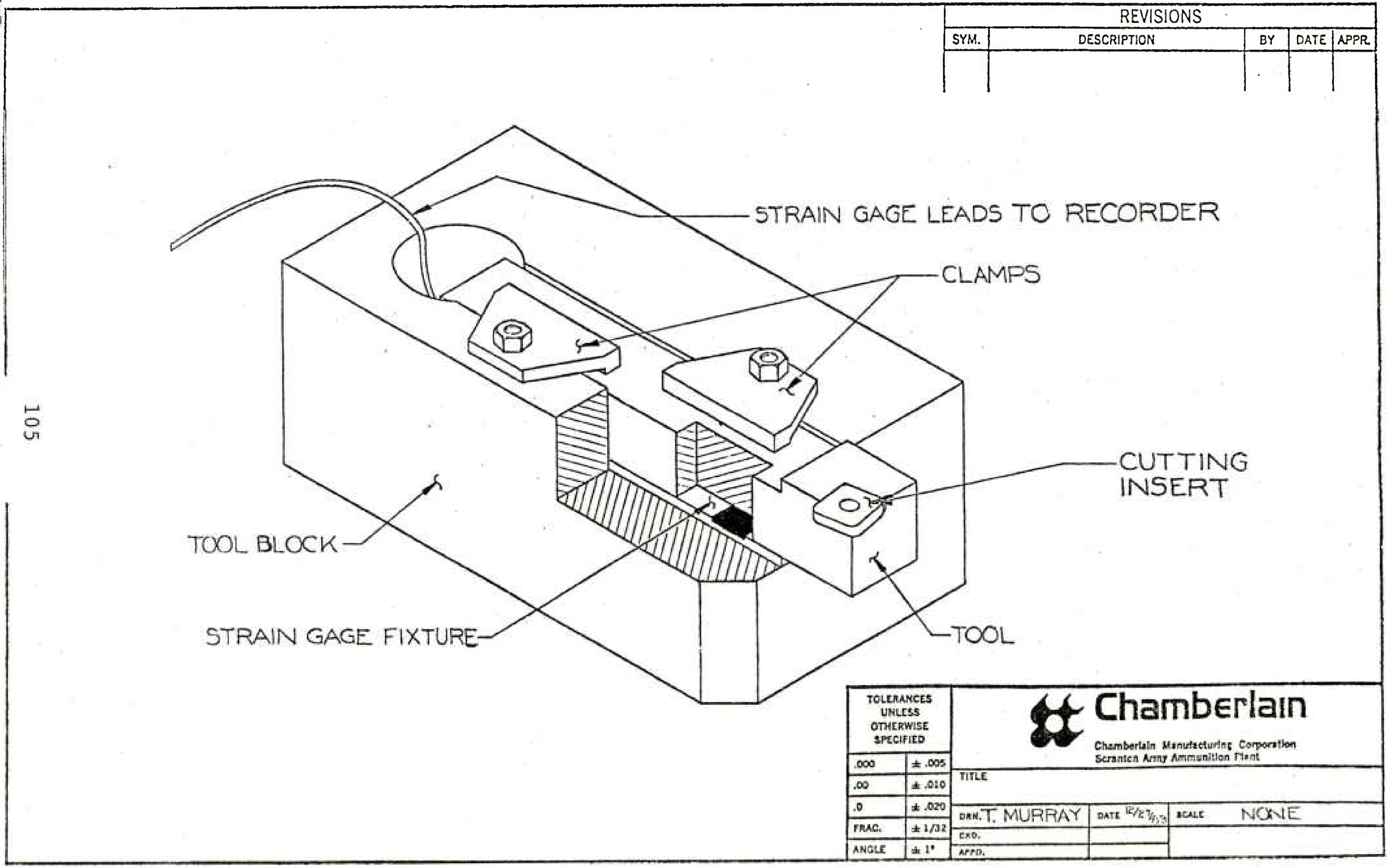


Figure 55. Illustration of strain gage installment for acquiring tangential tool pressure.

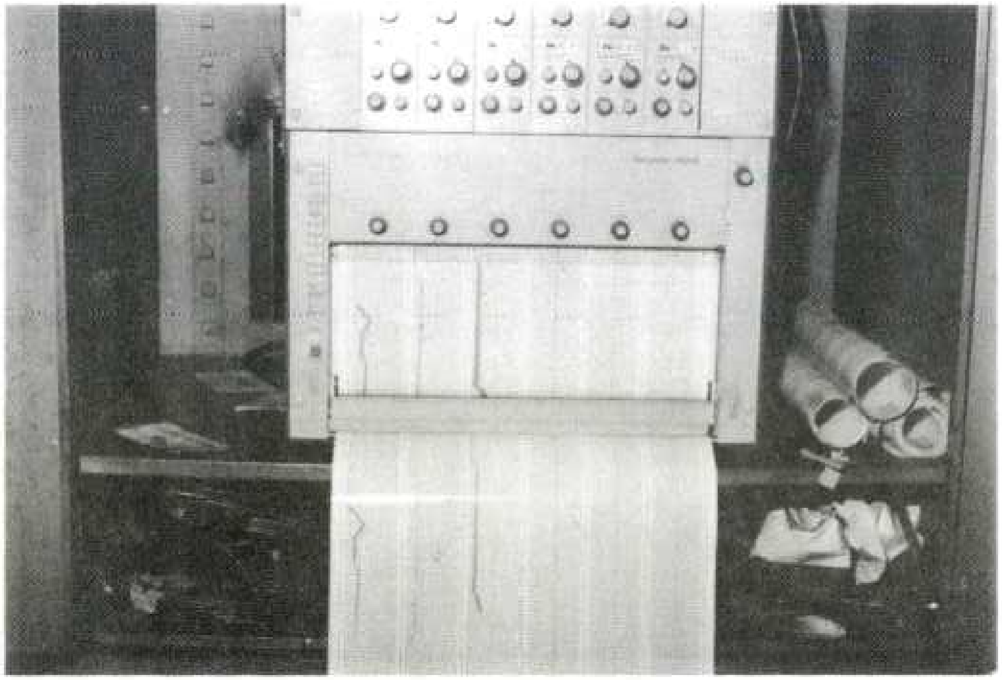


Figure 56. Photograph illustrating the recording of tangential tool pressures at the rough turn operation.

Explanation of Rough Turn Testing Stages

Tasks C, D and E are all concerned with the acquisition of rough turn machinability data and thus are interrelated. The overlapping of data concerning the three tasks can be confusing, therefore, a brief description of the objectives, and also the manner in which the tests were conducted to obtain the required data for the subject tasks, is presented below:

Task C - The objective of this task was to assess the feasibility of producing a machinable forging without the need for employing a spheroidize annealing process, and to verify that the forging is machinable by obtaining tool life data comprising various tooling grades, types, feeds, speeds, etc.

Task D - This task sought to further investigate and optimize the tooling required for the rough turn operation. It included the machining of a statistically significant sample of shells in the as-forged condition to obtain a tooling base which would be used for comparison of tool life between the annealed and as-forged shells. Also, tooling pressures were recorded and compared for both groups of forgings.

Task E - The rough turn section of this task sought to confirm the tooling results obtained in Task D, make further recommendations concerning the optimization of tooling where applicable, and to note the difficulties and problems encountered at this stage of the manufacturing process.

The manner in which the results and the tooling data were obtained for Task C has already been discussed and presented at the beginning of this section of the report.

Originally, 750 shells, forged during Task E of this project, were to be utilized to confirm the rough machining process. However, delays in the delivery of the instrumentation needed to obtain tooling pressures during the performance of Task D were encountered. In order to expedite the testing program while awaiting the arrival and set-up of the instrumentation, it was agreed upon by Chamberlain Manufacturing Corporation and the Government Technical Advisor that the rough machining tests for Task E would be conducted concurrently with the Task D effort.

The testing for Tasks D and E was conducted as follows:

1. Rough machine 500 forgings (of the 750 that was to be utilized in Task E) to obtain tool wear data in order to optimize the rough turn process. (Tasks D and E)

2. Rough machine 300 forgings (150 each of as-forged and annealed) for comparison of tool wear data and tool pressure. (Task D)

3. Rough machine the remaining 250 forgings to verify tooling results and confirm the rough turn operation. (Task E)

Testing (Task D)

Five hundred (500) shells in the as-forged condition (a part of those shells that were forged during Task E of this project) were processed through the rough turn operation in order to further investigate and optimize the tooling prior to conducting comparison tool life tests with the annealed forgings.

Although numerous tooling data, collected prior to Task C on the machining of HF-1 steel in the as-forged condition, has been acquired and listed in Tables 12 and 13, it cannot be stated that any of the tooling listed in these tables is truly the optimum for machining HF-1 steel. Since tooling optimization is a continual on-going task in the machining field, additional types of tooling were utilized in this study to further acquire a more comprehensive data base on tooling life. The results of these efforts were to be used for comparison with the data listed in Tables 12 and 13 at the completion of the rough turn section in Task E. The purpose of utilizing this approach was to aid in the determination of which tooling employed in this study yielded the best results, and to develop recommendations for future direction in continuing the optimization of tooling for machining HF-1 steel.

As previously mentioned, the rough machining operation was performed on the 175 mm line tracer lathe. Therefore, a surface speed of 267 ft./min. and feed rate of 0.035 in./rev. and 0.0115 in./rev. were utilized for the turning and facing operations respectively.

A toolholder with a 15° lead angle (type B) was selected for the turning operation, since it had already been determined that the use of a holder with a 0° lead had caused the inserts to chip and break prematurely. A style C (No. 16) brazed toolholder was employed for facing the base of the shell.

Table 14 lists the tooling utilized and results obtained for the 500 piece production run for the three heats of steel (1, 2A and 2B) combined. (A separate breakdown of tool life for each individual heat is presented in the Rough Turn section under Task E of this report.)

In reference to the table, footnote "c" states that the data for tool position No. 1 was obtained prior to the installation of the parting tool on the rough turn machine. An explanation of this footnote is presented as follows:

Table 14. Rough Turn tooling test results for 500 piece "as-forged" production run (all heats combined).

Speed - 267 SFPM   Feed - 0.035 in./rev.

Avg. depth of cut 0.105 in.

Tool Pos.[a]	Insert Style	Insert Grade	Shells Run	Avg. Shells Per Index	Avg. Inches Per Index[b]
1	SNMG-866	1025	281	7.4	40.7
1	SNMG-866	1025	186	6.2[c]	34.1
1	TNMA-666	315	27	1.8	9.9
1	TNMA-666	TX10[d]	4	1.0	5.5
1	TNMM-666	V-90	1	1.0	5.5
1	TNGA-666	HC-2	1	1.0	5.5
2	TNMA-666	315	500	25.0	193.8
3	TNMA-666	315	500	29.4	227.9
4	Special[e]	K-21	450	25.0	59.4
4	TNMG-542	518	50	5.6	13.2
5	DE/46/4	VR-75	243	7.4	2.8
5	DE/46/4	CF-7	37	3.7	1.4
5	DE/46/4	CF-6	1	1.0	.4

a. 1, 2 & 3-Turning; 4-Facing; 5-Parting.

b. 25.4 mm = 1 inch.

c. Data obtained prior to installation of parting tool (Pos. #5) on Rough Turn machine.

d. Ceramic insert.

e. 5/16" sq. x 1" lg. w/ground chip breaker.

A TNMN-666 style and 315 grade insert was first utilized in position No. 1. The table reveals that the resultant tool life for this insert was poor (1.8 shells/index). An SNMG-866 style and 1025 grade insert was then employed in this position. The tool life had increased from 1.8 to 6.2 shells/index. An effort to further increase the life of this insert was then undertaken.

The excess material (ring) at the open end of the shell was being cut off at the center drill machine during this stage of the machining effort. Upon obtaining the results of tool life for tool position No. 1 after machining 186 shells with the ring already removed, it was decided that adding a parting tool to the rough turn machine set-up might increase the tool life for tool position #1. The thought being that the tool was exiting the cut too abruptly at the completion of cutting the angle at the open end of the shell. The addition of the parting tool had increased the life of tool No. 1 from 6.2 shells per index (cutting edge) to 7.4 shells/index. An illustration of the rough turned shell with the ring parted but still attached, is depicted in figure 57.

Upon review of the data presented in Table 14, the tooling utilized for comparison of tool life between the annealed and as-forged shells was selected and is presented in figure 58. This figure also depicts the tool positions and approximate cutting lengths for each tool utilized during the rough turn operation.

A comparison of results obtained for the rough turn tool life between the annealed and as-forged shells is presented in Table 15.

The table lists the tooling utilized and also the results obtained in both shells/index and inches/index. (The

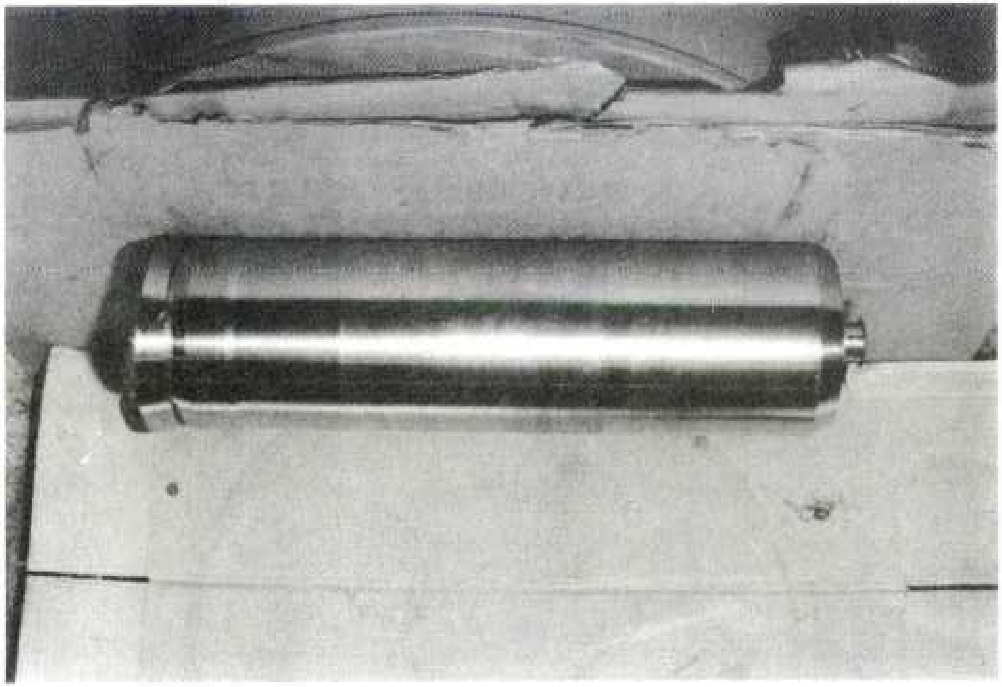
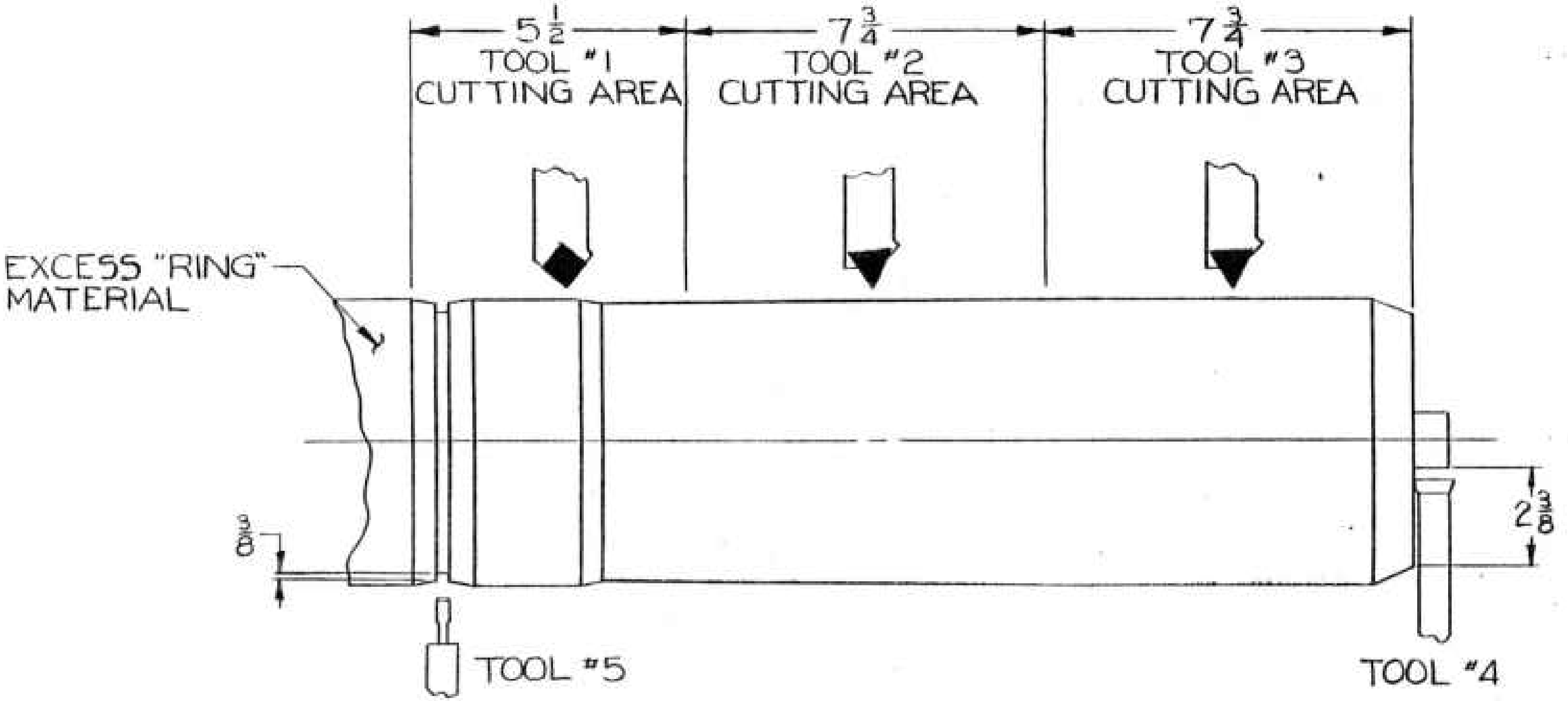


Figure 57. Photograph depicting the rough turned shell with the "ring" parted but still attached. (Left side of photo.)

REVISIONS

SYM.	DESCRIPTION	BY	DATE	APPR.



TOOL	DESC.	INSERT TYPE	GRADE/MFR.	HOLDER*
1	BODY	SNMG 866	1025 SANDVIK	MSBNL-24-8
2	BODY	TNMA 666	315 SANDVIK	MTBNL-24-6
3	BODY	TNMA 666	315 SANDVIK	MTBNL-24-6
4	BASE	SPECIAL	K-21 KENNAMTL.	NEWCOMER C-16 DESIGN
5	PARTING	DE/46/4	VR-75 FANSTL.	DEHR-106-4

* Refer to the Appendix for insert & holder indentification

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.000	± .005
.00	± .010
.0	± .020
FRAC.	± 1/32
ANGLE	± 1°

M-549 155 MM

Chamberlain

Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE ROUGH TURN TOOLING IDENTIFICATION

DRN. T. MURRAY DATE 1/31/82 SCALE NONE

CKD.

APPD.

Figure 58. Rough Turn tooling identification list (M-549, HF-1 Steel).

Table 15. Comparison of rough turn tool life between "Annealed" and "As-Forged" shells.

Speed - 267 SFPM Feed - 0.035 in./rev.

Avg. depth of cut 0.105 in.

Tooling			"Annealed"			"As-Forged"		
Tool Pos.	Insert Style	Insert Grade	Shells Run	Avg. Shells Per (1) Index	Avg. Inches Per (1) Index	Shells Run	Avg. Shells Per (1) Index	Avg. Inches Per (1) Index
1	SNMG 866	1025	138	46.0	253.0	144	16.0	88.0
2	TNMA 666	315	138	69.0	534.8	144	24.0	186.0
3	TNMA 666	315	138	69.0	534.8	144	48.0	372.0
4	Special[b]	K-21	138	46.0	109.3	144	24.0	57.0
5	DE/46/4	VR-75	138	27.6	10.4	144	8.0	3.0

a. 25.4 mm = 1 inch

b. 5/16" sq. x 1" lg. w/ground chip breaker.

word "index" represents one cutting edge on the insert and is standard terminology in machining studies.) For ease of comparison, the results are presented in histogram form for the turning operation, figure 59, and parting operations, figure 60. The results indicate that a substantial increase in tool life was obtained for the annealed forgings when compared to those in the as-forged condition.

The results obtained for tool Nos. 3 and 4 indicate that the tool life for the annealed shells was approximately double the life attained for the as-forged shells. This was expected since the forgings in the annealed condition is approximately "half as hard" as that in the as-forged condition.

Tool life for tool Nos. 1, 2 and 5 was approximately triple for the annealed shells when compared to those machined in the as-forged condition. Tool life obtained for those tool positions was expected to be poorer than that of Nos. 3 and 4 tools in the as-forged condition due to the progressive increase in hardness of the shell at the areas where these tools are employed. (Reference fig. 21.)

The results of the tooling life for the shells machined in the as-forged condition will be further utilized for analysis at the completion of obtaining additional machinability data during the performance of Task E of this project.

During the course of the rough machining test, inserts were removed from various tool positions at different time intervals and examined for wear conditions.

Typical wear conditions of the inserts obtained from tool positions Nos. 1 through 5, comparing the tool wear for the annealed and as-forged shells, are presented in figures 61 through 65 respectively. Also presented in the figures are

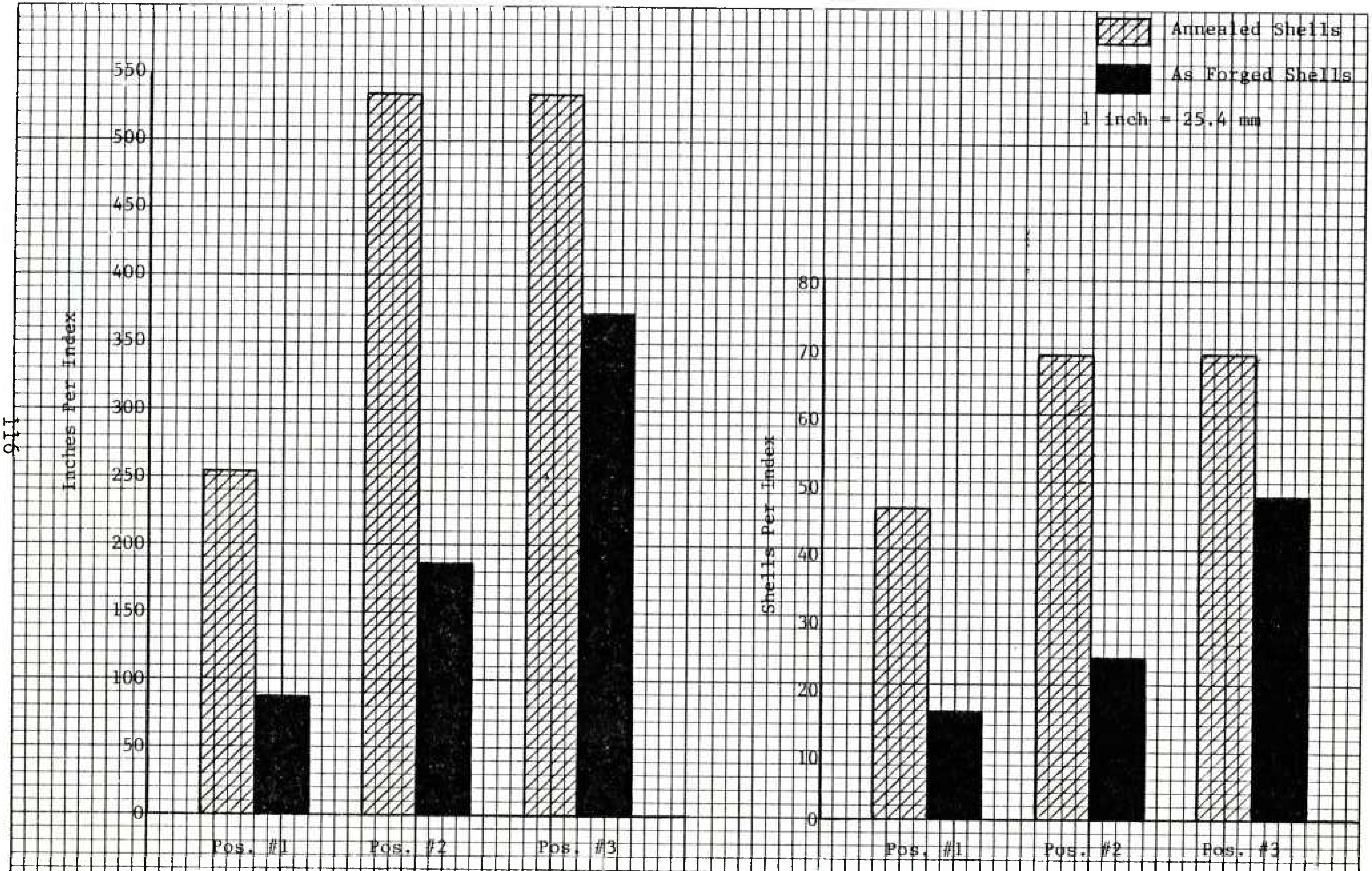


Figure 59. Comparison of "Turning" tool life between "Annealed" vs "As-Forged" shells.

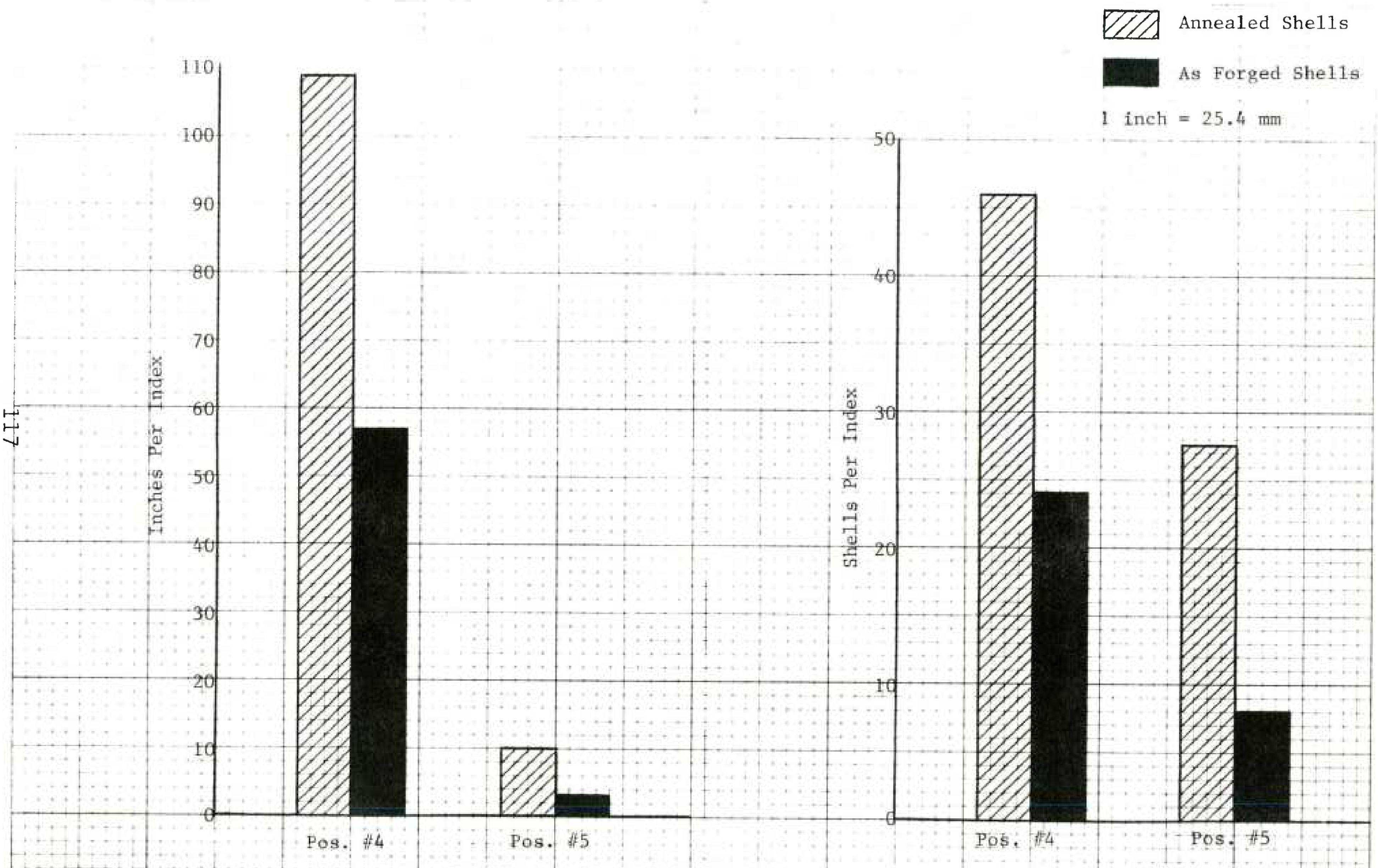
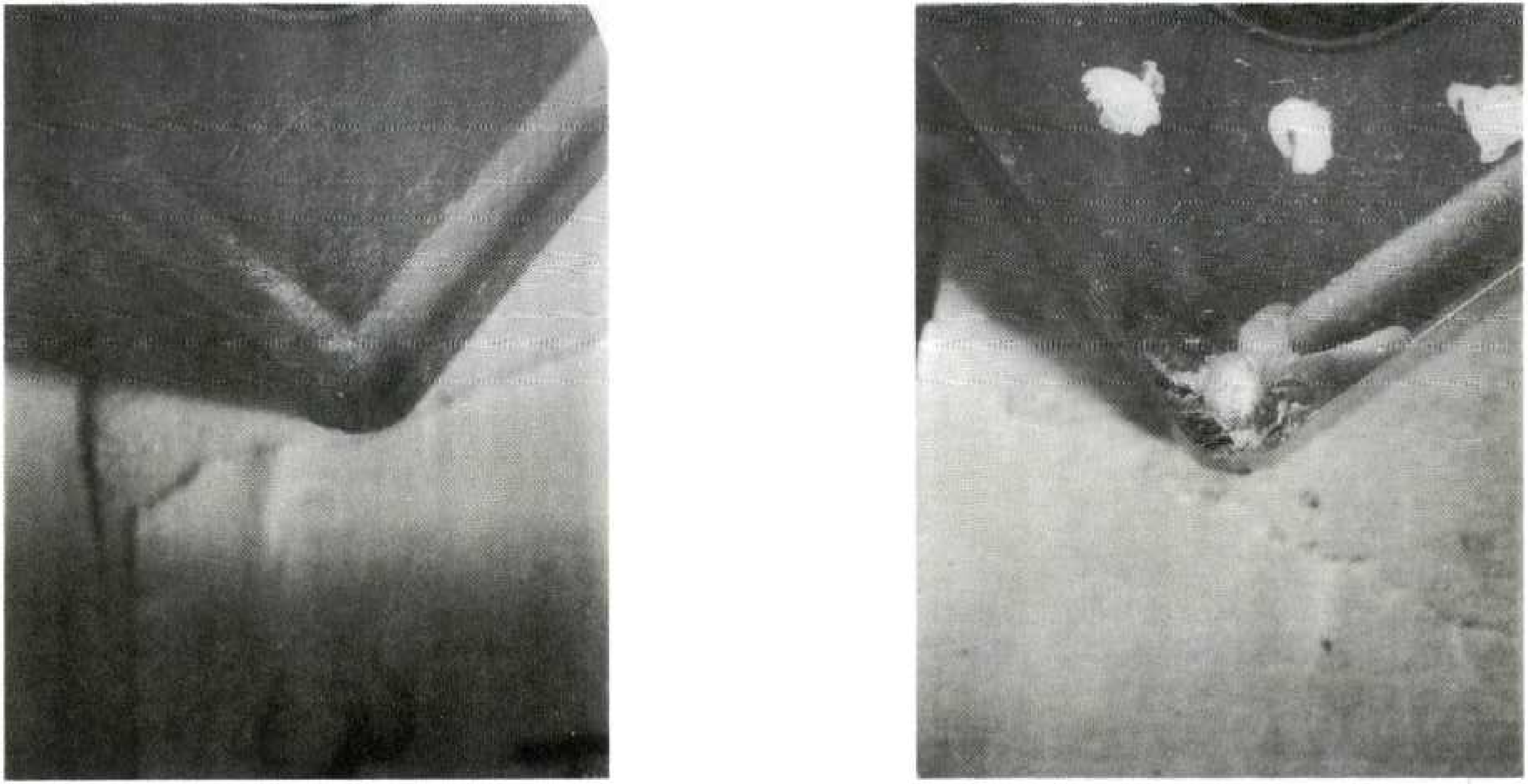
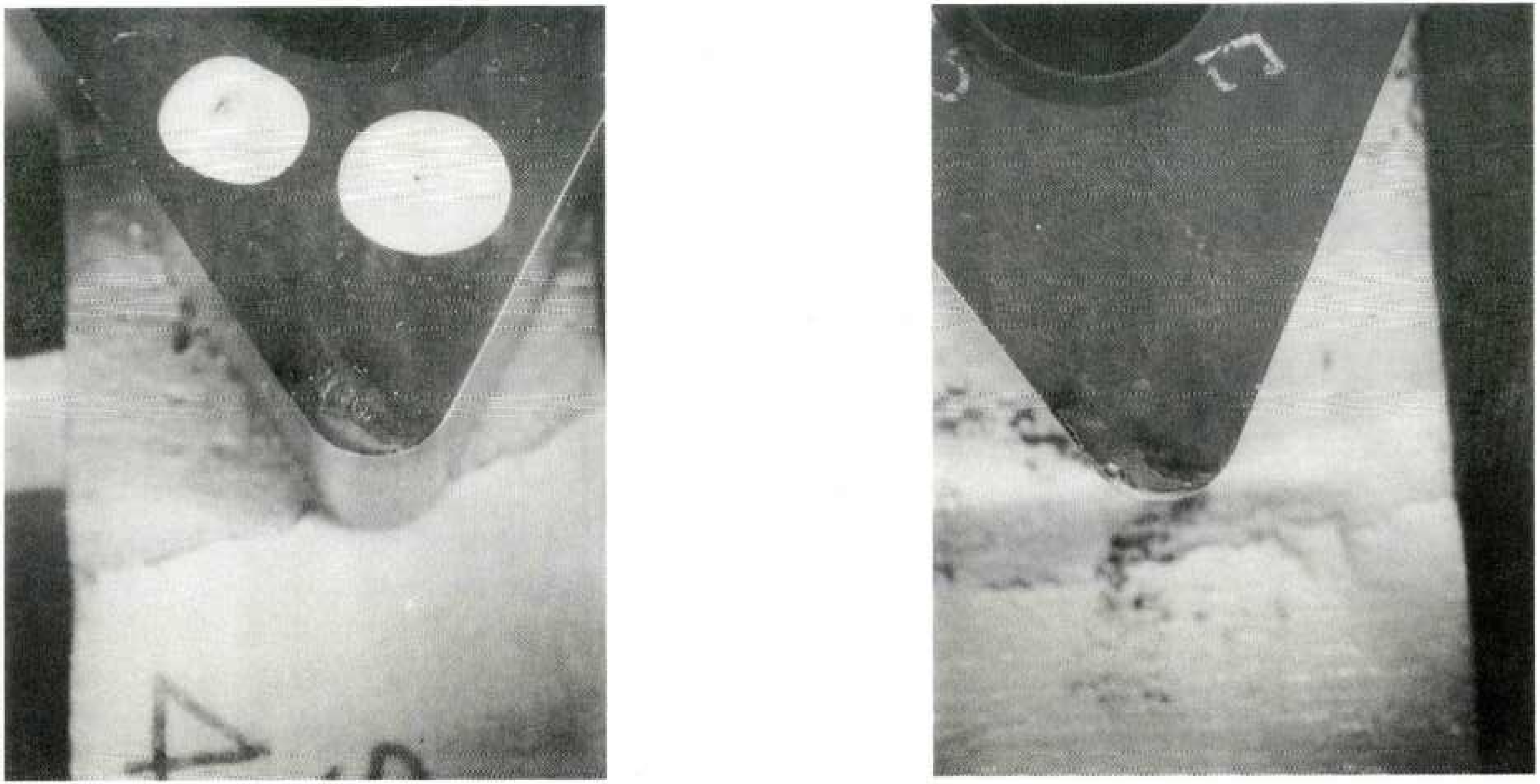


Figure 60. Comparison of "Facing" and "Parting" tool life between "Annealed" vs "As-Forged" shells.



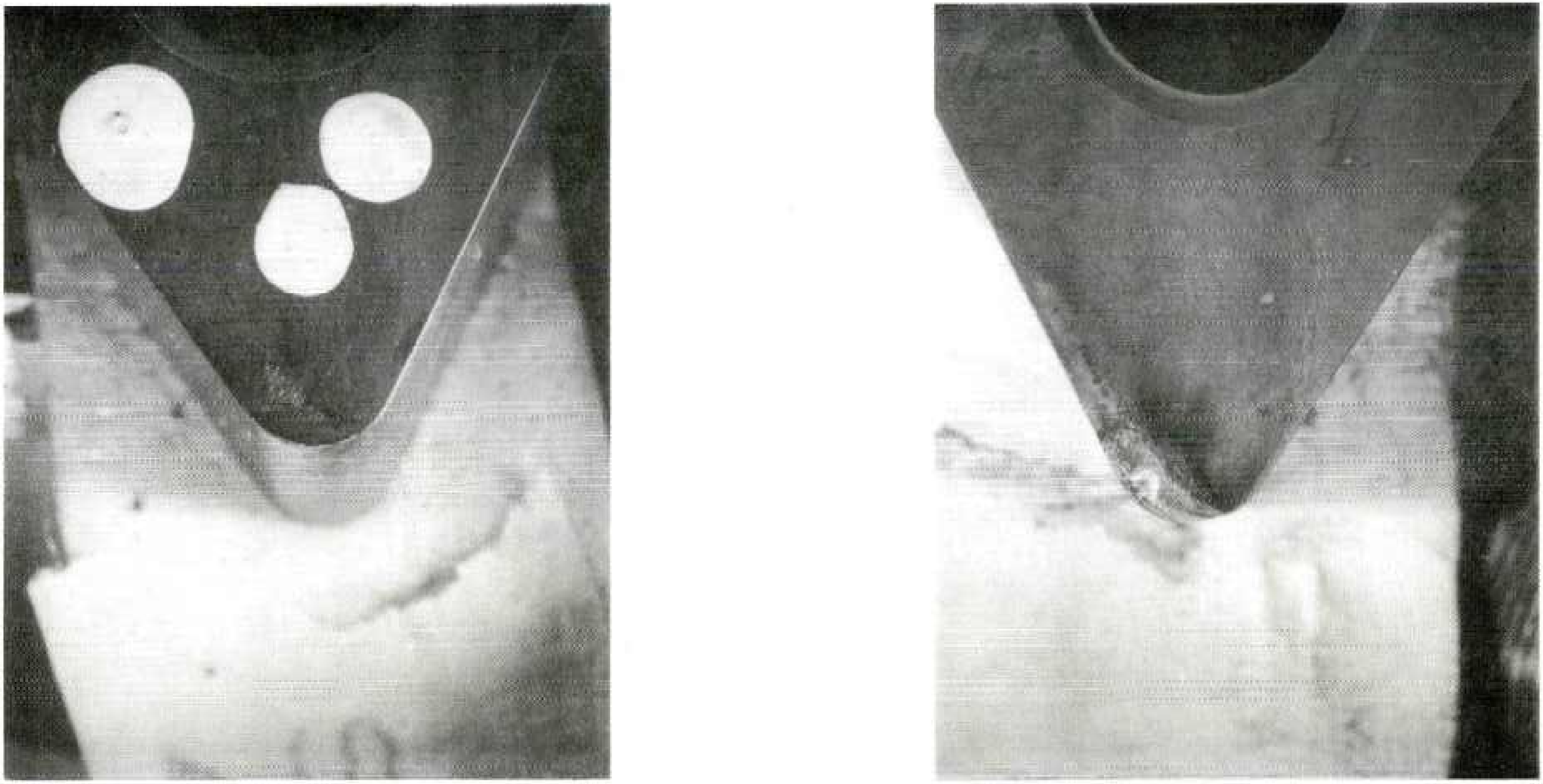
"Annealed"	Shell Type	"As-Forged"
SNMG-866	Insert Style	SNMG-866
1025	Insert Grade	1025
35	No. of Pieces of Insert	14
None	Wear Condition	Chipped

Figure 61. Photo depicting tool wear conditions for tool position #1. (Mag. 5x)



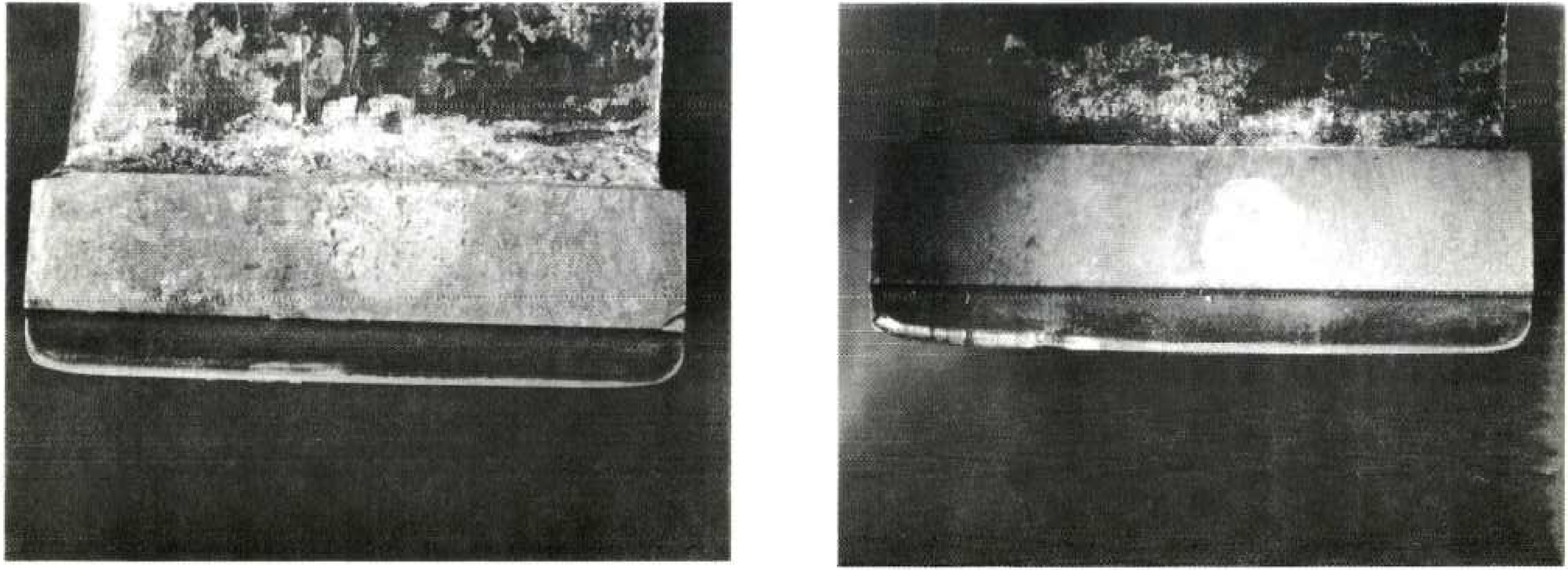
"Annealed"	Shell Type	"As-Forged"
TNMA-666	Insert Style	TNMA-666
315	Insert Grade	315
40	No. of Pieces	30
Build-Up	Wear Condition	Crater Formation

Figure 62. Photo depicting tool wear conditions for tool position #2. (Mag. 5x)



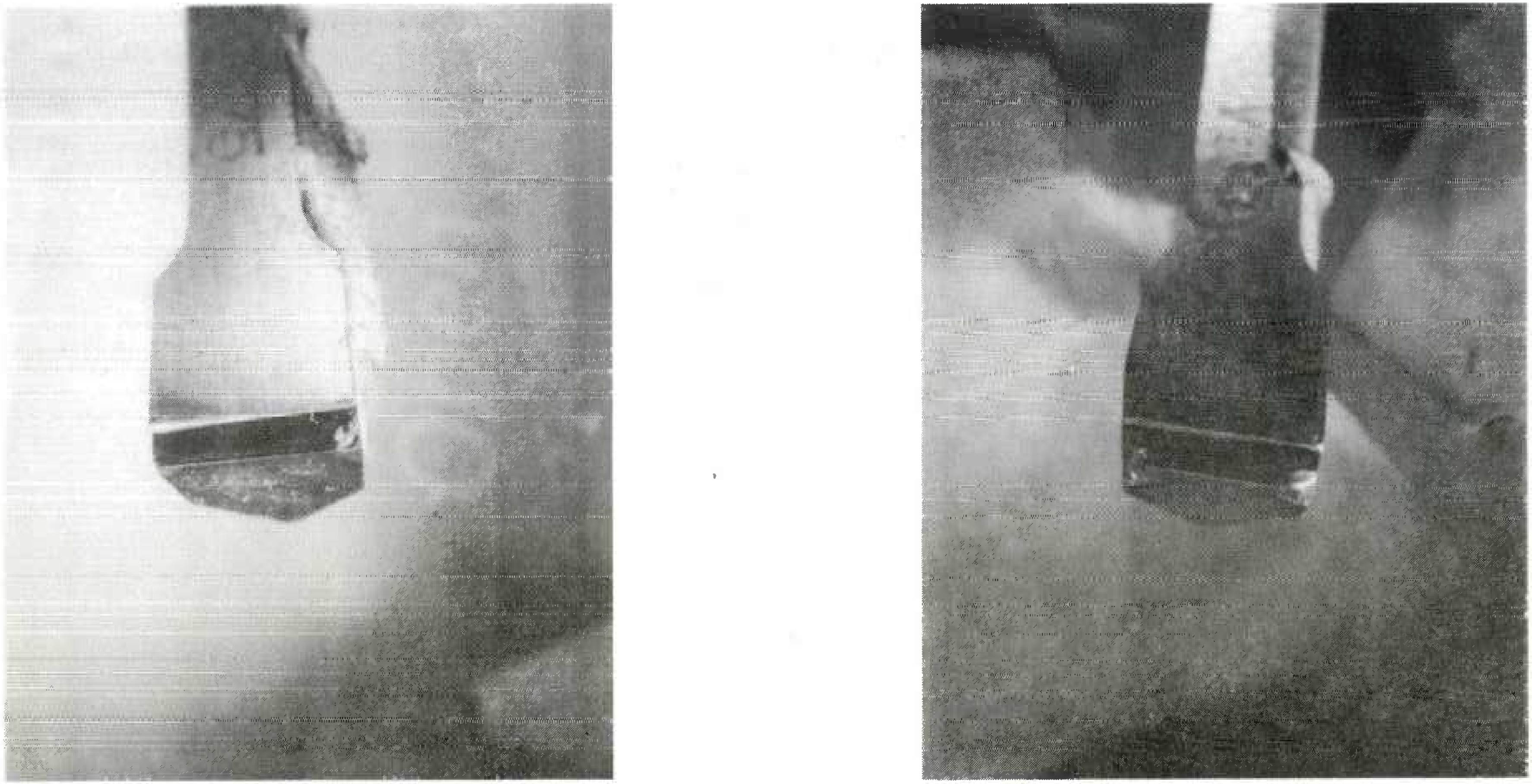
"Annealed"	Shell Type	"As-Forged"
TNMA-666	Insert Style	TNMA-666
315	Insert Grade	315
40	No. of Pieces	45
Slight Build-up	Wear Condition	Crater

Figure 63. Photographs depicting tool wear condition for tool position #3. (Mag. 5x)



"Annealed"	Shell Type	"As-Forged"
5/16" Sq. x 1" Lg. w/chip breaker	Insert Style	5/16" Sq. x 1" Lg. w/chip breaker
K-21	Insert Grade	K-21
43	No. of Pieces	34
Slight Wear	Wear Condition	Wear/Slight Cratering

Figure 64. Photographs illustrating tool wear conditions for tool position #4. (Mag. 4x)



"Annealed"	Shell Type	"As-Forged"
DE/46/4	Insert Style	DE/46/4
VR-75	Insert Grade	VR-75
33	No. of Pieces	17
Edge Chipping	Wear Condition	Edge Chipping

Figure 65. Photographs illustrating tool wear conditions for tool position #5. (Mag. 5x)

the insert style and grade, the number of shells produced on the insert upon its removal and a brief description of the condition of the insert.

It must be stated that the procedure of checking the wear conditions of the inserts while gathering tool life data has some effect on the accuracy of the data presented in Table 14, but to a non-appreciable degree.

The tooling data presented does confirm the fact that the subway cooling technique utilized at the Scranton AA Plant does produce a machinable HF-1 forging without the need for a spheroidize annealing process.

Tool Pressures

Tangential tool pressures were monitored and recorded for the three turning tools utilized in rough turning both the annealed and as-forged shells. Unfortunately, the data obtained for Heat No. 2B (Bethlehem - bung cooled) is omitted from this report. During the analysis of data obtained from Heat No. 2B, it was discovered that a malfunction of the strain gages utilized to acquire the data for this heat of shells had occurred. The data acquired for both the annealed and as-forged shells was quite erratic and had to be considered invalid. However, since microstructures and hardness data presented in this and also the previous report (Reference No. 1) had indicated that there is no significant metallurgical difference between the box (Heat No. 2A - Bethlehem) and bung (Heat No. 2B - Bethlehem) furnace cooled material, it is believed that the tool pressures for Heat No. 2B are similar to those of Heat No. 2A.

The results of the tooling pressures acquired for Heat Nos. 1 and 2A are presented in Table 16. For comparison, the mean loads for the as-forged and annealed shells are

Table 16. Average Rough Turn tool pressure (pounds) obtained for Heats #1 & 2A (as-forged vs annealed shells).

Tool No.	Heat #1		Heat #2A	
	As-Forged	Annealed	As-Forged	Annealed
1	1132	1066	1466	1432
2	986	981	1010	989
3	1067	965	995	940
Avg.	1062	1004	1157	1120

Average load for both heats combined as-forged 1110 lbs.

Average load for both heats combined annealed 1062 lbs.

presented at the bottom of this table. As noted in the table, the tool pressures acquired for tool No. 1 are greater than that obtained for tool Nos. 2 and 3 for both heats of steel in both the as-forged and annealed condition. This is attributed to the fact that tool No. 1 encounters the maximum depth of cut when rough turning the O.D. surface of this projectile. The depths of cut encountered for tool Nos. 1, 2 and 3 are 3.38 mm (0.133 in.), 2.66 mm (0.105 in.) and 2.16 mm (0.085 in.) respectively. These figures do not include the effect of eccentricity. If it were included, the depths of cut listed could be increased by as much as 0.25 mm (0.100 in.) if the maximum allowable eccentricity value was encountered. The values obtained for tool No. 1 pertaining to Heat No. 2A are quite high and questionable. It could not be determined whether the higher load readings obtained for this particular tool were due to the heat of steel involved, or to a possible transducer fault.

The load values of randomly selected shells for Heat Nos. 1 and 2A (as-forged and annealed) are presented in Tables F-1 through F-4, listed in the appendix. The results from those tables were then summarized as formerly presented in Table 16.

Figures 66 and 67 are samples of load recordings obtained during the rough machining of the as-forged and annealed shells respectively. Specific areas of the curves are labeled on the as-forged curve for clarification. The area of the curves where the tool pressure values are numerically labeled are typical locations indicating where the tooling pressure values were obtained and analyzed in this study. Figure 68 represents the load curves superimposed below the shell body in order to relate their position with respect to the shell body.

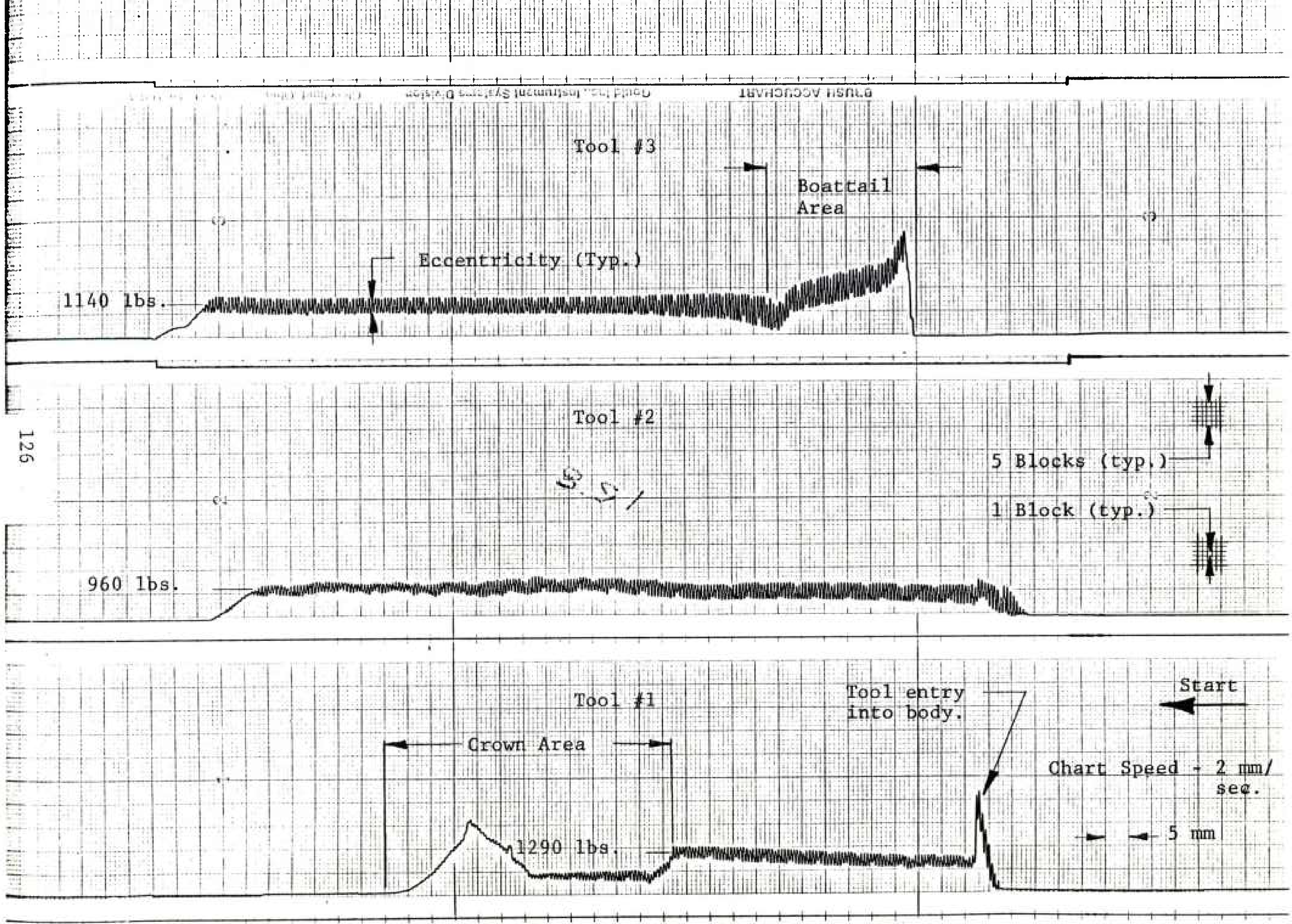


Figure 66. Sample of tool load recording for shell #158 - "as-forged".

Figure 67. Sample of tool load recording for shell #109 - "annealed".

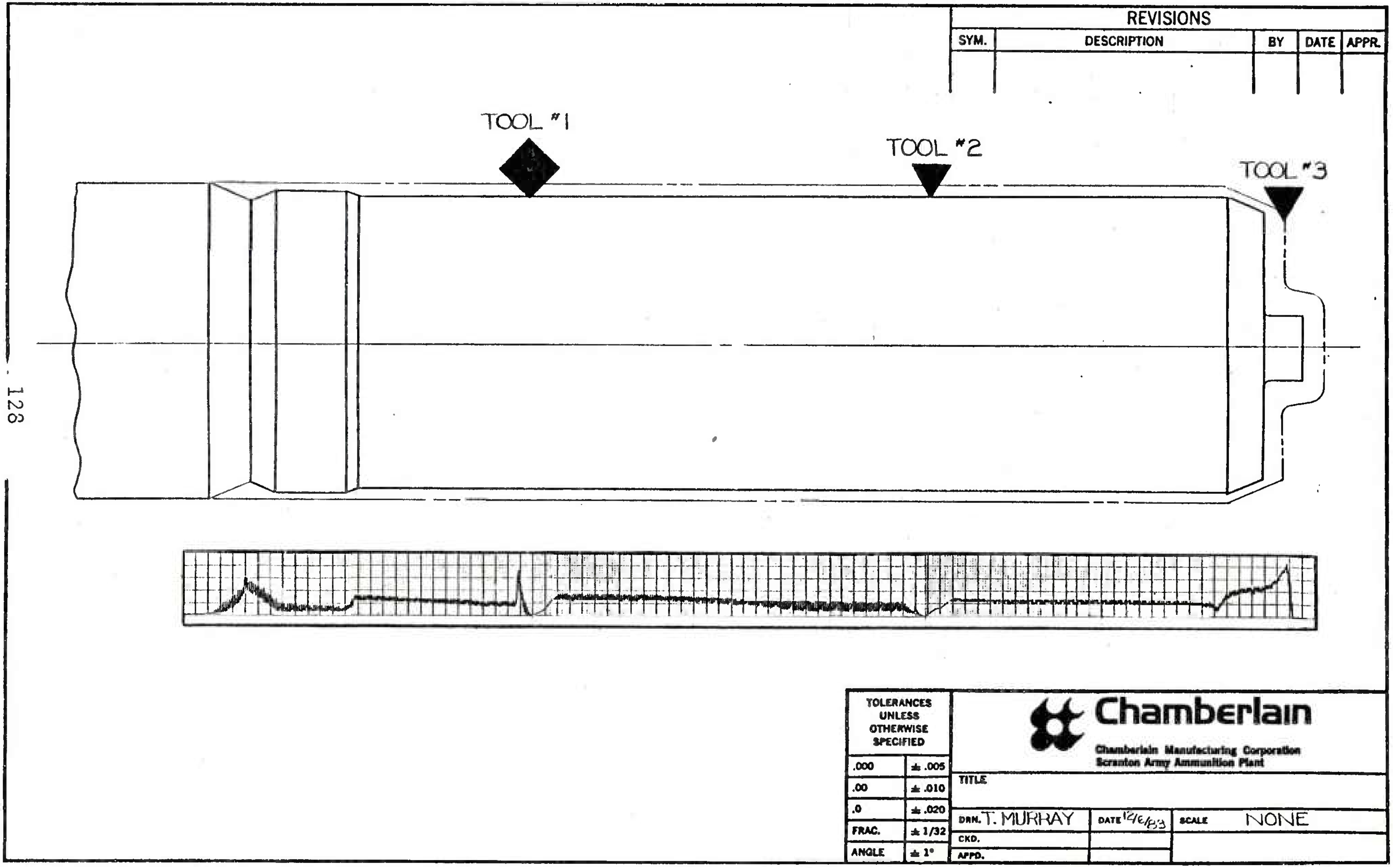


Figure 68. Illustration of tooling load chart superimposed beneath shell body to reveal the relation of the load curve with respect to the proper tool.

In order to determine load values from the curves, the transducers (strain gages) had to be calibrated. To ensure accurate calibration of the transducers with respect to their positions in the tool blocks, the tool block, strain gage fixture and turning tool were removed from the rough turn machine intact (Reference figure 55) at the completion of the testing period. Each individual tool block was then mounted on a Tinius Olsen tensile testing machine. A known load was then applied to the tip of the insert for each specific tool. The load was then noted while the displacement was recorded on a chart (figure F-6, Appendix F). This calibration procedure was utilized for the three turning tools involved.

The information contained on the chart recordings was then utilized to construct the calibration curves from which the load readings were obtained. The calibration curves are presented in figure F-7, listed in the appendix.

Problems Noted

During the performance of the rough machining operation, a problem area was noted during the removal of the ring (excess material) from the rough turn body. This condition resembled a "chipping" or "tearing" effect and was located at the inside diameter area of the ring/shell body separation area and is illustrated in figure 69. It was noted that this problem only occurred on the shells that were in the as-forged condition.

This condition was first noted when the rings were being cut off on the Sundstrand lathe, concurrent with the center drilling operation. At this operation, two methods of removing the ring from the shell body were tried. The first method employed was that of cutting the ring completely off by utilizing a parting tool to perform the operation. The

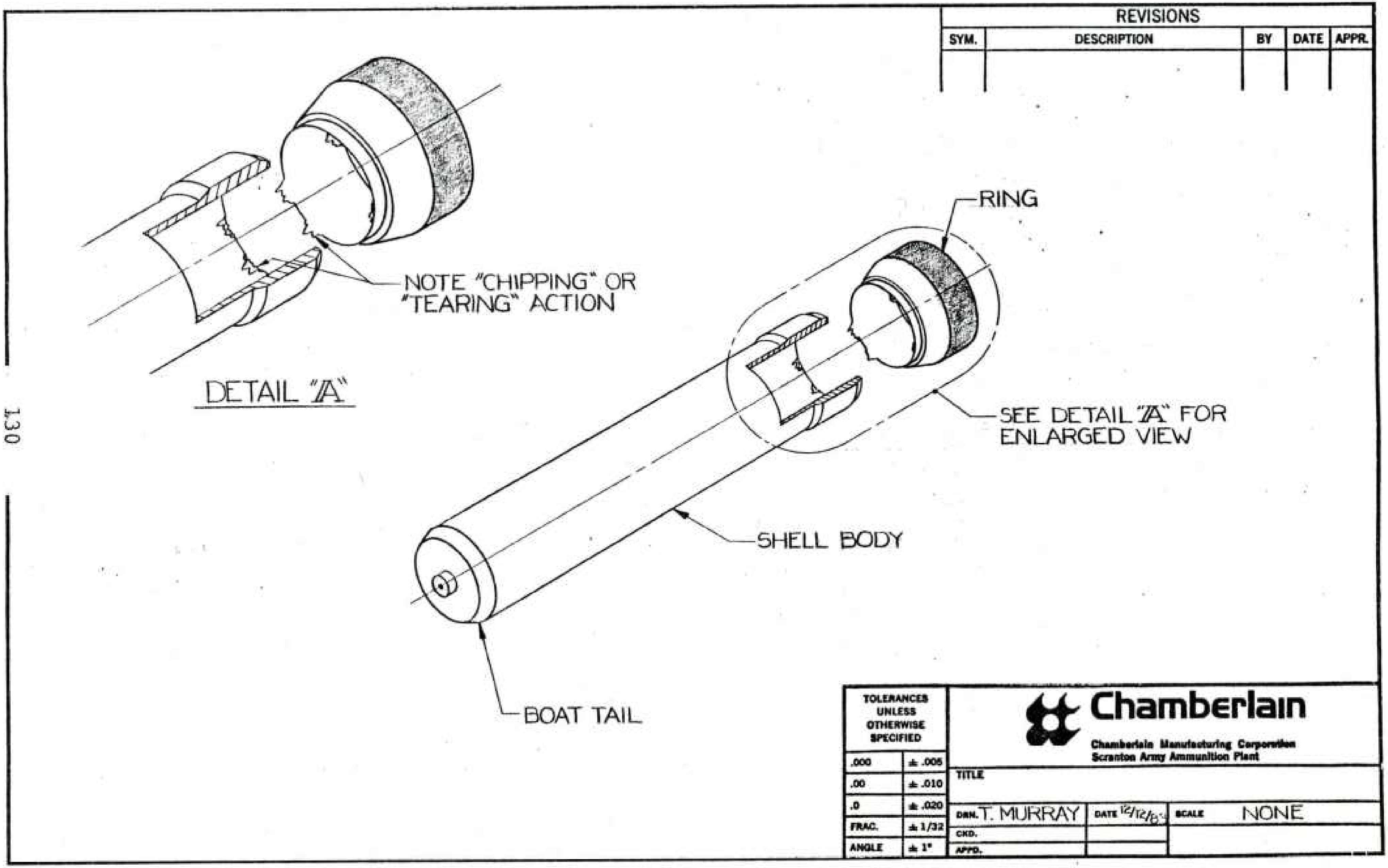
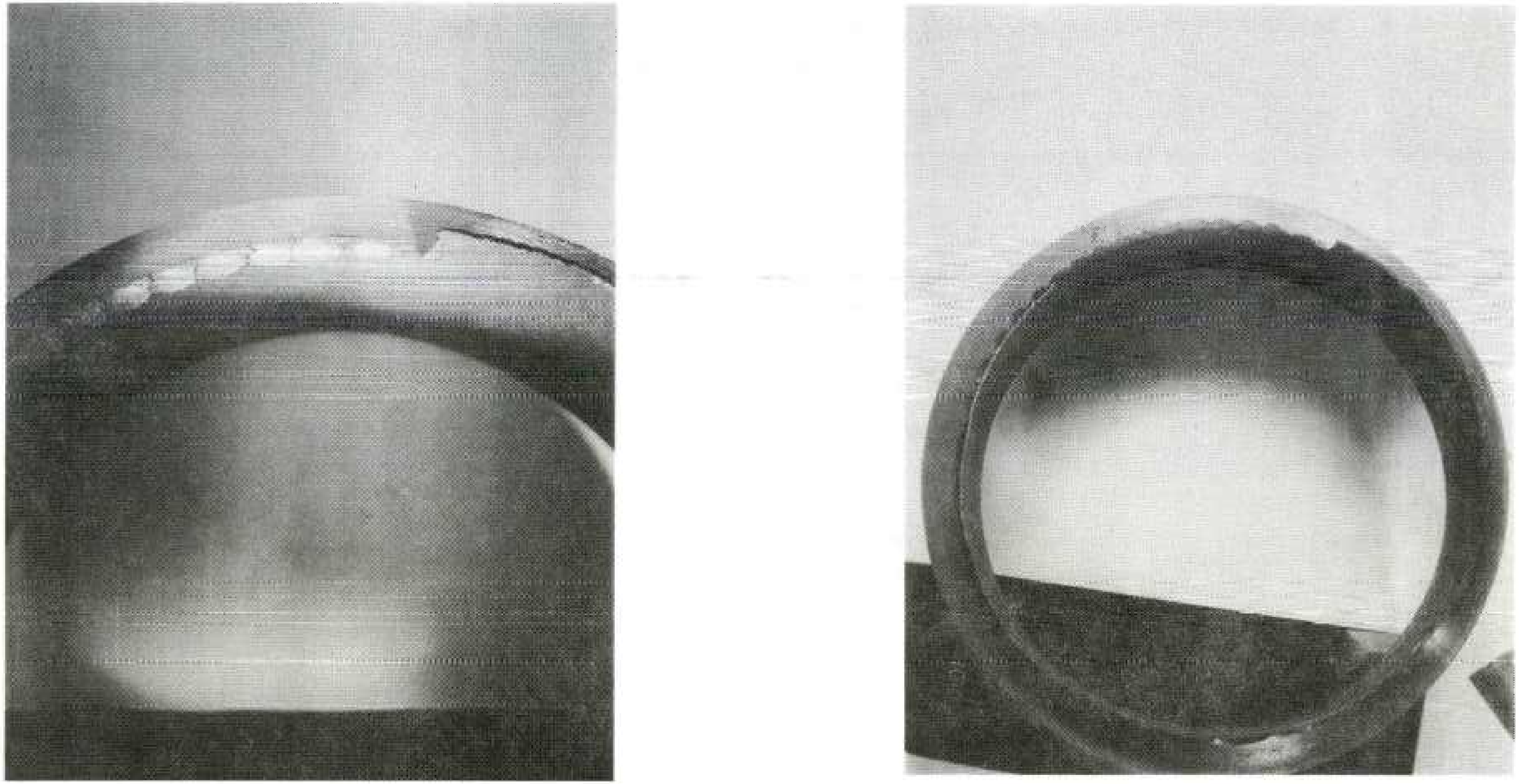


Figure 69. Illustration of area where a "chipping" condition occurred during removal of the ring from the shell body.

parting tool was fed into the shell until separation of the ring from the body had occurred. Normally, the result of this method produces proper separation of the ring from the shell body since the area of metal at the separation point is completely "cut" away as the tool approaches and finally penetrates through the inside diameter wall of the shell body. However, as the parting tool was about to penetrate the I.D. of the shell wall of the as-forged shells, the ring abruptly broke away from the shell body with the resulting "chipping" condition occurring.

The second method employed was that of utilizing the parting tool to cut away the material until a wall thickness of 0.03 in. was attained. At that time the tool was retracted from the cut. The ring was still attached to the shell body at this point. The ring was removed by the action of applying a sharp "hammer blow" to the ring. The resultant "chipping" or "tearing" effect was still encountered when this method was utilized.

Since it was previously decided that parting the ring on the rough turn machine might be an aid in obtaining longer tool life for tool postion No. 1, the thought also occurred that this action might resolve the "chipping" problem. The idea behind this was that the mandrel on the rough turn machine would provide more rigidity at the parting area compared to that offered by the mandrel utilized on the Sundstrand lathe. The results were not completely successful. The condition was still occurring, but to a lesser degree of severity. Both methods of completely cutting through the shell wall and applying a sharp hammer blow to the ring were once again used to separate the ring from the shell body during this trial. Figure 70 contains two photographs of the ring further depicting the chipping condition.



(Mag. - 1X)

(Mag. - 1/2X)

Figure 70. Photographs of "ring" revealing the "chipping" condition encountered upon removal of the ring from the shell body.

Since the chipping condition will directly affect the quality of the bore area of the shell at completion of the nosing operation, it was imperative that the condition be resolved. Therefore, another method was used in an effort to correct this problem. Twenty shells (ten in the as-forged and ten in the annealed condition) with the ring parted but still attached, had the rings removed on a Detroit Broach ring shear machine. This machine is typically interjected in projectile production lines for shearing the rings at the completion of the rough turn operation. It is utilized for the purpose of insuring that the open end of the shells is clean and square in preparation for the nosing operation.

The results of employing this machine to shear the rings were again unsuccessful as the "chipping" condition was still occurring on the as-forged shells. This has led to a preliminary conclusion that an additional "facing" (machining) operation might be required when processing HF-1 steel in the as-forged condition. Further evaluation of the problem would be required to confirm that conclusion.

PROCESSING OF REMAINING STEEL (TASK E)

Mult Parting

Evaluation of the forgings produced from the mults that were parted during Task B, showed that the weight of the mult could be further reduced. During Task E. the final task for this study, mult weight was targeted at 29.93 kg. (66 lbs.) minimum. Sawing speed and feed rates were again set at 420 SFPM and 13 in./min. respectively. A total of 904 mults were sawed during Task E. The number of mults sawed per Heat No. was as follows:

Heat #1 (Republic) - 348 mults
Heat #2A (Bethlehem) - 281 mults
Heat #2B (Bethlehem) -276 mults

Of the 904 mults sawed during Task E, 108 mults from the three (3) heats of steel involved were measured for length and weighed. The results, displayed in chart form for ease of comparison, are presented in figure 71. The chart shows that Heat #1 exhibits fairly stable weight and dimensional characteristics, while Heats #2A and 2B are erratic, necessitating more careful control of length. This is due to the poor surface quality of the billets.

Speed & Feed Rates

As previously mentioned, speed and feed rates for sawing the HF-1 steel were set at 420 SFPM and 13"/min. respectively during Task B. Due to the insufficient number of mults sawed during this task, conclusive data on tool life could not be garnered. Therefore, the same speed and feed rates were used during the start of Task E. Utilizing these cutting rates, the blade became dull and had to be changed after cutting approximately 125 pieces. For the M549

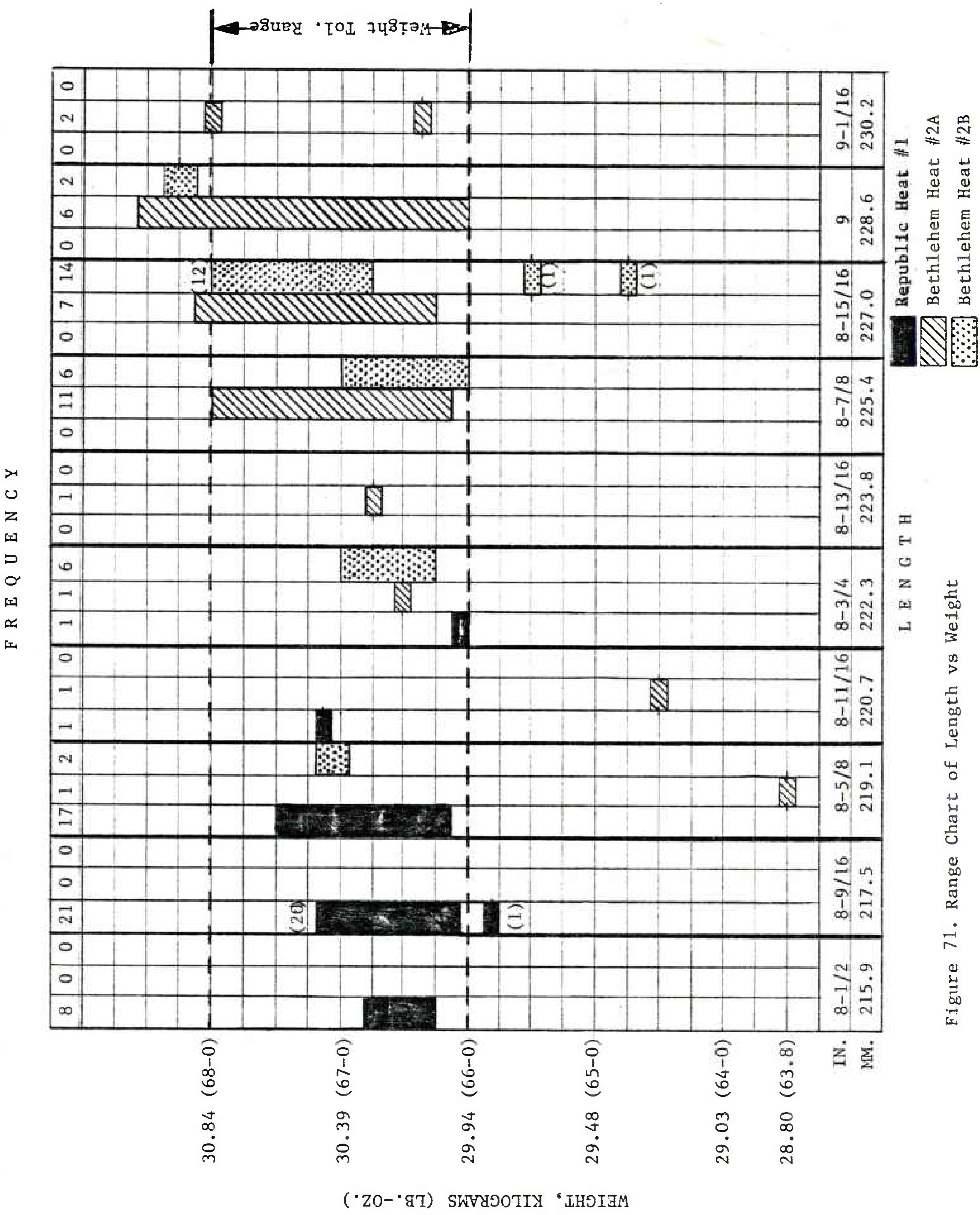


Figure 71. Range Chart of Length vs Weight

projectile, this translates to 3,430 in.^{2} of metal removed prior to dulling of the blade. Various saw blade manufacturers use 15,000 to 20,000 in.^{2} as their figure for average blade life. With this figure in mind, cutting rates were changed from the initial settings to 390 SFPM and 8.5 in./min. feed rate. Approximately 270 cuts/blade (7,410 in.^{2}) were achieved using these cutting rates with no signs of blade dulling. Unfortunately, the allotted amount of mults to be sawn for this task had been met, thereby necessitating a change back to sawing SAE 1046 steel for production of the M107. The same blades were kept on the machines and an additional 350 cuts/blade (9,605 in.^{2}) were recorded for the SAE 1046 steel before the blades became dull. While the above gives preliminary data, additional cutting of HF-1 steel would have to be performed in order to determine whether the cutting rates of 390 SFPM and 8.5 in./min. are optimal. Also, it could not be determined at this time whether the difference in heats had any bearing on tool life.

Forging Operation

The final phase of forging the M549 was conducted on March 28th, 29th and 30th, 1983. All mults forged during this task were parted by the sawing method. The number of mults forged was as follows:

Heat #	Mult #	Amount
1	649 thru 996	348
2A	997 thru 1277	281
2B	1278 thru 1552	275

Furnace temperatures were again set at 1177°C (2150°F) for this phase of forging.

Instrumentation

Forge load and displacement recordings were obtained while forging the M549 during this task. A pressure transducer was tapped into the hydraulic lines for the standard equipment gauges on the presses. The conditioned output from the transducers was connected to channels 1, 3, and 5 of the 6-channel strip recorder. Channel 2, 4 and 6 of the recorder were connected to the output of the displacement transducers to measure the ram displacements for all three (3) presses. The housings of the displacement transducers were bolted to a plate on the shop floor, while its activating cable was attached to the press platen.

Temperature readings were obtained at several stages of the forging operation, with the use of an infrared two-color pyrometer. Temperature readings were acquired and recorded for as many forgings as possible to aid in the analysis of forging of HF-1 steel. A complete list of instrumentation is presented in Appendix G.

Forging Loads

Table 17 lists the minimum, maximum and average forging loads obtained at the preforming, piercing and hot drawing operations for the three (3) heats of steel involved during this study along with the temperatures at which these loads occurred. Also, the combined average loads of the three (3) groups of HF-1 steel are presented in order that forging load comparisons can be made between HF-1 steel, in general, and other steels with known forging loads.

For ease of comparison, a bar chart depicting the average forging loads that appear in the table, is presented in figure 72.

TABLE 17. PREFORM, PIERCE & DRAW LOADS @ OPERATION TEMPERATURE

Operation	Heat #1				Heat #2A				Heat #2B				Combined			
	Load		Temperature		Load		Temperature		Load		Temperature		Load		Temperature	
	MN	(Tons)	°C	(°F)	MN	(Tons)	°C	(°F)	MN	(Tons)	°C	(°F)	MN	(Tons)	°C	(°F)
Preform:																
Min.	4.8147	(541.2)	991	(1815)	4.5407	(510.4)	1028	(1882)	4.5407	(510.4)	1027	(1880)	4.5407	(510.4)	991	(1815)
Max.	6.3209	(710.5)	1080	(1976)	5.7729	(648.9)	1069	(1956)	5.6358	(633.5)	1066	(1950)	6.3209	(710.5)	1080	(1976)
Avg.	5.4134	(608.5)	1046	(1915)	5.1928	(583.7)	1045	(1913)	5.0353	(566.0)	1049	(1920)	5.2302	(587.9)	1047	(1916)
Pierce:																
Min.	5.9473	(668.5)	936	(1717)	4.9883	(560.7)	954	(1750)	4.9883	(560.7)	954	(1750)	4.9883	(560.7)	954	(1750)
Max.	6.4954	(730.1)	926	(1700)	5.9473	(668.5)	902	(1655)	5.9473	(668.5)	874	(1605)	6.4954	(730.1)	926	(1700)
Avg.	6.2667	(704.4)	926	(1700)	5.5443	(623.2)	914	(1677)	5.4945	(617.6)	910	(1670)	5.7685	(648.4)	921	(1690)
Draw:																
Min.	1.1245	(126.4)	845	(1553)	0.9848	(110.7)	839	(1543)	1.1245	(126.4)	829	(1525)	0.9848	(110.7)	846	(1555)
Max.	1.2642	(142.1)	788	(1450)	1.1948	(134.3)	826	(1519)	1.3336	(149.9)	827	(1520)	1.3336	(149.9)	827	(1520)
Avg.	1.1566	(130.0)	851	(1563)	1.1334	(127.4)	831	(1527)	1.2019	(135.1)	835	(1535)	1.1628	(130.7)	843	(1550)

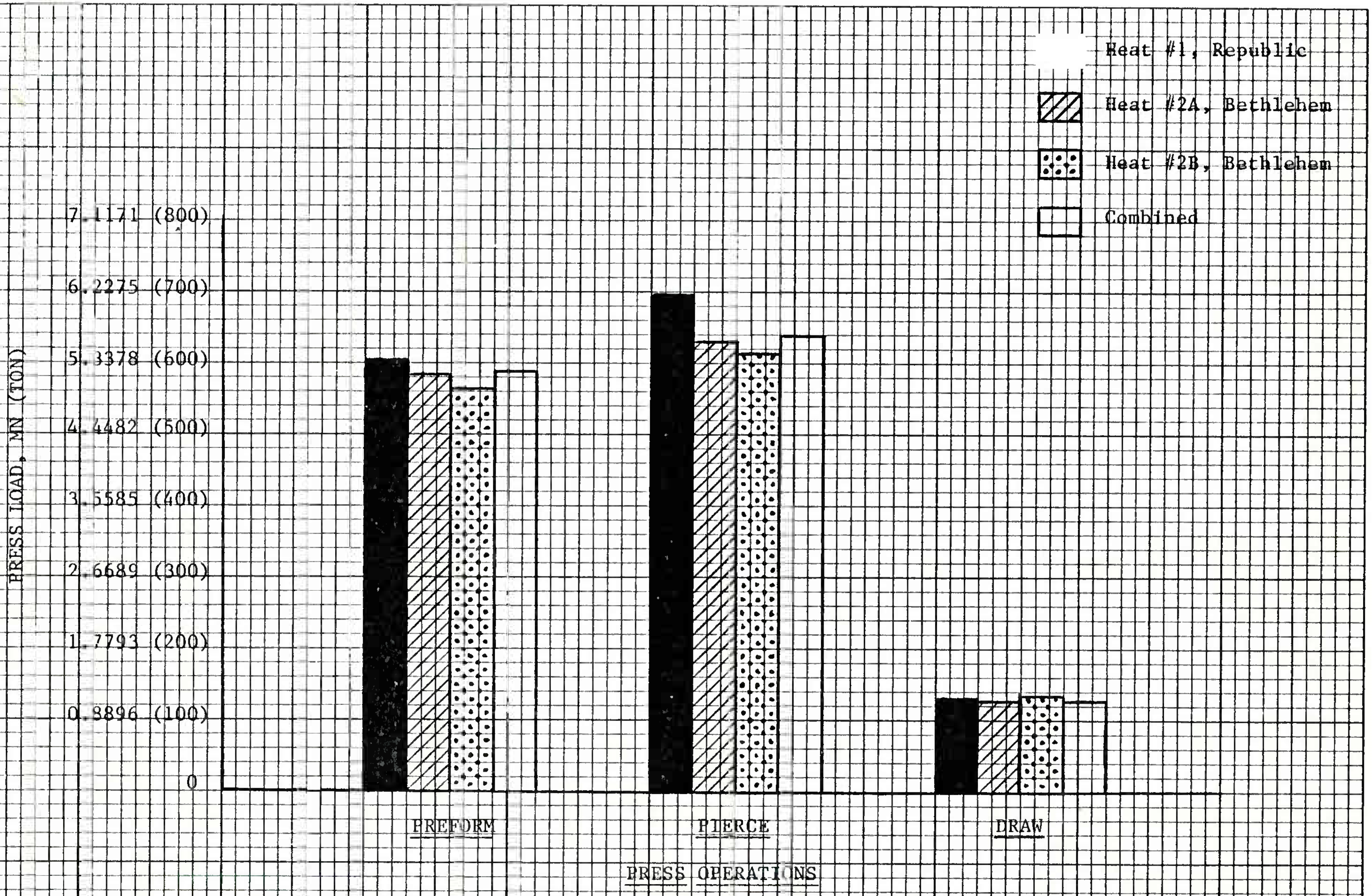


Figure 72. Average Forging Loads vs Heat Nos. 1, 2A & 2B

A graphical representation of the "preforming" and "piercing" loads obtained at several process temperatures for Heats #1, 2A and 2B are presented in figures 73 and 74. As noted in both figures, the forging loads obtained for Heat #1 are greater than those of Heats #2A and 2B.

The difference in forging loads noted can be explained by the difference in grain size. Metallurgical analysis revealed that Republic Steel billets had a smaller grain size (No. 4) than that of Bethlehem Steel (No. 1). Mathematically it can be explained using the "Hall-Pitch" equation, which in part states that the yield stress of the material is inversely proportional to the square root of the grain diameter. Furthermore, strengthening, due to increased grain boundaries (smaller grain size), results from mutual interference to slip within the grains.[2]

Also noted in figures 73 and 74, is the fact that Heat #2A requires a greater forging load than that of Heat #2B, both of which are manufactured by Bethlehem Steel Co. The reason for the difference in forging load requirements is being attributed to the difference in cooling methods utilized at the steel mill.

The "box" cooled material (Heat #2A) has a structure which contains more fine pearlite than that of the "bung" cooled material (Heat 2B). Therefore, Heat #2A is somewhat tougher, requiring higher forging loads than that required for the coarse pearlite structure contained in Heat #2B.

In viewing these graphs, it is also noted that the load curves are somewhat irregular in shape. An insufficient number of data points, required for proper curve plotting, is suspected as the reason for this condition. The subject

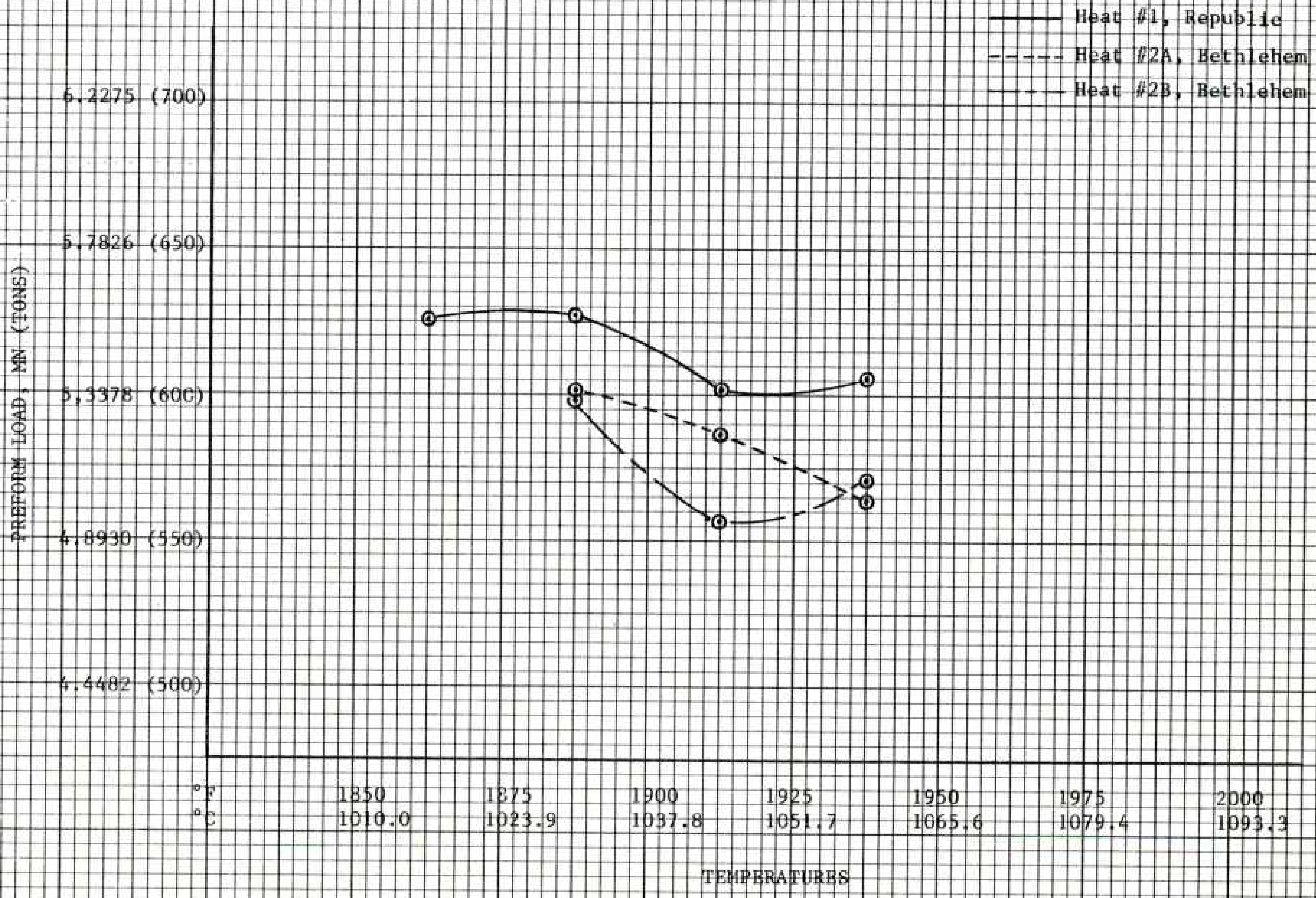


Figure 73. Comparison of Preform Loads for Heat Nos. 1, 2A & 2B vs Temperature

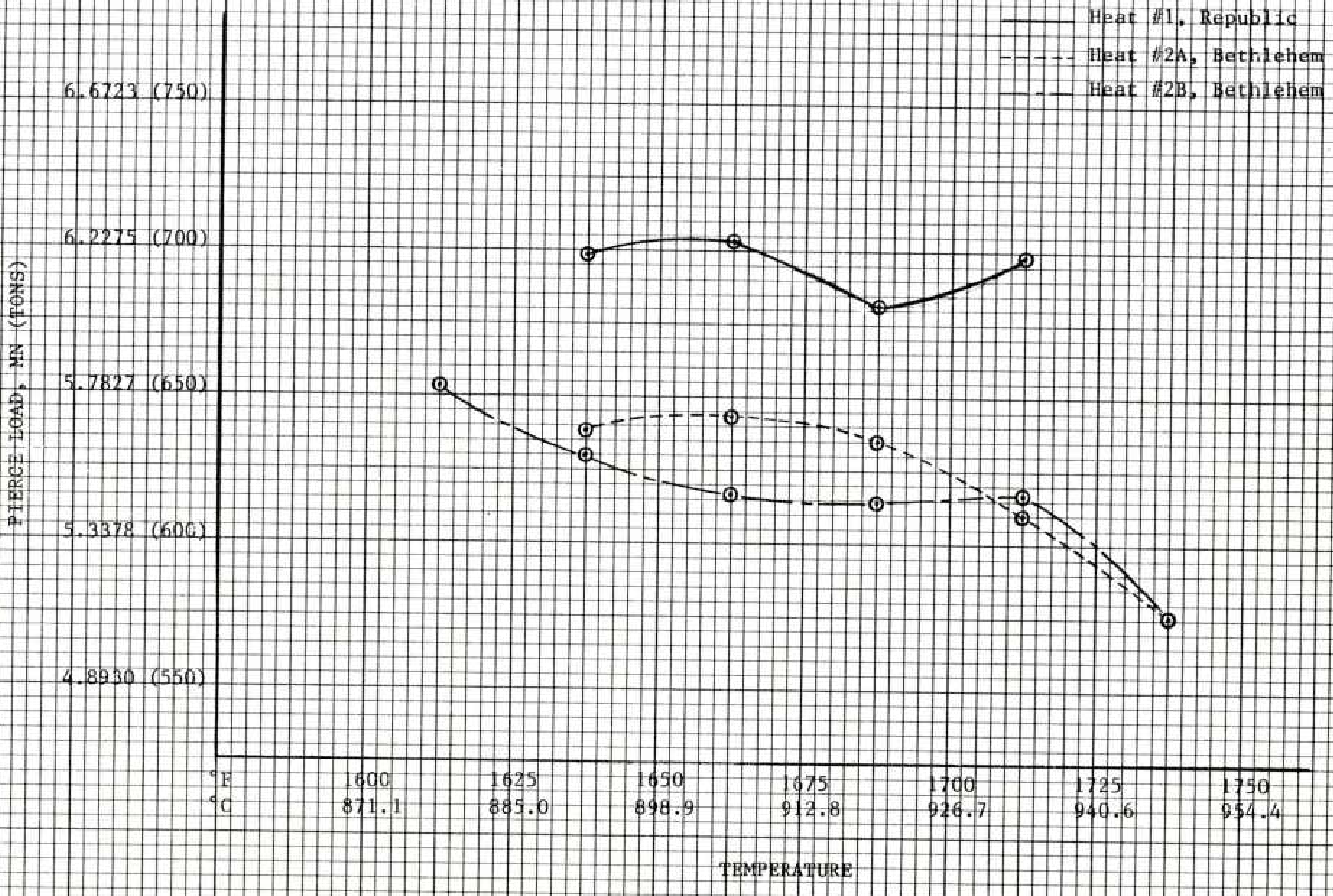


Figure 74. Comparison of Piercing Loads for Heat Nos. 1, 2A & 2B vs Temperature

of insufficient data points for proper plotting of the curves is presented more thoroughly in the discussion of the "drawing" load curves.

Figures 75 and 76 are graphical representations depicting the average preform and piercing "combined" loads at the various recorded temperatures. Also present in the figures are the minimum and maximum loads which occurred at these temperatures. As mentioned previously, this data is presented so that forging load comparisons can be made between HF-1 steel, in general, and other types of steel with known forging loads. Also, the maximum and minimum loads that were incurred are listed to show the range of forging loads encountered during this study.

Figure 77 compares the average "Drawing" loads of Heats #1, 2A and 2B obtained at the various operation temperatures listed, while figure 78 displays the average combined drawing loads of the three (3) heats of steel, along with the minimum and maximum load values obtained during the drawing operation.

Referring to figure 77, the curve for Heat #2A appears fairly consistent as compared with the other two (2) curves, which indicate a slight erratic condition at 808°C (1487°F) temperature mark for Heat #1 and 822°C (1512°F) temperature mark for Heat #2B. Attempting to evaluate this condition is difficult since many factors could be involved such as a false temperature reading due to a scaly condition of the pierce bottle prior to drawing, or a variation in temperatures of the draw tooling. But the most likely cause for this condition could be attributed to the small incremental temperature range (25°F spread) used in plotting the graph. If a (50°F) incremental range was used, the curves would be

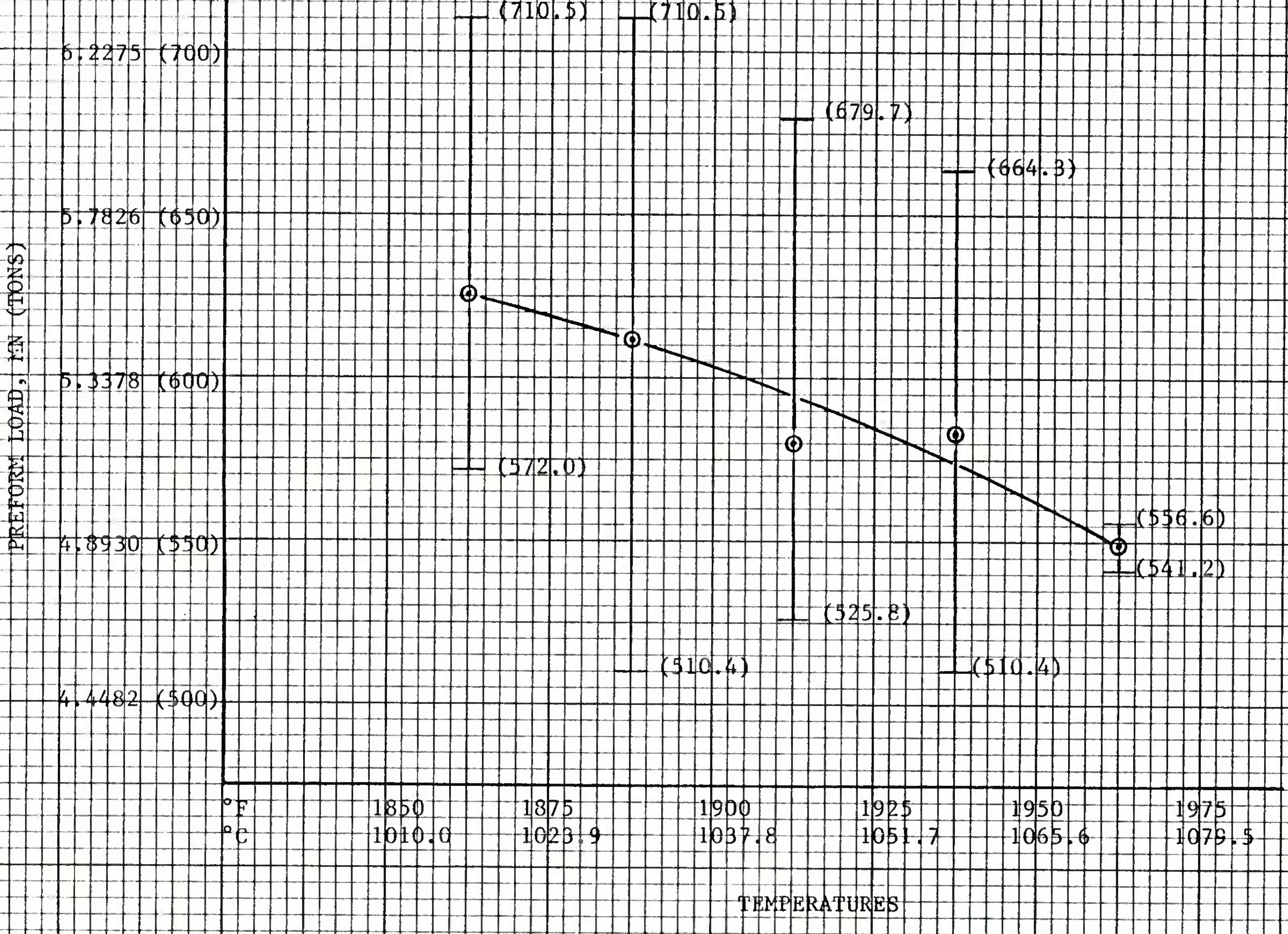


Figure 75. Average Preform Loads for Heat Nos. 1, 2A & 2B vs Temperature (combined).

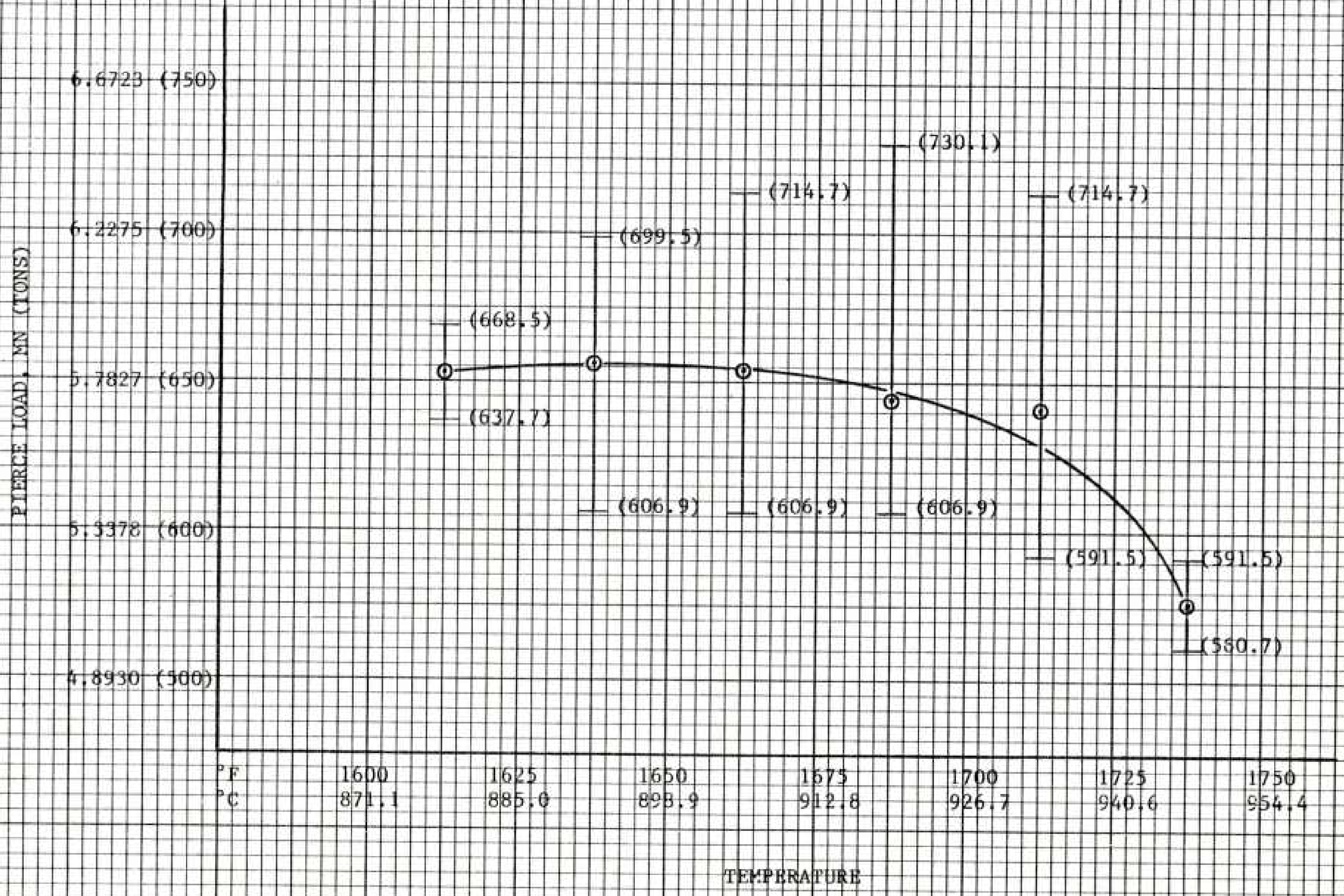


Figure 76. Average Pierce Load vs Operation Temperature (combined Heats Nos. 1, 2A & 2B)

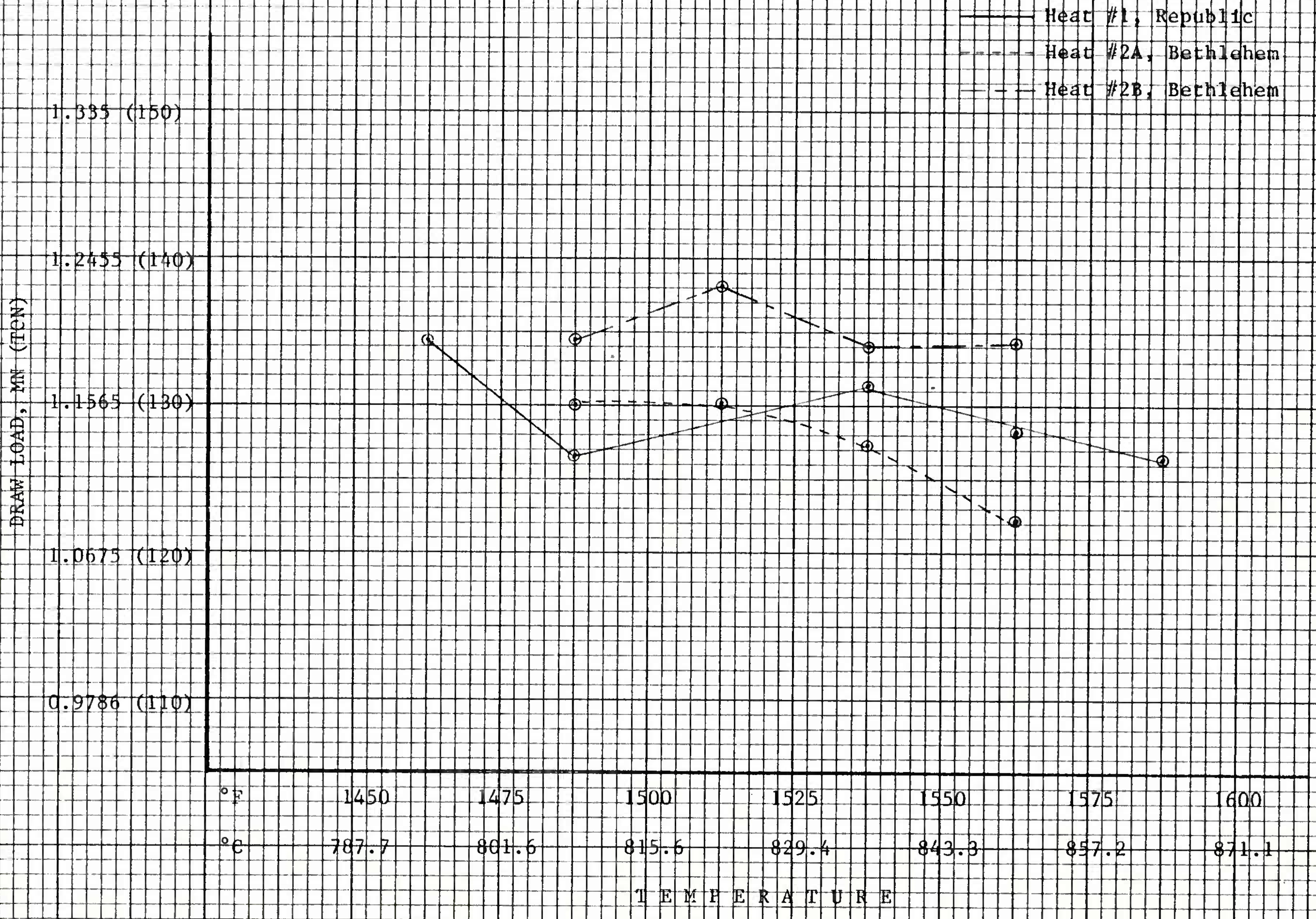


Figure 77. Comparison of Drawing Loads for Heat #'s, 1, 2A & 2B vs Temperature

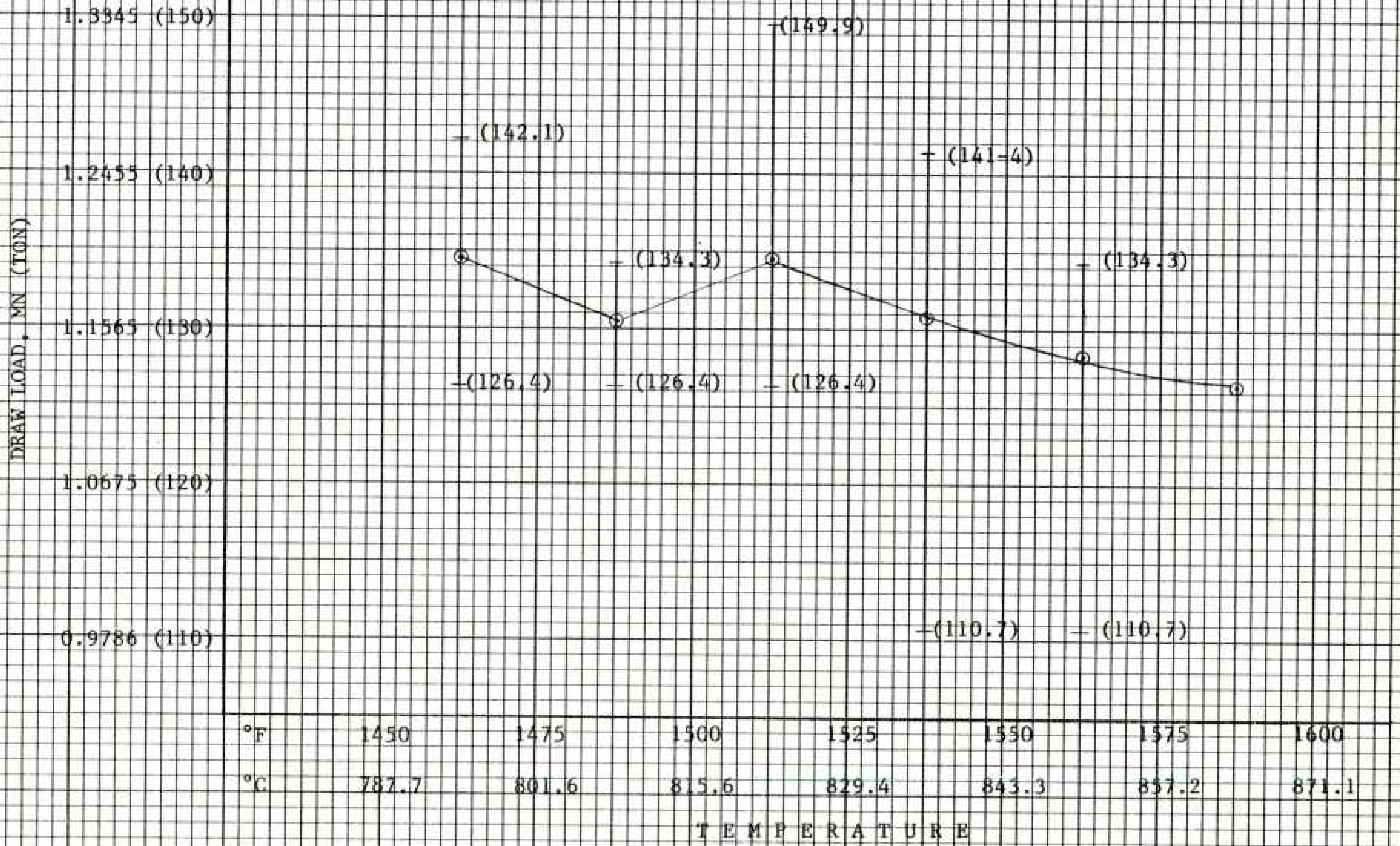


Figure 78. Average Draw Load vs Operation Temperature (Combined Heats #1, 2A, & 2B)

similar in shape to that of Heat #2A. However, if the increased incremental range was used it would not yield a sufficient number of points to plot the curves at all. Tables H-1 thru H-9, listed in the appendix, delineate the data used to plot the graphs of the preform, pierce and draw load versus temperature. It can be seen, from the data, that the temperature range of the majority of forgings was between 815°C (1500°F) and 843°C (1550°F) for the drawing operation. If more drawing tonnages had occurred at the other temperature intervals listed, a more statistically significant graphical representation could have been presented. The data listed does present the fact that the forging temperatures can be held fairly close to the desired temperature utilizing the furnace and forging equipment as previously listed in this report.

Forging Load Recordings

Figure 79 represents a typical ram pressure and displacement recording of the preforming process for the 155 mm, M549 projectile (HF-1 steel). As soon as the punch touches the billet the pressure starts to build up. At the end of the stroke, a coining type of deformation takes place when the ram speed slows down to nearly zero speed while the ram pressure builds up rapidly to a preset cut-off level. Beyond this point, the pressure starts to drop rapidly as the ram begins to retract.

A typical ram pressure and displacement recording for the piercing operation is presented in figure 80. Metal deformation takes place from the point "Begin" to the peak of the "Part Tonnage" point on the load diagram. At this point, back pressure (the pressure required to prevent the ram from going into a free-fall condition) is removed from the ram. Pressure continues to build up while the ram is on the press

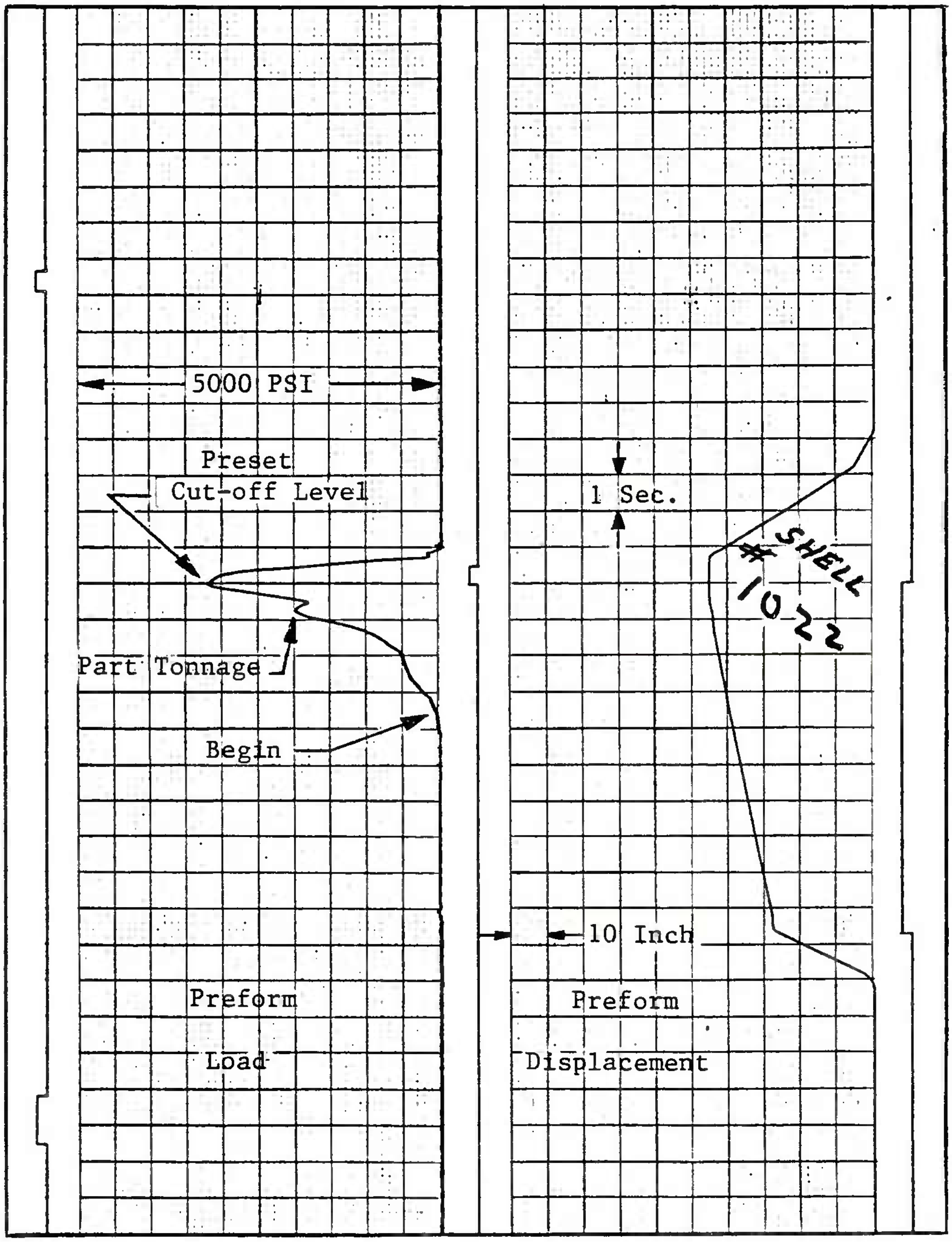


Figure 79 . Typical ram pressure and displacement recording of the preforming of a 155MM - M549 projectile. (HF-1 steel)

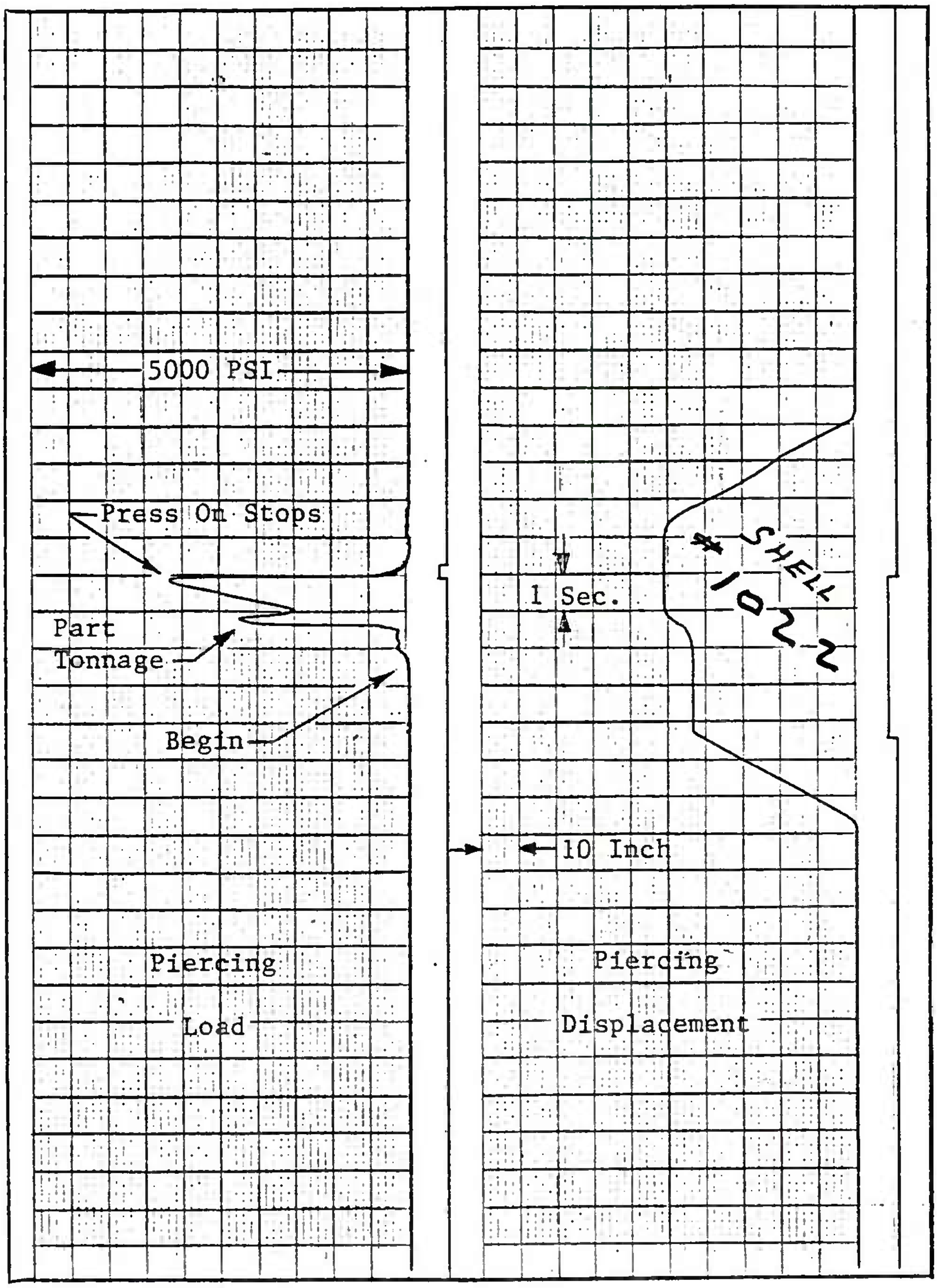


Figure 80. Typical ram pressure and displacement recording of the piercing of a 155MM - M549 projectile. (HF-1 steel)

stops until it reaches a pre-set cut-off level at which time pressure reduces rapidly and the retraction of the ram begins.

Figure 81 represents a ram pressure and displacement recording obtained for the drawing operation. The recording illustrates the drawing loads as the shell progresses through the three (3) draw rings. As can be seen from the recording, the maximum drawing load occurs as the shell progresses through the second draw ring. These results are typical for the three (3) heats of steel forged during this test. It was originally assumed that the maximum drawing load would occur while the shell was progressing through the first draw ring. This assumption was based on the "reduction of areas" as the shell progressed through the three (3) draw rings. The calculated reduction of areas through each ring are:

1st Ring - Approx. 20.1%
2nd Ring - Approx. 18.7%
3rd Ring - Approx. 16.8%

It is surmised that the reason the maximum load occurred on the second ring is that as the shell is progressing through the first ring, some of the reduction is in reality the compressing of the shell wall to conform to the mandrel diameter; therefore, the actual reduction in area is less than the calculated value. As the shell progresses through the second and third rings, the calculated reduction in area more closely approaches the actual, as the shell wall is reduced.

The forging load values for this task were obtained by noting the forging load on the recording, converting its value from PSI to tonnage and then subtracting from this

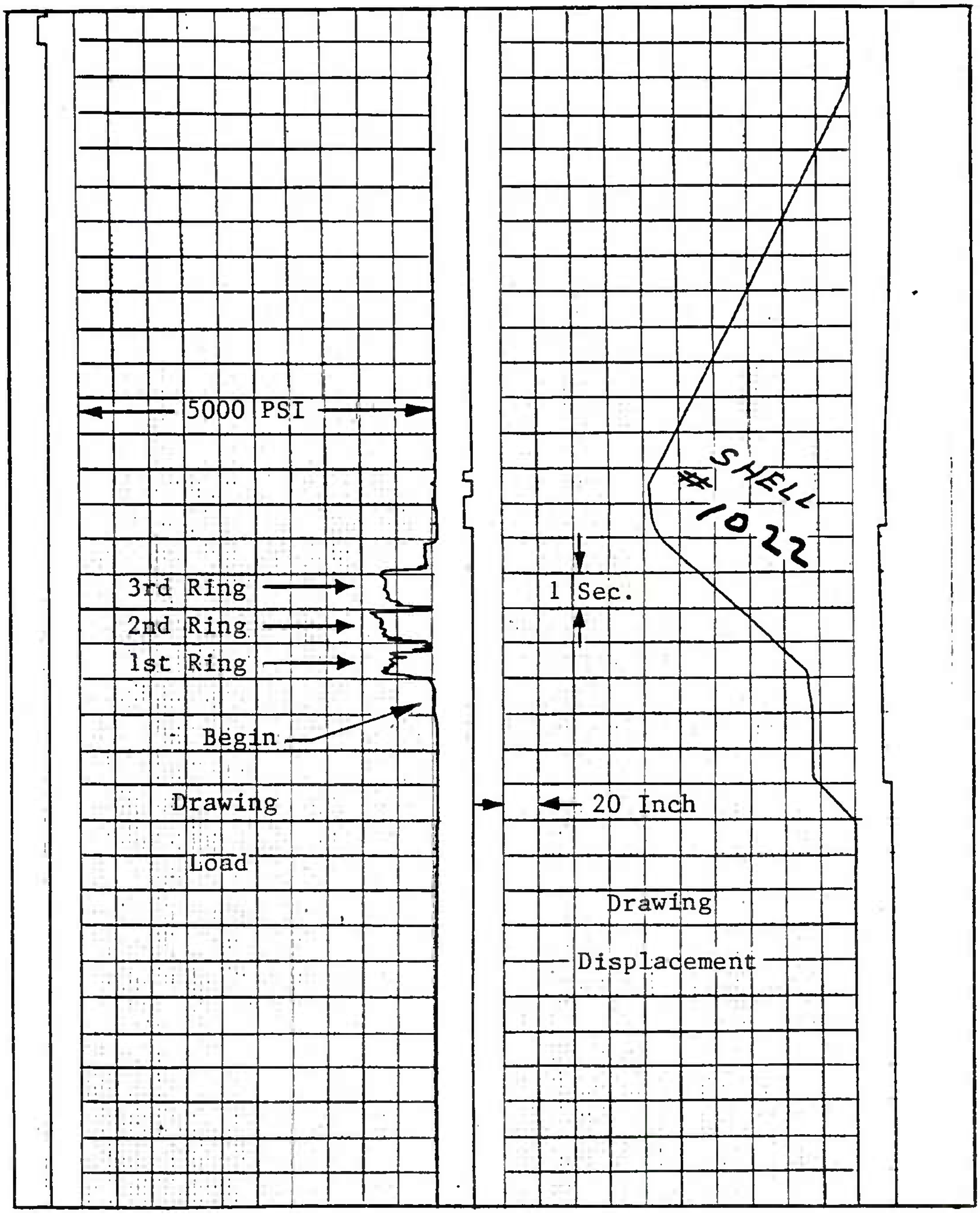


Figure 81. Typical ram pressure and displacement recording of the drawing of a 155MM - M549 projectile. (HF-1 steel)

value, the preload pressure (back pressure) to obtain the actual part tonnage. Preload pressures for the preform, pierce and draw presses were 0.249, 0.552 and 0.133 MN (28, 62 and 15 tons) respectively.

The preload pressures for the preform and pierce operation were acquired utilizing the same instrumentation that was used to obtain the forging load value contained in this report.

The pressure transducer was tapped into the hydraulic lines of the "haulback" cylinders. (The haulback cylinders are used to prevent the press from going into a free-fall condition, and also to return the press to the top position of the stroke.) The conditioned output from the transducer was connected to the strip recorder from which the pre-load values were determined.

The preload pressure for the drawing press was determined during an earlier study, and thus its value of 0.133 MN (15 tons) was utilized in this report.

Tooling Life

At the completion of Task B, during which 417 pieces were forged, the pierce tip was polished and draw rings reworked, in preparation for the forging operation of this task. Although signs of tool wear were minimal, the "reworking" was deemed necessary to ensure that no tooling change would be required when forging the 904 mults during this task.

It is difficult to accurately determine tool life upon forging such a small quantity of projectiles, but based on wear conditions of the tooling at the completion of this task, the following estimates of tool life are presented:

Preform Operation:

Preform punch, ejector and die - 1552 pieces were forged with this tooling. The condition of the tooling indicated that this tooling should yield comparable life as is expected when forging type 1046 material.

Pierce Operation:

Pierce tip - Periodic visual inspections were performed on the pierce tips during the forging process. Based on the wear condition of the tip known as "mushrooming" (flattening) that was observed, a tool life of approximately 500 shells/tip is projected for this tool when forging HF-1 steel.

Pierce Ejector and die - Should yield comparable tool life as is expected when forging type 1046 material.

Drawing Operation:

Mandrels - no accurate indication of tool life could be established since the mandrels were polished several times in order to help alleviate the problem of the shells sticking to the mandrel, encountered on several occasions during this project.

Rings - After forging a total of approximately 650 pieces on the rings during Tasks A & B, the rings were reworked to avoid any problems from occurring during the forging of 904 pieces during this task.

Based on the wear condition of the rings, and also the condition of the outside diameter of the forgings that was observed, the projected tool life for the rings will be 4,000 to 5,000 pcs./set.

Quality of Forgings

The inspection data deemed pertinent to this project were comprised of the following:

1. Dimensional - lower and upper cavity datums, cavity length, base thickness and outside diameters.
2. Eccentricity of forgings at the base, middle and open end.
3. Visual inspection of cavity surface conditions.
4. Metallurgical analysis.

Dimensional -

An analysis and review of the dimensional data from Item #1 above reveals that the forgings produced form Heats #1, 2A and 2B were within the required dimensional value as originally specified during the design phase of this project.

Eccentricity -

The forging eccentricity data, obtained from "hot" inspection records is summarized and presented in Table 18. It lists the minimum, maximum and average values obtained for the three (3) heats of steel involved. The maximum value allowed for eccentricity is 2.54 mm (0.100 inch) TIR. This value was exceeded on a few occasions due to the preform and/or pierce tips becoming loose while forging. Re-tightening of the tips corrected this problem, bringing the eccentricity back to within specifications. There is no significant difference of eccentricity values among the three heats of steel involved.

Visual Inspection -

Visual inspection results pertaining to the cavity conditions of the forging are listed in Table 19. The majority of visual defects were due to circumferential tears located in the cavity near the open end of the forging. It was not unexpected that this condition might occur, since it was noted that the open end of the pierced bottle was at a lower temperature than the remaining portion of the shell. The

TABLE 18. FORGING ECCENTRICITY DATA - TASK E

Heat #	Position	Min. (In.)	Max. (In.)	Average
1	Base	0.020	0.110	0.040
1	Center	0.020	0.120	0.040
1	Open End	0.010	0.110	0.040
2A	Base	0.020	0.100	0.040
2A	Center	0.020	0.110	0.040
2A	Open End	0.010	0.130	0.040
2B	Base	0.020	0.080	0.060
2B	Center	0.020	0.100	0.060
2B	Open End	0.030	0.110	0.060

NOTE: Eccentricity values presented in the table above are based on the following sample size:

Heat #1 - 60
Heat #2A - 53
Heat #2B - 40

TABLE 19. CAVITY DEFECTS - TASK E

Heat No.	Parting Method	Defect Conditions Scale Holes Base & Wall	 Laminations Base & Wall	 Cold Tears Cavity & Open End	Total Forged Pieces	% Defective Cavities
1	Saw	5	----	13	348	5.17
2A	Saw	4	1	19	281	8.54
2B	Saw	----	2	28	275	10.91

temperature variance could be readily detected by observing the difference in color from one end of the bottle to the opposite end. The open end appeared to be black in color progressing to a bright orange at the base. The temperature at the black area was not determined due to the inability of the pyrometer to detect temperatures below 760°C (1400°F). The lower temperature at the open end, is attributed to both the forge tooling, which imposes a chilling effect on the forging, and an increased cooling rate at this location due to the thin wall section of the M549 projectile. It was noted that as the forging operation continued and the tooling temperature stabilized, the blackened condition at the open end of the shell was not as pronounced, indicating that the chilling effect imposed by the tooling was reduced.

The condition of scale depressions at the base of the cavity on some shells was very noticeable upon completion of the shot blast operation. Although only nine (9) forgings were detected with this condition, particular attention must be given to scaling of the mult which greatly affects the cavity condition for this particular projectile and material. The cavity conditions for the M549 projectile manufactured from HF-1 steel, are very stringent (per military Spec. MIL-W-50577C(AR), 20 June 1979, Sec. 3.6.1 and 3.6.2. Therefore, it is imperative that a minimum scale atmosphere be maintained in the forging furnace and that all descaling equipment is operating properly when producing this projectile.

Table 20 is a listing of the shells that were scrapped out while conducting the forging operation. All of the defects listed are temperature related and were directly caused by delays in material handling. A malfunction with the billet transfer unit which transfers the mults from the preform operation to the pierce operation and a faulty conveyor section

TABLE 20. M-549 FORGING SCRAP SHELL REPORT - TASK E

(All Mults Parted By Sawing)

Heat #	Shell I.D. #	Defect
1	649	Pierce Bottle
	650	Preform Slug
	651	Cold Tear
	652	Short - Heavy Base
	657	Stuck on Draw Mandrel
	659	Stuck on Draw Mandrel
	660	Stuck on Draw Mandrel
	752	Short - Heavy Base
	919	Pierce Bottle
	931	Preform Slug
	932	Preform Slug
2A	997	Short - Heavy Base
	998	Short - Heavy Base
	999	Short - Heavy Base
	1000	Short - Heavy Base
	1001	Short - Heavy Base
	1002	Short - Heavy Base
	1003	Short - Heavy Base
	1004	Short - Heavy Base
	1005	Short - Heavy Base
	1006	Short - Heavy Base
	1010	Short - Heavy Base

Table 20. (cont'd.)

Heat #	Shell I.D. #	Defect
2A	1191	Pierce Bottle
	1192	Pierce Bottle
	1193	Pierce Bottle
	1194	Pierce Bottle
	1195	Pierce Bottle
	1196	Pierce Bottle
2B	1344	Short

at the descaler unit were the cause of delays attributed to the scrapped forging (pierce bottle and preform slug, respectively).

Metallurgical Analysis -

Numerous "forging defects" were discovered. They are analyzed and categorized in the following paragraphs:

Category I -

Figure 82, shell no. 997, illustrates the first category of defects, it is normally located near the open end of the forging within four (4") inches of the open end. Figure 83 is a photomacrograph with two (2) defects. Notice that there are definitive strain lines which bisect the normal forging flow lines at or about 45°. Figure 84 is a composite photomicrograph of one of the defects. Notice that at the apex of the defect there are numerous microstrain lines which indicate that the defect was formed below 1380°F (lower critical, A_e[1]).

This defect is, therefore, called a "cold tear". It is a serious defect but can easily be eliminated in production by controlling the forging temperature and optimizing continuity of operation.

This type of defect was visible in steel from both vendors and all types of cooling methods.

Category II -

This category is defined as those defects of a circumferential nature in the O.D. base area of the forging, the

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[1] Reference I.T.T. Curve (Figure I-1, Appendix I).

M-549
Forging Defect
Category I

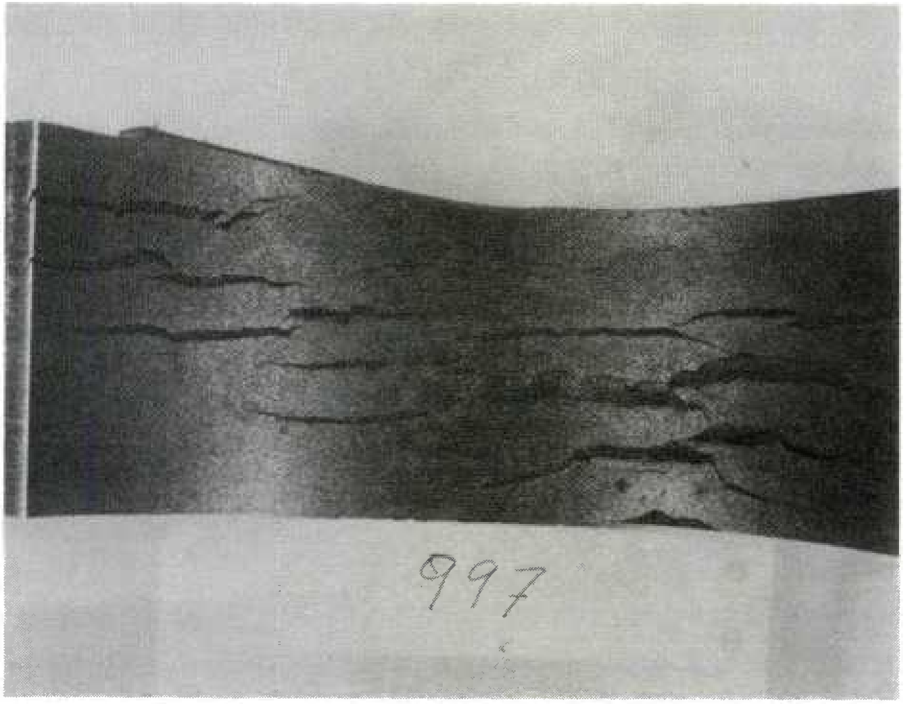


Figure 82. "Cold Tear" defect near open end of forging.
1X Unetched

M549
Forging Defect
Category I

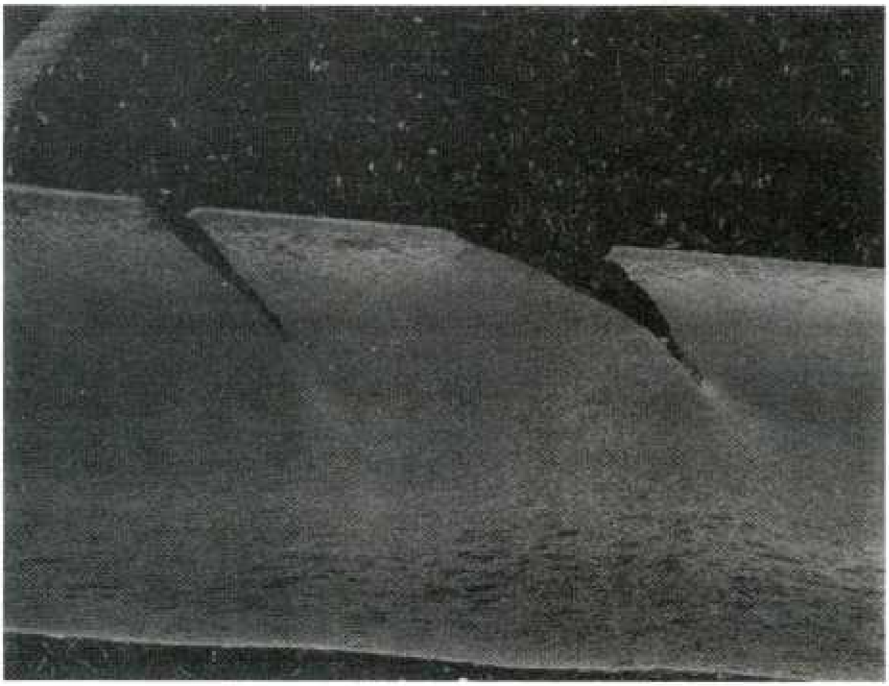


Figure 83. Photomacrograph of sidewall of forging showing two "cold tears". 5X Villella's Reagent.

M-549
Forging Defect
Category I

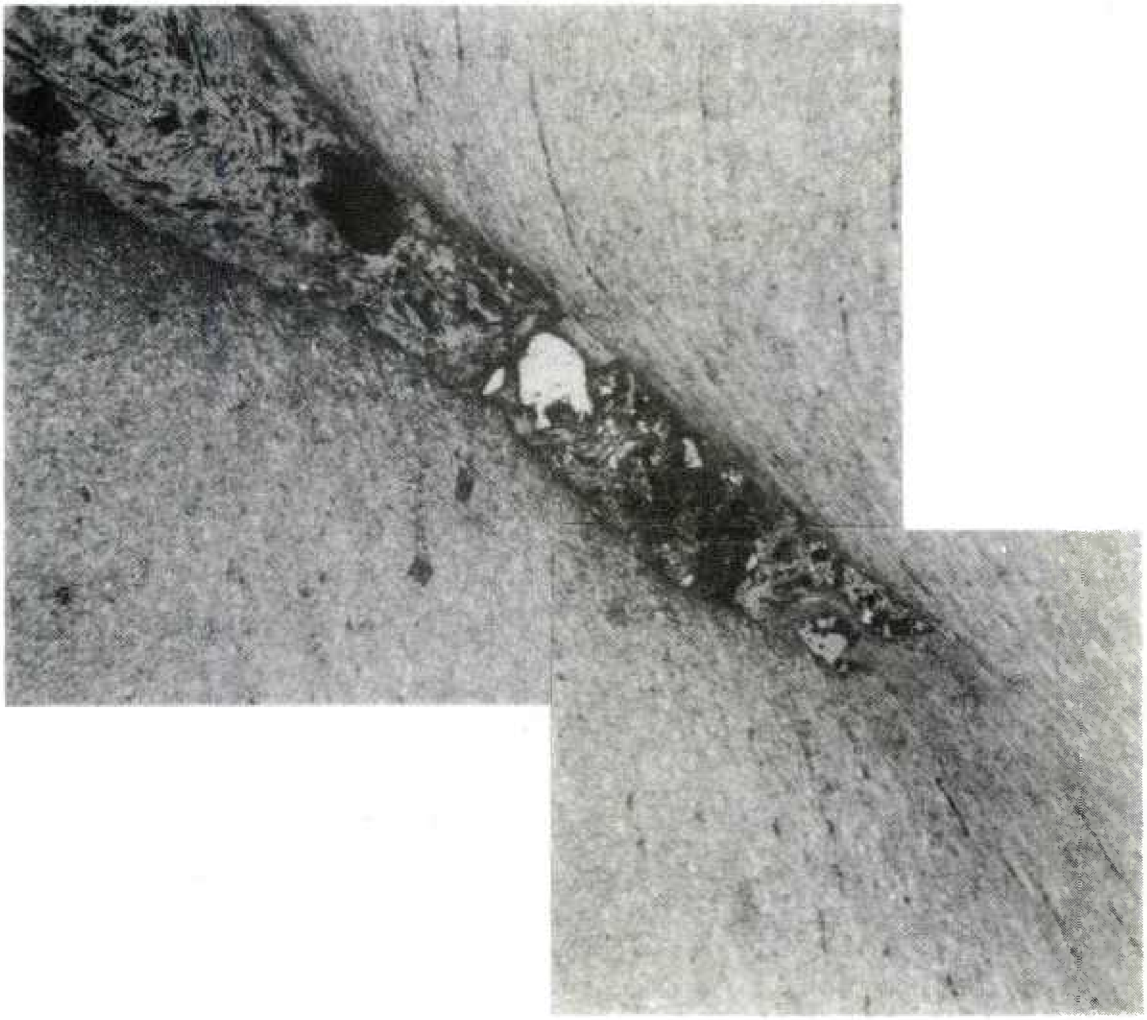


Figure 84. Composite photomicrograph of apex of one cold tear. 63x Villella's Reagent.

boattail area. These defects were only noticed in the Bethlehem Steel material.

Figures 85 thru 87 illustrate this type of defect. Notice that they are both somewhat (nonlinear) longitudinal and somewhat circumferential in nature. Figures 88 thru 90 illustrate the metallographic analysis of the defects. Only one-third to one-half of the open defect is decarburized and the bottom of the defect has some scale in it. Microhardness evaluation of the white (non etching) area is R_b 80 and the bottom of the defect has an R_c of 33. The matrix has an R_c of 37 indicating that the bottom of the defect is a carbon depleted zone (not enough to show ferrite). Since decarburization is a time-temperature phenomena, it can be concluded that the area which is decarburized to pure ferrite (R_b 80) was at a higher temperature for a longer time and more open to the atmosphere of the furnace than the area at the bottom of the defect.

Furthering this analysis, the defects were "opened" during the preform operation which was performed between 1700°F and 1900°F. During this operation bulging takes place and the entire billet is subjected to severe hoop stresses, which would have a tendency to open up any areas of significant stress raisers especially in a longitudinal direction, but also in a circumferential direction if the metallurgical notches were multi-directional. Subsequent operations do induce tension stresses in the boattail area which further opens the defects.

In order to investigate the possible types of metallurgical notches that could possibly contribute to the defects, billet surfaces were examined. Figures 91 and 92 illustrate the grinding areas on the Bethlehem billets. Bethlehem

M-549
Forging Defect
Category II

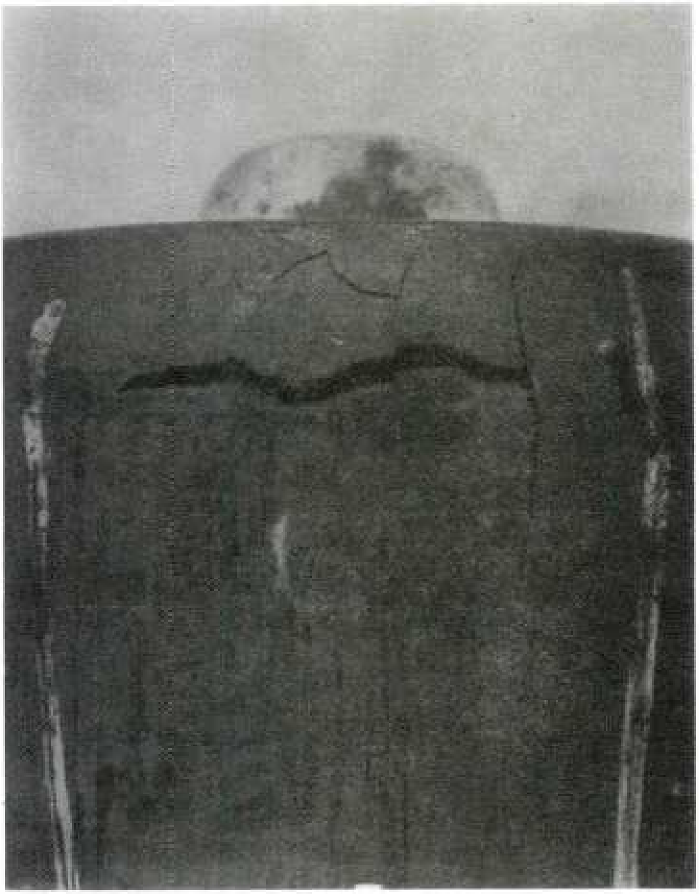


Figure 85. Photograph of O.D. defect. (Shell #1060)
IX Unetched.

M-549
Forging Defect
Category II

Figure 86. Photograph of O.D. defect. (Shell #1042)
IX Unetched.

M-549
Forging Defect
Category II

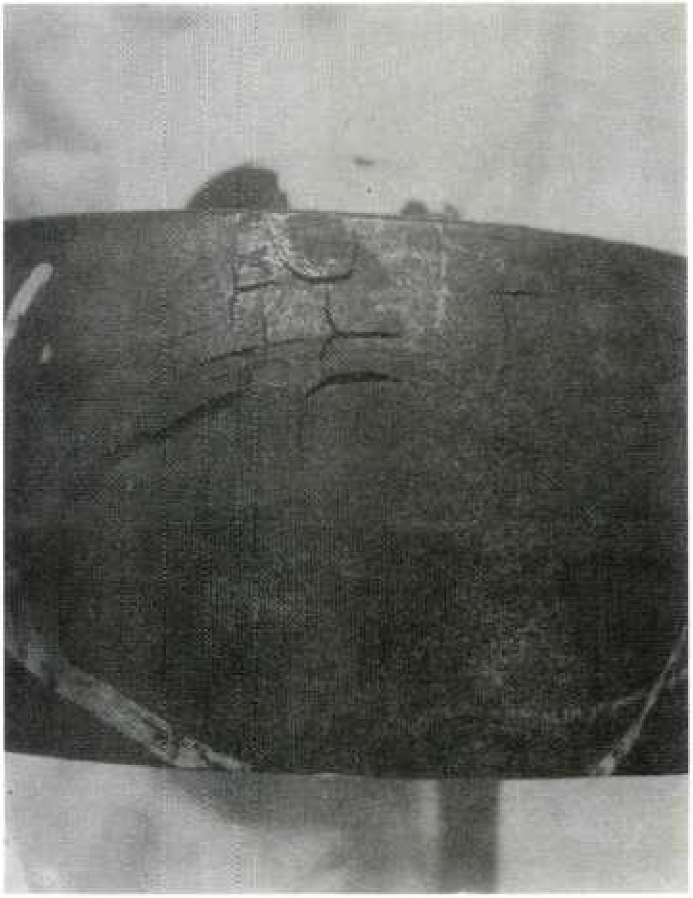


Figure 87. Photograph of O.D. defect. (Shell #1432)
IX Unetched.

M-549
Forging Defect
Category II

Figure 88. Photomicrograph of longitudinal section showing decarburized area. 63x Nital Etch (Shell #1042)

M-549
Forging Defect
Category II

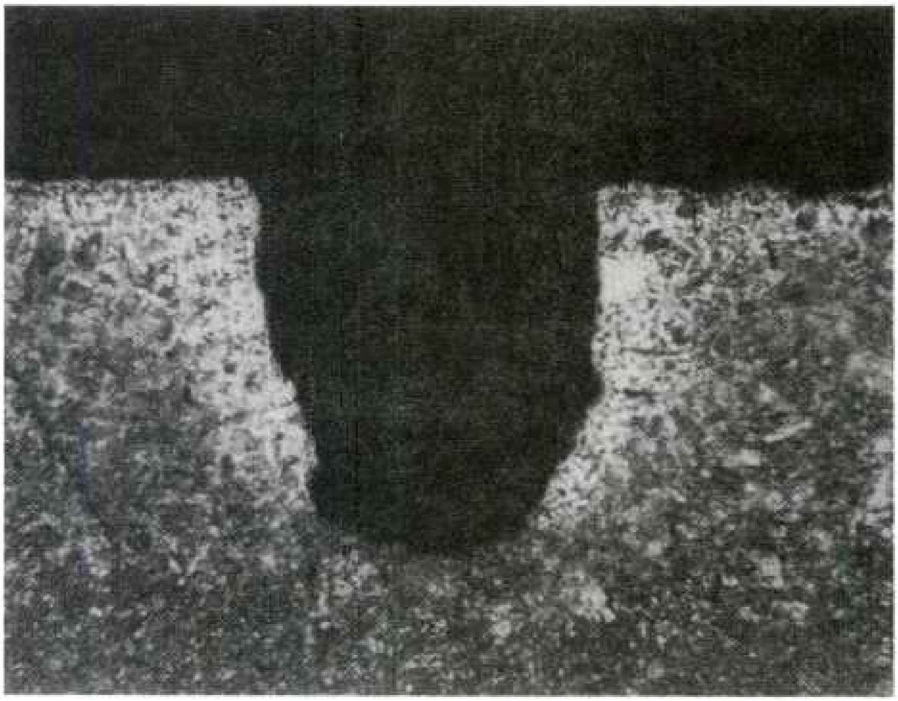


Figure 89. Photomicrograph of longitudinal section showing decarburized area. 63x Nital Etch (Shell #1432)

M-549
Forging Defect
Category II

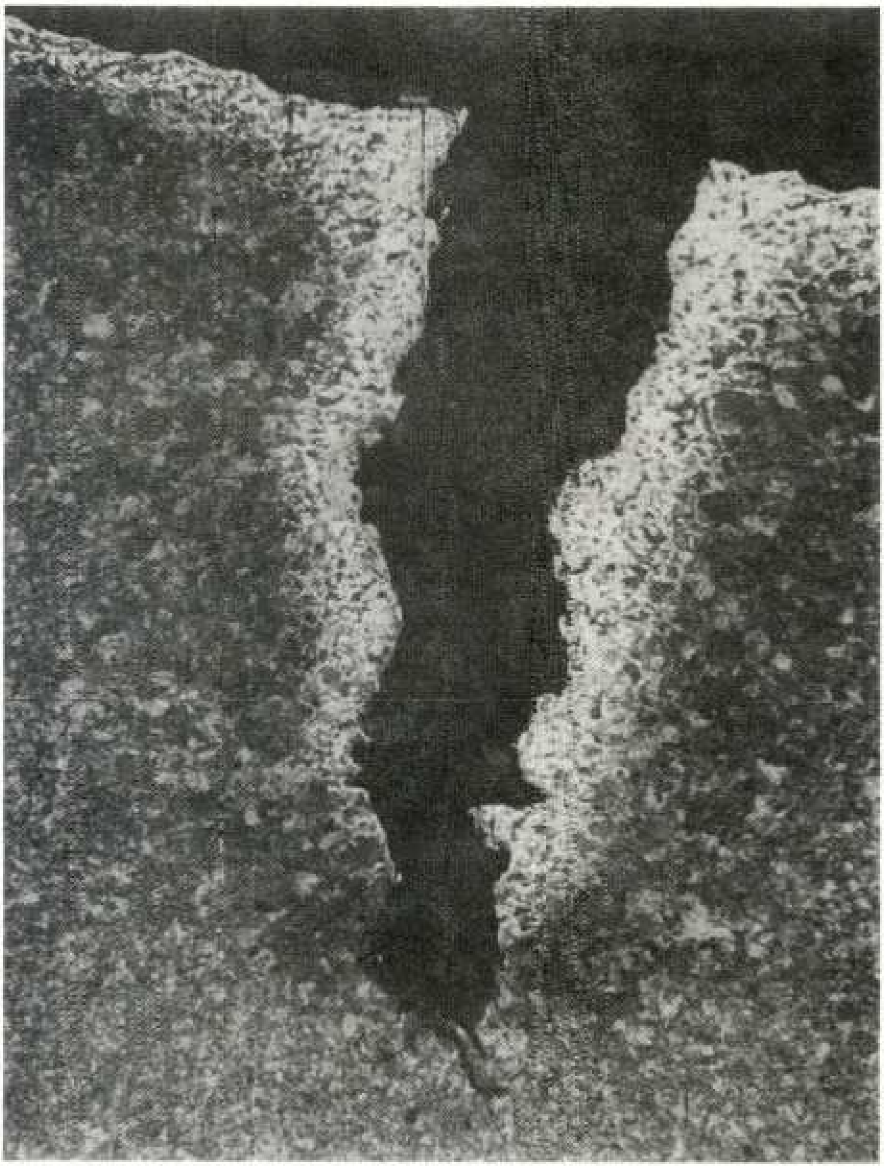


Figure 90. Photomicrograph of longitudinal seciton showing decarburized area. 63x Nital Etch (Shell #1060)

M-549
Forging Defect
Category II

Figure 91. Photograph of severe ground area producing a square corner.

M-549
Forging Defect
Category II

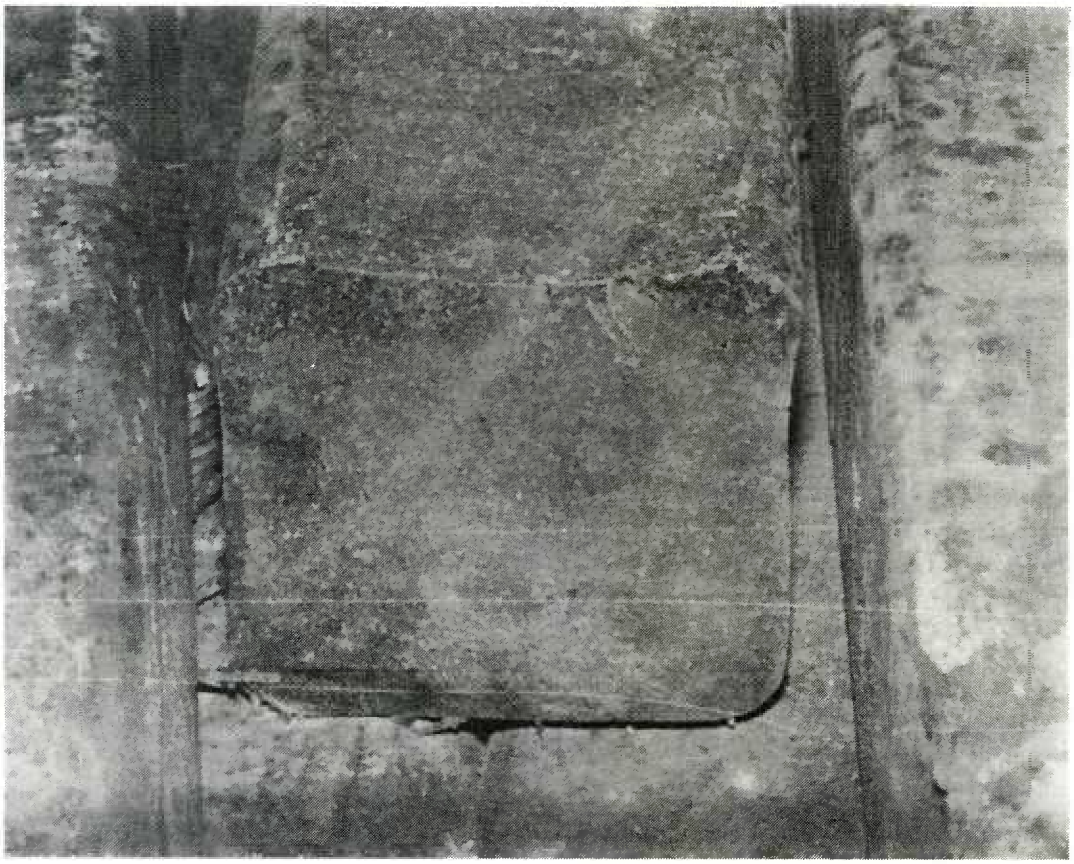


Figure 92. Photograph showing a severe case of concave grinding. It is a cross section of a billet that broke on dropping.

steel conditions (grinds away defects) in the last operation of their process. As was noted in a previous report, reference #1, many billets were severely conditioned, to such a degree that they ceased to be round cornered squares and became square cornered by the action of the grinding. Figure 92 is a cross section of a billet showing a concave surface produced by grinding. It shows a fracture surface caused by the billet breaking after being dropped from a height of 10 feet.

Metallographic analysis revealed the area to contain intergranular cracks (grinding cracks) illustrated by figures 93 and 94. They measured 0.007 inches and 0.014 inches.

It is therefore suggested that the defects in the boattail area are caused by the stresses induced by the preform operation from the metallurgical notches created by the grinding cracks. It is believed that some of the circumferential cracks were greatly opened during the draw (last) operation which could be a combination of the effect of the metallurgical notches and lower temperature at that operation.

Category III

Figures 95 thru 97 illustrate the third type of defect and are classified as irregular cavity defects. Figures 98 thru 100 show metallographically prepared cross-sections. Notice that they are of a "slivered" nature; that is, they are open on one end and are part of the base metal on the other end. The open end is severely decarburized and proceeds to have increased carbon content until it becomes sound HF-1 metal. Several ferrite fingers are in the area also.

M-549
Forging Defect
Category II

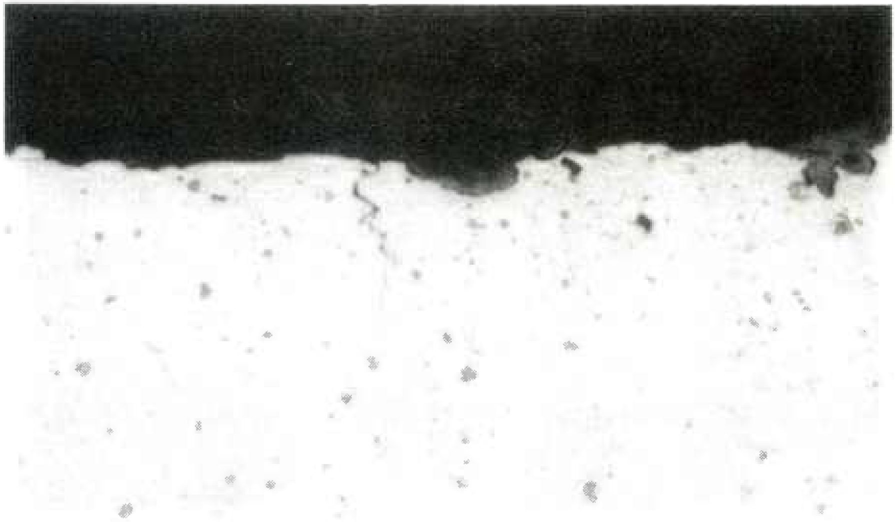


Figure 93. Photomicrograph of ground area in as-received billet showing intergranular grinding cracks. (Bar 11I)

125x Unetched

M-549
Forging Defect
Category II

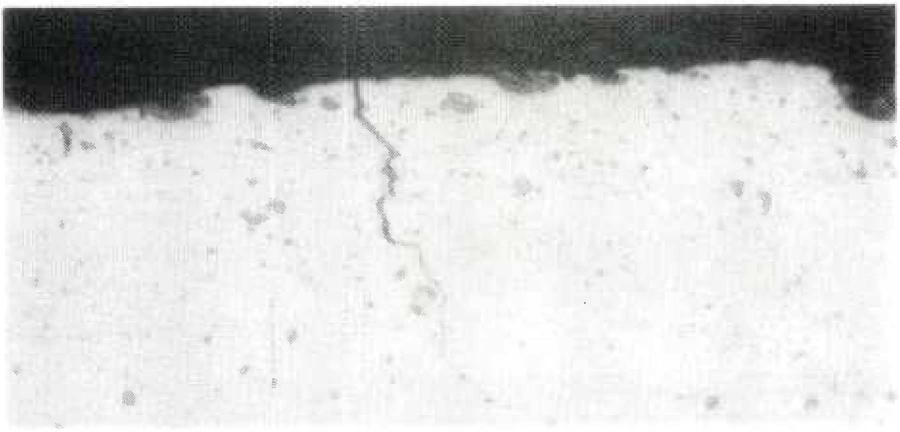


Figure 94. Photomicrograph of ground area in as-received billet showing intergranular grinding cracks. (Bar 11B)

125x Unetched

M-549
Forging Defect
Cateogry III

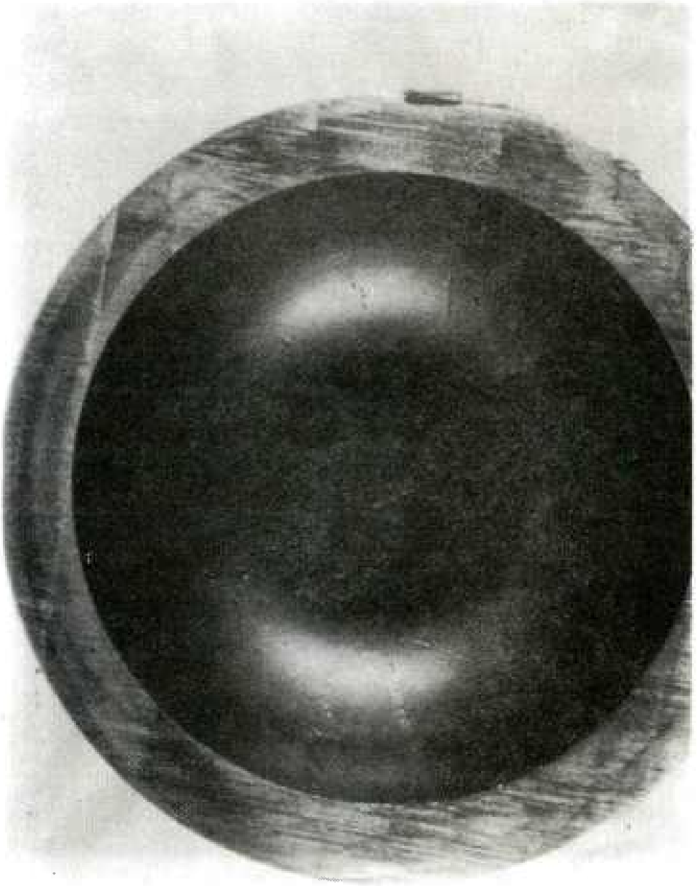


Figure 95. Photograph of cavity defect. (Shell #1381)
1/2X Unetched.

M-549
Forging Defect
Category III

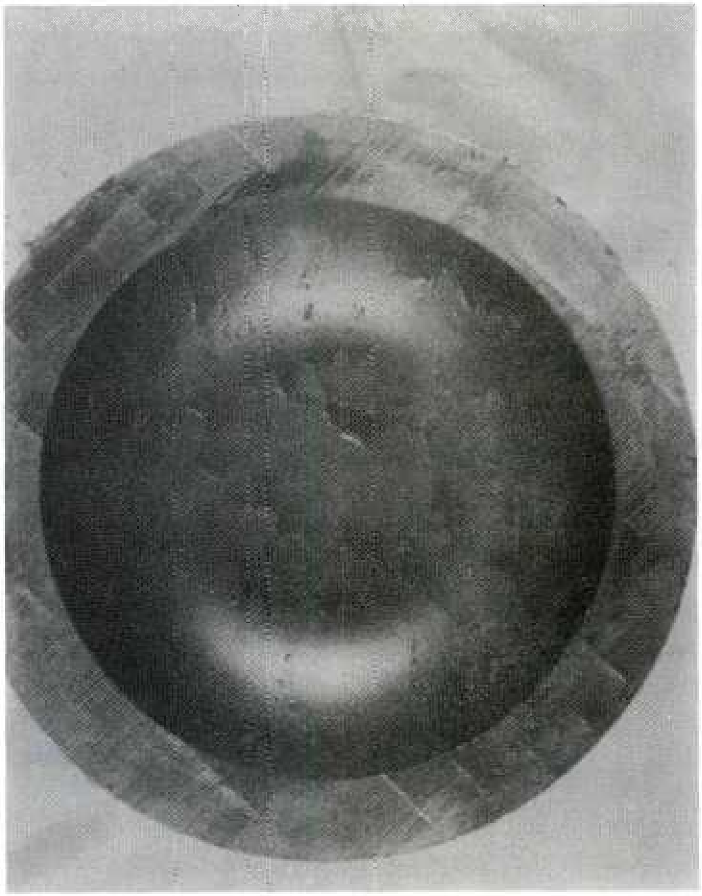


Figure 96. Photograph of cavity defect. (Shell #1217)
1/2X Unetched.

M-549
Forging Defect
Category III

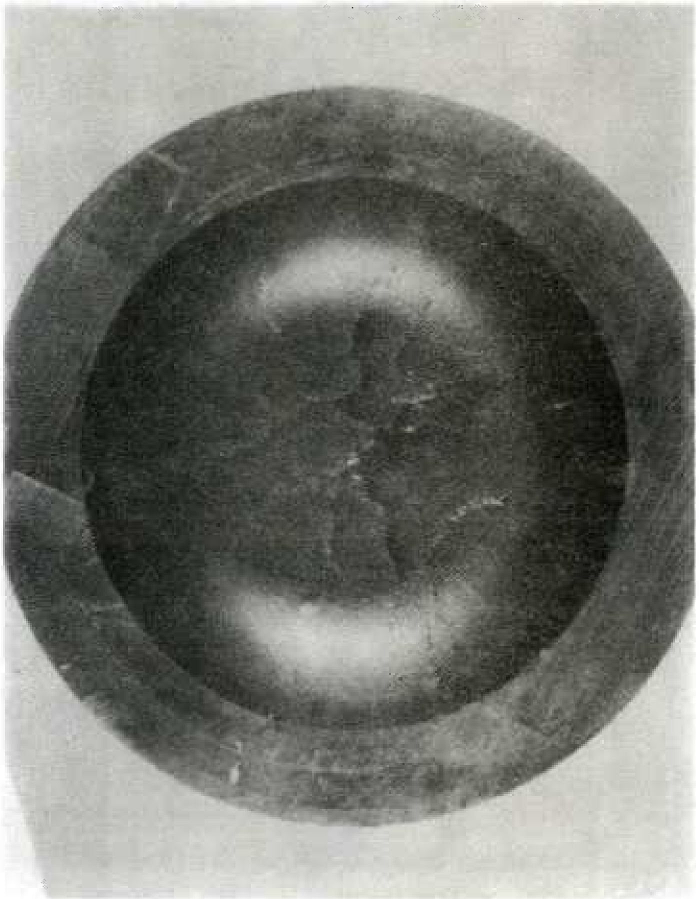


Figure 97. Photograph of cavity defect. (Shell #1359)
1/2X Unetched.

M-549
Forging Defect
Category III

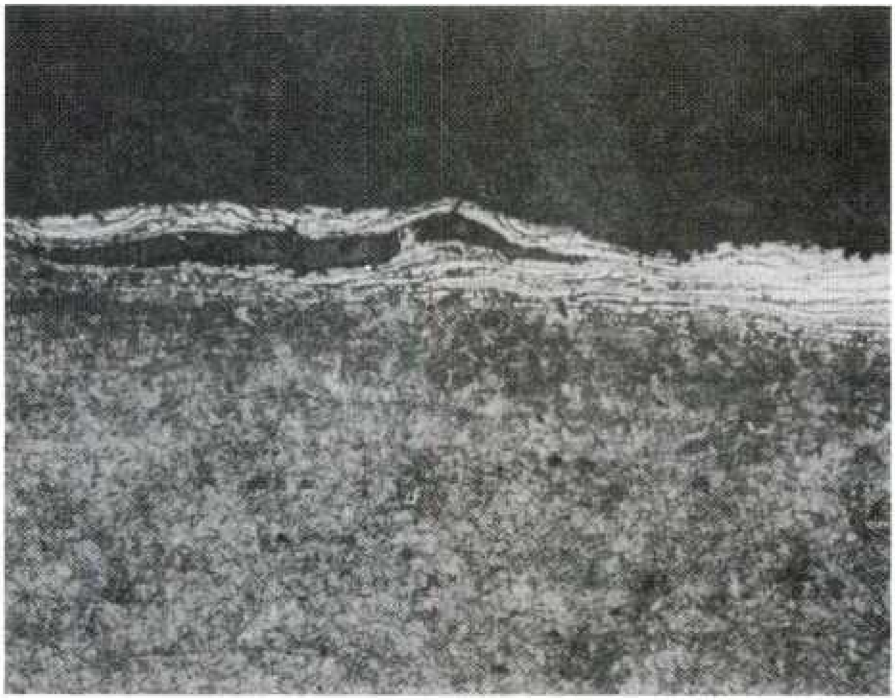


Figure 98. Photomicrograph of cavity defect slivers. (Shell #1381)
63x Nital Etch

M-549
Forging Defect
Category III

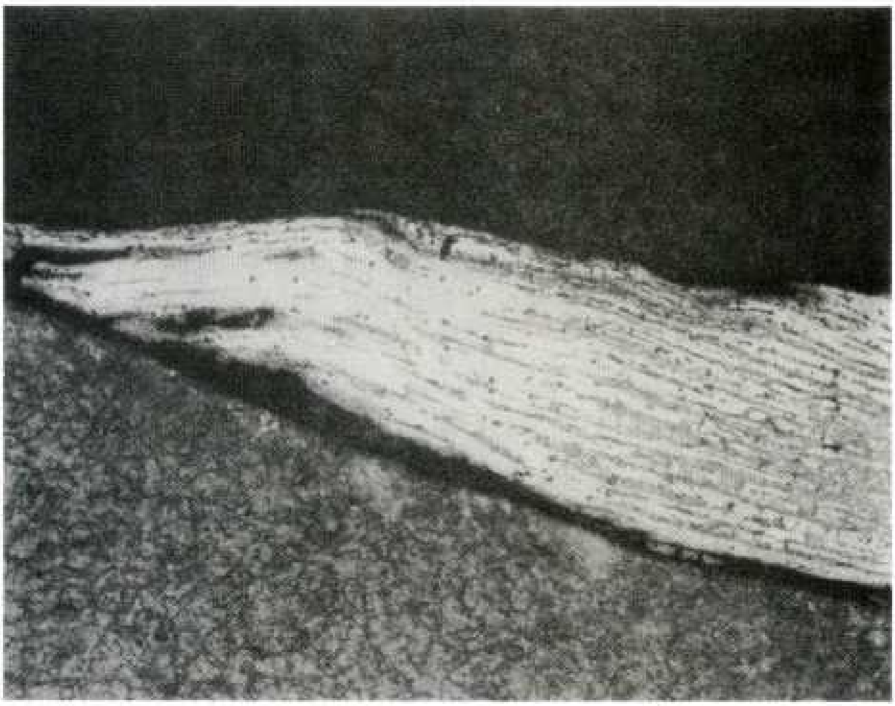


Figure 99. Photomicrograph of cavity defect slivers. (Shell #1217)
63x Nital Etch

M-549
Forging Defect
Category III

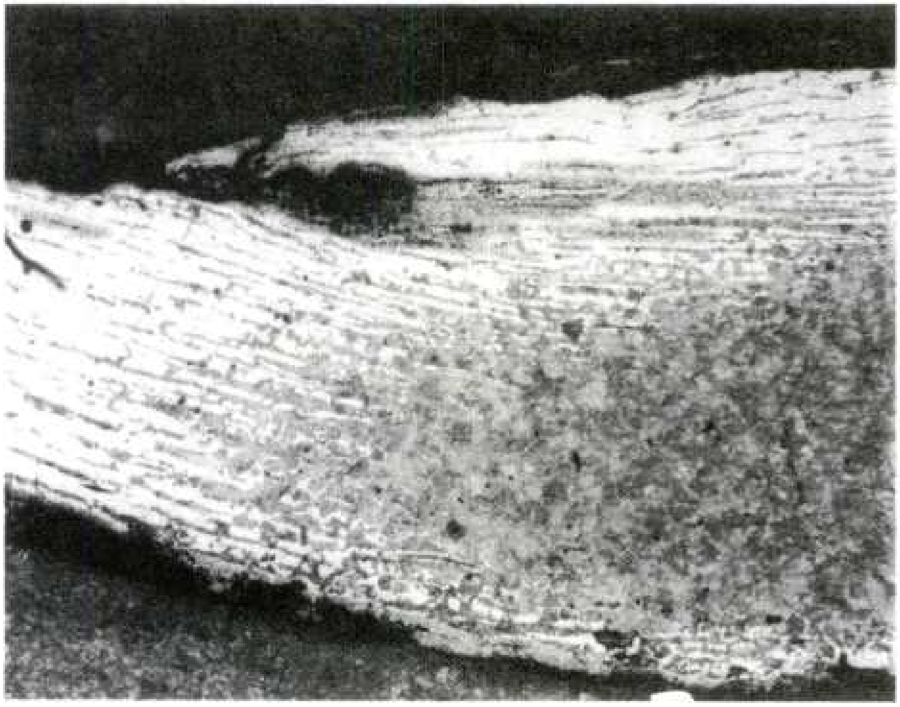


Figure 100. Photomicrograph of cavity defect slivers. (Shell #1359)
63x Nital Etch

It is possible that parts of the metal were lifted up as slivers by the forge punch during initial forging operation, decarburized almost completely in a short period of time because of its thin section and then partly welded by the subsequent operation.

It is, therefore, postulated that a cold preform tool pressed against a hot mult at 1900°F, stuck fast and tore the surface of the mult on retraction. The sliver tears became decarburized from the high temperature and small area. They were subsequently, partially self-welded by the piercing operation.

Analysis of forging data indicated that some of these shells were run after a break or trouble in line which would have cooled the preform tool.

This type of defect was common to the three heats of steel involved, and none of the forgings possessing this defect were processed from mults obtained from the ends of the bars.

Category IV -

Figure 101 is a photograph of a base cavity defect. Figure 102 is a photomacrograph of a cross section of this defect showing a uniform contour. It shows no decarburization or strain lines. Figure 103 is a photomicrograph of the midpoint of the defect supporting the above observation.

It is, therefore, concluded that the defect was caused by having foreign material either on the preform tip or pierce tip.

M-549
Forging Defect
Category IV

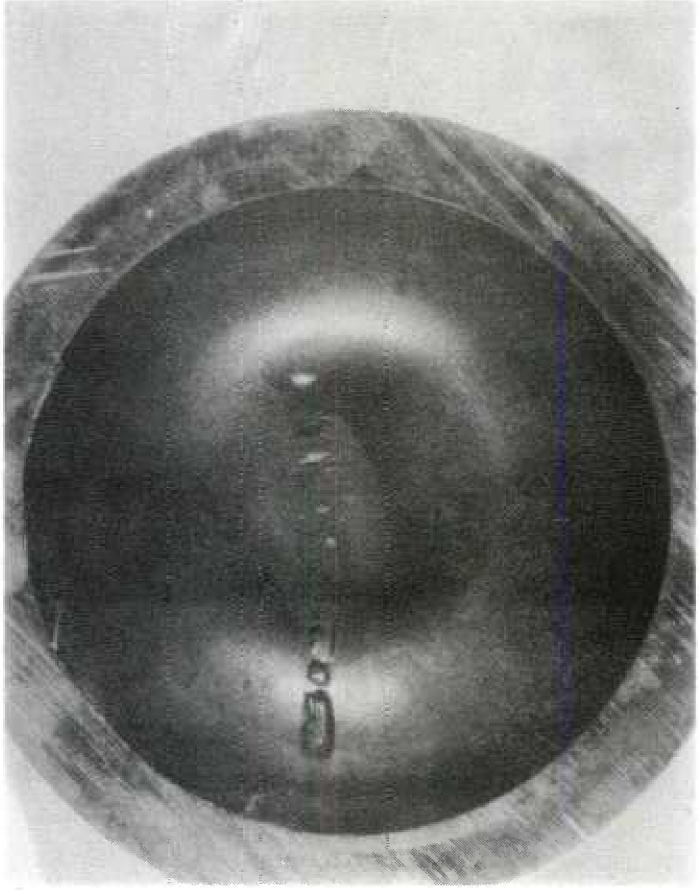


Figure 101. Photograph of cavity defect. (Shell #1166)
1/2X Unetched.

M-549
Forging Defect
Category IV

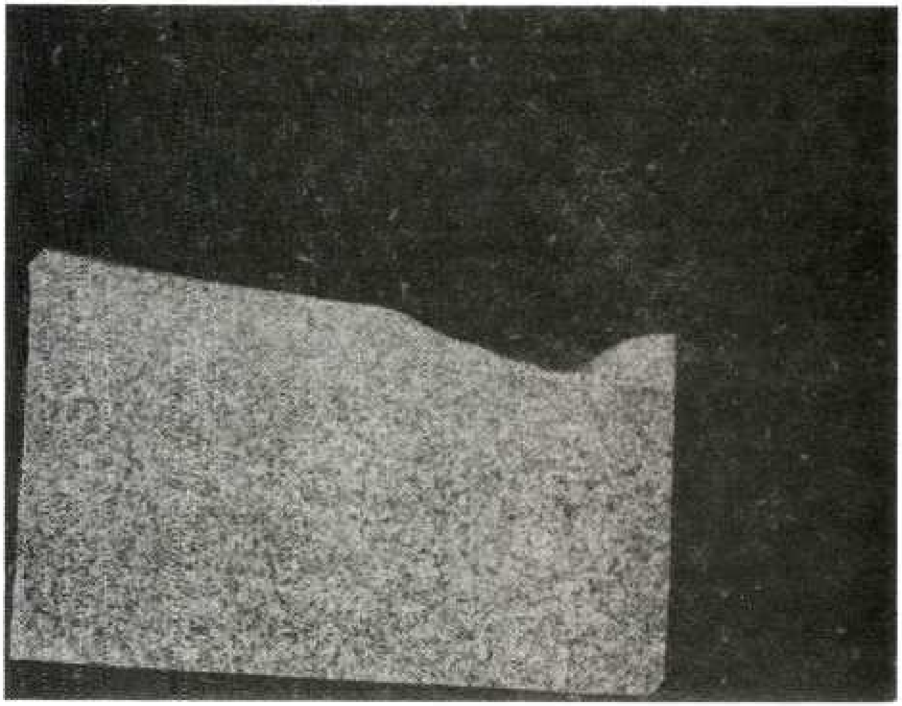


Fig.102. Photomacrograph of cross section of defect. 5X Nital Etch.

Fig.103. Photomicrograph of longitudinal section of defect showing no decarburization or flow lines. 63X Nital Etch.

Category V -

Figures 104 thru 106 illustrates longitudinal cracks present in material from both vendors. Figures 107 and 108 are cross sections of the defect. Metallographic evaluation revealed that they are of the same nature as those in Category I; that is, they are decarburized only part way into the cracks, they have no stress lines, the base has some scale in it and apex is carbon depleted.

Again, from a time and temperature analysis, they were most probably opened up in the preform operation from the hoop stresses. The metallurgical notch precipitating the defects is probably a bar seam as various seam-like defects are present further up on the body.

Category VI -

Figure 109 is a photograph of a base illustrating some raised and depressed areas. Figure 110 is a photomicrograph of a longitudinal section of same area. It reveals patches of untempered martensite which seem to be causing the raised area with fine pearlite between the raised areas. The entire surface is slightly decarburized.

Microhardness readings were taken in all areas and are tabulated below:

Structure	Hardness
Untempered Martensite (0.016" deep at places.)	48-58 Rc
Fine Pearlite between Untempered Martensite.	40 Rc
Decarburized area at surface of Fine Pearlite.	77 Rb
Decarburized area at surface of Untempered Martensite.	43 Rc

M-549
Forging Defect
Category V

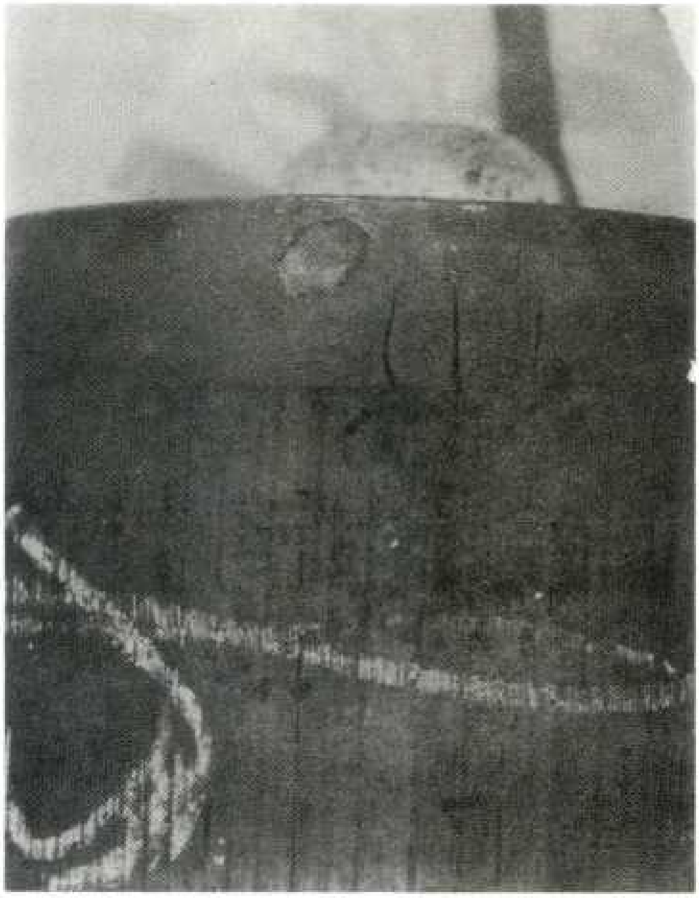


Figure 104. Photograph of longitudinal cracks. (Shell #1011)
1X Unetched.

M-549
Forging Defects
Category V

Figure 105. Photograph of longitudinal cracks. (Shell #470) 1X Unetched.

M-549
Forging Defects
Category V

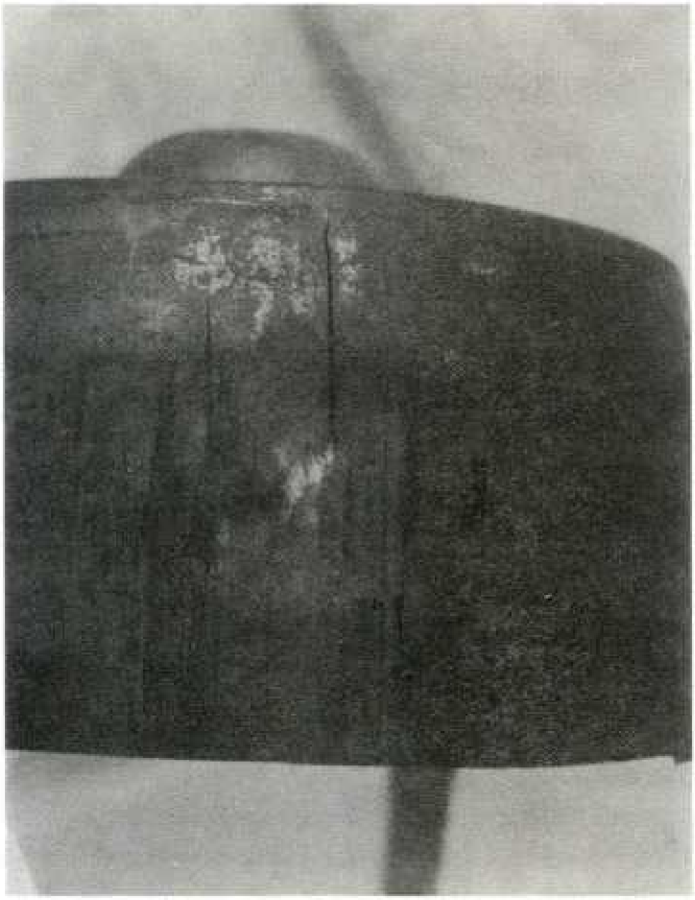


Figure 106. Photograph of longitudinal cracks. (Shell #723)
1X Unetched.

M-549
Forging Defect
Category V

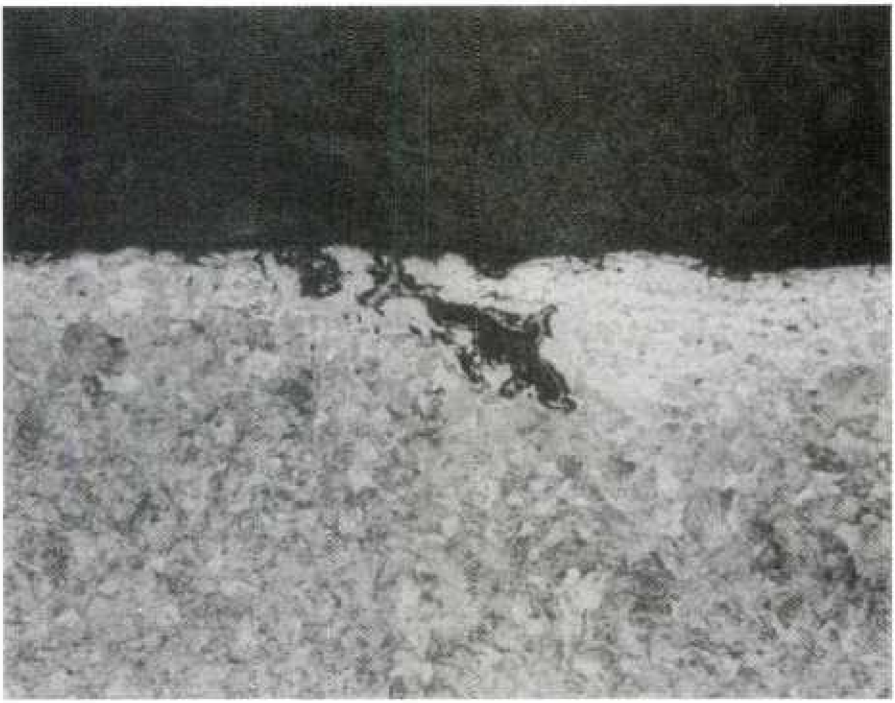


Figure 107.Photomicrograph of cross section of defect. (Shell #1011)
63x Nital Etch

M-549
Forging Defect
Category V

Figure108.Photomicrograph of cross section of defect. (Shell #470)
63x Nital Etch

M-549
Forging Defect
Category VI

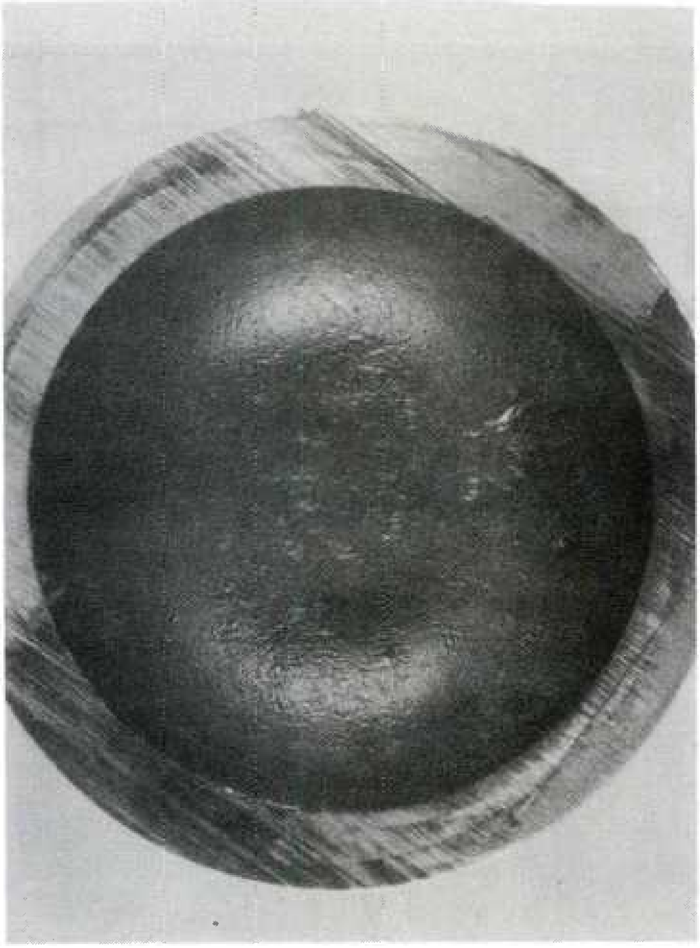


Figure 109. Photograph of a base showing high and low areas. 1/2X Unetched.

M549
Forging Defect
Category VI

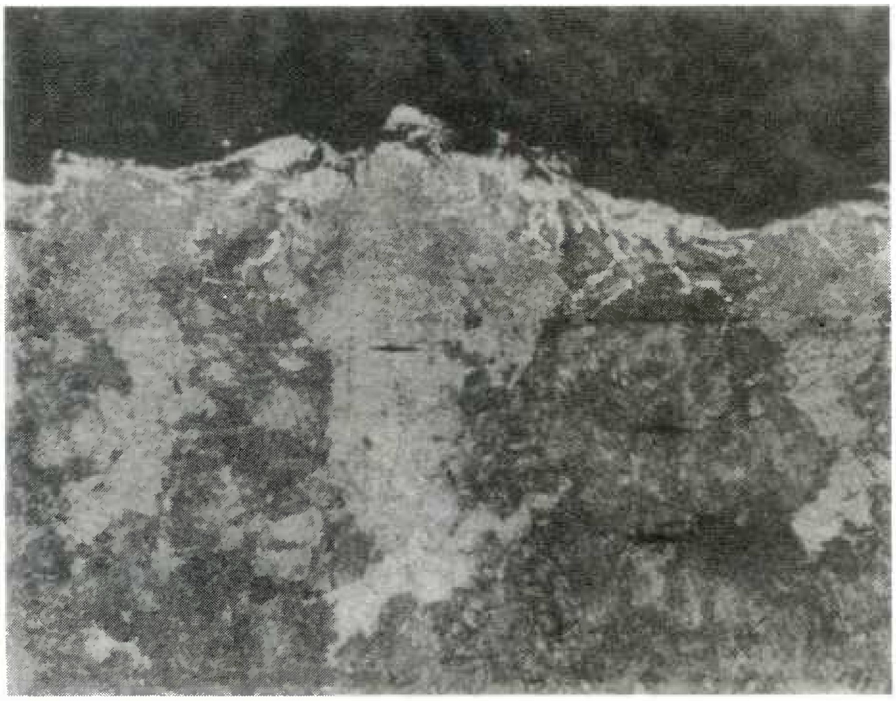


Figure 110. Photomicrograph of longitudinal section showing patches of untempered martensite. 125X Nital Etchant.

The areas of martensite and pearlite have different expansion volumes as can be seen in the volume expansion of martensite transformation in 1% carbon steel. Reference is Physical Metallurgy Principles by Read-Hill[3]. Since the martensite areas have a volume expansion of 4.4% over that of pearlite and are bounded by the fine pearlite, the volume expansion must be within the martensite structure itself; upward into the cavity.

Metallography

While processing the remaining steel from this task, samples were taken from forgings representing each vendor's cooling method. One of the sections analyzed is four (4) inches from the open end and the other section is four (4) inches from the base area.

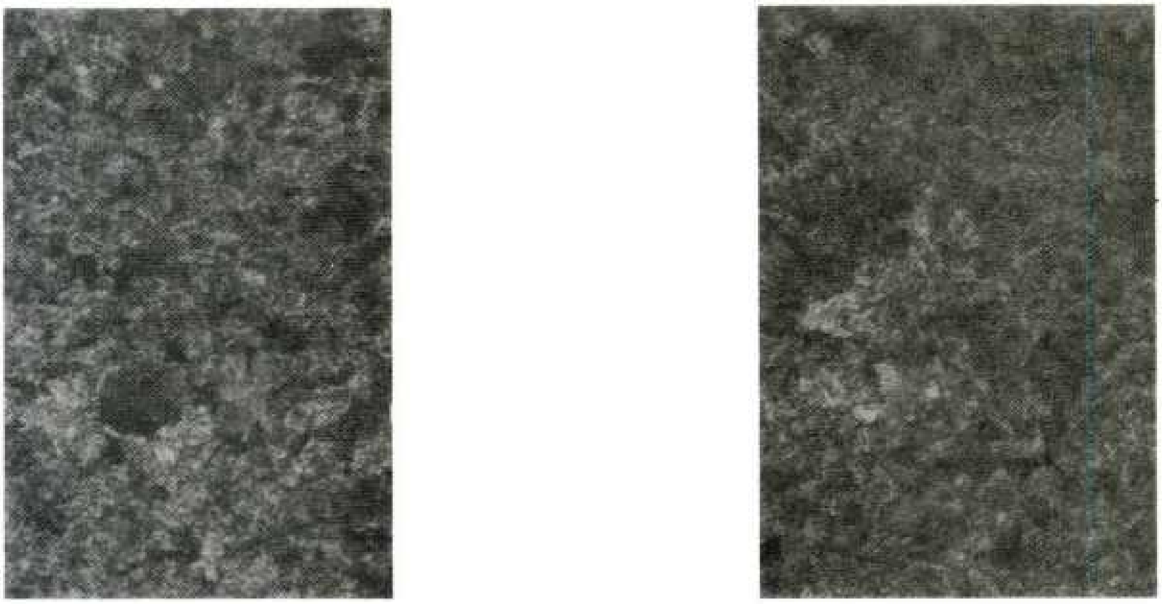
The structure is fine pearlite with all samples being similar. There is no untempered martensite or precipitated carbides. These structures are illustrated in figures 111 thru 116.

During Task A, when utilizing Republic steel, it was suggested that the forgings should be machinable. The metallurgical data is additional evidence to affirm that the material utilized from all vendor cooling methods is machinable.

Hardness Pattern

Figures 117 through 119 show the relative hardness pattern of the different cooling methods.

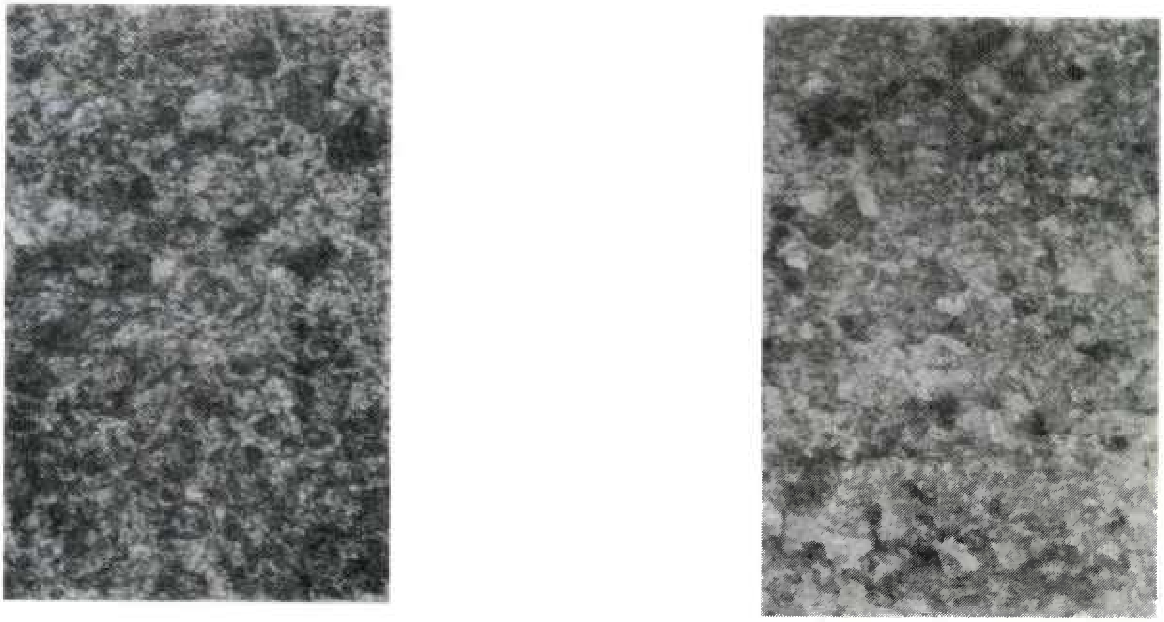
Notice the similarity of the hardness pattern further illustrating the grain refining effect of forging, discussed in Reference 1.



Open End

Base End

Figure 111.Two photomicrographs illustrating structures at different areas of forging. Shell No. 1464. 500X Picral.



Open End

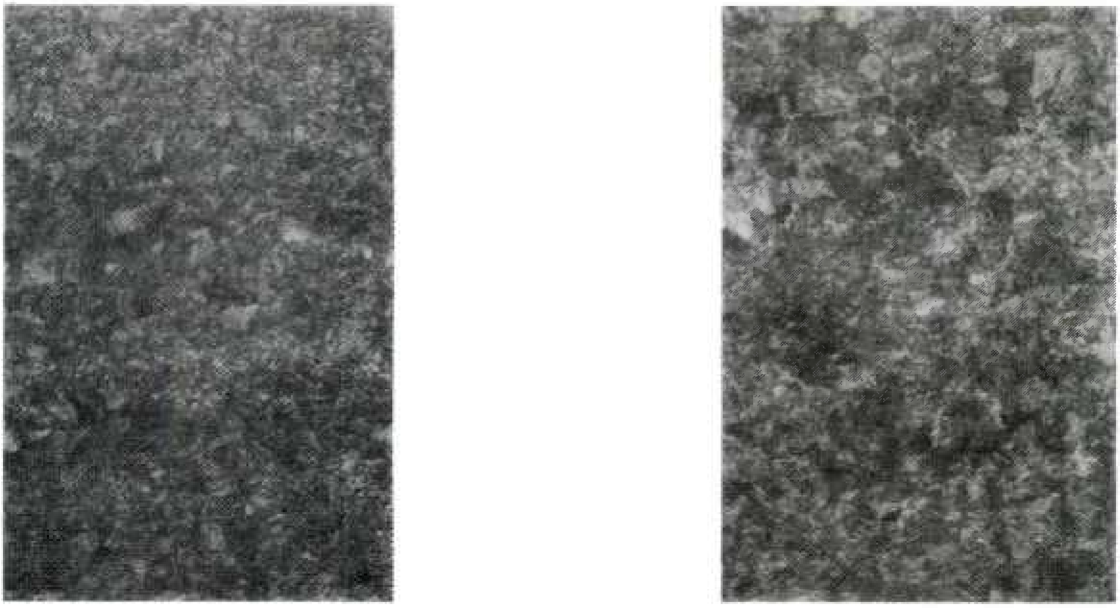
Base End

Figure 112. Two photomicrographs illustrating structures at different areas of forging. Shell No. 1452. 500X Picral.

Open End

Base End

Figure 113. Two photomicrographs illustrating structures at different areas of forging. Shell No. 1272. 500X Picral.



Open End

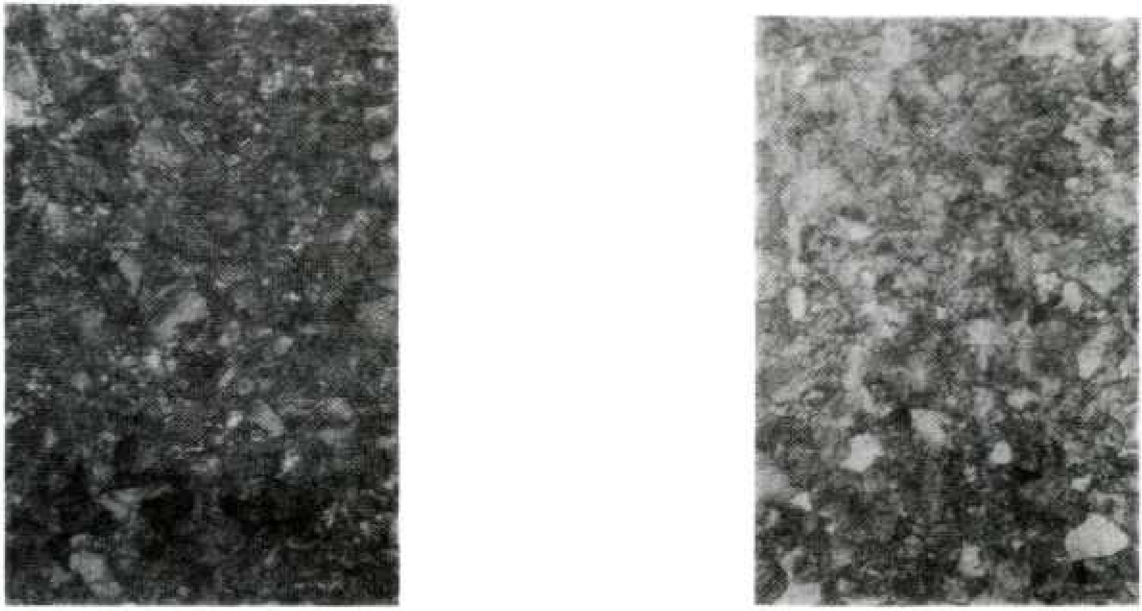
Base End

Figure 114. Two photomicrographs illustrating structure at different areas of forging. Shell No. 1120. 500X Picral.

Open End

Base End

Figure 115. Two photomicrographs illustrating structures at different areas of forging. Shell No. 459. 500X Picral.



Open End

Base End

Figure 116. Two photomicrographs illustrating structures at different areas of forging. Shell No. 491. 500X Picral.

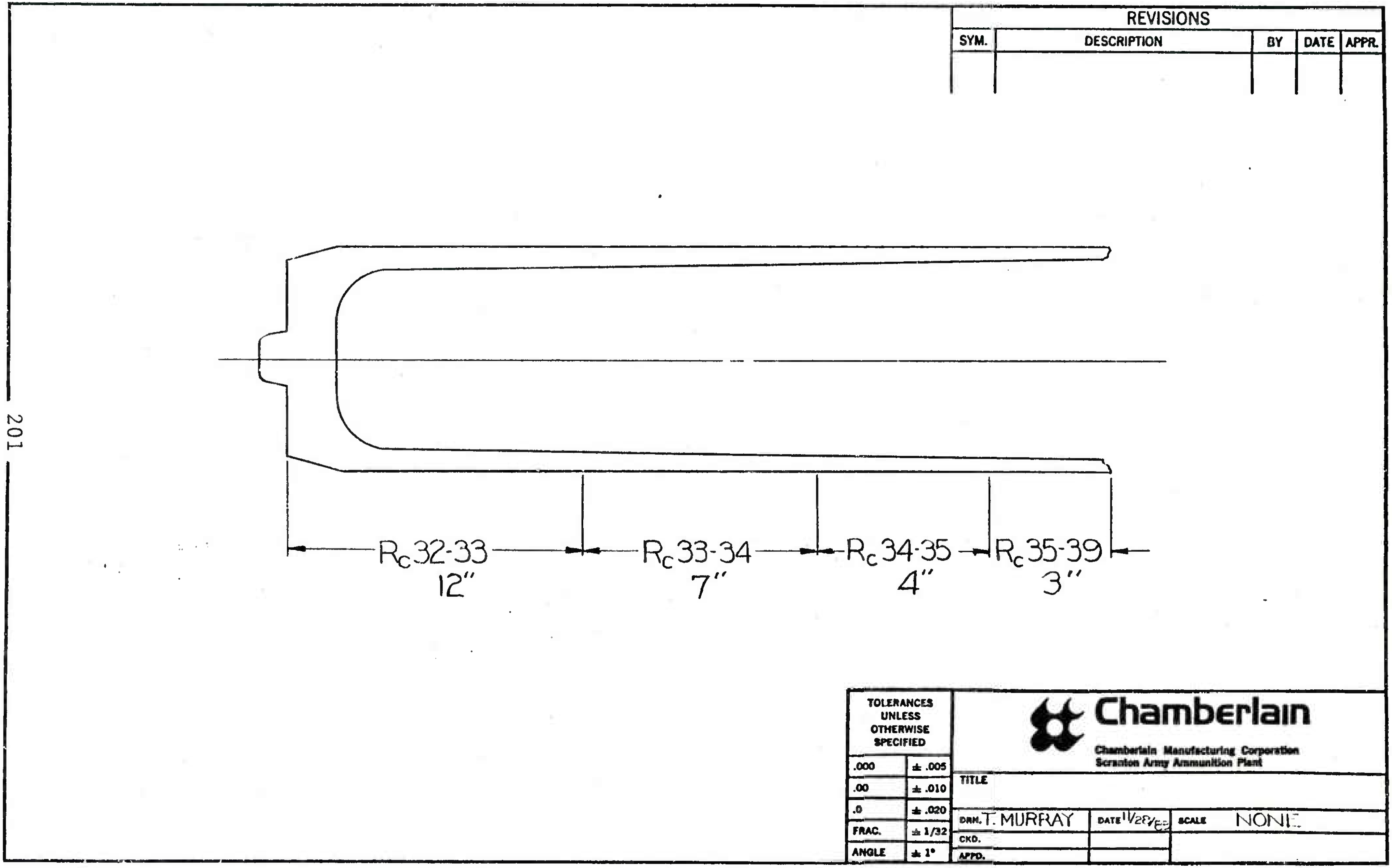


Figure 117. Republic Steel forging - hardness pattern.

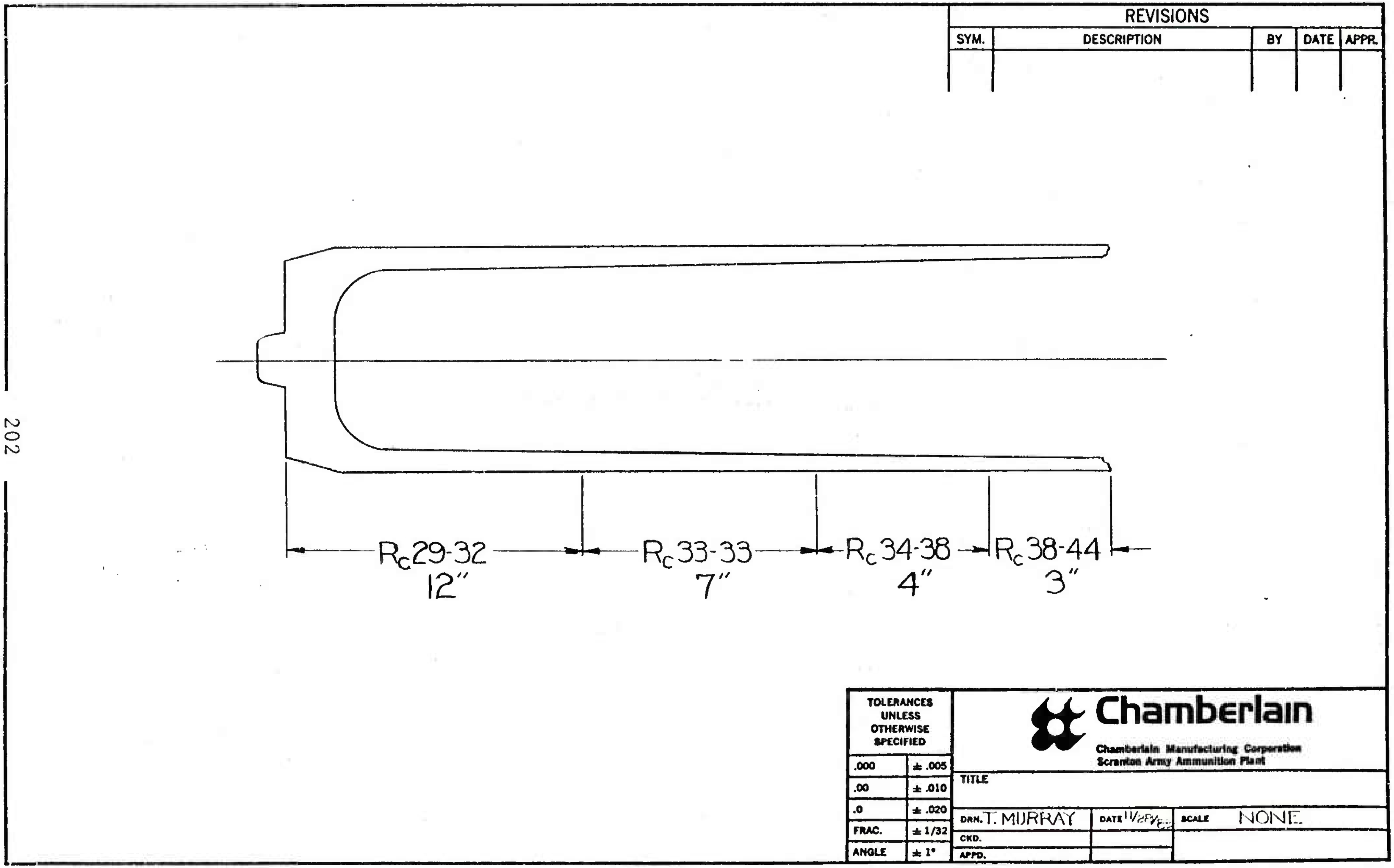


Figure 118. Bethlehem 2A steel forging - hardness pattern "box cooled".

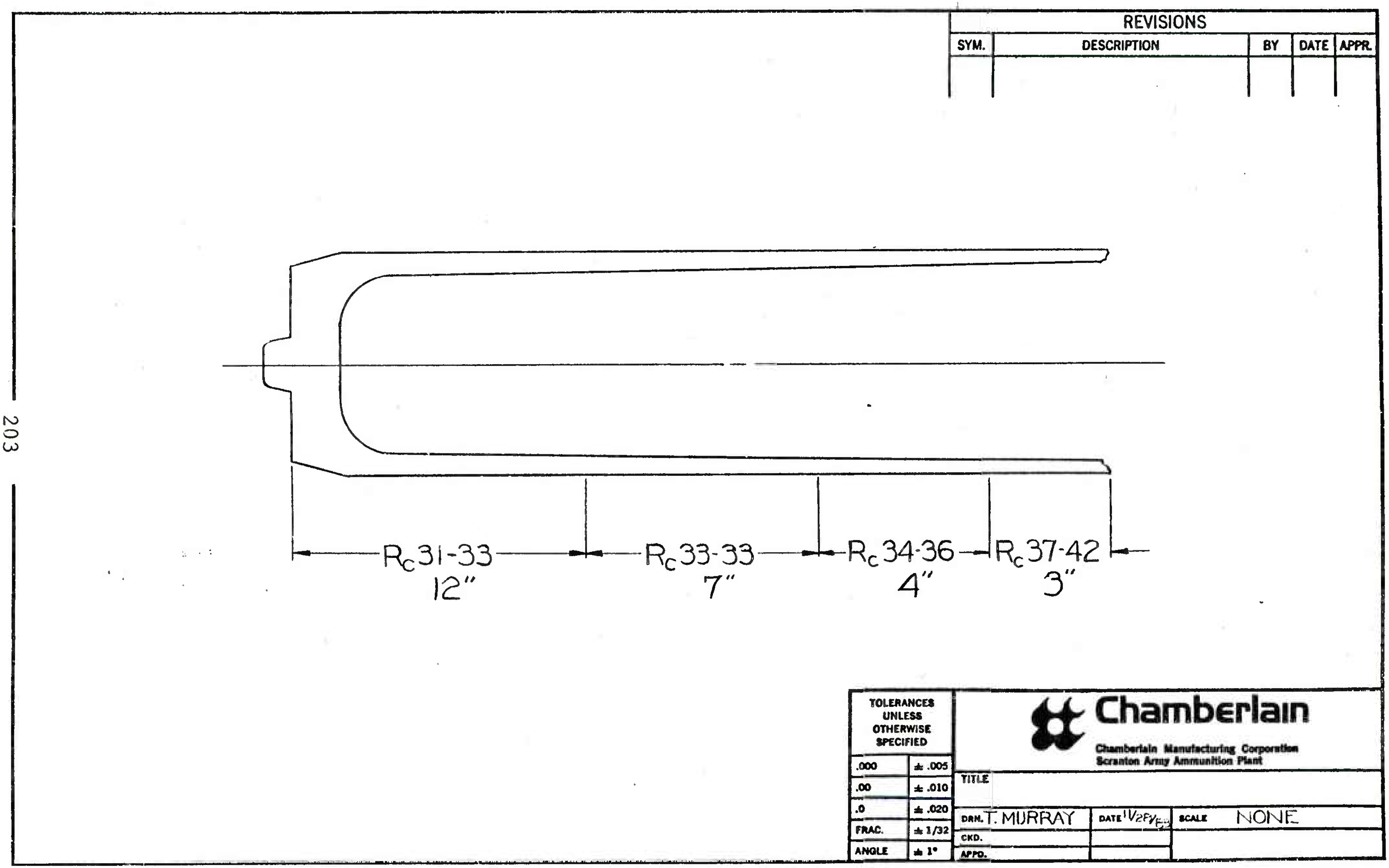


Figure 119. Bethlehem 2B steel forging - hardness pattern "bung cooled".

Flow Pattern

Figure 120 illustrates the smooth flow lines typical of a part after backward extrusion (pierce).

Figure 121 illustrates the smooth flow lines typical of the drawn forgings produced by the forge tooling during this project.

Mechanical Properties

Table 21 is a list of mechanical properties obtained from all cooling methods produced by both vendors and used in this project. The values confirm the metallographic evaluation that the hot forging operation and techniques used by Chamberlain Manufacturing, Scranton Division refines any metallurgical and metallographic differences present in the material prior to forging regardless of the method of production by either vendor. The tensile graphs may be found in Appendix J.

Rough Turn Machining

Tooling

During the performance of this task, 250 shells, in the as-forged condition, were processed through the rough turn operation. In order to obtain a sufficient sample size for proper analysis of tool life data, the same tooling that was utilized for the machining of 500 shells during the performance of Task D was employed. This method provided a total sample size of 750 shells machined in the as-forged condition, from which reasonably accurate tool life could be determined. The results of the tooling life obtained for all tooling tested during the machining of the 750 shells are listed in Table 22.

M-549
Forging

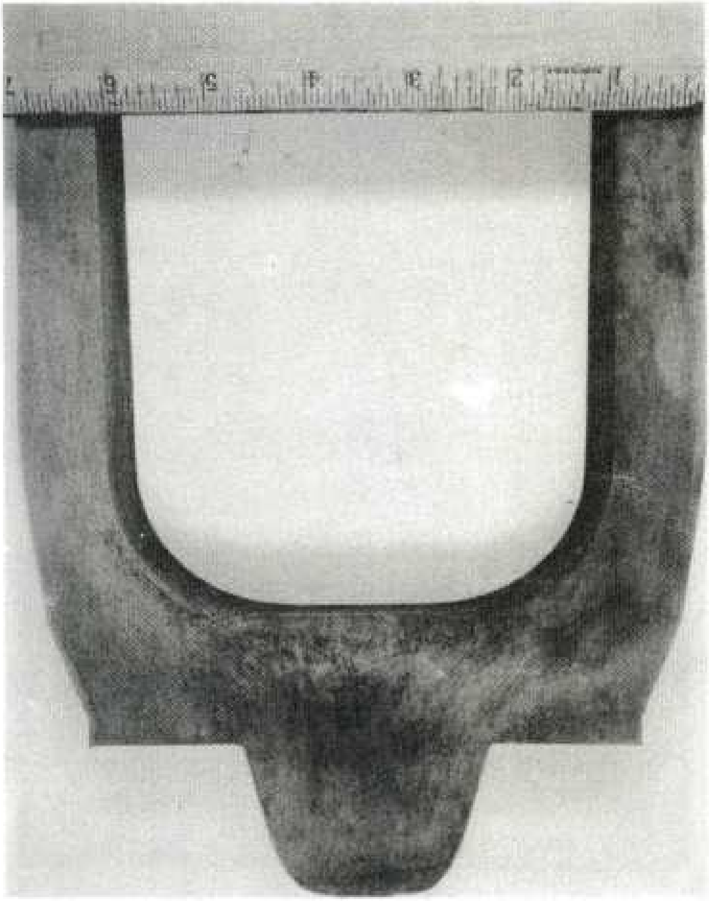


Figure 120. Photograph of flow lines in pierce bottle. 1/2X
50% Hydrochloric Acid Etch.

M549
Forging

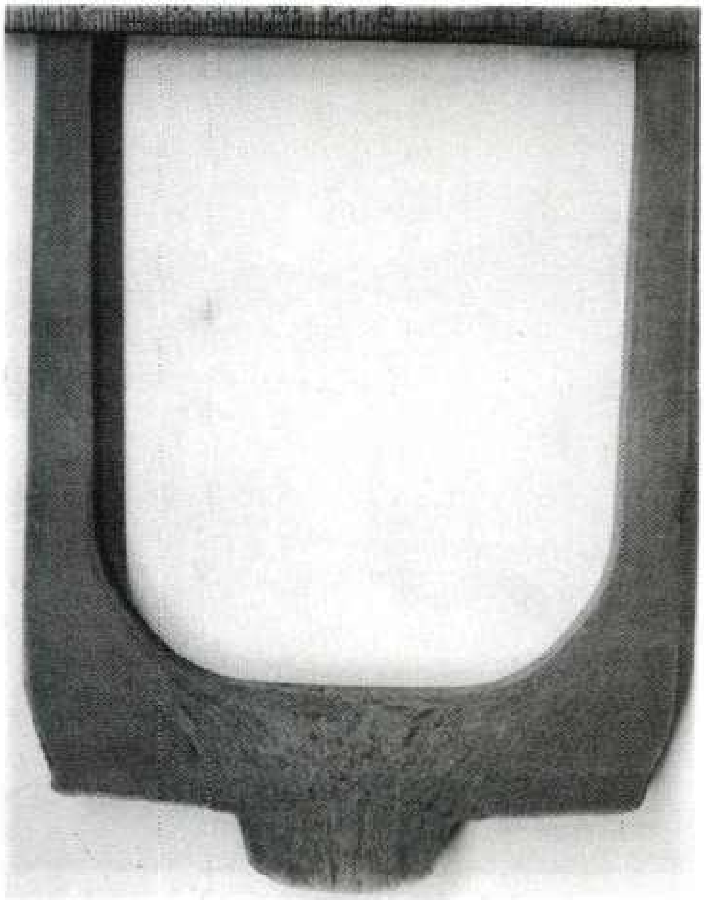


Figure 121. Photograph of typical flow lines in an as-drawn forging. 1/2X 50% Hydrochloric Acid Etch.

Table 21. Illustrates the mechanical properties of the three cooling methods from the two vendors.

Cooling Method	Shell No.	Yield Strength Ksi	Yield Strength MPa	Tensile Strength Ksi	Tensile Strength MPa	% Elongation	Location
Bethlehem Steel "Bung" Furnace	1452	108.1	746	162.9	1123	6.7	Longitudinal
		106.1	731	162.7	1121	4.1	Longitudinal
		93.4	644	137.2	946	1.4	Transverse
Bethlehem Steel "Bung" Furnace	1464	102.5	707	163.6	1128	5.5	Longitudinal
		106.1	731	162.7	1121	5.6	Longitudinal
		96.9	668	137.2	946	1.0	Transverse
Bethlehem Steel Box	1272	101.1	697	165.7	1142	5.2	Longitudinal
		105.3	725	164.3	1133	4.0	Longitudinal
		96.9	668	136.9	944	1.0	Transverse
Bethlehem Steel Box	1120	109.6	755	177.0	1220	5.5	Longitudinal
		106.1	731	161.2	1112	6.0	Longitudinal
		94.5	651	133.7	922	1.4	Transverse
Republic Steel Pit	491	101.1	697	168.5	1162	5.5	Longitudinal
		104.7	722	175.4	1209	5.5	Longitudinal
		100.4	692	154.2	0163	2.2	Transverse
Republic Steel Pit	459	106.1	731	169.0	1165	5.9	Longitudinal
		106.1	731	173.7	1198	5.1	Longitudinal
		100.6	694	154.6	1066	2.2	Transverse

Table 22. Tool Life Data Obtained for 750 Shell Production Run (As Forged Shells)

Speed 267 SFPM Feed 0.035 in./rev.

Avg. Depth of Cut 0.105 in.

Heat No.	Tool Pos.[a]	Insert Style	Insert Grade	Shells Run	Avg. Shells Per Index	Avg. Inches Per Index[b]
1	1	SNMG-866	1025	186	6.2[c]	34.1
1	1	SNMG-866	1025	67	16.8	92.4
1	1	TNMA-666	315	27	1.8[c]	9.9
1	1	TNMA-666	TX10[d]	4	1.0	5.5
1	1	TNMM-666	V-90	1	1.0	5.5
1	1	TNGA-666	HC-2	1	1.0	5.5
1	2	TNMA-666	315	286	35.8	277.1
1	3	TNMA-666	315	286	47.7	369.4
1	4	Special[e]	K-21	236	39.3	93.4
1	4	TNMG-542	518	50	5.6	13.2
1	5	DE/46/4	VR-75	67	6.1	2.3
2A	1	SNMG-866	1025	243	5.9	32.6
2A	2	TNMA-666	315	243	27.0	209.3
2A	3	TNMA-666	315	243	22.1	171.2
2A	4	Special[e]	K-21	243	24.3	57.7
2A	5	DE/46/4	VR-75	206	6.9	2.6
2A	5	DE/46/4	CF-7	36	3.6	1.4
2A	5	DE/46/4	CF-6	1	1.0	.4
2B	1	TNMA-666[f]	315	22	17.0	93.5
2B	1	SNMG-866	1025	142	7.1	39.1
2B	2	TNMA-666	315	142	28.4	220.1
2B	3	TNMA-666	315	142	35.5	275.1
2B	4	Special[e]	K-21	142	23.7	56.2
2B	5	DE/46/4	VR-75	142	12.9	4.8

a. 1, 2 and 3-Turning; 4-Facing; 5-Parting.

b. 25.4 mm = 1 Inch.

c. Data obtained prior to installation of Parting Tool (Pos. #5) on Rough Turn Machine.

d. Ceramic Insert.

e. 5/16" Sq. X 1" Long with ground chip breaker.

f. Increase in tool life obtained after the installation of the parting tool (tool #5).

Attention is directed to footnote "c" listed at the bottom of the table. This footnote pertains to the insert style TNMA-666 of a 315 cast iron grade (as listed for Heat #1). During the start of the 500 shell production run, this insert was the first one to be tested in tool position #1 before the parting tool was added to the rough turn machine. The life attained was only 1.8 shells per index. It was then removed and replaced by an SNMG-866 insert style with a 1025 steel grade. The life attained on this insert was 6.2 shells/index prior to the installation of the parting tool. With the parting tool installed, the life of the SNMG-866 insert was increased to 16.8 shells/index (in regards to Heat #1).

As a further comparison of the effects of adding the parting tool to the rough turn machine, the original insert of the TNMA-666 style and 315 grade was then reinstalled during the final day of this testing period. The result was an increase in tool life to 17 shells/index (Heat #2B - footnote "f"). This essentially confirms the theory that the tool was exiting the cut too abruptly prior to the installation of the parting tool.

Unfortunately, only 22 shells were machined using this tool before the shell supply was exhausted. However, the results did supply adequate information for determining which tooling should be recommended for machining HF-1 steel presented later in this report.

A comparison of tool life data across Heats #1, 2A and 2B listing the tooling which produced the best results, is presented in table 23, while table 24 lists the tooling data and results obtained for the three heats of steel "combined" for the 750 shell production run. To clarify data

Table 23. Comparison of Tool Life Data between Heats #1, 2A & 2B for 750 Shell Production Run (As Forged).

Speed 267 SFPM Feed 0.035 in./rev.
Avg. Depth of Cut 0.105 in.

Heat No.	Tool Pos.[a]	Insert Style	Insert Grade	Shells Run	Avg. Shells Per Index	Avg. Inches Per Index
1	1	SNMG-866	1025	67	16.8	92.4
1	2	TNMA-666	315	286	35.8	277.1
1	3	TNMA-666	315	286	47.7	369.4
1	4	Special[c]	K-21	236	39.3	93.4
1	5	DE/46/4	VR-75	67	6.1	2.3
2A	1	SNMG-866	1025	243	5.9	32.6
2A	2	TNMA-666	315	243	27.0	209.3
2A	3	TNMA-666	315	243	22.1	171.2
2A	4	Special[c]	K-21	243	24.3	57.7
2A	5	DE/46/4	VR-75	206	6.9	2.6
2B	1[d]	TNMA-666	315	22	17.0	93.5
2B	1	SNMG-866	1025	142	8.1	39.1
2B	2	TNMA-666	315	142	28.4	220.1
2B	3	TNMA-666	315	142	35.5	275.1
2B	4	Special[c]	K-21	142	23.7	56.2
2B	5	DF/46/4	VR-75	142	12.9	4.8

a. 1, 2 & 3 - Turning; 4 - Facing; 5 - Parting.

b. 25.4 mm = 1 inch.

c 5/16" sq. x 1" long with ground chipbreaker.

d. Originally used prior to installation of parting tool. The data displayed notes the increase in tool life after installation of the parting tool on the rough turn machine. This data is not included in the histogram charts due to the insufficient number of shells run on this tool during the testing period.

Table 24. Rough Turn tooling test results for 750 piece "As Forged" Production Run (all heats combined).

Speed 267 SFPM Feed 0.035 in./rev.

Avg. Depth of Cut 0.105 in.

Tool Pos.[a]	Insert Style	Insert Grade	Shells Run	Avg. Shells Per Index	Avg. Inches Per Index
1	SNMG-866[f]	1025	531	6.7	30.7
1[c]	SNMG-866	1025	186	6.2	34.1
1[c]	TNMA-666	315	27	1.8	9.9
1	TNMA-666	315	22	17	93.5
1	TNMA-666	TX-10[d]	4	1.0	5.5
1	TNMM-666	V-90	1	1.0	5.5
1	TNGA-666	HC-2	1	1.0	5.5
2	TNMA-666[f]	315	750	30.0	232.5
3	TNMA-666[f]	315	750	31.3	242.2
4	Special[e] [f]	K-21	700	26.9	63.9
4	TNMG-542	518	50	5.6	13.2
5	DE/46/4 [f]	VR-75	493	8.2	3.1
5	DE/46/4	CF-7	37	3.7	1.4
5	DE/46/4	CF-6	1	1.0	.4

a. 1, 2 & 3 - Turning; 4 - Facing; 5 - Parting.

b. 25.4 mm = 1 inch.

c. Data obtained prior to installation of parting tool (Pos. #5) on Rough Turn machine.

d. Ceramic insert.

e. 5/16" sq. x 1" long with ground chipbreaker.

f. The information for these tools were utilized in constructing the histogram on tool life comparisons.

from these tables, the tooling which had yielded the best results is presented in histogram form for ease of comparison between the heats of steel involved. The tooling life is depicted in figure 122 for the three turning tools (tools #1, 2 and 3) and in figure 123 for the facing and parting tools (tools #4 and 5).

The results indicate that greater tool life was attained for Heat #1 when compared to Heats #2A and 2B for tools #1 thru 4 with Heat #2B obtaining a greater tool life for the parting tool. (Ref. Table 23). The reason for this has not been determined since the hardness values (as presented in Task C of this report) are similar for the three heats of steel involved. Additional machining, involving a larger amount of shells, would have to be undertaken to determine if the trend in tool life would continue in the manner as presented in the histogram charts.

Analysis of the tooling data obtained in Tasks C, D and E of this report has provided the supporting information required to present the following recommendations for the continued optimization of the rough turn tooling for machining HF-1 steel in the as-forged condition.

1. It is believed that the tool life for tool #1 can be improved by utilizing the square style insert (SNMG type), but in combination with a cast iron grade such as a 315 or NT2. (Both are the same grade, but are manufactured by different vendors.)
2. Although a triangular cast iron grade insert was utilized for tools #2 and 3, the use of a square insert should also yield additional life.
3. Tool life for tool #4 (base tool), although considered good, can possibly be increased by utilizing a tool

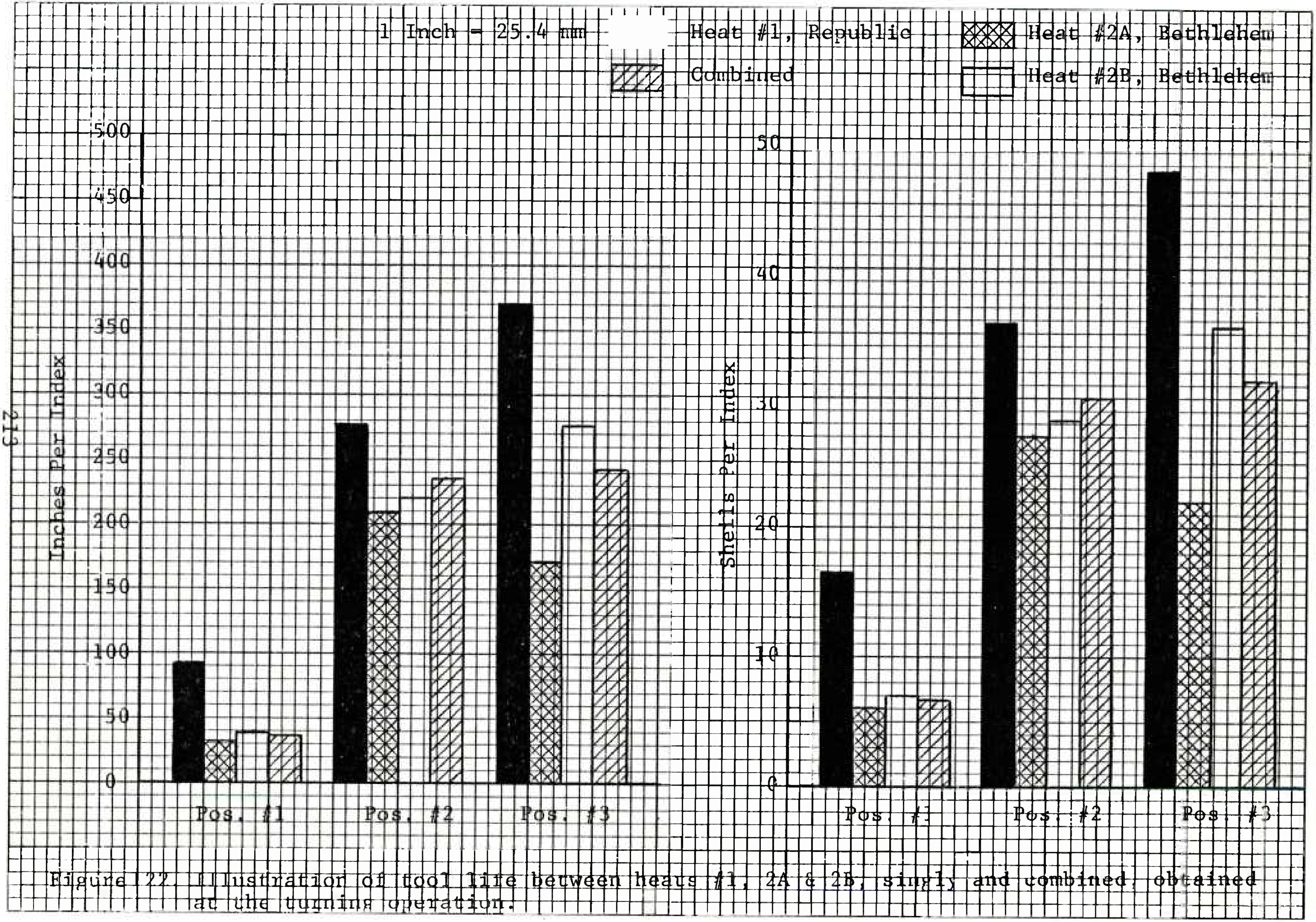


Figure 22. Illustration of tool life between heats #1, 2A & 2B, singly and combined obtained at the turning operation.

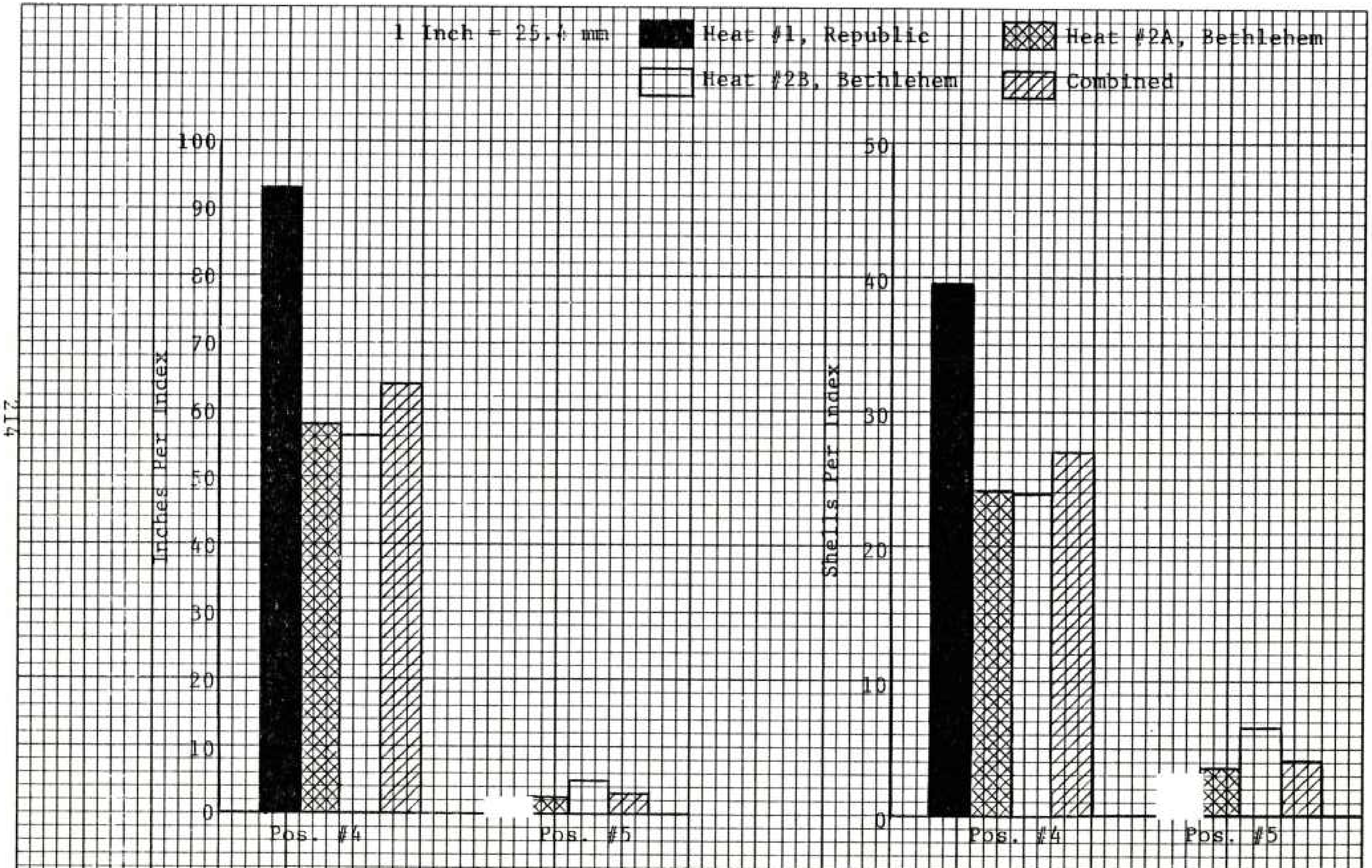


Figure 123. Illustration of tool life between heats #1, 2A & 2B, singly and combined, obtained at the facing (tool #4) and parting operation.

without a chip breaker. An NT2 or 315 grade should also be tested for this application as well as for tool position #5.

4. An 1/8" radius could also be tested on the turning tools, but the effect of the surface finish attained with the nose radius must be considered. A rough finish (approximately 250 micro inch) is normally required for good graphite spray adhesion on the rough turned surface in order to perform the nosing operation successfully.
5. A toolholder with a lead angle greater than 15° can also be tested, but the use of an increased lead angle will increase the radial forces on the shell, possibly causing a "chatter" condition to occur on a shell of this type with its thin wall section.

Problems Encountered

Besides the problem of the "chipping" condition that was previously discussed in this report, two additional problem areas were encountered during the performance of the rough turn operation.

One problem involved the "splitting" of some shell bodies while being processed through the rough turn operation, while the other problem encountered had involved the non-cleanup of the boattail area of the shell during machining.

A total of seven (7) shell bodies split while being machined. Six (6) of the shells were from Heat 2B while the remaining one was from Heat 2A. It was determined that the splitting (cracking) of the shells was due to the "cold tear" condition on the inside diameter at the open end of the forging. The "cold tear" condition was previously discussed in the metallography section of this task. Figure 124 illustrates the cold tear condition located at the I.D. of the open end of the shell while figure 125 depicts the splitting condition of the shell which was caused by the cold tear.

It must be stated that the splitting condition that was encountered had caused premature tool breakage to occur thereby lowering the average tool life attained for tool position #1. This condition must also be considered when reviewing the tool life data contained in this report.

The second problem mentioned was that of a non-cleanup condition which had occurred at the boattail area of the shell. This condition is illustrated in figure 126. This problem was not due to eccentricity of the forging but to a condition known as "bent boattail" which occurred during the forging operation. The condition was undetected during the inspection of the forgings since it is not readily noticeable and is not detected by the eccentricity gage utilized in the inspection process.

Although the non-cleanup condition had occurred in approximately 32% of the shells from Heat #1 and 48% of the shells from both Heats #2A & 2B, the majority of the shells had only slight traces of this condition. Nonetheless they were included in the percentage figures listed.

Figure 127 depicts the shells with the slight condition of non-cleanup, while figure 128 illustrates the minimum and maximum condition of non-cleanup that was incurred during the rough turn operation.

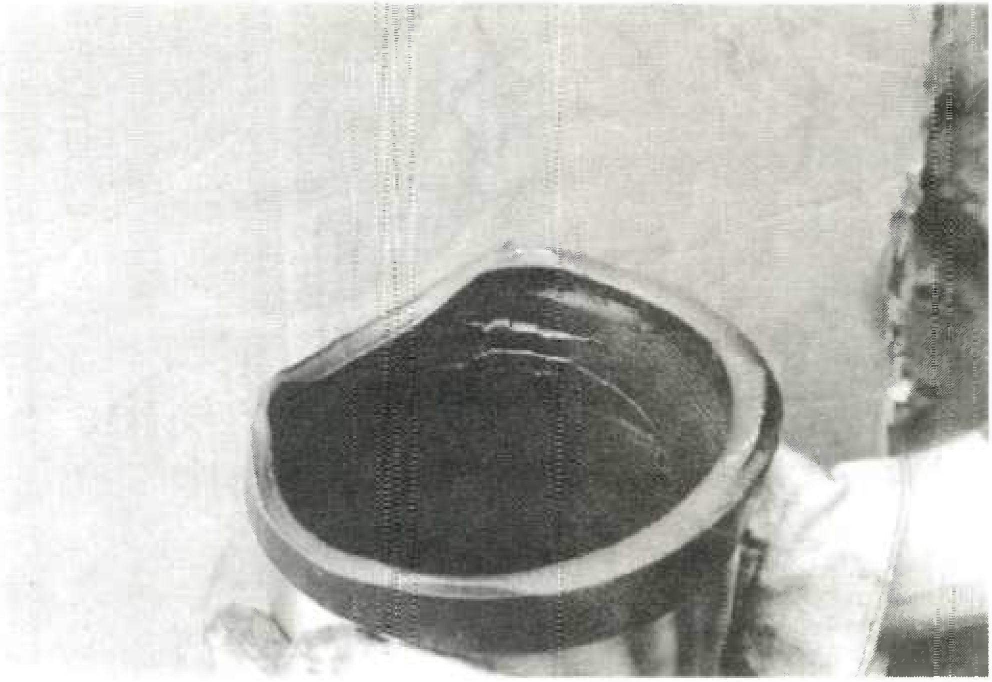


Figure 124. Photo depicting the "cold tear" condition located at the inside diameter of the shell body.

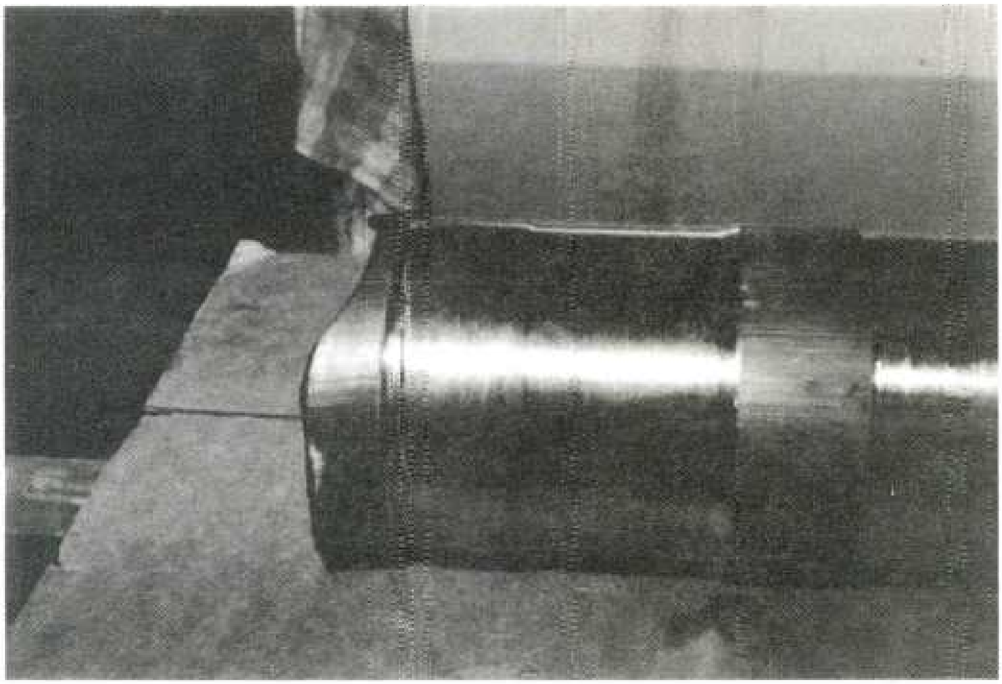


Figure 125. Splitting condition of shell body caused by the "cold tears".

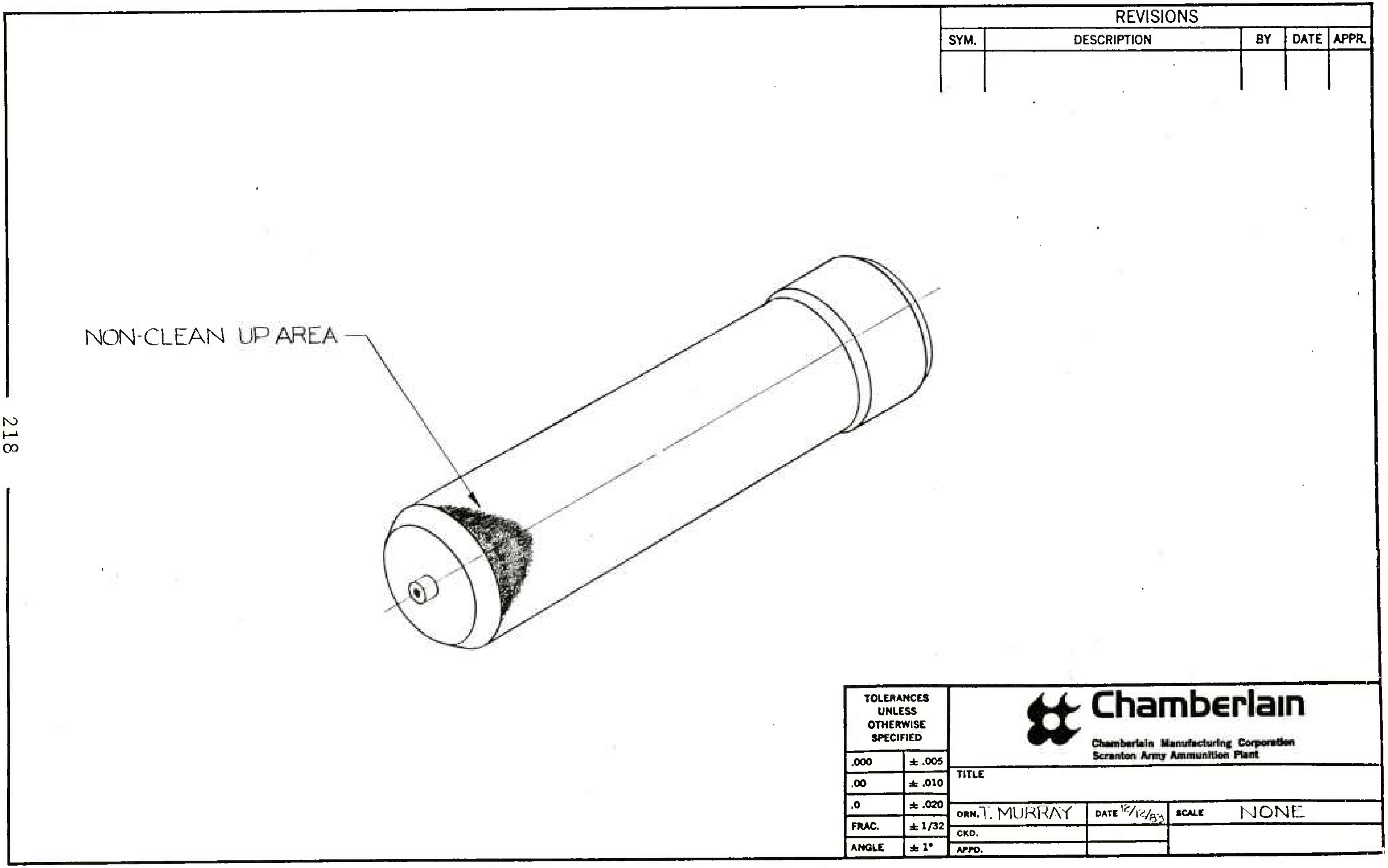


Figure 126. Illustration of "non-cleanup" at the boattail area of shell body.

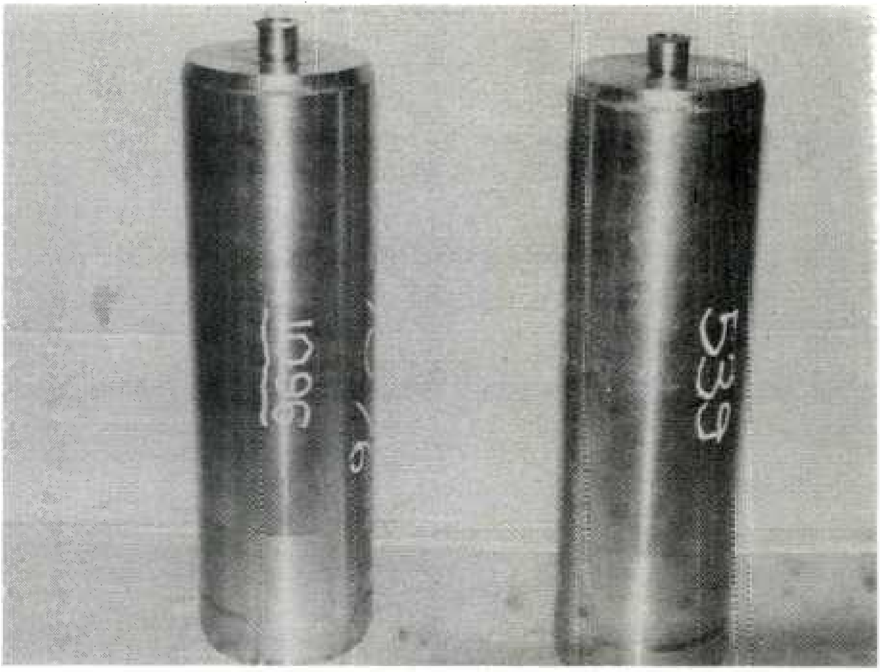


Figure 127. Photo depicting slight "non-cleanup" at the boattail area of shell, which occurred on a majority of the shells.

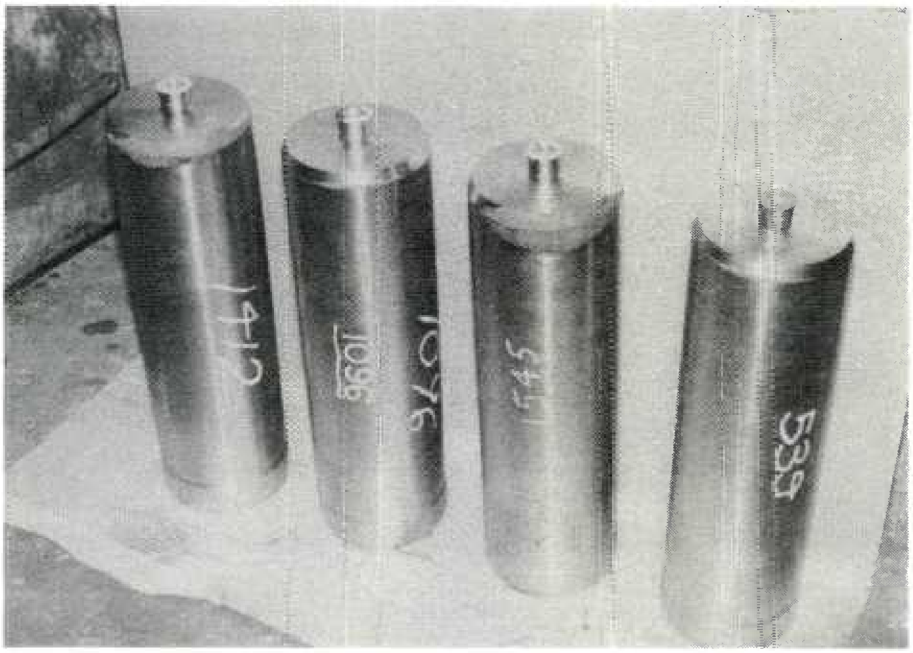


Figure 128. Photo revealing the minimum and maximum "non-cleanup" condition that was incurred.

The condition can be corrected with slight modification to the forge tooling.

Although the condition had occurred, it would not have any effect on the nosing operation since the non-clean-up occurred at the boattail area of the shell. Also, a subsequent finish turn machining operation is normally performed on the shells. Judging the extent of the condition, it is estimated that most of the shells would clean-up on completion of the process sequence.

Economic Analysis of Mult Parting

Due to some changes that were made to the original scope of work during the course of this project, the original requirement pertaining to an economic analysis of mult parting methods had become a moot point.

Originally, approximately 7000 mults were to be equally distributed and processed through both the sawing and nick & break mult parting techniques. Consequently, due to the changes made to the original scope of work, a total of 1552 mults were parted during this project. Of this figure, only 180 mults were parted utilizing the "nick & break" process. Parting this minute quantity of mults through the nick & break operation did not provide sufficient and sound data to properly develop an economic analysis.

Additionally, regarding the sawing operation, a larger quantity of mults would have to be parted in order to develop a sound basis for evaluating blade life.

Based on past experience concerning the processing of the M107 projectile, the consequences of reduced production rates and increased tooling costs associated with the saw (as compared to the nick and break process) are more than compensated for by a reduction in repairable and non-repairable cavity defects.

CONCLUSIONS

Based on the analysis of data contained in this report, the following conclusions are presented:

1. Surface conditioning of the billets in the final size at the steel mill by large mechanical grinders has created metallurgical notches which have propagated surface defects in the forging.

2. Nicking of the billet, in the nick and break operation, caused the formation of a mixed structure in the nicked area, resulting in cracks traversing into the substrate of the mult. The cracks varied from 0.010 inches to 0.040 inches.

3. No defects were attributable to the different cooling methods employed by the steel vendors in the production of the steel.

4. The method employed by Chamberlain Manufacturing Corporation, Scranton Division, for cooling forgings to room temperature produced material that is machinable in the "as forged" condition. Therefore, spheroidize anneal of HF-1 steel is not requried at SAAP.

5. Load requirements for forging the M549 (HF-1) were all within the capabilities of the presses utilized in the study (800 ton rating).

6. Whenever forgings entered the hot draw operation at a temperature of 1450°F or below, cold tears resulted in the I.D. mouth area.

7. A problem of non clean-up at the boat tail area of the shell, which was detected during the rough turn operation, was traced to a "bent boat tail" which occurred at the hot draw operation. (This condition can be remedied with minor alteration and experimentation.)

8. When the conventionally cooled forgings were cut to length, chipping occurred on the inside diameter at the excess metal ring/shell body interface.

9. Forging eccentricity values were within the designed limits from both the nick and break and sawed mults.

10. The minimum mult weight of 29.93 kg (66 lbs.) provided sufficient material for performing subsequent machining operations using the hot forge process.

11. Steel of ASTM grain size No. 4 required a higher forging load than that of ASTM grain size No. 1.

12. The nick and break operation was not affected by the difference in grain size.

13. One hit nosing was used during this study with the only problem encountered being wall variation. Visual inspection of the nosed bodies did not detect any cracking.

14. No problems were encountered in sawing the HF-1 steel from either vendor or any cooling method.

RECOMMENDATIONS

1. Surface conditioning of the steel billets at the steel mill should be controlled so as not to induce any heat build-up on the surface of the billet.

2. Caution should be exercised if the nick and break process is utilized for mult parting, since it induces metallurgical notches which have the potential to propagate into major defects.

3. Larger quantities of shells must be produced to further the optimization of tools at the rough machining operation of the as forged material.

4. Further investigation into the maximum allowable mult temperature should be considered in an effort to minimize the cold tearing condition encountered at the hot draw operation.

5. If the condition of chipping creates problems in the subsequent operations of nosing and machining, facing of the open end of the shell may be required after removal of the excess material.

6. Where forging press load capacity is questionable, the use of larger grain size material may be beneficial.

7. Further experimentation should be conducted to optimize one hit nosing.

REFERENCES

1. C. MacCrindle and W. Sharpe, "High Fragmentation Steel Production Process" Final Engineering Report, Contract No. DAAA09-74-C-4009, ARRADCOM, Dover, NJ, 07801, August, 1981.

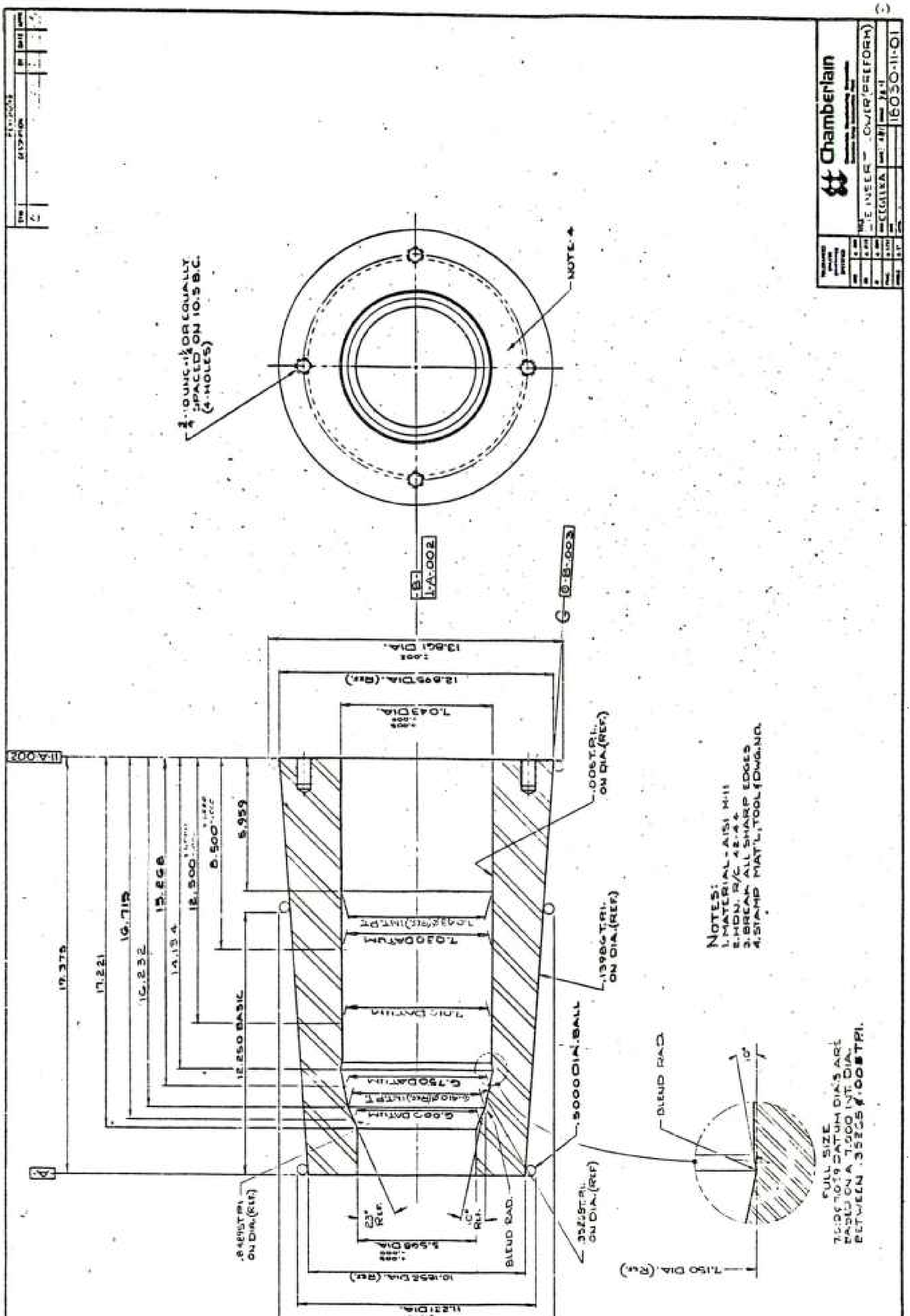
2. G. Dieter, "Mechanical Metallurgy", 2nd Edition, McGraw-Hill, 1976.

3. R. E. Reed-Hill, "Physical Metallurgy Principles", 2nd Edition, Brooks/Cole Engineering Division, 1973.

4. L. E. Samuels, "Optical Microscopy of Carbon Steels", American Society for Metals, 1980.

APPENDIX A

FORGE TOOLING

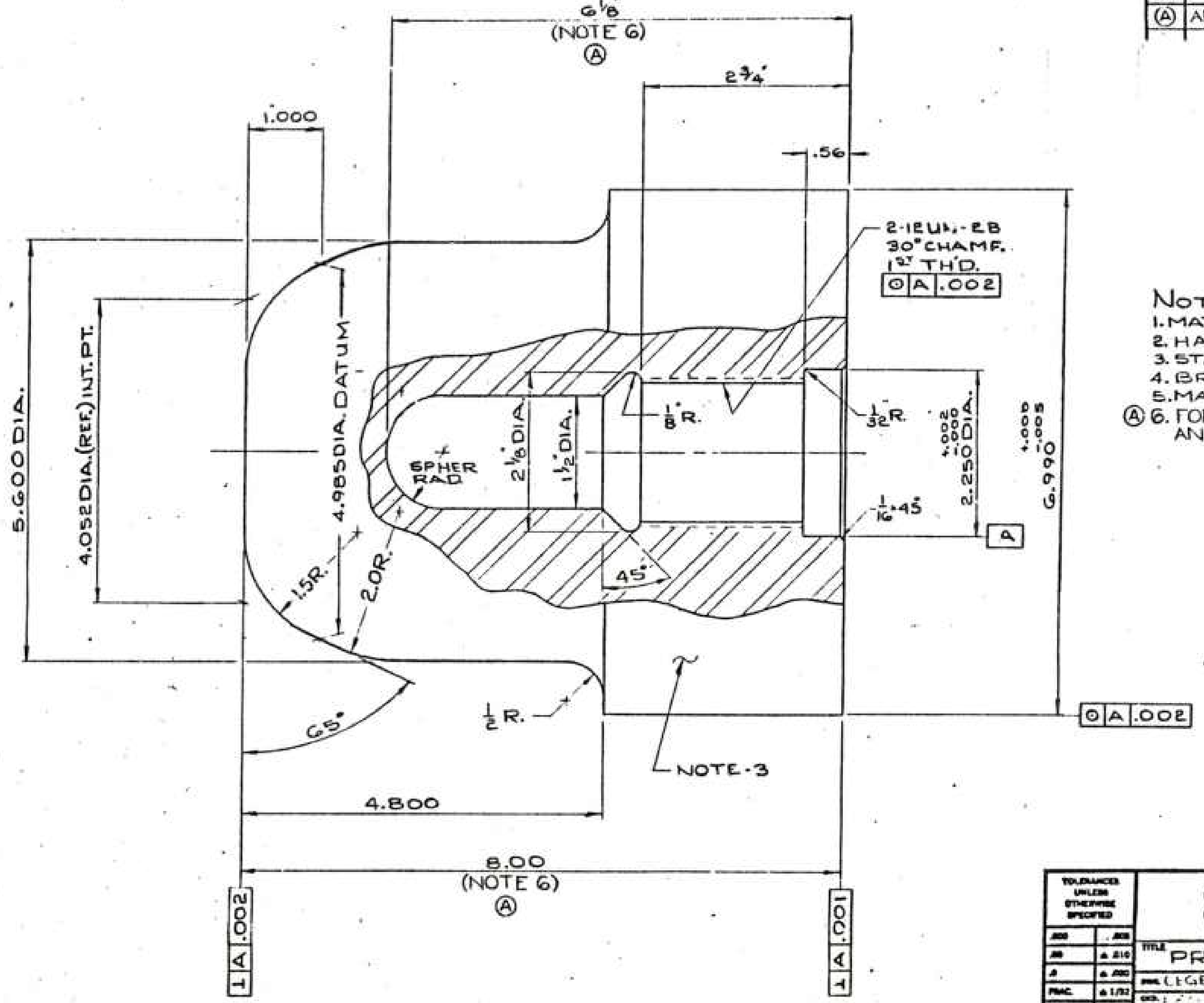


7.0.DE TO 7.9 DATUM DIA'S ARE BASED ON A 7.000 INT. DIA. BETWEEN .3525 & .008 TRI.

NOTES:
1. MATERIAL - AISI H-11
2. HDN. R/C 42-44
3. BREAK ALL SHARP EDGES
4. STAMP MAT'L, TOOL & DWG. NO.

Figure A-1 Preform Die Insert, Lower, M-549

REVISIONS				
SYM	DESCRIPTION	BY	DATE	APPR
Ⓐ	ADDED NOTE 6.	[illegible]	[illegible]	[illegible]



NOTES:
1. MAT'L. AISI H-11
2. HARDEN TO Rc 44-48
3. STAMP MAT'L.-TOOL & DWG. NO
4. BREAK ALL SHARP EDGES.
5. MAX. CUT BACK 1 1/2
Ⓐ 6. FOR FABRICATION - 6 1/8 DIM. = 8 1/8 AND 8" DIM. = 10".

TOLERANCES UNLESS OTHERWISE SPECIFIED	
.XXX	±.005
.XX	±.010
.X	±.030
FRAC.	±1/32
ANGLE	±1°

Chamberlain
Chamberlain Manufacturing Corporation
Scranton Army Ammunition Plant

TITLE PREFORM TIP
DWN. LEGELKA   DATE 3/18/74   SCALE FULL
CKD.
APPD.
18030-11-02

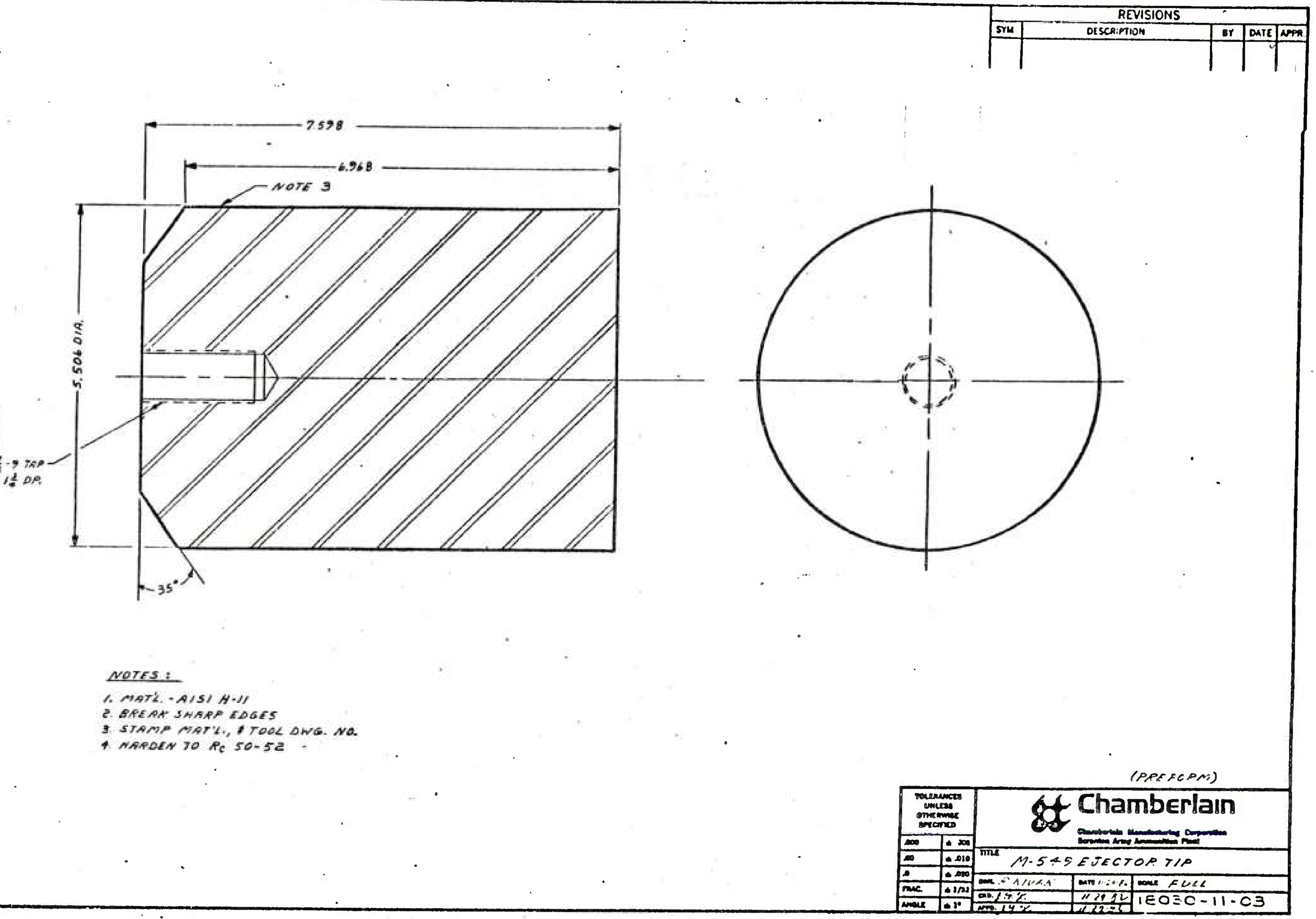


Figure A-3. Preform Ejector Tip - M-549

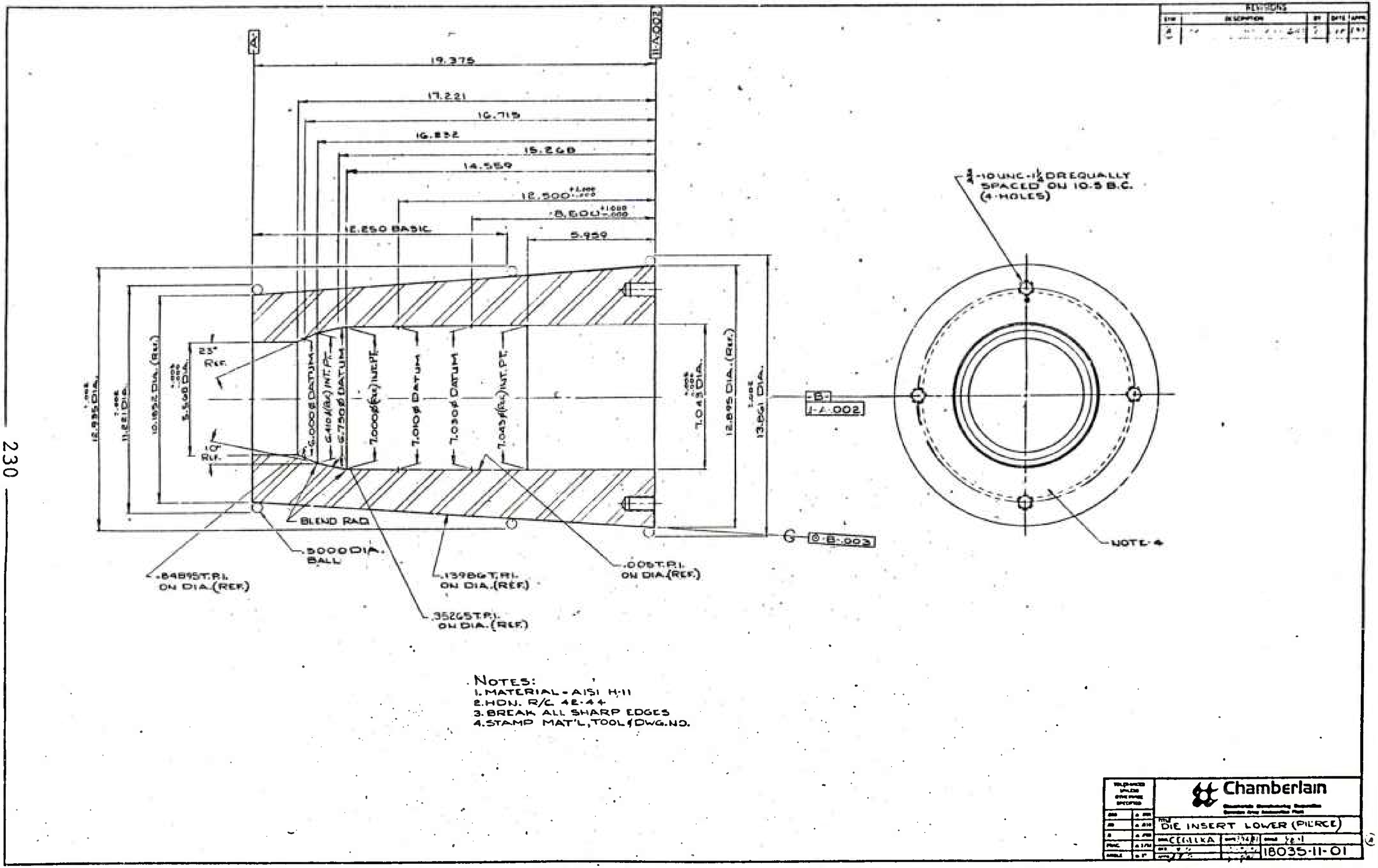


Figure A-4 Pierce Die Insert, Lower - M-549

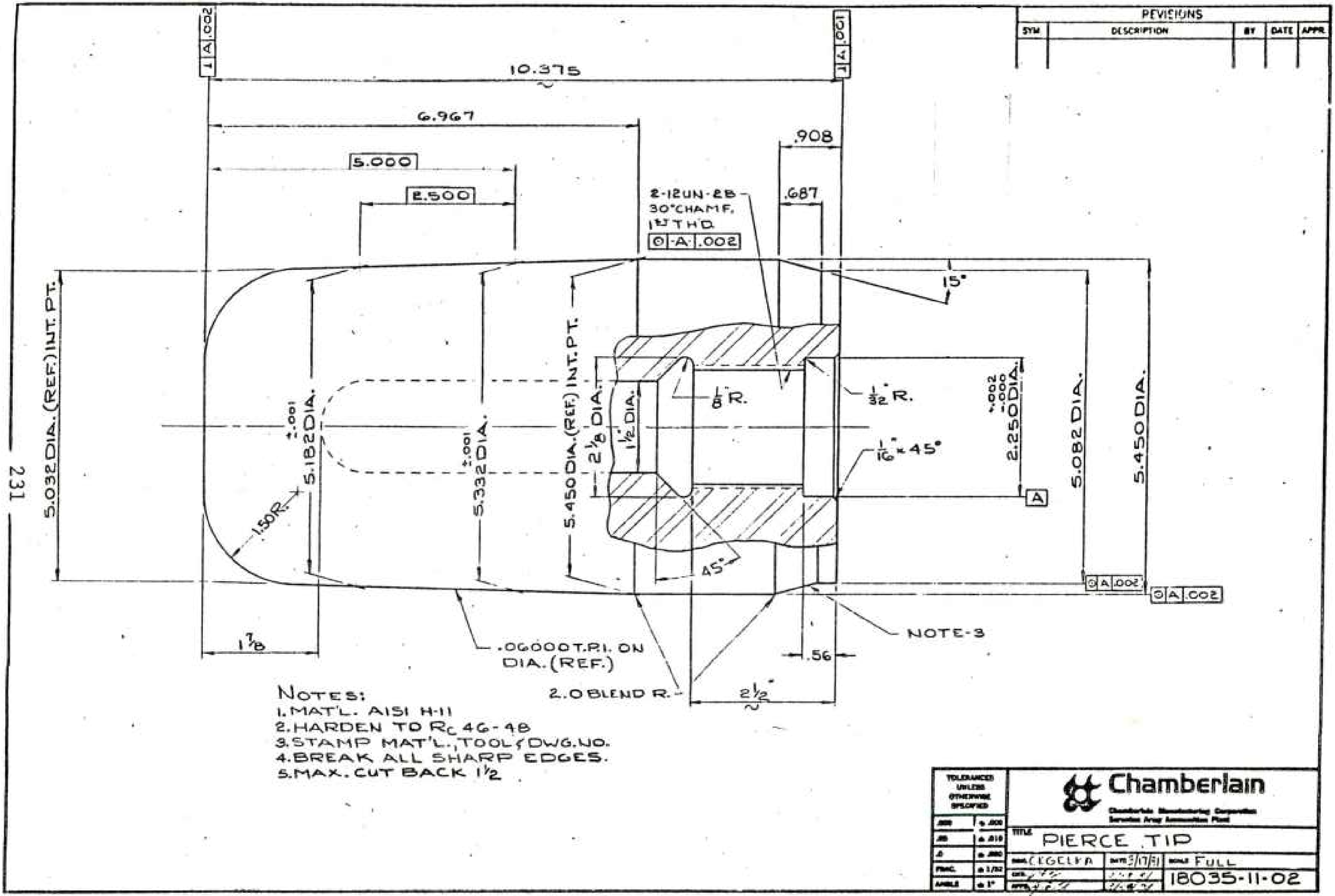


Figure A-5.Pierce Tip - M-549

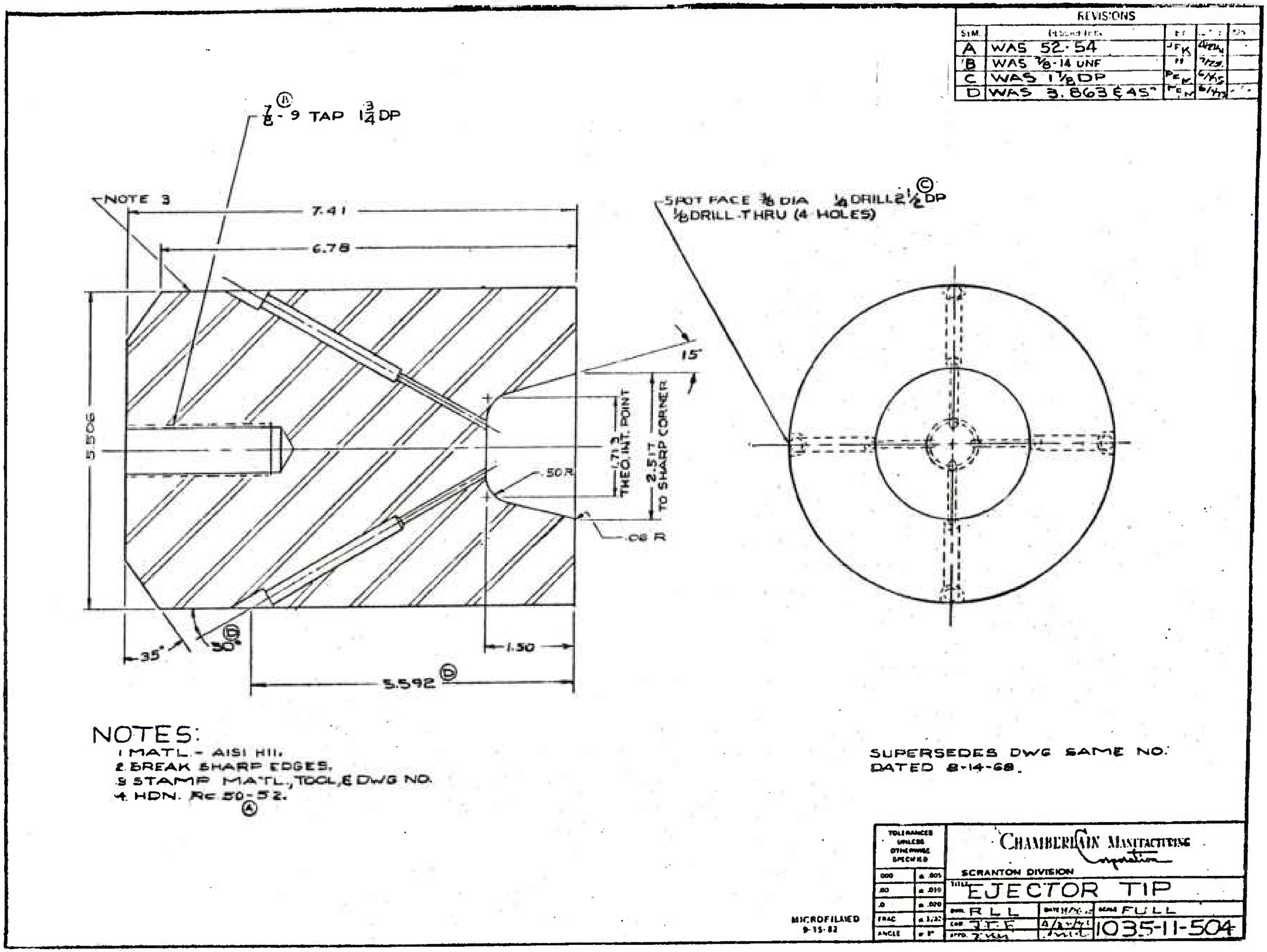


Figure A-6. Ejector tip utilized for M-549. (Initial design - see Fig. A-7 for revised drawing.)

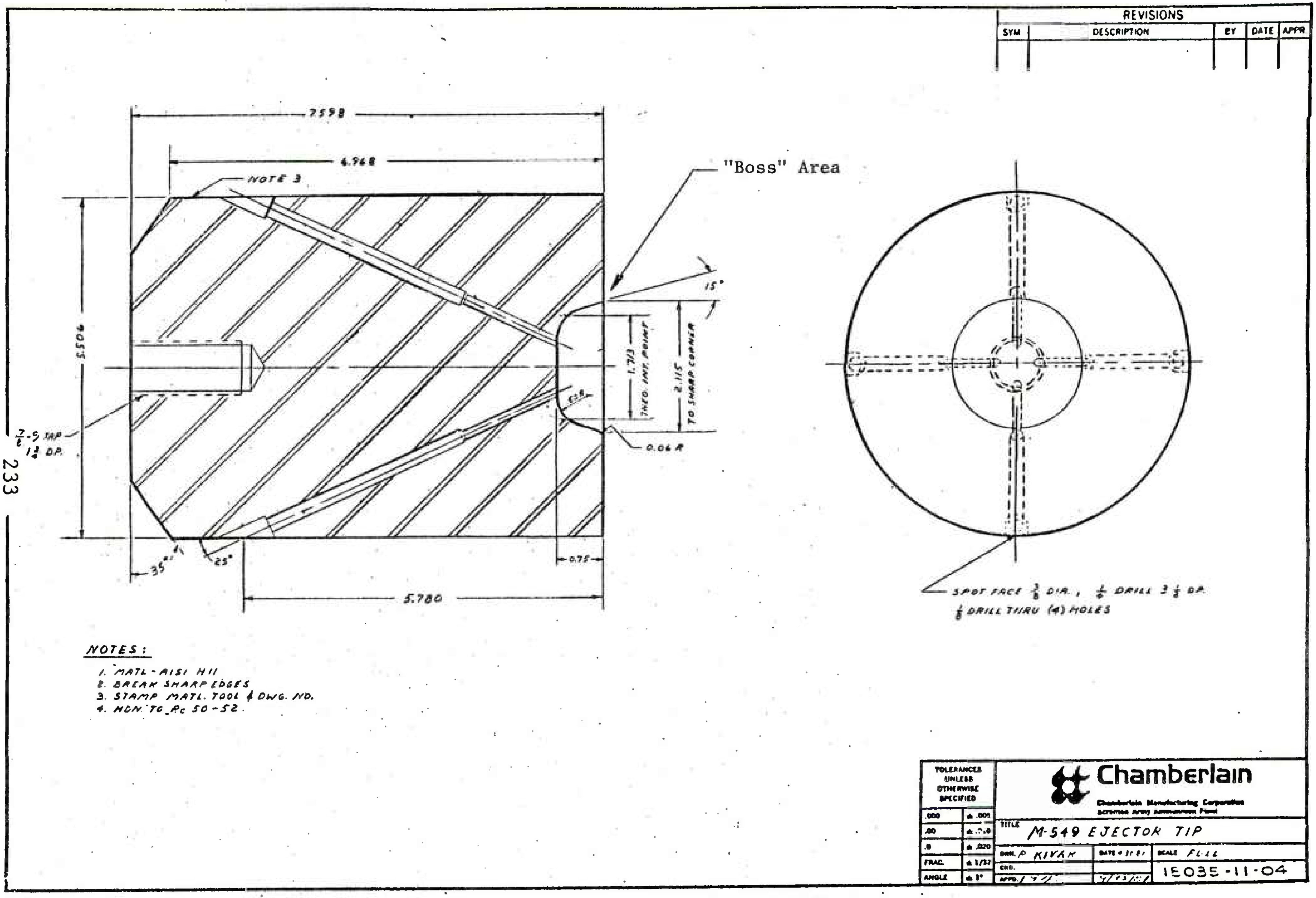


Figure A-7.Pierce Ejector.Tip - M-549, illustrating the reduction in "Boss" size.

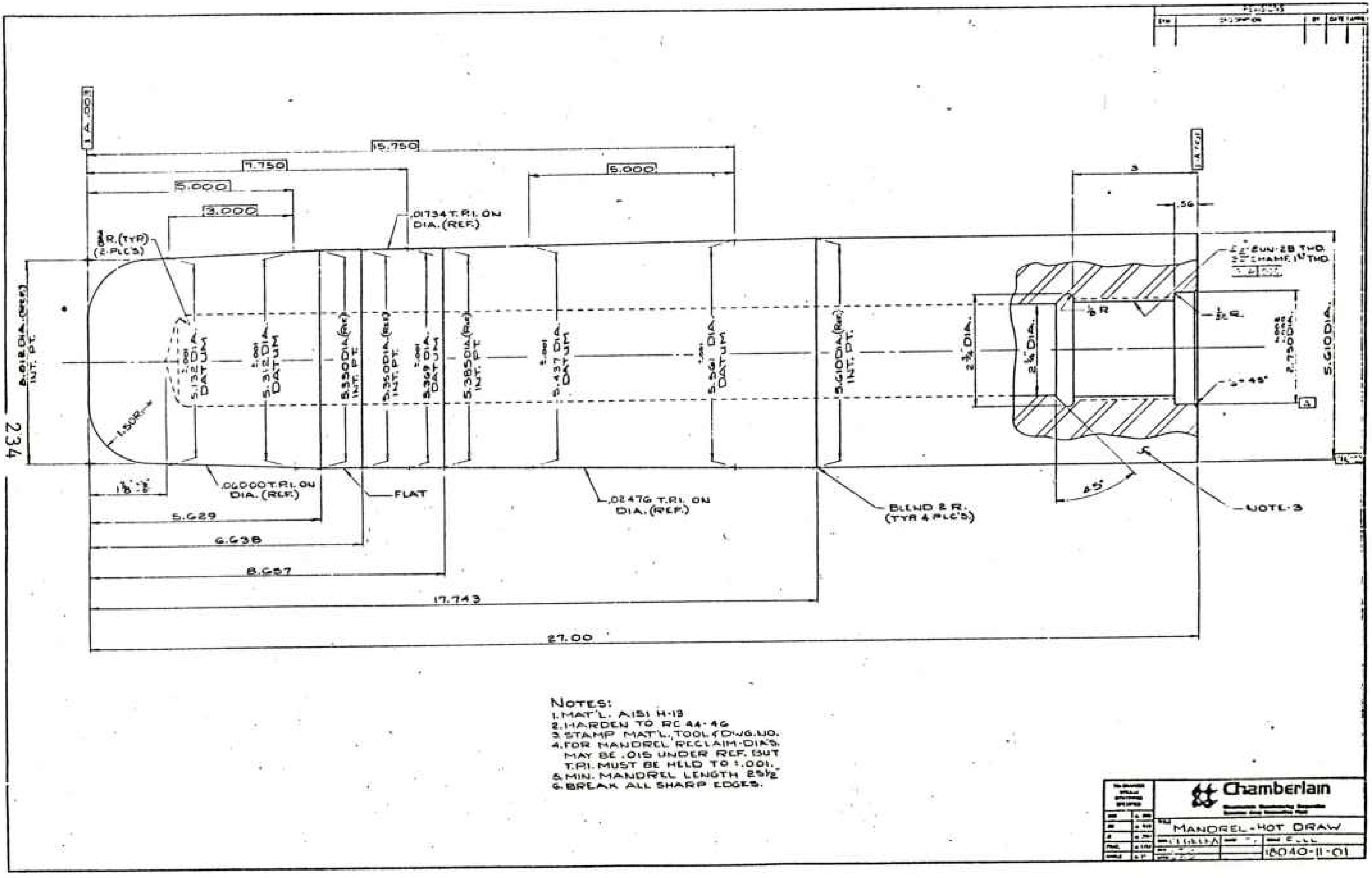
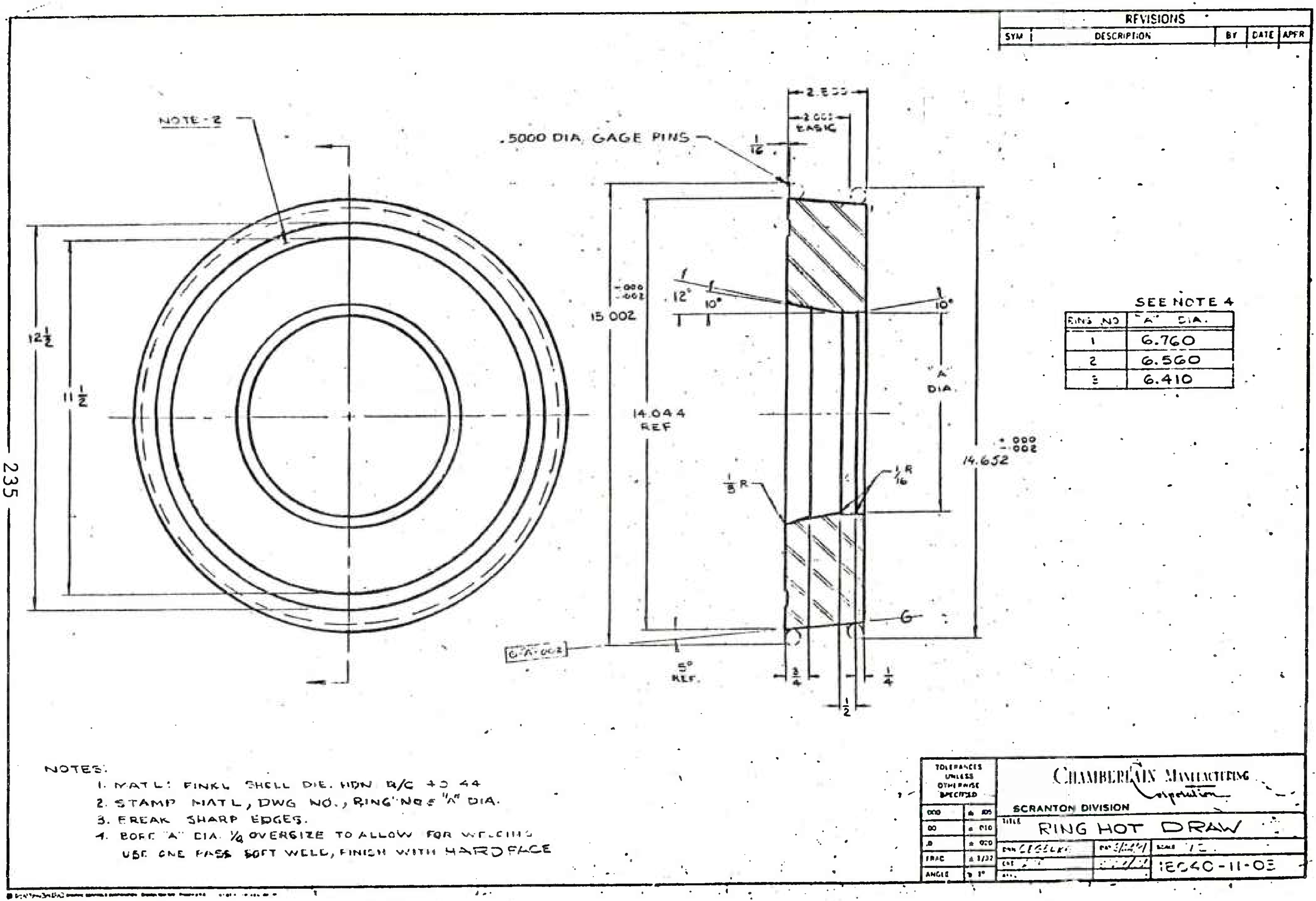


Figure A.8 Mandrel - Hot Draw - M 5/0



SEE NOTE 4

RING NO	"A" DIA.
1	6.760
2	6.560
3	6.410

NOTES:

1. MATL: FINKL SHELL DIE. HDN R/C 40 44
2. STAMP MATL, DWG NO., RING NO & "A" DIA.
3. BREAK SHARP EDGES.
4. BORE "A" DIA. 1/4 OVERSIZE TO ALLOW FOR WELDING USE ONE PASS SOFT WELD, FINISH WITH HARDFACE

Figure A-9. Rings, Hot Draw - M-549

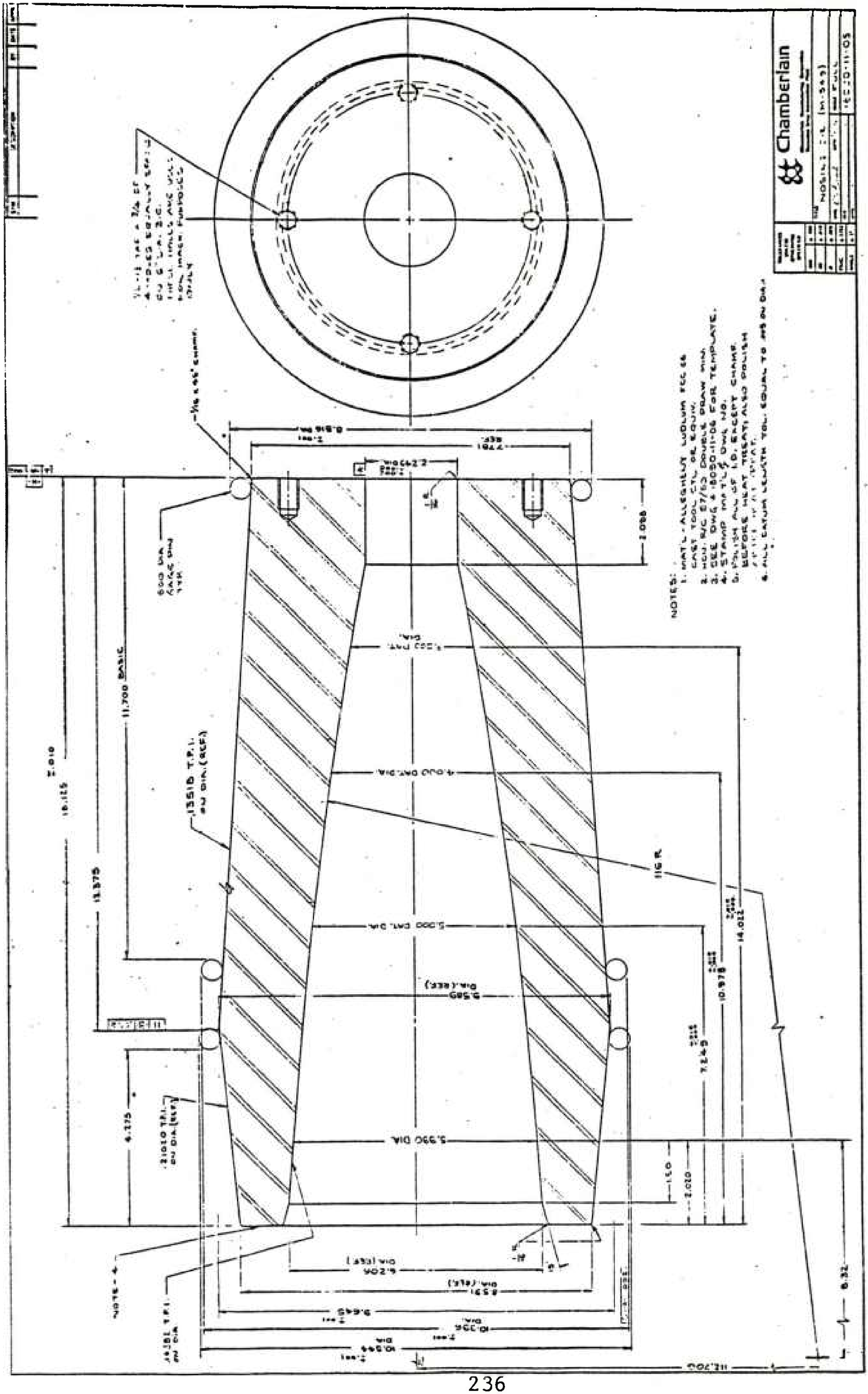


Figure A-10. Nosing Die - M-549

APPENDIX B

INSPECTION GAGES

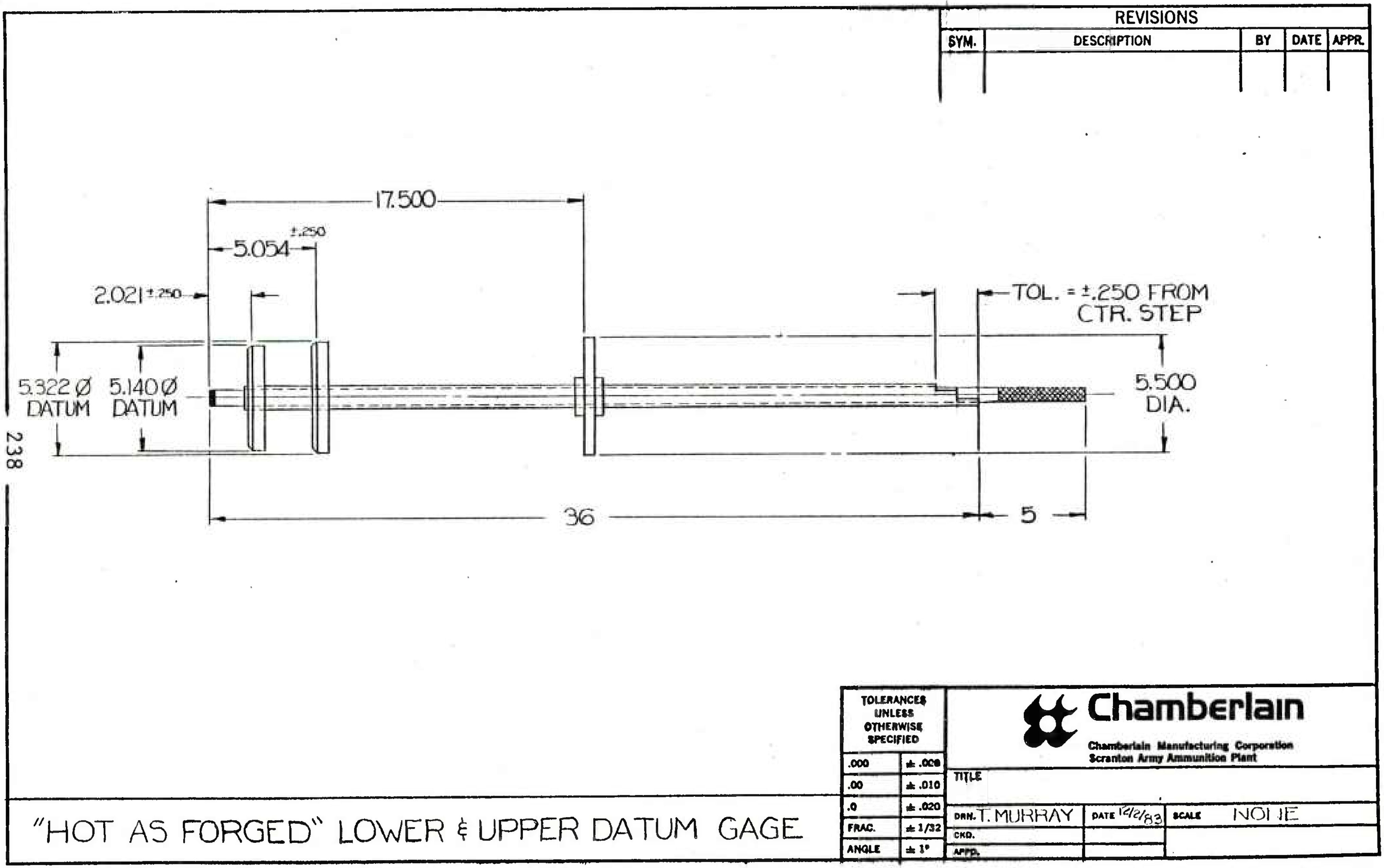


Figure B-1. Datum gage utilized for the inspection of the "hot" forgings.

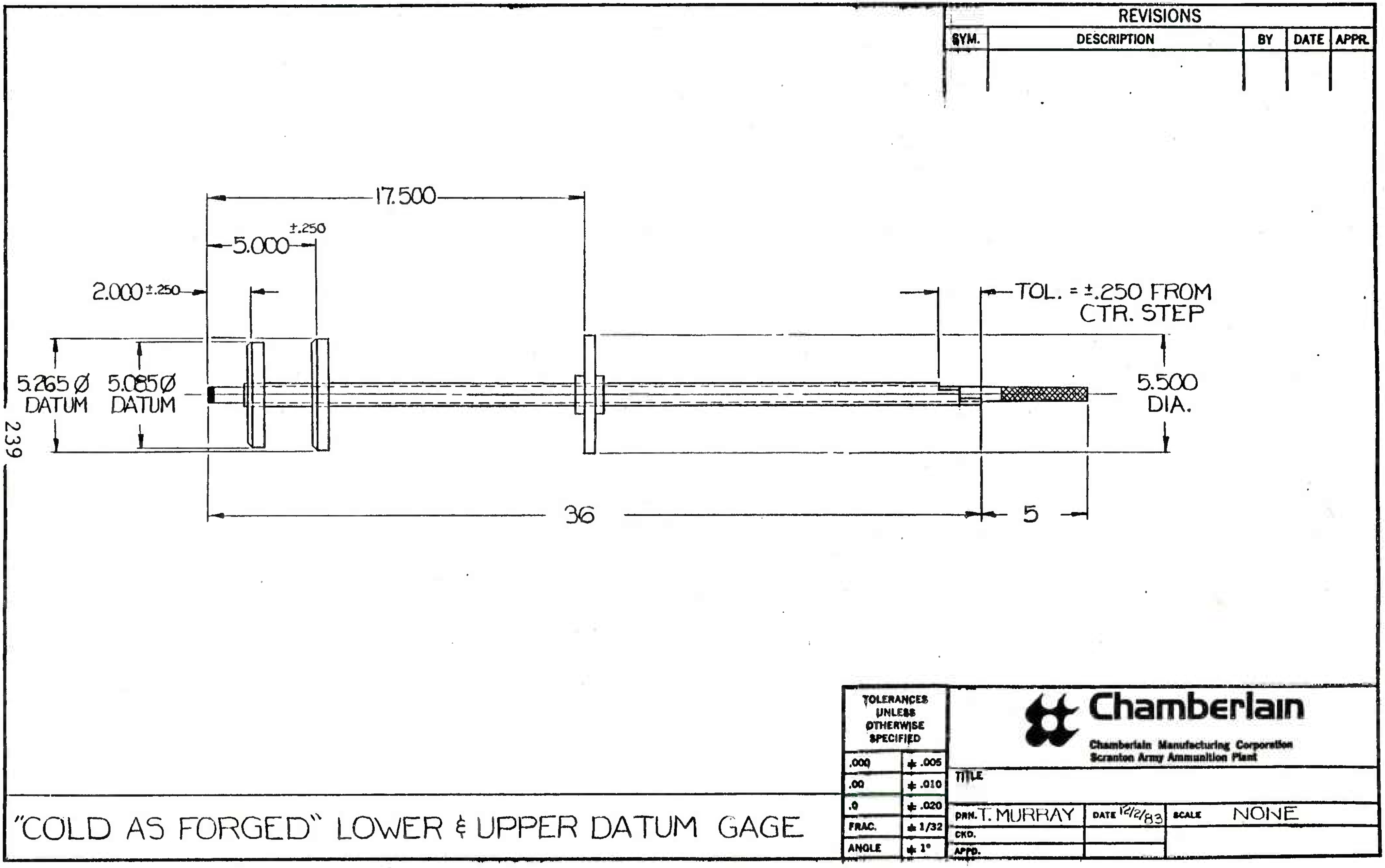


Figure B-2. Datum gage utilized for the inspection of the "cold" forgings.

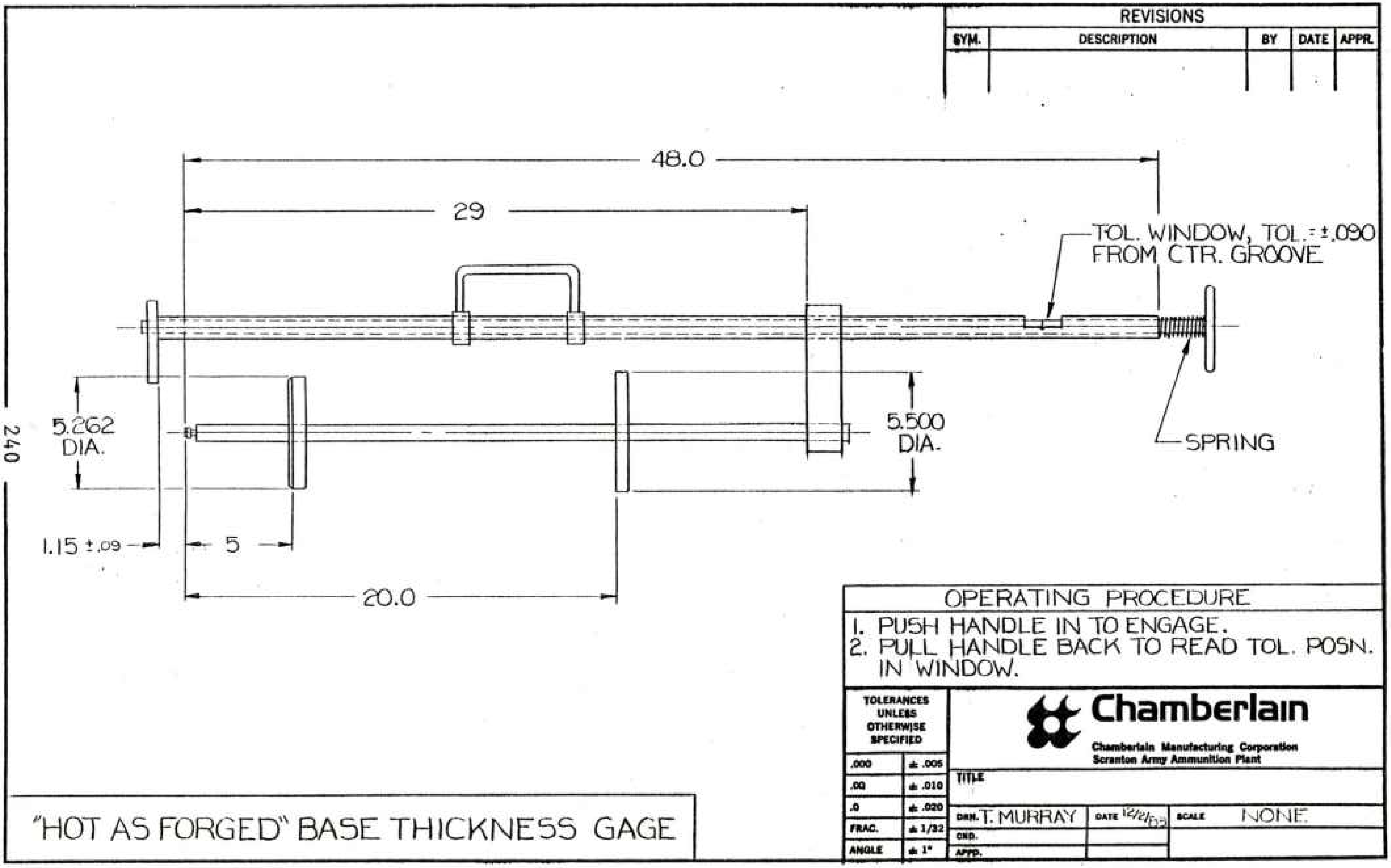


Figure B-3. Base thickness gage utilized for the inspection of the "hot" forgings.

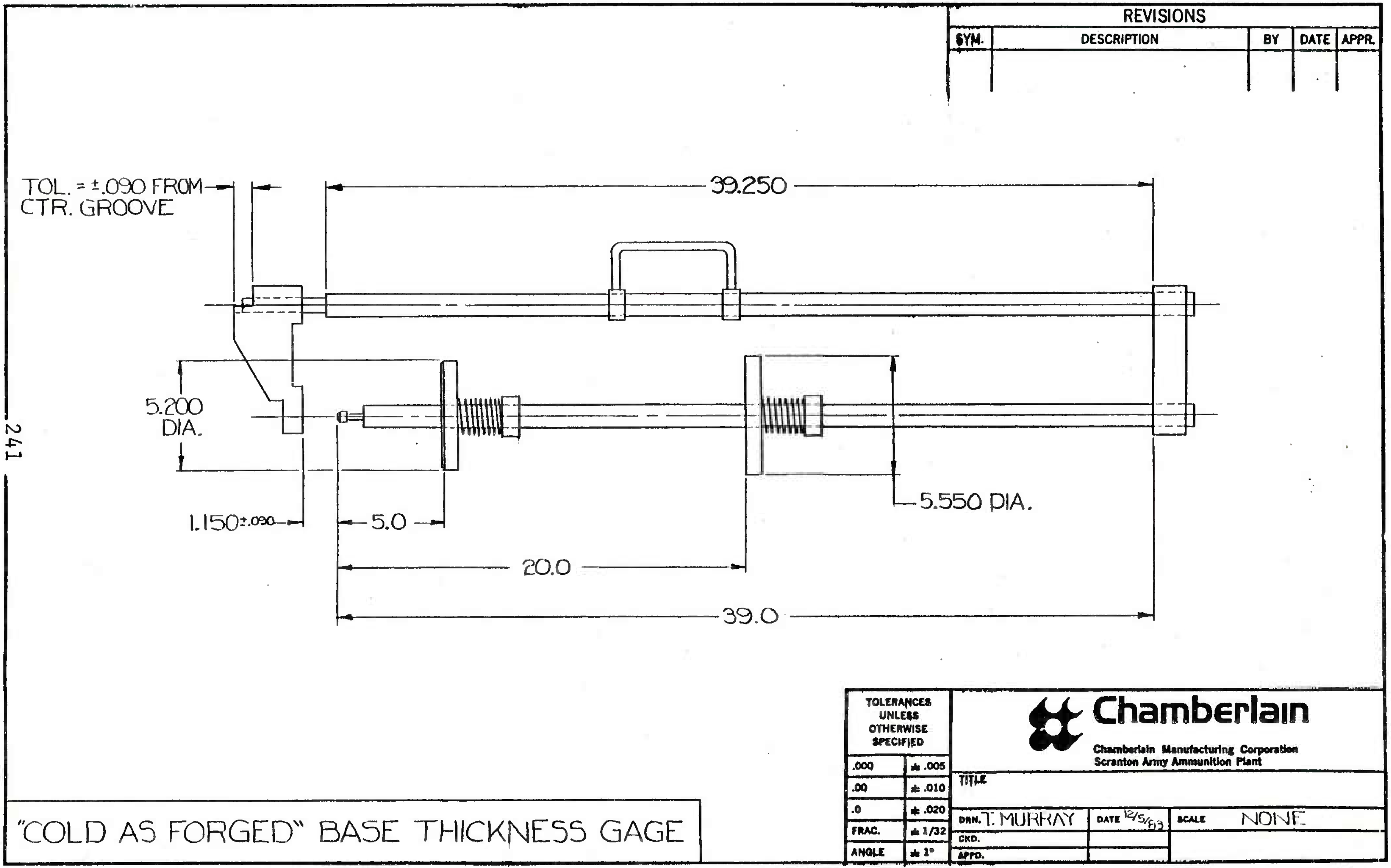


Figure B-4. Base thickness gage utilized for the inspection of the "cold" forgings.

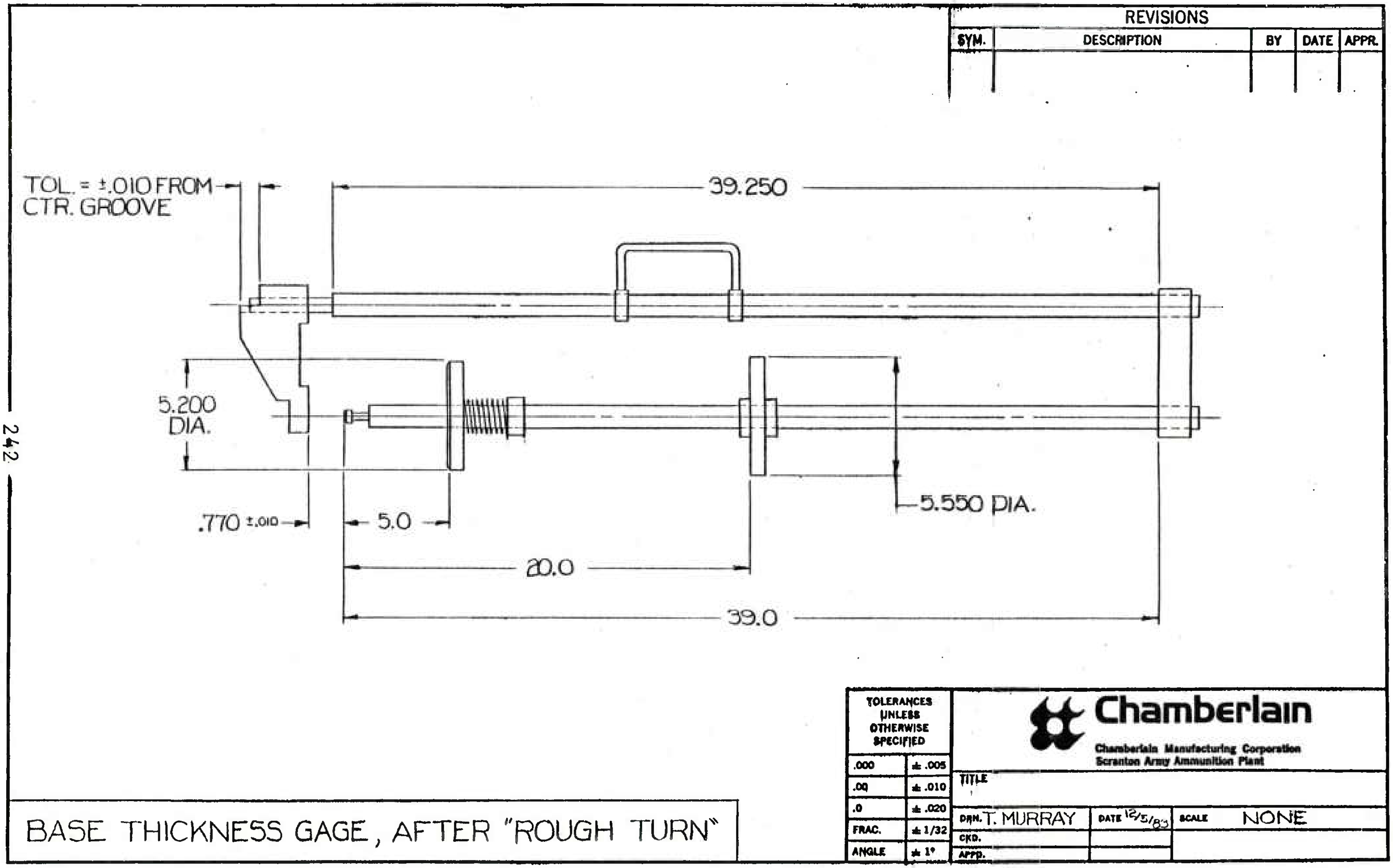


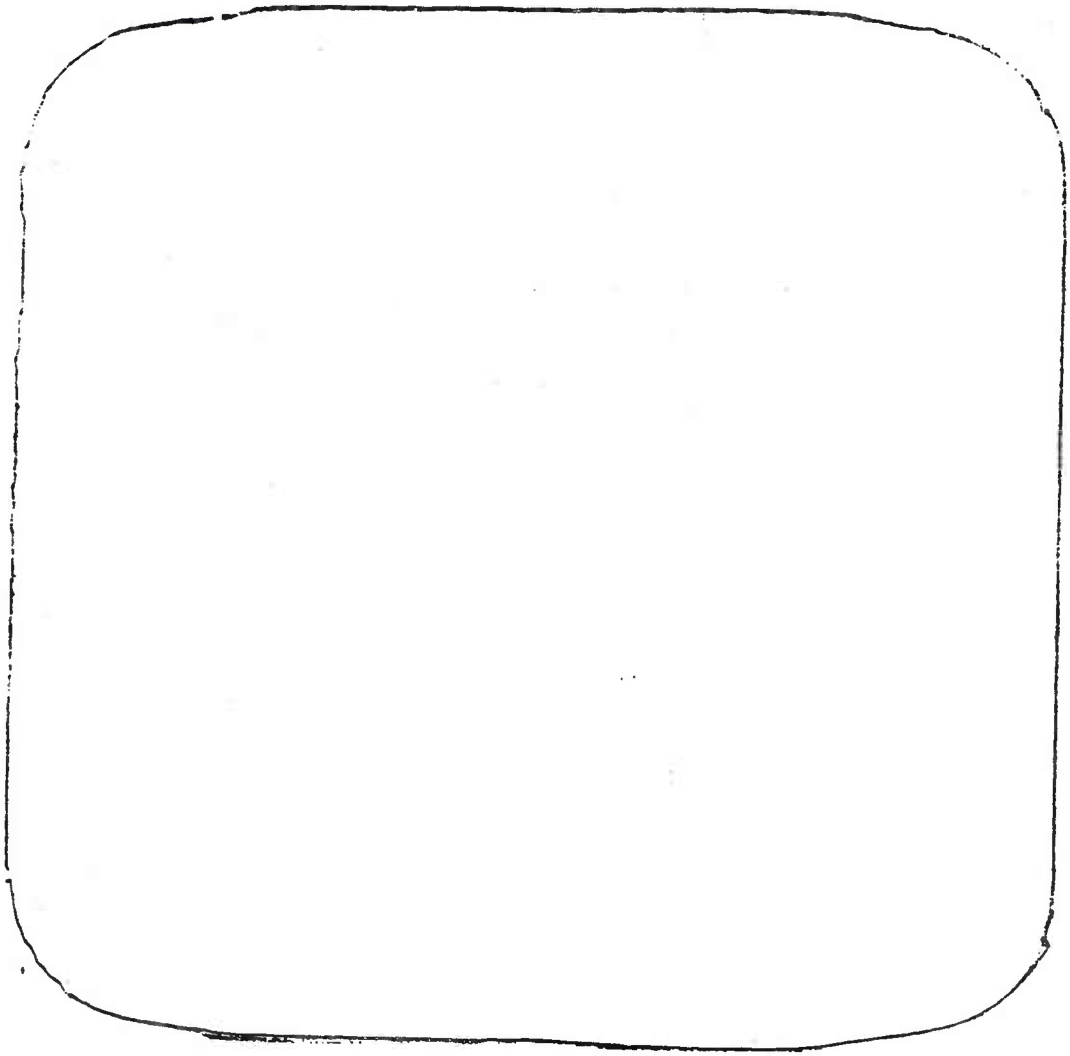
Figure B-5. Base thickness gage utilized for inspection after rough turn.

APPENDIX C

BILLET (MULT) PROFILES

Manufacturer:	Republic
Bar #:	25BC
Mult #	278
Heat #:	1

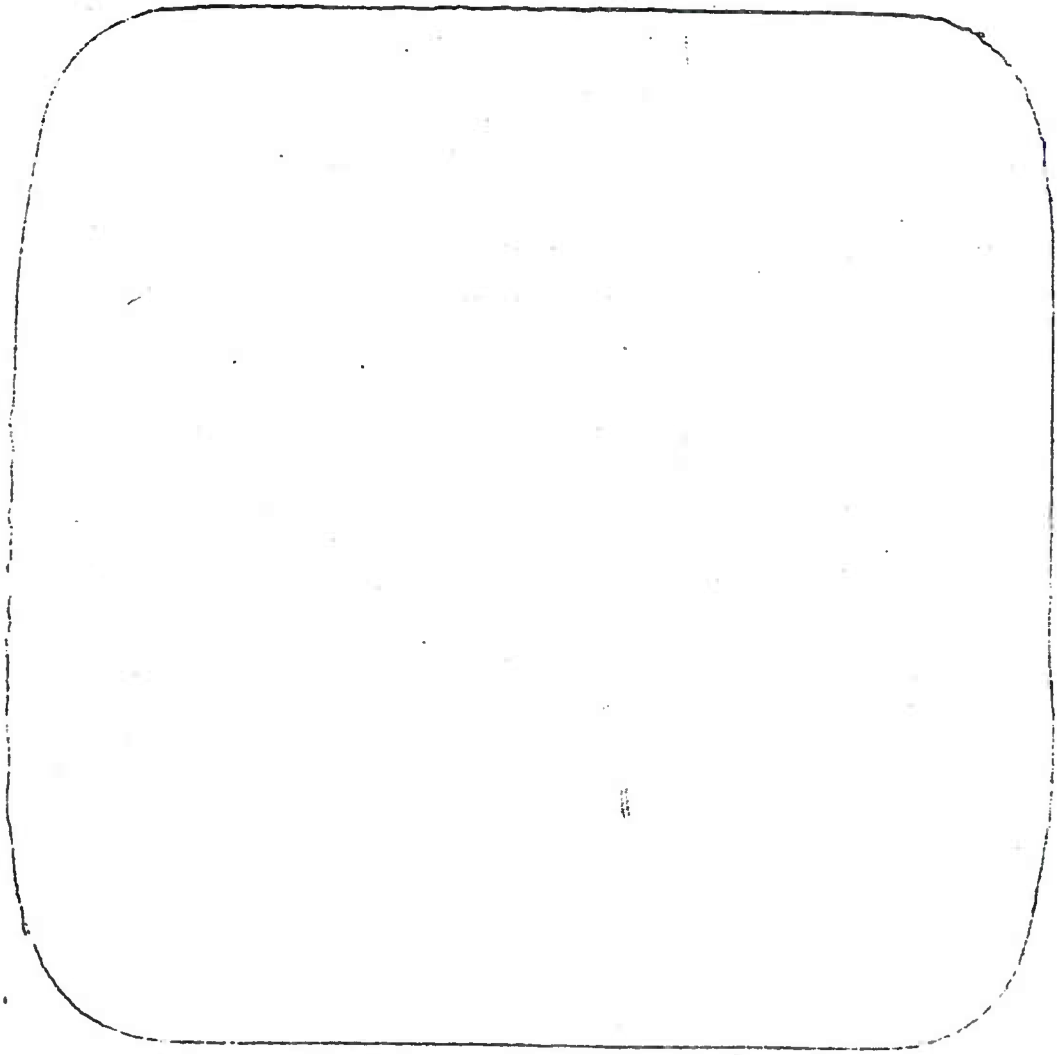
FRONT



BILLET PROFILE

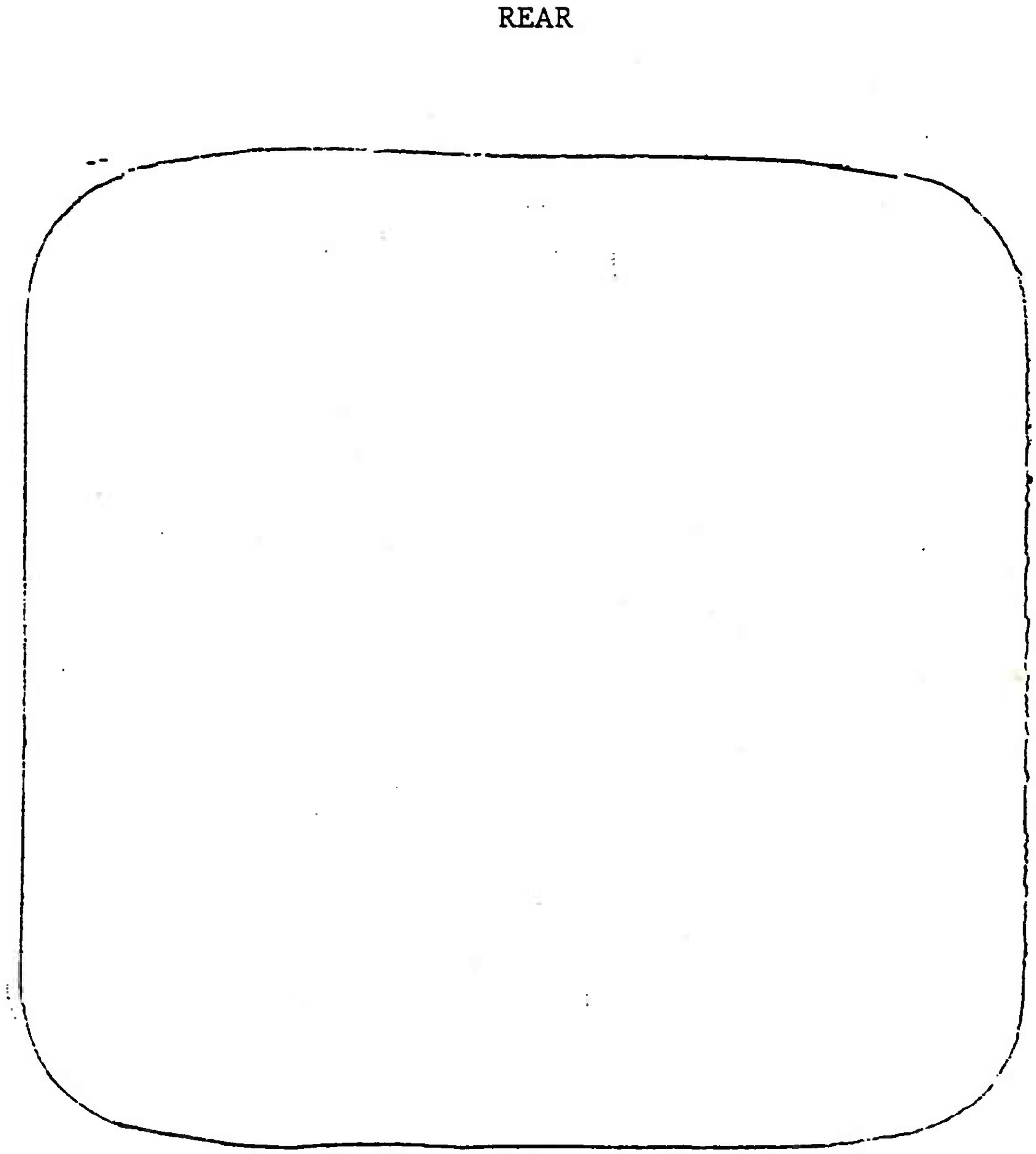
Manufacturer: Republic
Bar #: 20BA
Mult #: 269
Heat #: 1

FRONT



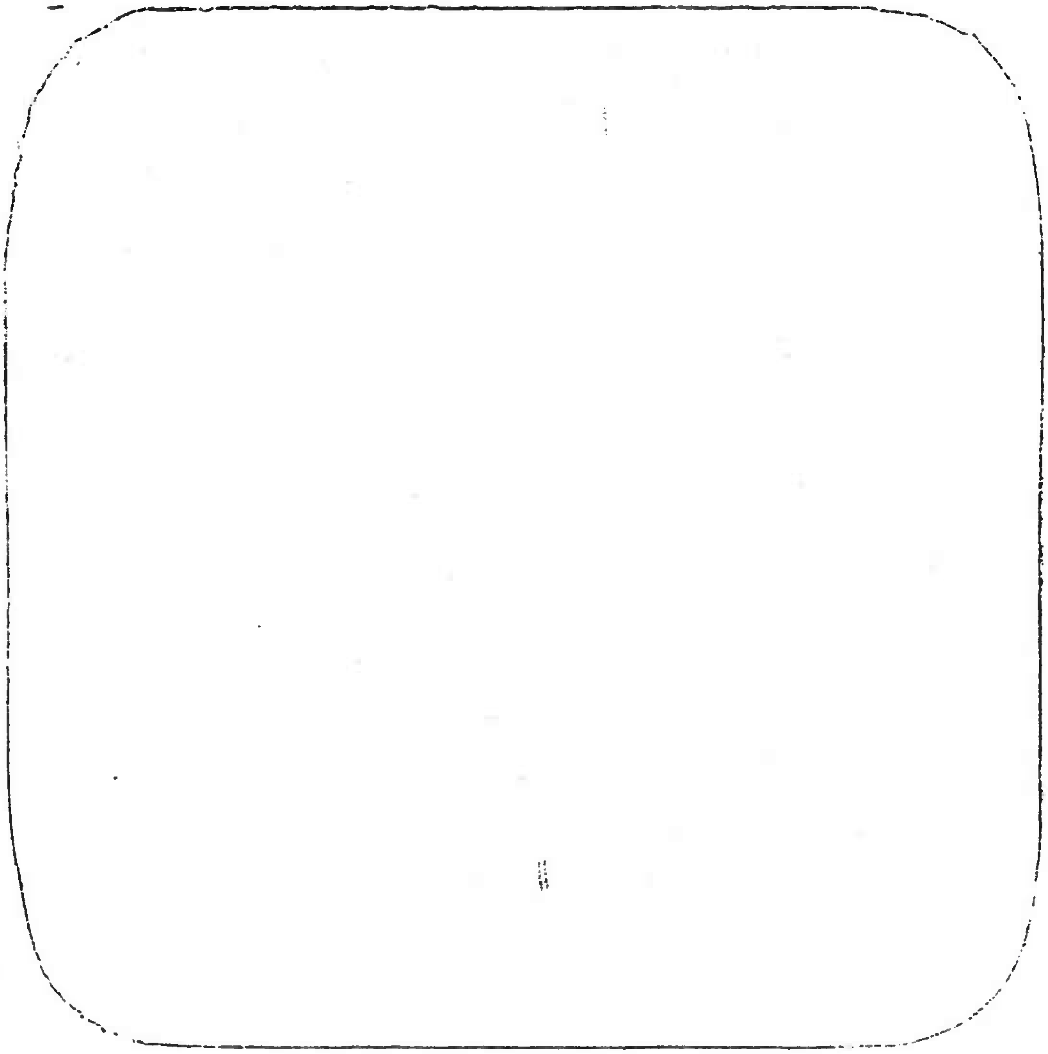
BILLET PROFILE

Manufacturer: Republic
Bar #: 20BA
Mult #: 264
Heat #: 1



BILLET PROFILE

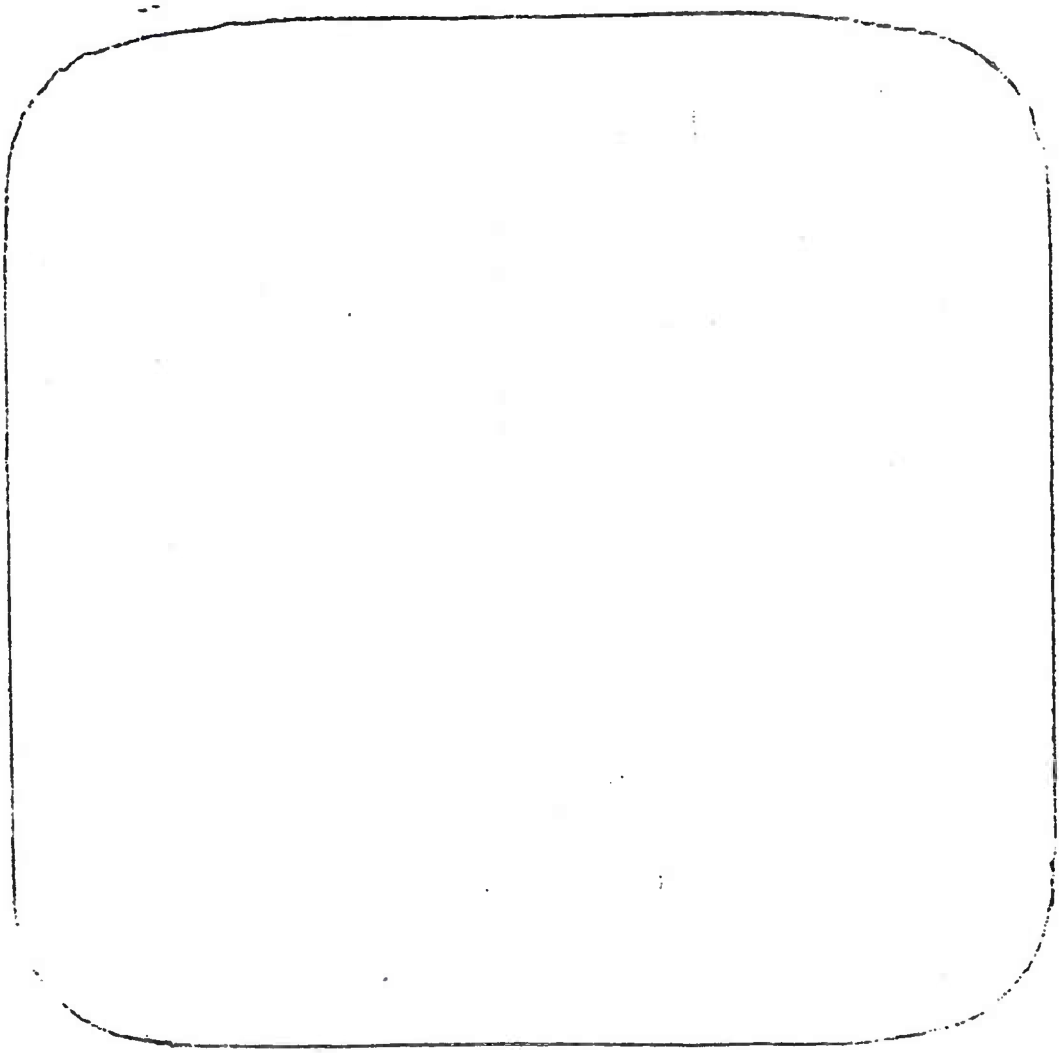
Manufacturer:	Republic
Bar #:	16AB
Mult #:	254
Heat #:	1



BILLET PROFILE

Manufacturer:	Republic
Bar #:	16AB
Mult #:	240
Heat #:	1

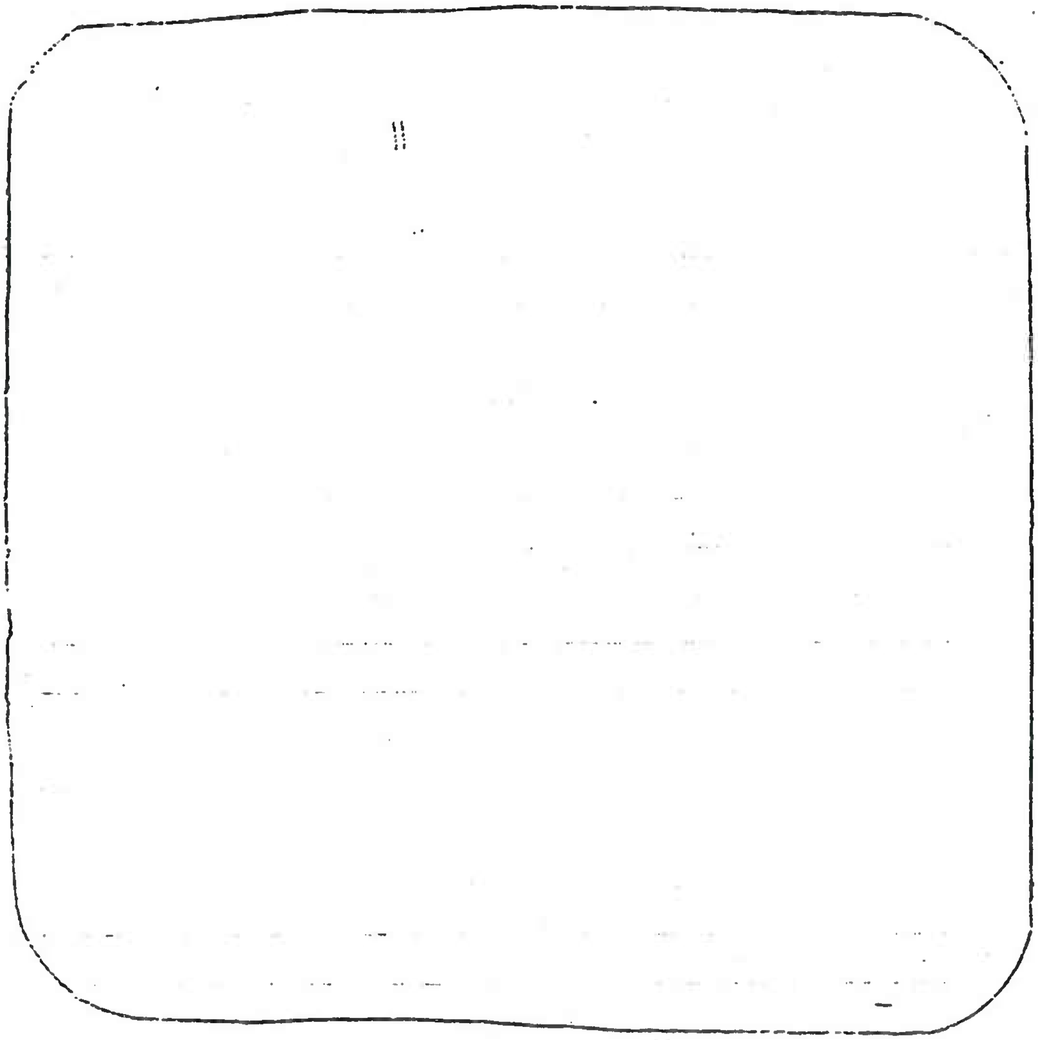
REAR



BILLET PROFILE

Manufacturer: Bethlehem
Bar #: 10-I
Mult #: 304
Heat #: 2-A

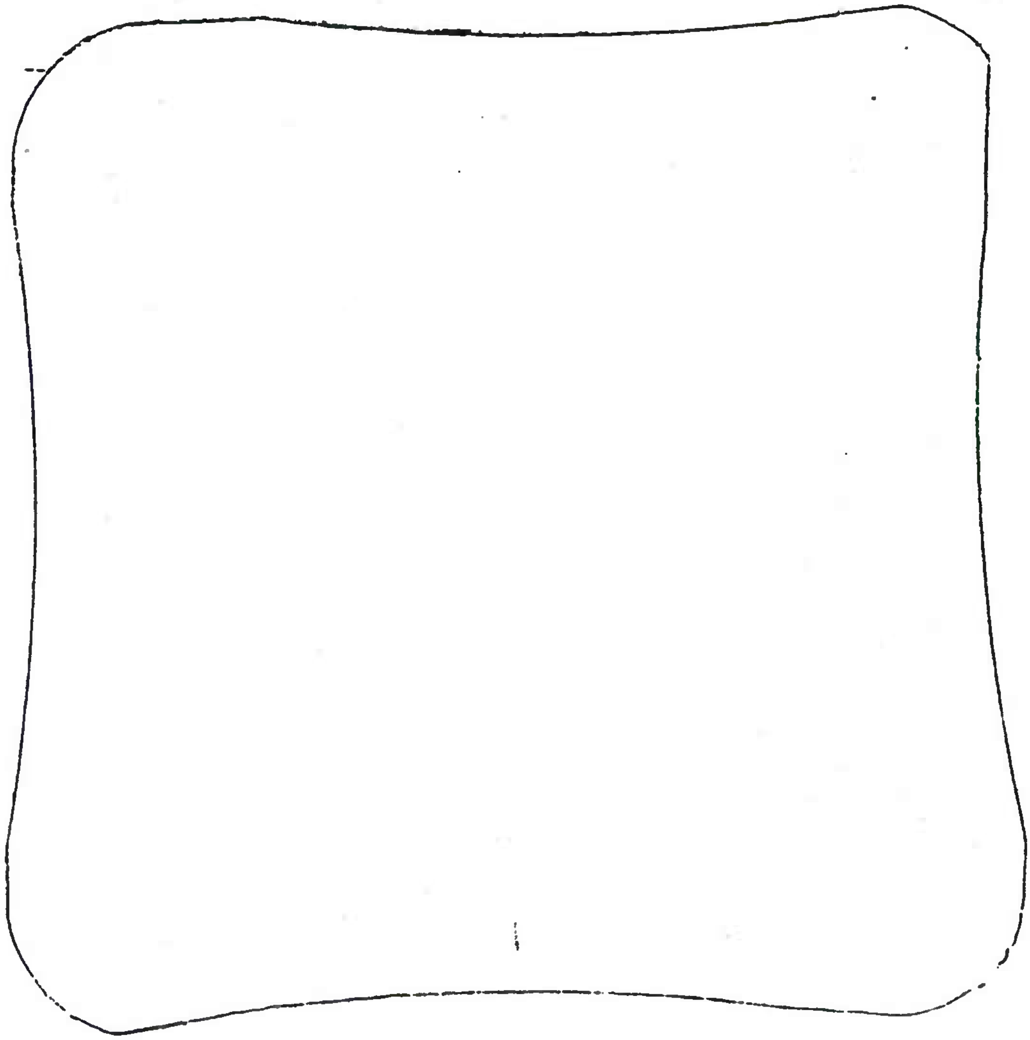
FRONT



BILLET PROFILE

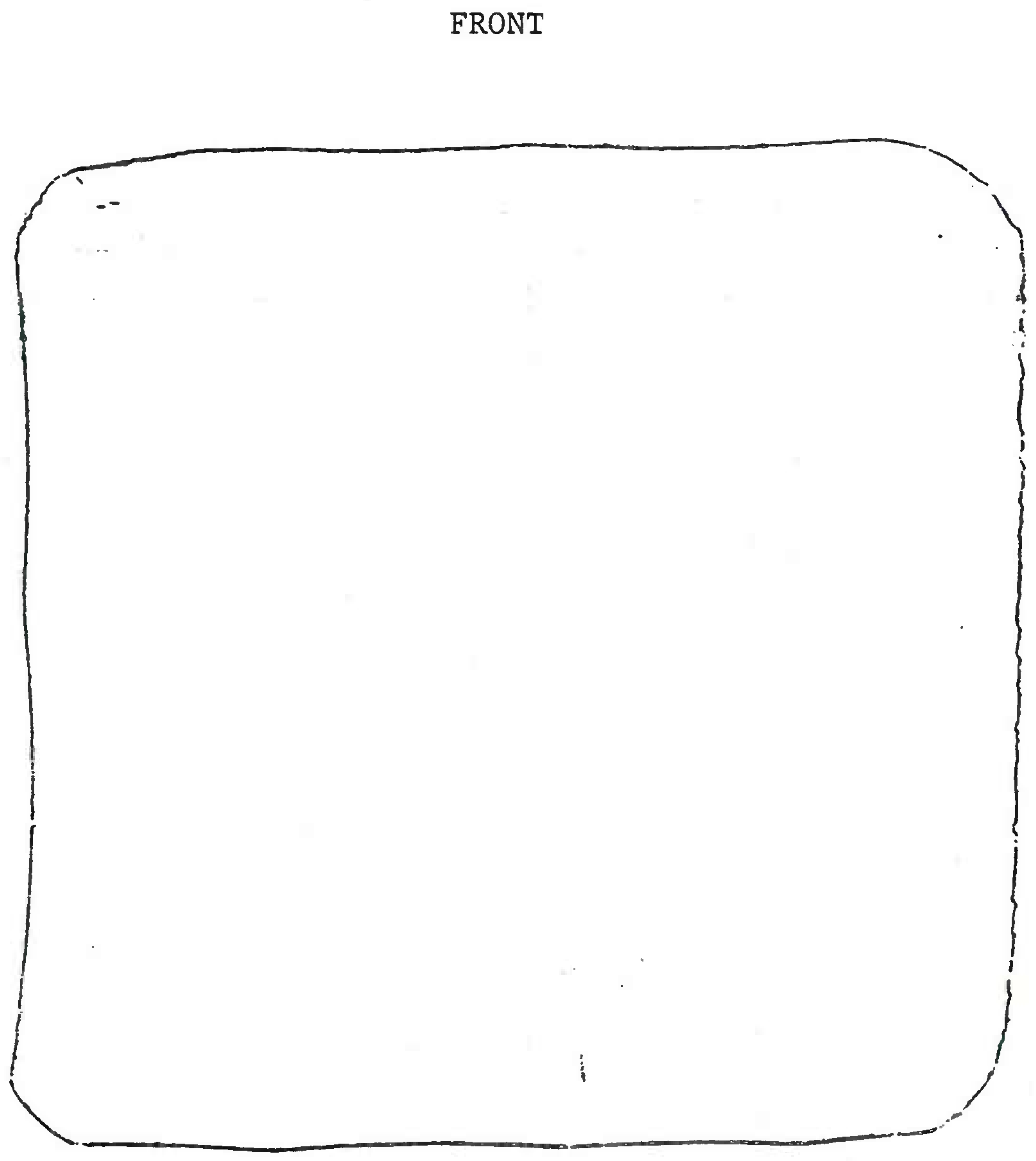
Manufacturer: Bethlehem
Bar #: 10-I
Mult #: 317
Heat #: 2-A

REAR



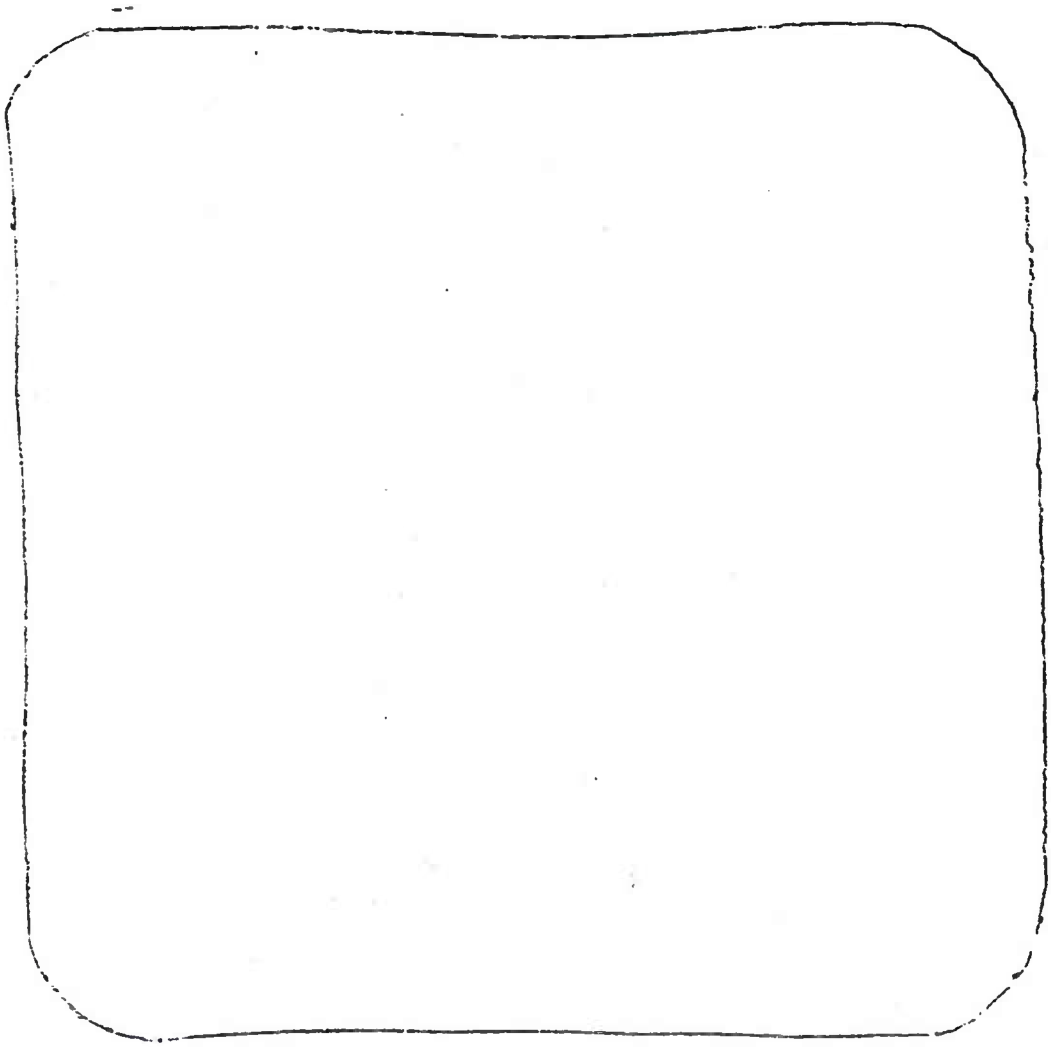
BILLET PROFILE

Manufacturer: Bethlehem
Bar #: H-1
Mult #: 414
Heat #: 2-A



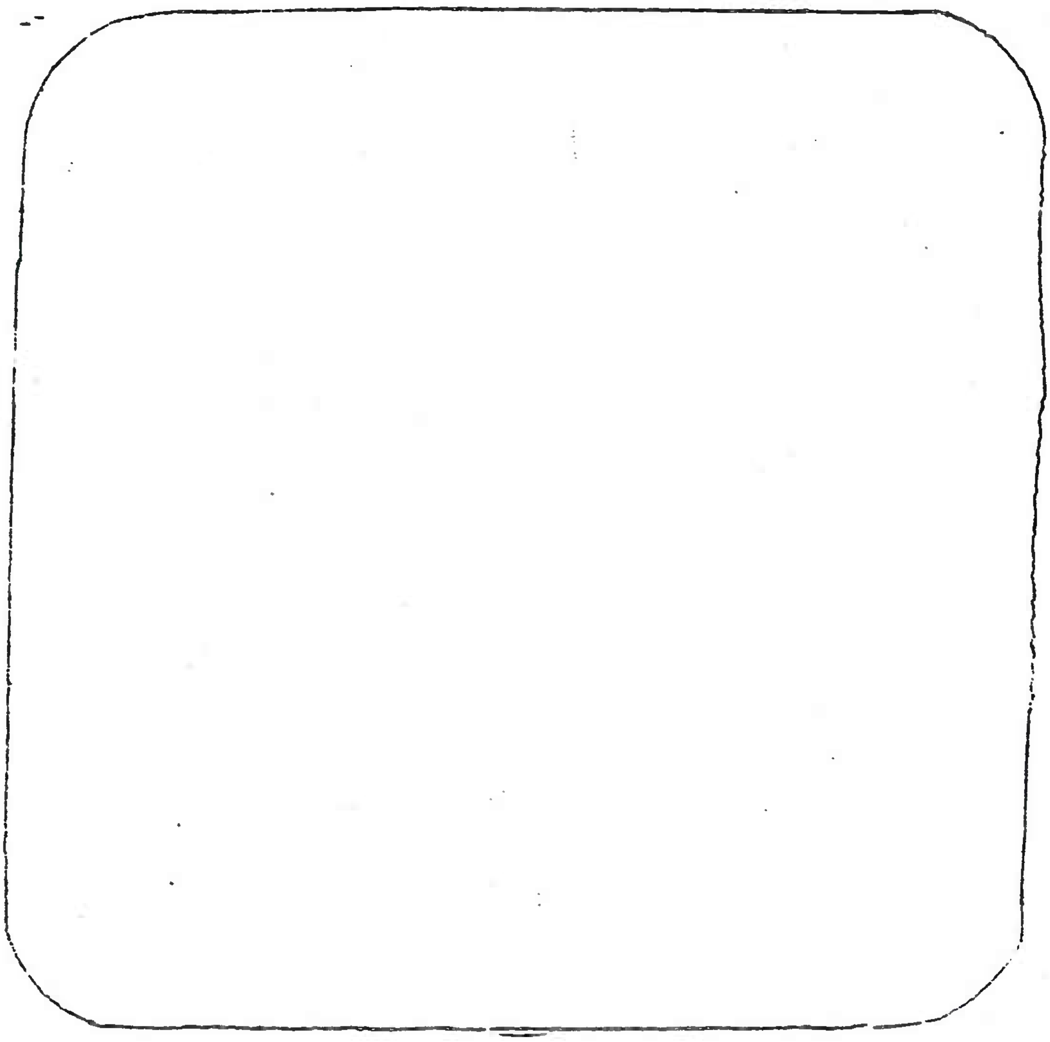
BILLET PROFILE

Manufacturer: Bethlehem
Bar #: 10-C
Mult #: 322
Heat #: 2A



BILLET PROFILE

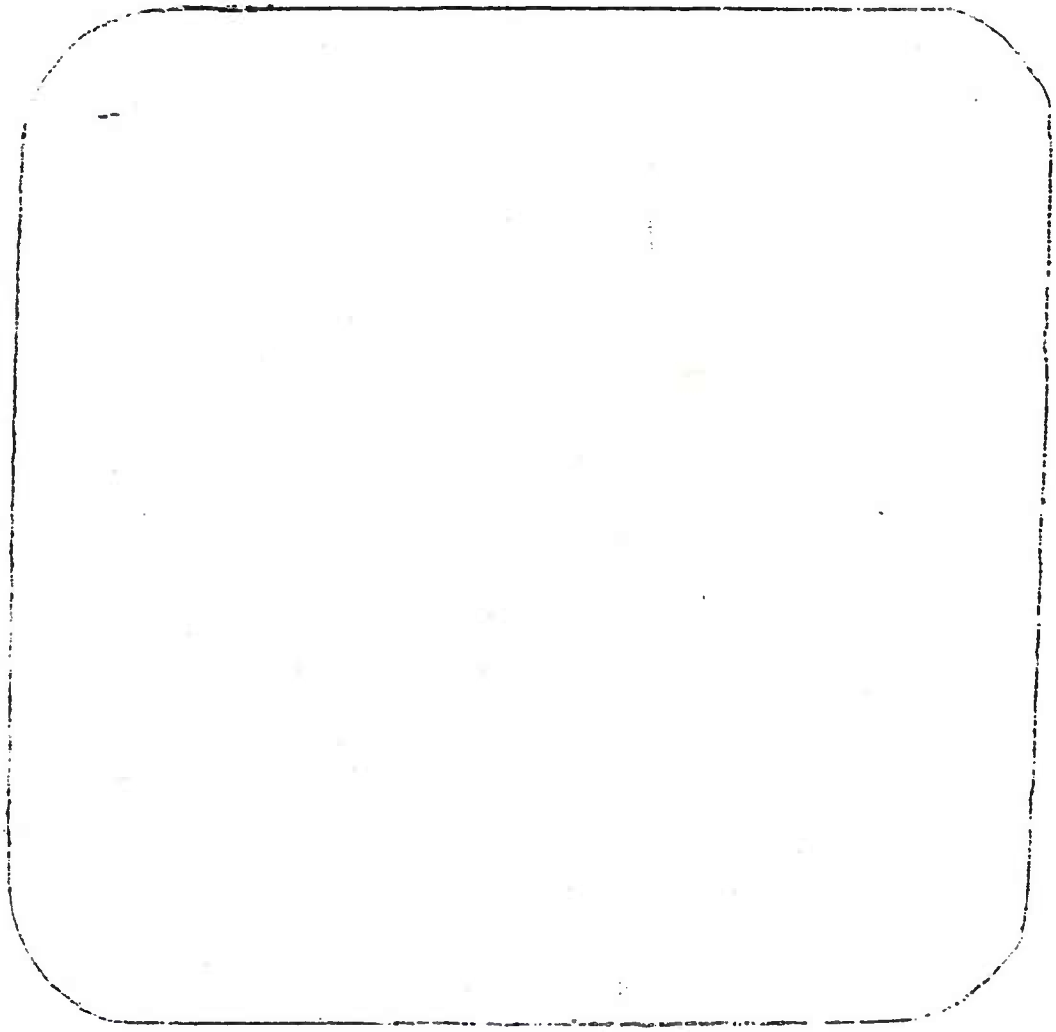
Manufacturer: Bethlehem
Bar #: 10-C
Mult #: 337
Heat #: 2-A



BILLET PROFILE

Manufacturer: Bethlehem
Bar #: 11C
Mult #: 382
Heat #: 2-B

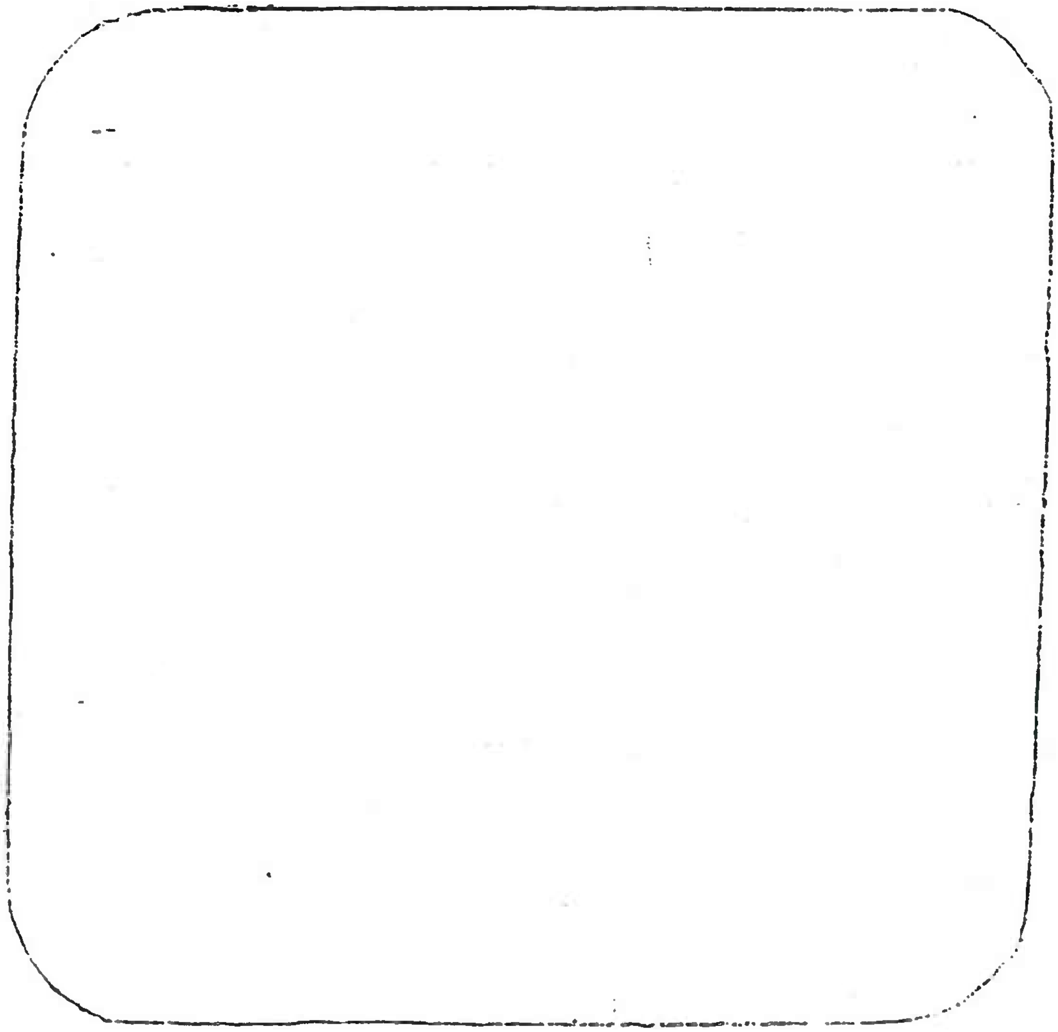
REAR



BILLET PROFILE

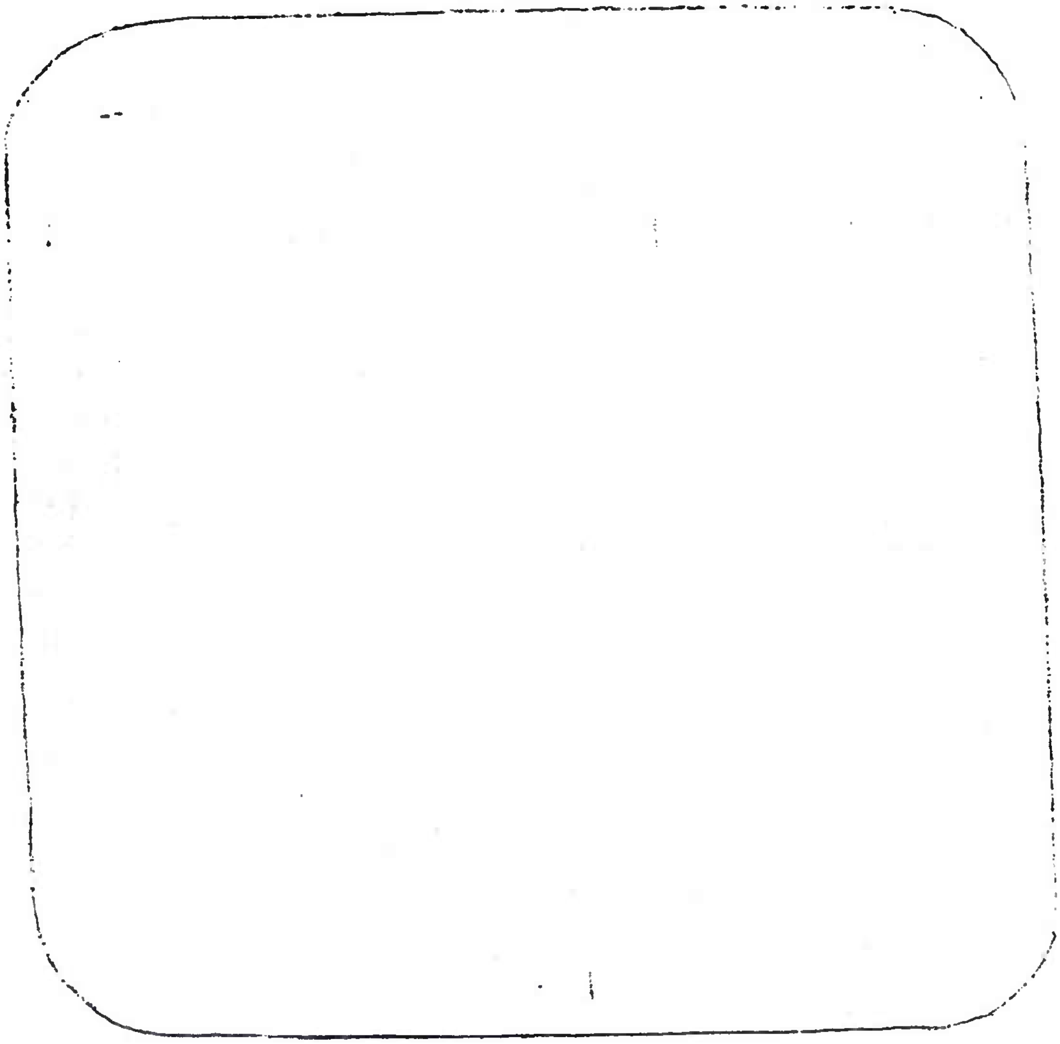
Manufacturer:	Bethlehem
Bar #:	11C
Mult #:	389
Heat #:	2-B

REAR



BILLET PROFILE

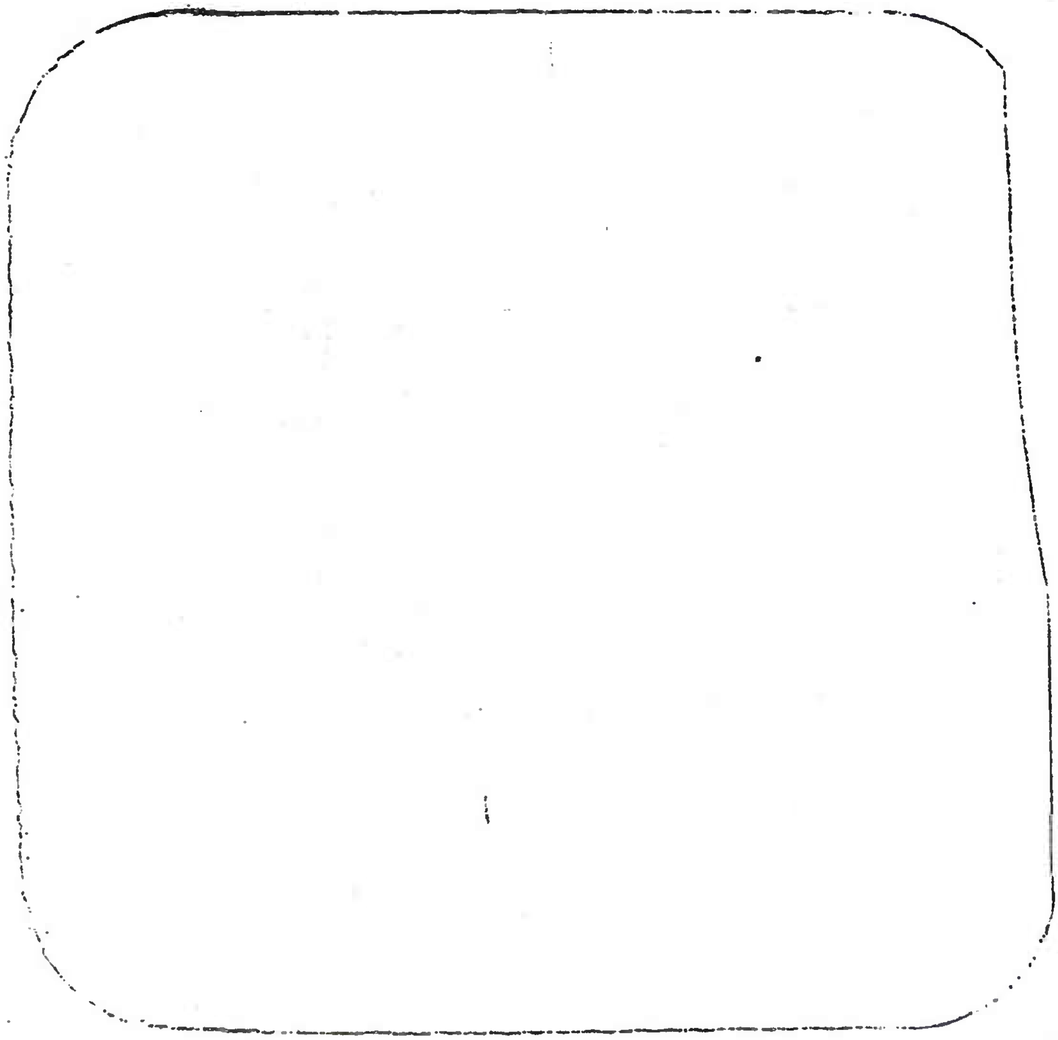
Manufacturer: Bethlehem
Bar #: 2-B
Mult #: 350
Heat #: 2-B



BILLET PROFILE

Manufacturer:	Bethlehem
Bar #:	2-I
Mult #:	378
Heat #:	2-B

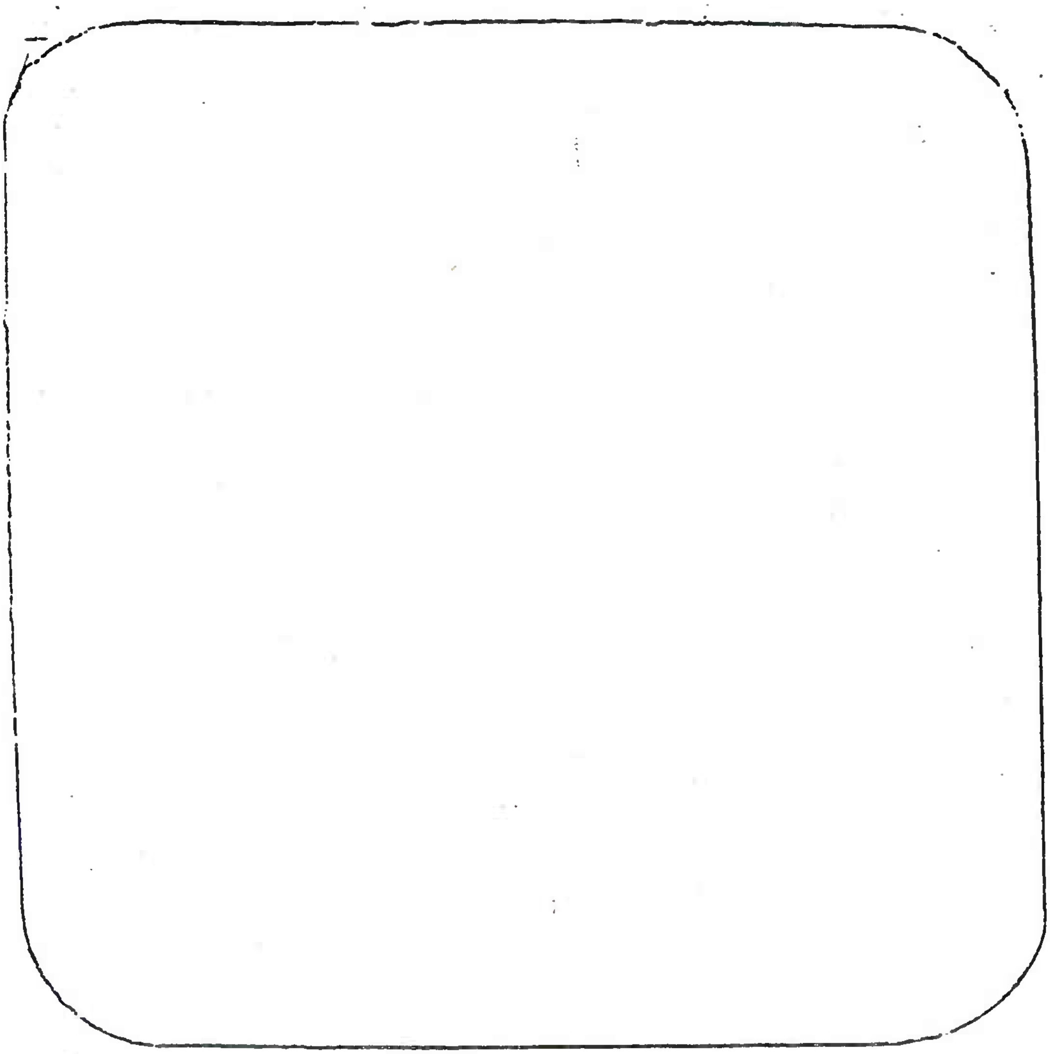
REAR



BILLET PROFILE

Manufacturer: Bethlehem
Bar #: 2-B
Mult #: 340
Heat #: 2-B

FRONT



BILLET PROFILE

APPENDIX D

NICK & BREAK PHOTOMICROGRAPHS

Nick and Break
M-549
Republic Steel

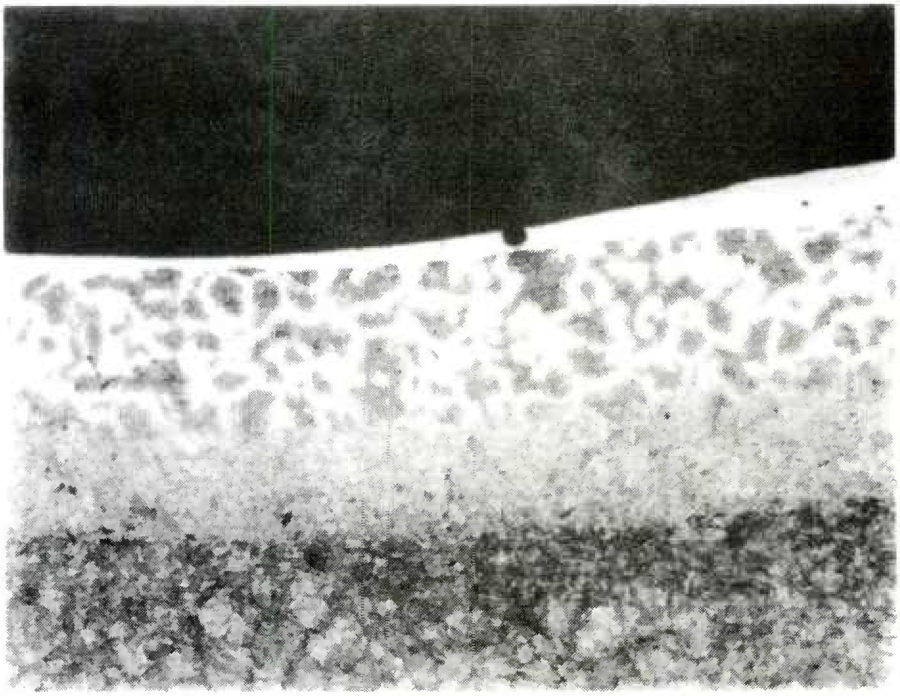


Figure D-1. Photomicrograph of bar 21 BC showing the various structure zones. It has a blow hole from the nicking rod. 63X Nital Etchant.

Nick and Break
M-549
Republic Steel

Figure D-2. Photomicrograph of Republic Steel billet 15 BB. It illustrates basically two zones; the coarse untempered martensite, retained austenite and fine untempered martensite. 63X Nital Etch

Nick and Break
M-549
Republic Steel

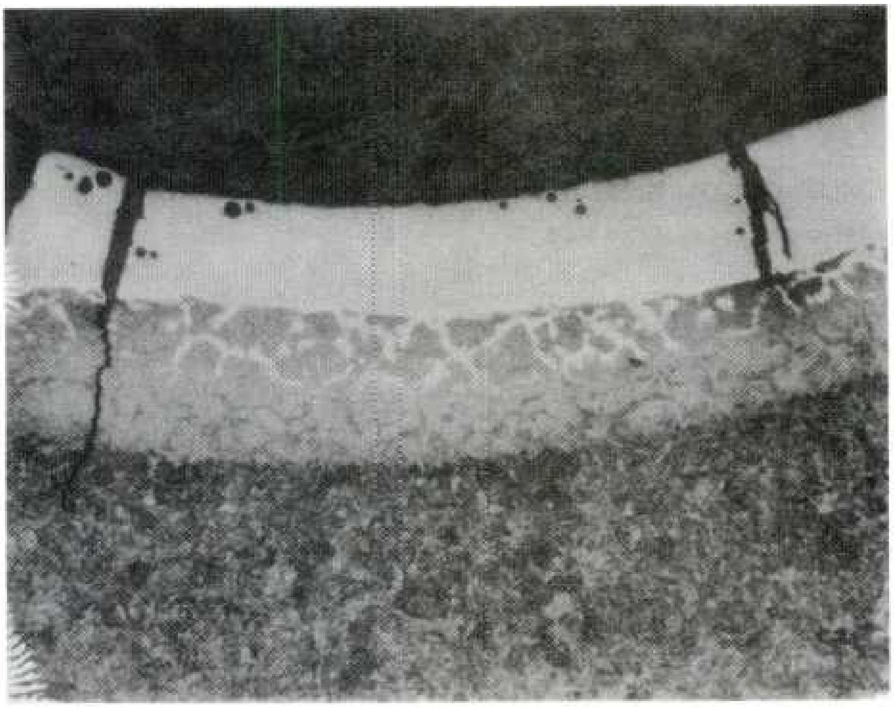


Figure D-3. Photomicrograph of bar 21 BC showing the various structure zones. This figure shows severe cracks not only in the retained austenite but in one area propagates through all zones into the main structure. It also shows various blow holes.

63X Nital Etchant

Nick and Break
M-549
Bethlehem Steel
Bung Furnace Cooled

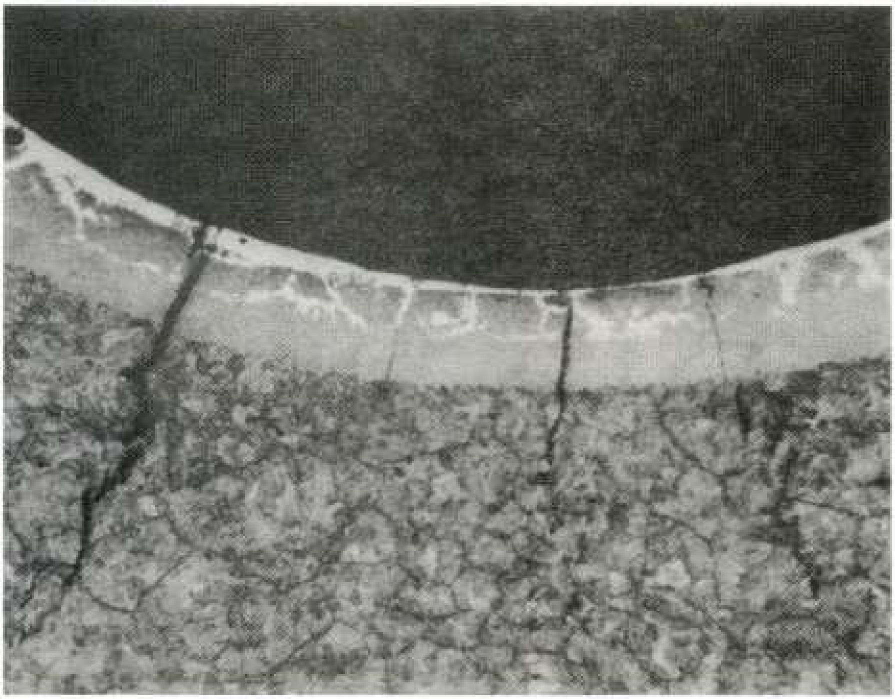


Figure D-4. Photomicrograph of Bar 2 H showing a slight area of retained austenite and relatively small zones of structure change. It also exhibits some severe cracks 0.036 inches deep.

63X Nital Etchant

Nick and Break
M-549
Republic Steel

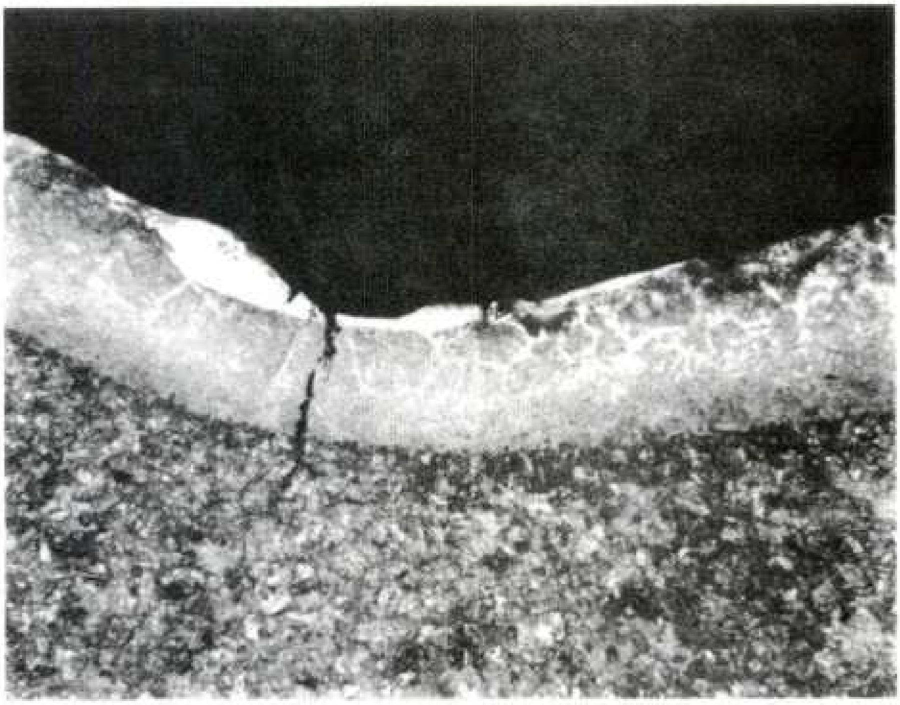


Figure D-5. Photomicrograph of Republic Steel billet 29 BC. It Illustrates two zones of coarse and fine untempered martensite. 63X Nital Etchant.

Nick and Break
M-549
Bethlehem Steel
Bung Furnace Cooled

Figure D-6. Photomicrograph of bar 5 I showing only two zones of structure change.
63X Nital Etch.

Nick and Break
M-549
Bethlehem Steel
Box Cooled

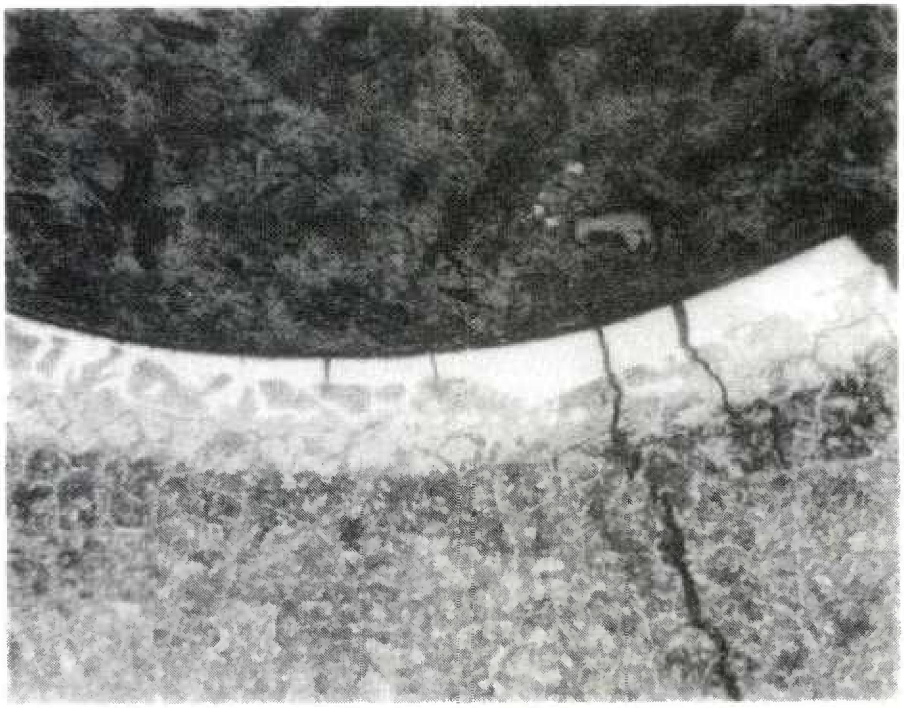


Figure D-7. Photomicrograph of bar 10 B showing the three zones of structure change and some severe cracks.
63X Nital Etch.

Nick and Break
M-549
Bethlehem Steel
Box Cooled

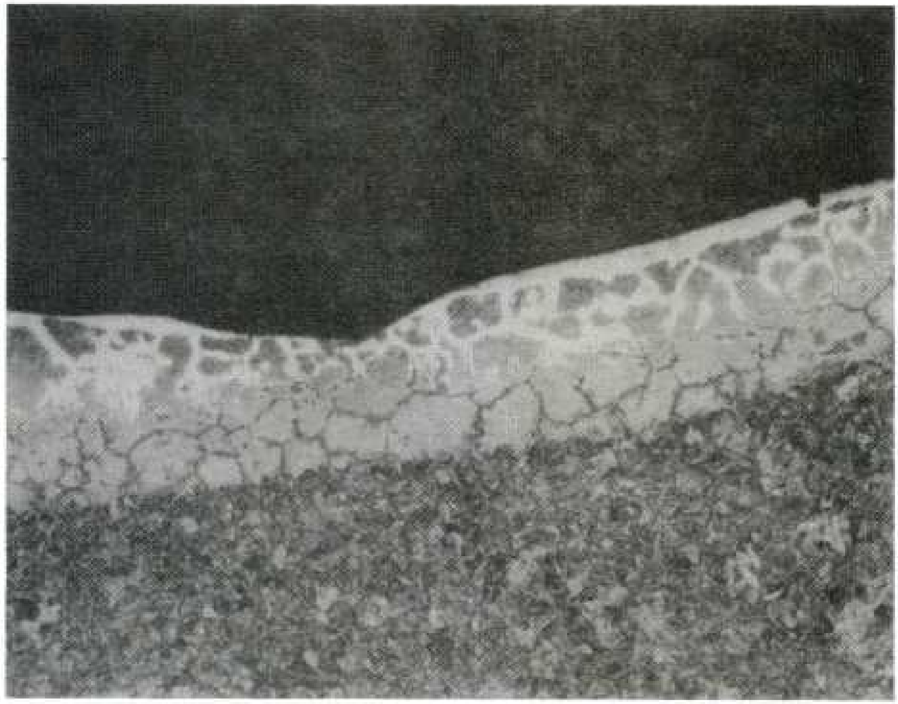


Figure D-8. Photomicrograph of bar 10 B, but different mult than previous figure.
63X Nital Etch.

Nick and Break
M-549
Bethlehem Steel
Box Cooled

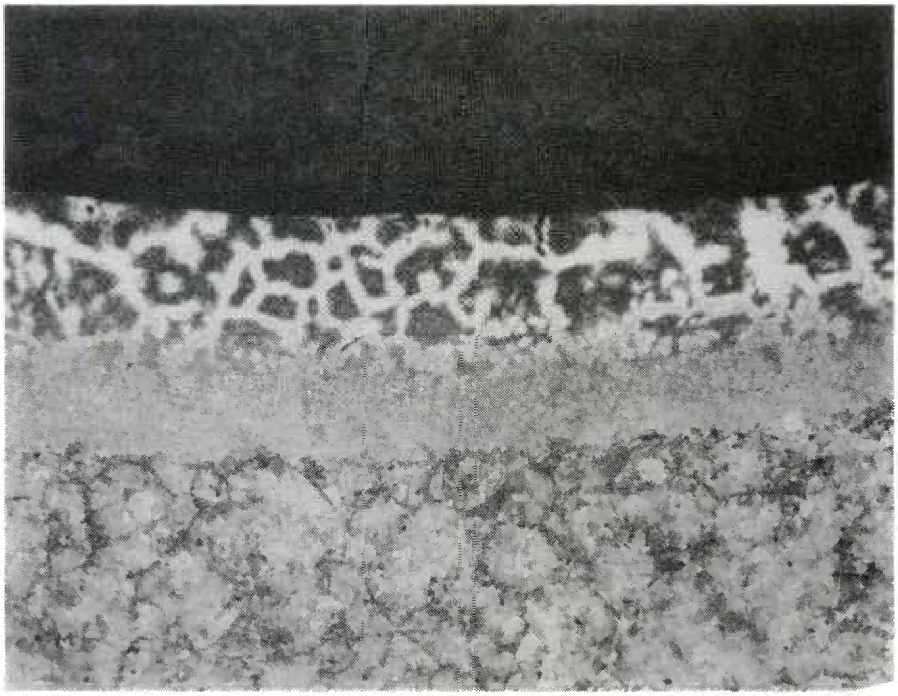


Figure D-9. Photomicrograph of bar 20 C showing only two zones of structure change.
63X Nital Etch.

Nick and Break
M-549
Bethlehem Steel
Box Cooled

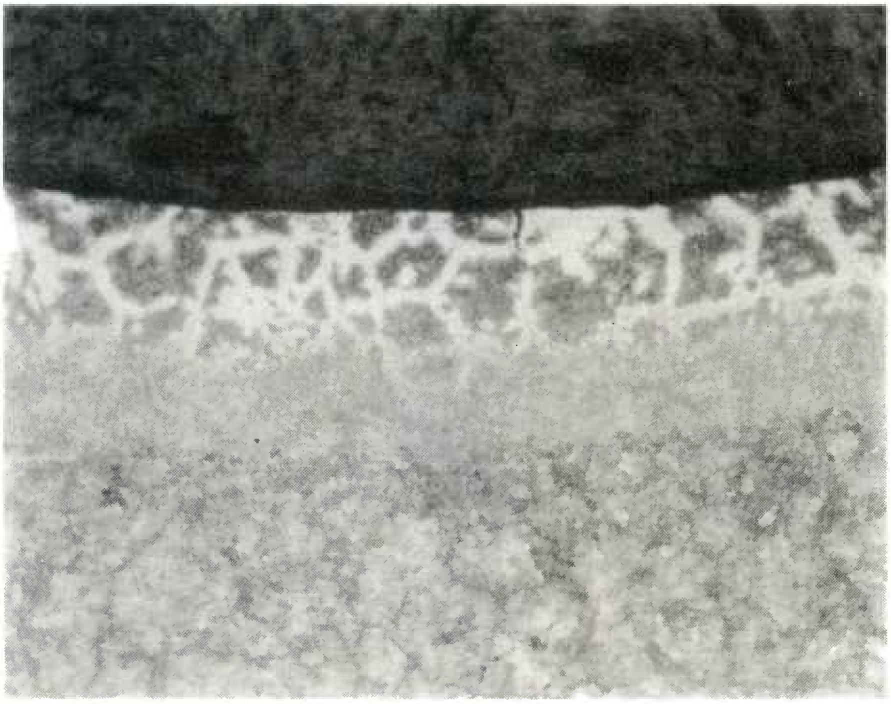


Figure D-10. Photomicrograph of bar 1 C showing only two zones structure change.
63X Nital Etch.

APPENDIX E

RETAINED AUSTENITE EVALUATION

RETAINED AUSTENITE EVALUATION

The white layer in billet 10H was determined to have a hardness of Rc 44. The structure did not react to nital or picral etchant. It therefore was suspected to be retained austenite. In order to confirm the suspicion, the sample was frozen in liquid nitrogen. A hardness evaluation determined that the hardness had increased to Rc 56.5. Relative hardness impressions are shown in figure E-1. The larger Knoop hardness impressions were taken before freezing with nitrogen while the smaller were taken after the nitrogen treatment. This difference in hardness indicates that the transformation from retained austenite to martensite had taken place. The smaller impression indicates a harder value. The second layer consisted of patches of platelet martensite measuring Rc 64 while the white boundaries had an Rc of 57. The third layer which is not relevant to the evaluation of retained austenite was a very fine platelet martensite structure measuring Rc 65. The matrix had an Rc 35.

The same sample was then tempered at 177°C (350°F) for 30 minutes. Figure E-2 illustrates a change in the structure. The white surface layer had a decrease in hardness from Rc 56.5 to Rc 42 indicating a tempering of the martensite. In the second layer, the white areas (grain boundaries) are reduced in amount while the hardness of the patches and boundaries had not significantly changed.

The white grain boundaries were evaluated before tempering at higher magnification. Figure E-3 shows the martensite platelets and the white grain boundaries. Figure E-4 shows the significant decrease in the area of the white grain boundary after tempering. It also shows a crack.

M549
Untempered Martensite Evaluation

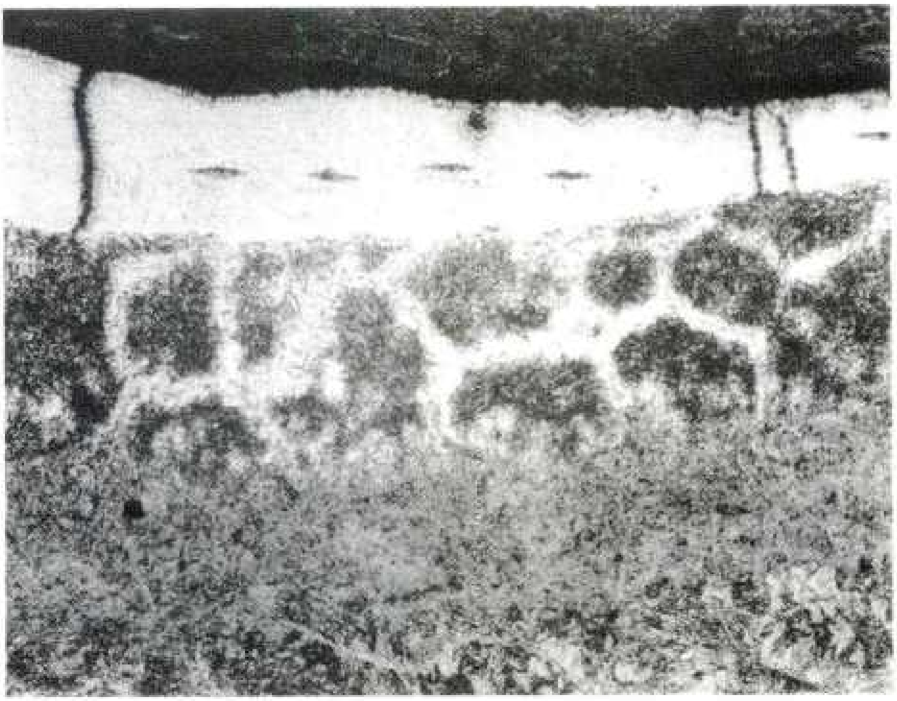


Figure E-1 Photomicrograph of billet 10 H showing layered structure. 100X Nital Etchant.

M549
Untempered Martensite Evaluation

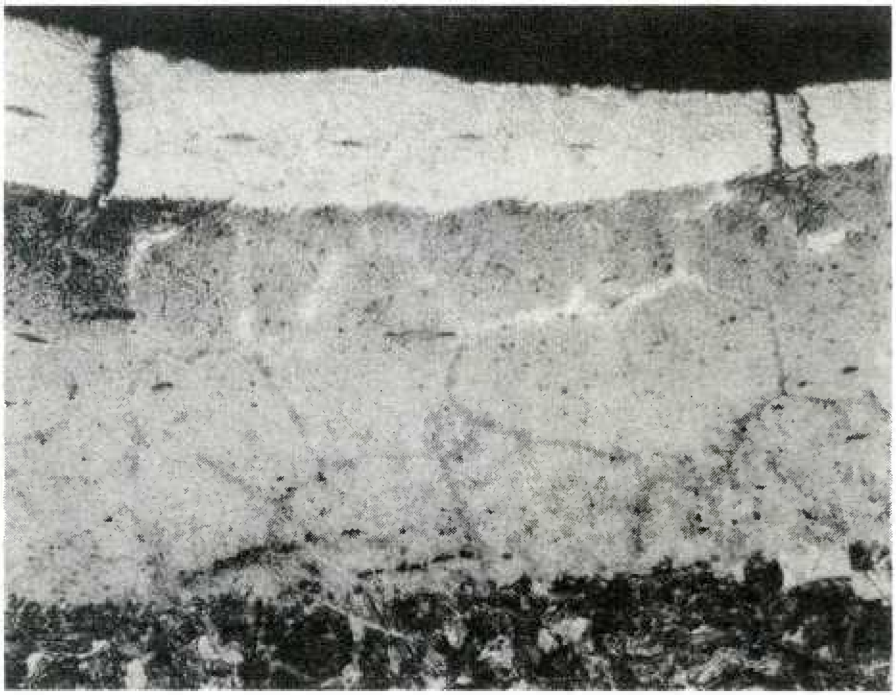


Figure E-2 Photomicrograph of billet 10 H after tempering at 177°C (350°F). 100X Nital Etchant.

M549
Untempered Martensite Evaluation

Figure E-3 Photomicrograph of billet 10 H untempered showing grain boundary area. 400X Nital Etchant.

Figure E-4 Photomicrograph of billet 10 H after tempering at 177°C (350°F) showing decrease in white grain boundary area. 400X Nital Etchant.

The white surface layer after tempering was then etched with nital and figure E-5 shows an as cast structure with some martensite platelets beginning to appear.

Another sample which was not treated with liquid nitrogen was compared with the previous sample. Figure E-6 is an as nicked sample showing the three layers. The white layer had a hardness of Rc 37 and the matrix had a hardness of Rc 36. It was postulated that if the sample was tempered as the previous sample with no appreciable hardness change, the white area must be retained austenite. Furthermore, there should be no visible platelets.

Figure E-7 shows the structure after a tempering at 177°C (350°F). Note as in a previous sample that the white grain boundary areas have decreased in area. The hardness of the surface layer was Rc 38, virtually identical to its untempered hardness. Figure E-8 shows the as cast structure of the white layer without platelet martensite.

It can therefore be concluded:

Layer	Structure
White surface area	Retained austenite
Patch area	Untempered martensite (tempered by mounting)
White grain boundary	Mixture of untempered martensite and retained austenite

M549
Untempered Martensite Evaluation

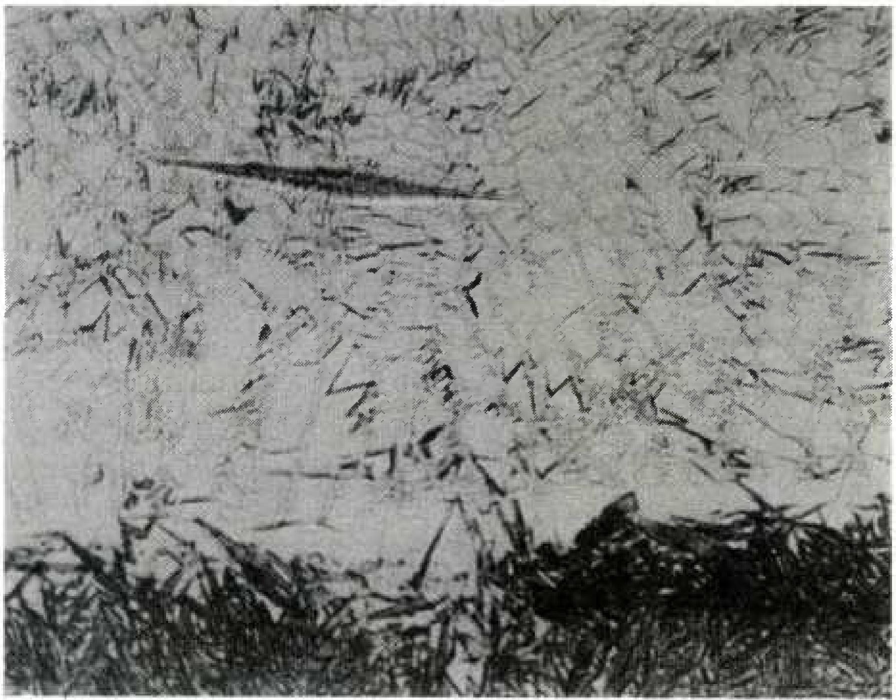


Figure E-5 Photomicrograph of billet 10 H after tempering at 177°C (350°F) showing cart structure and small martensite platelets. 800X Nital Etchant.

M549
Untempered Martensite Evaluation

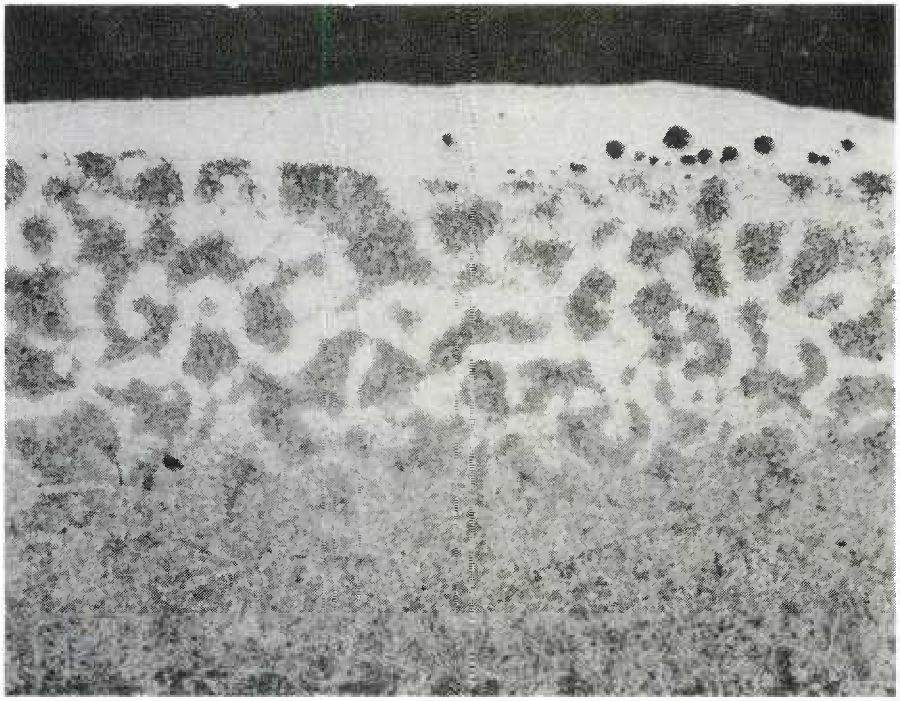


Figure E-6 Photomicrograph of billet 21 BC showing layered structure. 100X Nital Etchant.

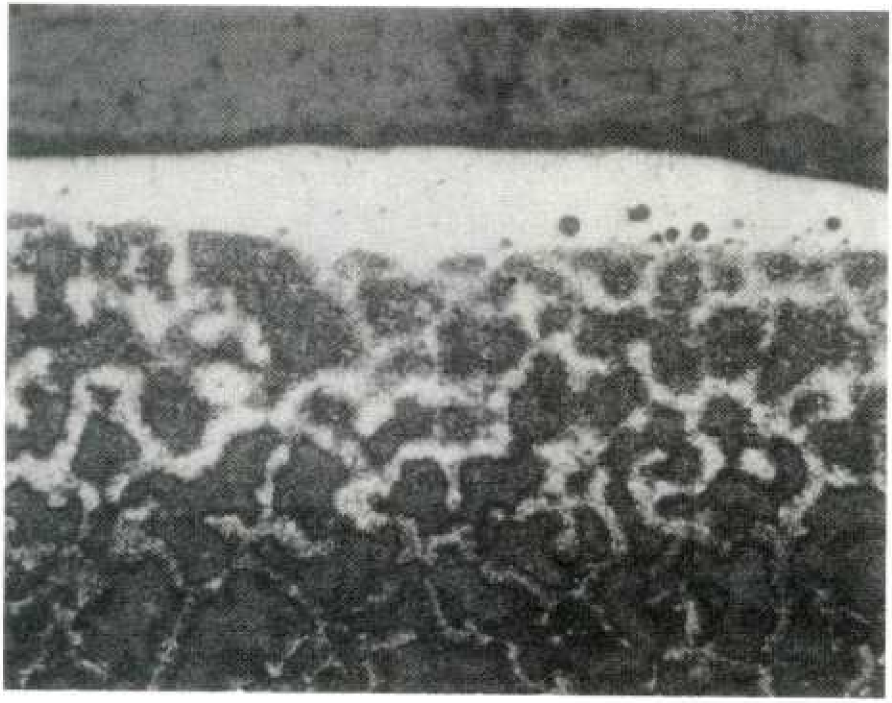


Figure E-7 Photomicrograph of billet 21 BC after tempering at 177°C (350°F) showing the area decrease in the white grain boundary structure. 125X Nital Etchant.

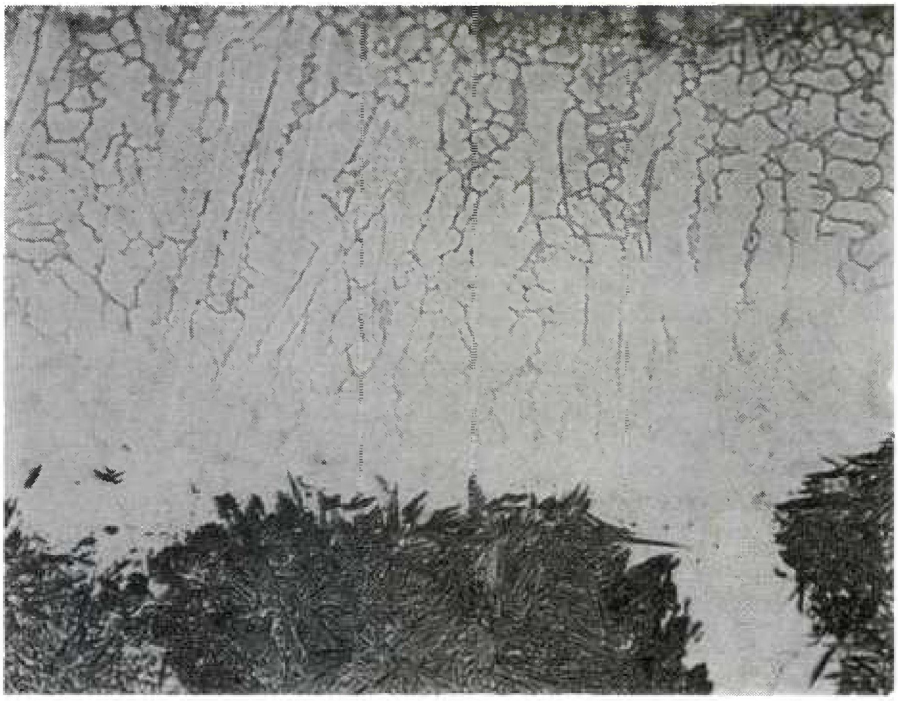
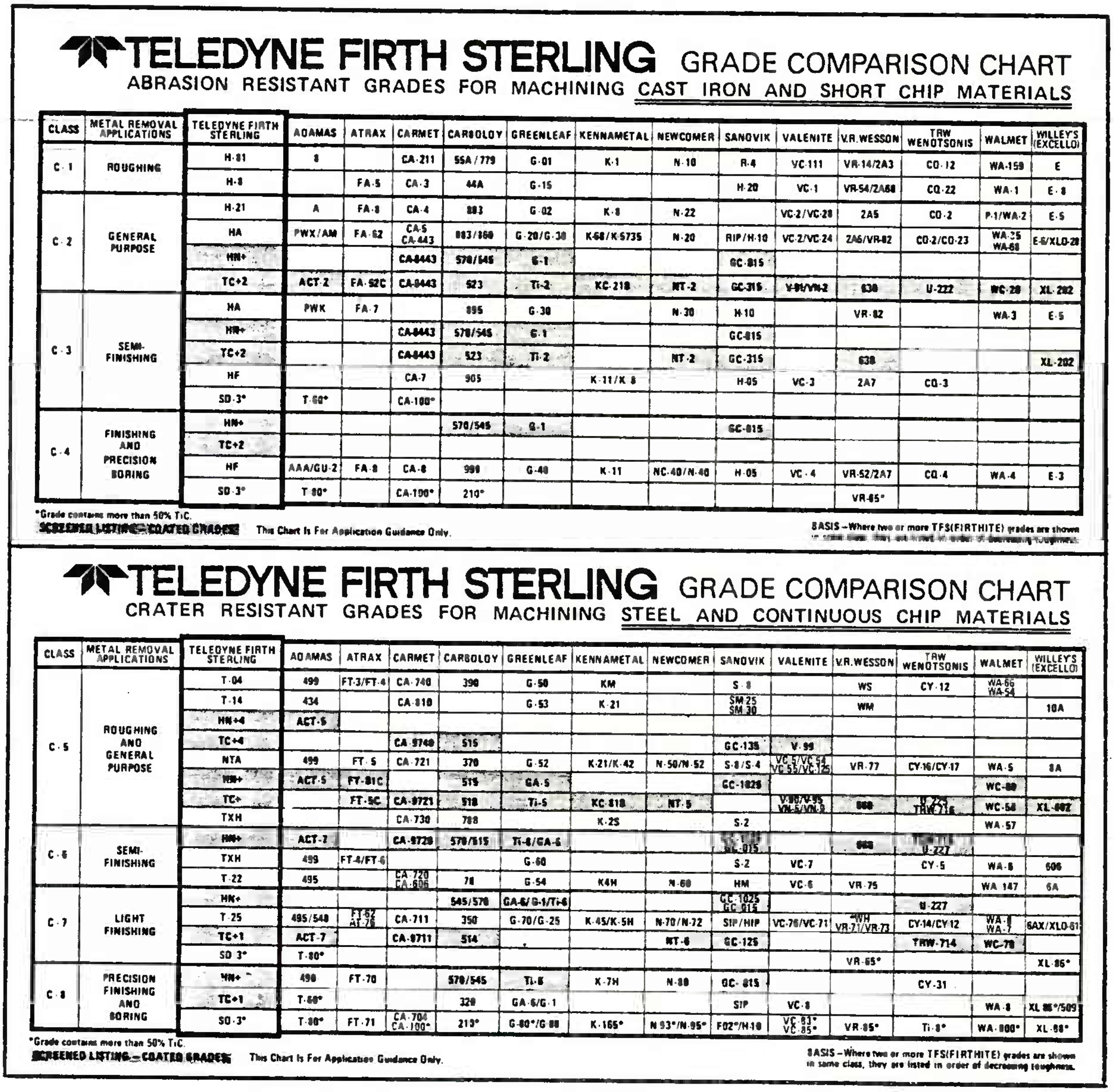


Figure E-8 Photomicrograph of billet 21 BC after tempering at 177°C (350°F) showing the as cast structure without martensite platelets. 800X Nital Etchant.

APPENDIX F

ROUGH TURN MACHINING DATA



TELEDYNE FIRTH STERLING GRADE COMPARISON CHART

ABRASION RESISTANT GRADES FOR MACHINING CAST IRON AND SHORT CHIP MATERIALS

CLASS	METAL REMOVAL APPLICATIONS	TELEDYNE FIRTH STERLING	ADAMAS	ATRAX	CARMET	CARBOLOY	GREENLEAF	KENNAMETAL	NEWCOMER	SANDVIK	VALENITE	V.R.WESSON	TRW WENDTSONIS	WALMET	WILLEY'S (EXCELLO)
C-1	ROUGHING	H-81	B		CA-211	55A/779	G-01	K-1	N-10	R-4	VC-111	VR-14/2A3	CQ-12	WA-159	E
		H-8		FA-5	CA-3	44A	G-15			H-20	VC-1	VR-54/2A68	CQ-22	WA-1	E-8
C-2	GENERAL PURPOSE	H-21	A	FA-8	CA-4	883	G-02	K-8	N-22		VC-2/VC-28	2A5	CQ-2	P-1/WA-2	E-5
		HA	PWX/AM	FA-62	CA-5 CA-443	883/860	G-20/G-30	K-68/K-5735	N-20	RIP/H-10	VC-2/VC-24	2A6/VR-82	CQ-2/CQ-23	WA-35 WA-68	E-6/XLO-28
		HN+			CA-8443	570/545	G-1			GC-015					
		TC+2	ACT-2	FA-52C	CA-8443	523	Ti-2	KC-210	NT-2	GC-315	V-01/VN-2	638	U-222	WC-28	XL-202
C-3	SEMI-FINISHING	HA	PWK	FA-7		895	G-30		N-30	H-10		VR-82		WA-3	E-5
		HN+			CA-8443	570/545	G-1			GC-015					
		TC+2			CA-8443	523	Ti-2		NT-2	GC-315		638			XL-202
		HF			CA-7	905		K-11/K-8		H-05	VC-3	2A7	CQ-3		
		SD-3*	T-60*		CA-100*										
C-4	FINISHING AND PRECISION BORING	HN+				570/545	G-1			GC-015					
		TC+2													
		HF	AAA/GU-2	FA-8	CA-8	999	G-40	K-11	NC-40/N-40	H-05	VC-4	VR-52/2A7	CQ-4	WA-4	E-3
		SD-3*	T-80*		CA-100*	210*						VR-65*			

*Grade contains more than 50% TiC.

SCREENED LISTING — COATED GRADES This Chart Is For Application Guidance Only.

BASIS — Where two or more TFS(FIRTHITE) grades are shown in same class, they are listed in order of decreasing toughness.

TELEDYNE FIRTH STERLING GRADE COMPARISON CHART

CRATER RESISTANT GRADES FOR MACHINING STEEL AND CONTINUOUS CHIP MATERIALS

CLASS	METAL REMOVAL APPLICATIONS	TELEDYNE FIRTH STERLING	ADAMAS	ATRAX	CARMET	CARBOLOY	GREENLEAF	KENNAMETAL	NEWCOMER	SANDVIK	VALENITE	V.R.WESSON	TRW WENDTSONIS	WALMET	WILLEY'S (EXCELLO)
C-5	ROUGHING AND GENERAL PURPOSE	T-04	499	FT-3/FT-4	CA-740	390	G-50	KM		S-6		WS	CY-12	WA-66 WA-54	
		T-14	434		CA-810		G-53	K-21		SM 25 SM 30		WM			10A
		HN+4	ACT-5												
		TC+4			CA-9740	515				GC-135	V-99				
		NTA	499	FT-5	CA-721	370	G-52	K-21/K-42	N-50/N-52	S-6/S-4	VC-5/VC-54 VC-55/VC-125	VR-77	CY-16/CY-17	WA-5	8A
		HN+	ACT-5	FT-81C		515	GA-5			GC-1025				WC-60	
		TC+		FT-5C	CA-9721	518	Ti-5	KC-810	NT-5		V-88/V-95 VN-5/VN-9	668	U-225 TRW-716	WC-58	XL-602
		TXH			CA-730	788		K-2S		S-2				WA-57	
C-6	SEMI-FINISHING	HN+	ACT-7		CA-9720	570/515	Ti-6/GA-6			GC-1025 GC-015		668	TRW-716 U-227		
		TXH	499	FT-4/FT-6			G-60			S-2	VC-7		CY-5	WA-6	606
		T-22	495		CA-720 CA-606	78	G-54	K4H	N-60	HM	VC-6	VR-75		WA 147	6A
C-7	LIGHT FINISHING	HN+				545/570	GA-6/G-1/Ti-6			GC-1025 GC-015			U-227		
		T-25	495/548	FT-62 AT-76	CA-711	350	G-70/G-25	K-45/K-5H	N-70/N-72	SIP/HIP	VC-76/VC-71	*WH VR-71/VR-73	CY-14/CY-12	WA-8 WA-7	6AX/XLO-61
		TC+1	ACT-7		CA-9711	514			NT-6	GC-125			TRW-714	WC-78	
		SD 3*	T-80*									VR-65*			XL-86*
C-8	PRECISION FINISHING AND BORING	HN+	490	FT-70		570/545	Ti-6	K-7H	N-80	GC-015			CY-31		
		TC+1	T-60*			320	GA-6/G-1			SIP	VC-8			WA-8	XL-86*/509
		SD-3*	T-80*	FT-71	CA-704 CA-100*	213*	G-80*/G-88	K-165*	N-93*/N-95*	F02*/H-10	VC-83* VC-85*	VR-85*	Ti-8*	WA-000*	XL-88*

*Grade contains more than 50% TiC.

SCREENED LISTING — COATED GRADES This Chart Is For Application Guidance Only.

BASIS — Where two or more TFS(FIRTHITE) grades are shown in same class, they are listed in order of decreasing toughness.

Figure F-1. Manufacturer's insert grade comparison chart.

Turning Inserts

This system is used in this catalog. The example used is a Carb-O-Lock® triangular insert, negative rake, with I.C. tolerance of ±.003" and thickness tolerance of .005", with hole and chip-breaker, one-half inch I.C. diameter, three-sixteenths inch thick, three sixty-fourths inch nose radius, honed medium feed and medium high force chip groove geometry, or TNMG-433E-48.

1	2	3	4		5	6	7	8		9
	N	M	G	-	4	3	3	E	-	48

1 SHAPE

R —Round
S —Square
T —Triangle
L —Rectangle
V —Diamond 35°
D —Diamond 55°
C —Diamond 80°
M —Diamond 85°
P —Pentagon
E —Parallelogram 55°
F —Parallelogram 70°
B —Parallelogram 82°
A —Parallelogram 85°
H —Hexagon
O —Octagon

2 RELIEF ANGLE

N —0°
A —3°
B —5°
C —7°
T —10°*
P —10°
D —15°
E —20°
F —25°
G —30°

3 TOLERANCES

INSERT I.C.	THICKNESS
A = ±.0002	±.001
B = ±.0002	±.005
C = ±.0005	±.001
D = ±.0005	±.005
E = ±.001	±.001
G = ±.001	±.005
** **M** = ±.002 ±.004	±.005
*** **U** = ±.005 ±.012	±.005

R = Blank with grind stock on all surfaces
S = Blank with grind stock on top and bottom surfaces only

*Carboloy Standard
**0.000-0.005 Radius
***Exact tolerance is determined by size of insert.

4 TYPE

A —With hole
B —With hole and one countersink
C —With hole and two countersinks
D —Smaller than 1/4" I.C. with hole
E —Smaller than 1/4" I.C. without hole
F —Clamp-on type with chipbreaker
G —With hole and chipbreaker
H —With hole, one countersink and chipbreaker
J —With hole, two countersinks and chipbreaker
K —Smaller than 1/4" I.C. with hole and chipbreaker
L —Smaller than 1/4" I.C. without hole and with chipbreaker
M —With hole and chip groove on one surface only
†**P** —10° positive land with hole and chipbreaker
Z —With hole and chipbreaker one side only

5 SIZE

Number of 1/32nds on inserts less than 1/4" I.C.
Number of 1/8ths on inserts 1/4" I.C., and over.
Rectangle and parallelogram inserts require two digits:
1st Digit—Number of 1/8ths in width.
2nd Digit—Number of 1/4ths in length.

6

Number of 1/32nds on inserts less than 1/4" I.C.
Number of 1/16ths on inserts 1/4" I.C. and over.
Use width dimension in place of I.C. on rectangle and parallelogram inserts.

7 POINT RADIUS, FLATS

****0** —Sharp corner	**3** —3/64 Radius
1 —1/64 Radius	**4** —1/16 Radius
2 —1/32 Radius	**6** — 3/32 Radius
	8 —1/8 Radius

A —Square insert with 45° chamfer
B —Square insert with 45° chamfer and 4° sweep angle, R.H. or neg

†Common usage but not A.N.S.I. Standard.

POINT RADIUS, FLATS (continued)

C —Square insert with 45° chamfer and 4° sweep angle, L.H.
D —Square insert with 30° chamfer, R.H. or neg.
E —Square insert with 15° chamfer, R.H. or neg.
F —Square insert with 5° chamfer, R.H. or neg.
G —Square insert with 30° chamfer, L.H.
H —Square insert with 15° chamfer, L.H.
J —Square insert with 5° chamfer, L.H.
K —Square insert with 30° double chamfer
L —Square insert with 15° double chamfer
M —Square insert with 5° double chamfer
N —Truncated triangle insert
P —Flatted corner triangle, R.H. or neg.
R —Flatted corner triangle, L.H.
S —Square negative insert with 10° double chamfer
T —Square negative insert with 30° positive rake double chamfer
V —Octagon negative insert with 22-1/2° corner chamfer

8 FINISH

E —Honed cutting edge
F —Unhoned cutting edge
*††**H** —When used with numeral, indicates nominal hone in thousandths ±.001
J —Polished cutting surface only
T —Chamfer—cutting edge

9 CHIP GROOVE GEOMETRY*

Chip groove geometry:
1st digit—relative feed range
2nd digit—relative force range

Feed		Force
1	Very Low	1
2	Low	2
3	Medium Low	3
4	Medium	4
5	Medium	5
6	Medium High	6
7	Medium High	7
8	High	8
9	Very High	9

††Shall be used only when required.

Figure F-2. Insert Identification System.

Standard Toolholders
(A.N.S.I. Identification System Except as Noted)

1	2	3	4	5	6		7		8	9	10
M	T	F	N	R	S	-	16	-	4	D	R

1 METHOD OF HOLDING MECHANICALLY SECURED INSERT

C	Clamp Lock Assembly
M	Multiple Lock Assembly (Pin and Clamp Lock)
P	Pin Lock Assembly
•T	Taper Stem

2 INSERT SHAPE

C	80° Diamond Shaped Insert
D	55° Diamond Shaped Insert
L	Rectangle Insert
R	Round Insert
S	Square Insert
T	Triangle Insert
V	35° Diamond Shaped Insert

3 TOOLHOLDER STYLE

A	Straight Shank with 0° (90°) Side Cutting Edge Angle
B	Straight Shank with 15° (75°) Side Cutting Edge Angle
C	Shank with 0° (90°) End Cutting Edge Angle
D	Straight Shank with 45° Side Cutting Edge Angle
E	Straight Shank with 30° (60°) Cutting Edge Angle
F	Offset Shank with 0° (90°) End Cutting Edge Angle

TOOLHOLDER STYLE (Continued)

G	Offset Shank with 0° (90°) Side Cutting Edge Angle
•H	Offset Shank for I.D. Threading and Shallow Grooving
I	Unassigned
J	Offset Shank with Negative 3° (93°) Side Cutting Edge Angle
K	Offset Shank with 15° (75°) End Cutting Edge Angle
L	Offset Shank with Negative 5° (95°) End or Side Cutting Edge Angle
•M	Offset Shank with 5° End Cutting Edge Angle
N	Straight Shank with 27° (63°) Side Cutting Edge Angle
O	Straight Shank with Centrally Located Round Insert.
P	Straight Shank with 27° (62½°) Side Cutting Edge Angle
Q	Unassigned
R	Offset Shank with 15° (75°) Side Cutting Edge Angle
S	Offset Shank with 45° Side Cutting Edge Angle
•T	Offset Shank with Negative 27½° (62½°) Side or End Cutting Edge Angle
•U	Offset Shank for Deep Grooving
•V	Offset Shank for O.D. Threading

TOOLHOLDER STYLE (Continued)

	and Shallow Grooving
W	Offset Shank wi 10° (80°) Side Cutting Edge Angle
X	Unassigned
•Y	Unassigned
•Z	Offset Shank fo Reverse Hand Threading and Shallow Groovin

4 RAKE ATTITUDE

N	Negative Rake
O	Neutral Rake
P	Positive Rake

5 HAND OF TOOL

L	Left
N	Neutral
R	Right

6 POCKET STYLE

S	Single Wall Pock Construction Fu Pocket Construc tion When Lette Position is Vaca

Note: The angles shown in brackets are the angles as shown in the A.N.S.I. standard.

Figure F-3. Toolholder Identification System.

7

BASIC TOOLHOLDER SHANK SIZE

The seventh position is a two-digit number which indicates shank size. For shanks ⅝ square and over the number represents the number of sixteenths of width and height. For shanks under ⅝ square the number represents the number of sixteenths of cross section. For rectangular holders the first digit represents the number of eights of width and the second digit represents the number of quarters of height.

8

INSERT SIZE I.C.

Number of eights of I.C.; rectangle and parallelogram inserts require two digits:

1st digit—number of eights in width.

2nd digit—number of quarters in length.

9

SHANK QUALIFICATION (Standard Options)

Letter	Qualified Value
A=	4.000 Length and Width Control
B=	4.500 Length and Width Control
C=	5.000 Length and Width Control
D=	6.000 Length and Width Control
E=	7.000 Length and Width Control
F=	8.000 Length and Width Control
*G=	5.500 Length and Width Control
*H=	9.000 Length and Width Control
J=	Special Length and Standard Width Control. Specify Length.
*K=	12.000 Length and Width Control
*L=	14.000 Length and Width Control

SHANK QUALIFICATION (Continued)

M=	4.000 Length and Side Control
N=	4.500 Length and Side Control
P=	5.000 Length and Side Control
R=	6.000 Length and Side Control
S=	7.000 Length and Side Control
T=	8.000 Length and Side Control
*U=	5.500 Length and Side Control
*V=	9.000 Length and Side Control
W=	Special Length and Standard Side Control. Specify Length.
*X=	12.000 Length and Side Control
*Y=	14.000 Length and Side Control
*Z=	Qualified Length Control Only. Specify Nominal Length. Eg.: MTJNRS-20.4Z (5.500)

10

SHANK MODIFICATION (Standard Options)

Letter	Modification Value
A	American Tool Standard Wedge Angle
B	Bullard Standard Wedge Angle
C	Unassigned
D	Unassigned
E	Unassigned
F	Unassigned
G	Gidding & Lewis Standard Wedge Angle
H	Unassigned
J	Unassigned
K	Unassigned
L	LeBlond Standard Wedge Angle
M	Monarch Standard End Angle
N	New Britain Machine Standard Wedge Angle
P	Unassigned
Q	Unassigned
R	Unassigned
S	Saginaw Machine Standard Wedge Angle
T	Unassigned
U	Unassigned
V	Unassigned
W	Unassigned
X	Unassigned
Y	Unassigned
Z	Unassigned

Note (1) Consult catalog for eligible qualifications. Not all styles may be qualified.
Note (2) The qualified value of the length control letter cannot exceed the basic toolholder length dimension per the catalog.
Note (3) Shank qualification Z available on all standard styles.
Note (4) Shank qualification letter other than Z must precede any shank modification
Note (5) All surfaces will be qualified +.003 over the proper gage insert radius listed below.
Note: Pre-set tooling is available from Carboloy Systems on a quotation basis. Please contact your Carboloy Systems Representative or the authorized Carboloy Systems Distributor in your area.

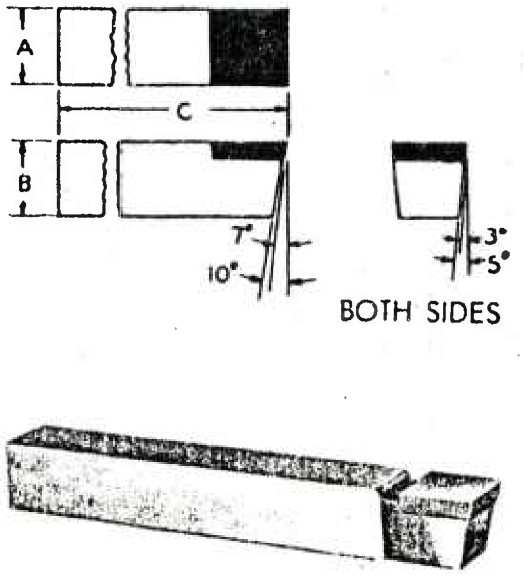
Note: Above example toolholder is offered solely for purposes of nomenclature explanation. Single Wall Pocket Toolholders are not available as qualified toolholders except where noted on length only.

*Carboloy Systems Standard

Figure F-3. Cont'd.

C

Broadnose – A general purpose tool of great utility for facing, chamfering, and turning – This tool is also generally used for making special form tools – Catalog number and carbide grade desired must be specified.



STYLE C

Tools shown are available in grades appearing in current price list. Items generally carried in stock for prompt delivery are also indicated in current price list.

	DIMENSIONS			
TOOL CATALOG NUMBER	A	B	C	BLANK CATALOG NUMBER
C-4	1/4	1/4	2	1030
C-5	5/16	5/16	2-1/4	1080
C-6	3/8	3/8	2-1/2	1090
C-7	7/16	7/16	3	1105
C-8	1/2	1/2	3-1/2	1200
C-10	5/8	5/8	4	0240
C-12	3/4	3/4	4-1/2	0340
C-16	1	1	7	0410
C-20	1-1/4	1-1/4	6	0480
C-44	1/2	1	2	0320
C-54	5/8	1	6	0400
C-55	5/8	1-1/4	8	0400
C-64	3/4	1	6	0405
C-66	3/4	1-1/2	8	0470
C-86	1	1-1/2	8	0475

Figure F-4. Facing Tool Identification System.

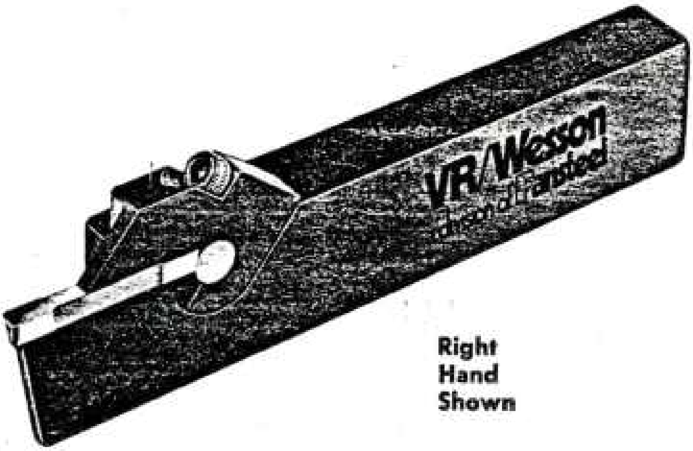
VR/Wesson
a division of Fansteel

TOOLHOLDERS

V-Insert Type

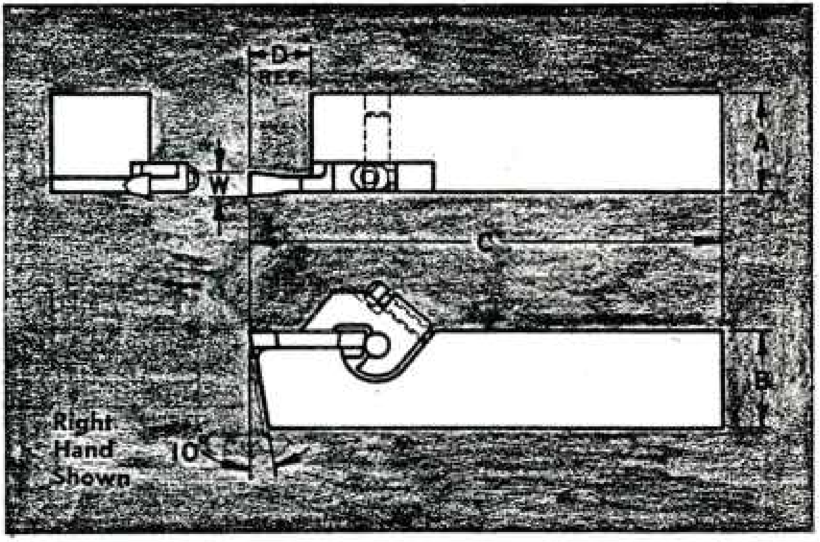
Styles DEHR - DEHL

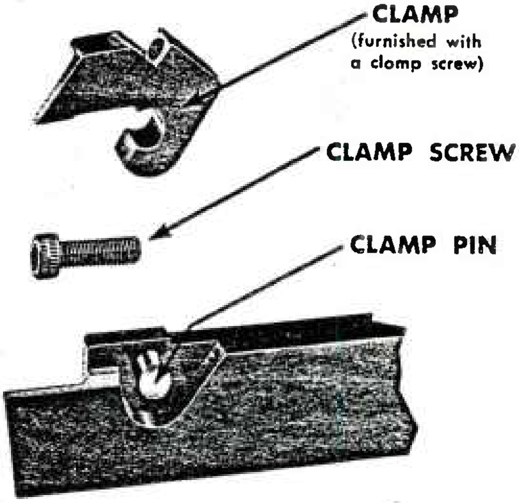
for deep grooving, forming, profiling and cut-off



Right Hand Shown

Patent Protection Pending





Toolholders are furnished without inserts

SHANK DIMENSIONS				INSERT* W - Width		TOOLHOLDER DESIGNATION		PART NUMBERS			
A Width	B Height	C Length	D Ref.	Standard Insert Width	Available Width Range	Right Hand	Left Hand	CLAMP (furnished with a clamp screw) R.H.	CLAMP (furnished with a clamp screw) L.H.	CLAMP SCREW	CLAMP PIN
1-1/4	1	6	.781	.187	.170 thru .215	DEHR-104-2	DEHL-104-2	DECR-2	DECL-2	DECS-S	DEP-P
				.250	.216 thru .289	DEHR-104-4	DEHL-104-4	DECR-4	DECL-4		
				.312	.290 thru .352	DEHR-104-5	DEHL-104-5	DECR-5	DECL-5		
				.375	.353 thru .375	DEHR-104-6	DEHL-104-6	DECR-6	DECL-6		
1-1/4	1-1/4	6	.781	.187	.170 thru .215	DEHR-20-2	DEHL-20-2	DECR-2	DECL-2	DECS-S	DEP-P
				.250	.216 thru .289	DEHR-20-4	DEHL-20-4	DECR-4	DECL-4		
				.312	.290 thru .352	DEHR-20-5	DEHL-20-5	DECR-5	DECL-5		
				.375	.353 thru .375	DEHR-20-6	DEHL-20-6	DECR-6	DECL-6		
1-1/4	1-1/2	7	.781	.187	.170 thru .215	DEHR-106-2	DEHL-106-2	DECR-2	DECL-2	DECS-S	DEP-P
				.250	.216 thru .289	DEHR-106-4	DEHL-106-4	DECR-4	DECL-4		
				.312	.290 thru .352	DEHR-106-5	DEHL-106-5	DECR-5	DECL-5		
				.375	.353 thru .375	DEHR-106-6	DEHL-106-6	DECR-6	DECL-6		

Prices shown in Price Supplement.

*See Insert Table for insert shapes stacked in the standard widths shown above.
Other insert widths are available upon request.

Figure F-5. Parting Tool Identification System.

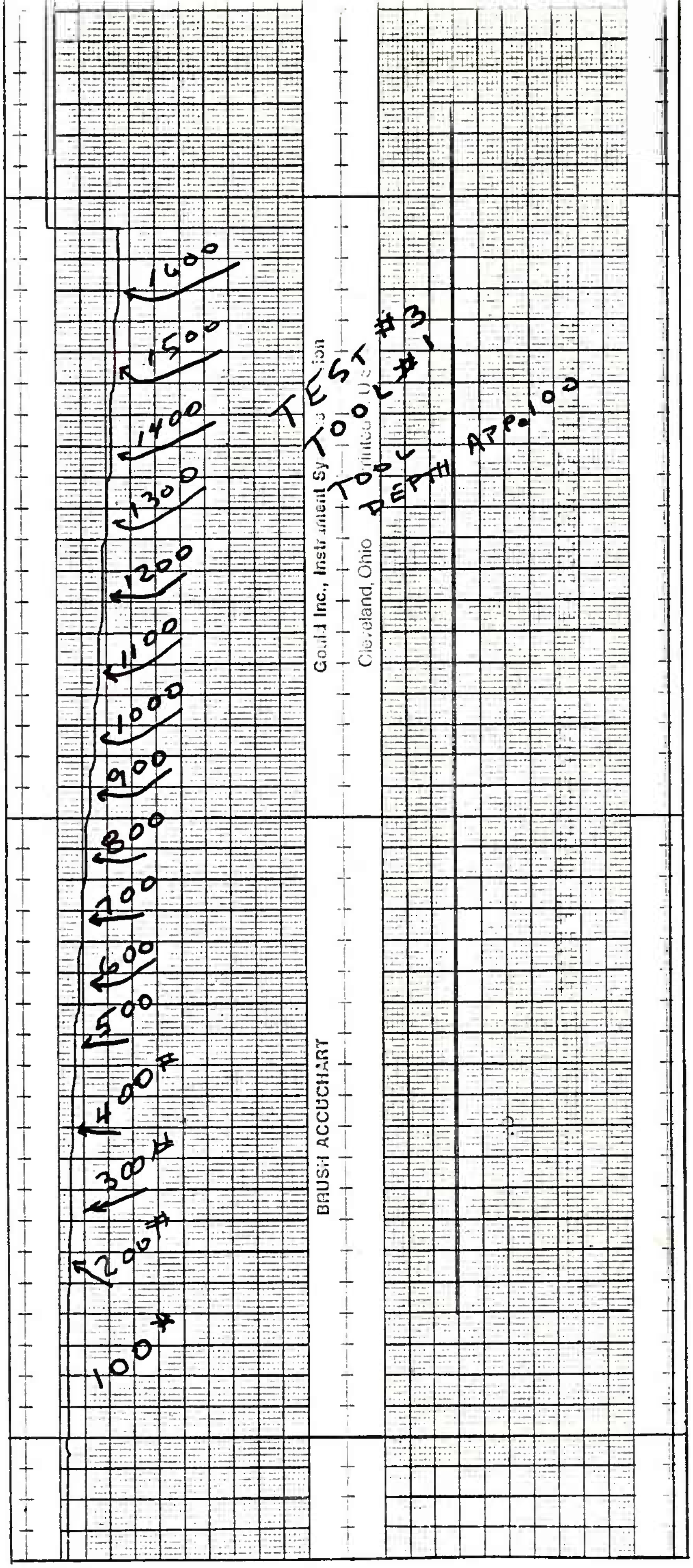


Figure F-6. Calibration chart for tool #1.

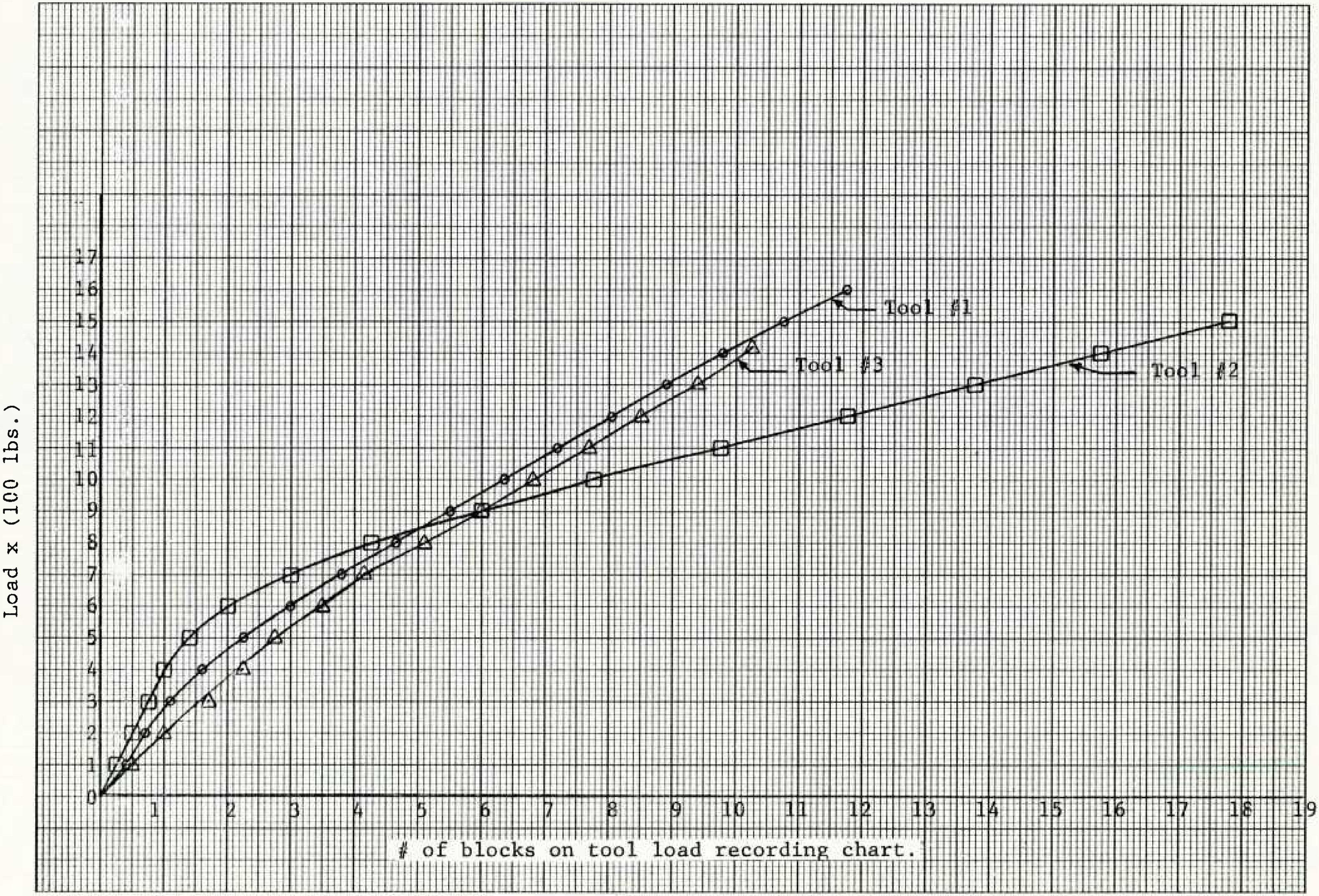


Figure F-7. Calibration curves for rough turn tool #'s 1, 2 & 3.

Table F-1. Rough Turn tooling pressures obtained for Heat #1 - "As-Forged" Shells.

Shell No.	Tool #1 Blocks	Tool #1 Load	Tool #2 Blocks	Tool #2 Load	Tool #3 Blocks	Tool #3 Load
178	6	960	7	960	7-1/2	1080
192	6-1/2	1030	7	960	8	1140
191	6-1/2	1030	8-1/2	1030	8	1140
190	7	1090	8	1000	8	1140
158 *	8-3/4	1290	7	960	8	1140
156	9	1310	7	960	8	1140
239	6	960	8-1/2	1030	7	1020
176	9	1310	7	960	7	1020
159	7	1090	7	960	7	1020
243	7	1090	8-1/2	1030	7-1/2	1080
256	7	1090	7	960	7	1020
253	9	1310	7	960	7	1020
234	8	1200	7	960	7	1020
287	7	1090	8-1/2	1030	7	1020
233	7-1/2	1140	9	1060	7-1/4	1050
465	7-1/2	1140	7	960	7	1020
	Min. = 960		Min. = 960		Min. = 1020	
	Max. = 1310		Max. = 1060		Max. = 1140	
	Avg. = 1132		Avg. = 986		Avg. = 1067	

*Used as sample curve in Rough Turn section - Task D.

NOTE: "Blocks" refers to an incremental unit as depicted on the tool load recording charts (ref. fig. 66).

Table F-2. Rough Turn tooling pressures obtained for Heat #1 - Annealed Shells.

Shell	Tool #1		Tool #2		Tool #3	
No.	Blocks	Load	Blocks	Load	Blocks	Load
127	6-1/2	1030	7-1/2	980	7	1020
106	6-3/4	1060	8	1000	7	1020
136	7	1090	7-1/2	980	6	900
111	7	1090	8	1000	6	900
105	6-1/2	1030	7-1/2	980	6-1/2	960
121	6-1/2	1030	7-1/2	980	7	1020
118	7	1090	8	1000	6-1/2	960
119	7	1090	8	1000	6-1/2	960
123	7	1090	7-1/2	980	6-1/2	960
102	6-1/2	1030	7	960	6	900
109 *	6-1/2	1030	7	960	6	900
92	7	1090	7-1/2	980	6-1/2	960
115	7	1090	7-1/2	980	6-1/2	960
88	6-1/2	1030	7-1/2	980	7	1020
101	6-1/2	1030	7-1/2	980	7	1020
84	7	1090	7-1/2	980	7	1020

Tool #1	Tool #2	Tool #3
Min. = 1030	Min. = 960	Min. = 900
Max. = 1090	Max. = 1000	Max. = 1020
Avg. = 1066	Avg. = 981	Avg. = 965

*Used as sample curve in Rough Turn section - Task D.

NOTE: "Blocks" refers to an incremental unit as depicted on the tool load recording charts (ref. fig. 66).

Table F-3. Rough Turn tooling pressures obtained for Heat #2A - "As-Forged" Shells.

Shell	Tool #1		Tool #2		Tool #3	
No.	Blocks	Load	Blocks	Load	Blocks	Load
575	11-1/2	1580	7-1/2	980	8-1/4	1160
564	11	1520	8	1000	6-3/4	990
507	11-1/4	1550	10-1/4	1120	6-1/2	960
511	11-1/2	1580	9-3/4	1100	6	900
540	11-1/2	1580	9	1060	6	900
323	10	1420	9	1060	6-1/4	930
303	11-1/2	1580	8-1/2	1030	6-1/2	960
306	11-1/2	1580	8	1000	7	1020
418	12-1/2	1680	8	1000	7	1020
538	9-1/2	1370	7-1/2	980	6-1/2	960
544	10	1420	8	1000	7	1020
555	9	1310	7-1/2	980	7	1020
523	10	1420	7	960	6-1/2	960
508	8	1200	7-1/2	980	7-1/2	1080
518	10	1420	7	960	7	1020
525	8-1/2	1260	7	960	7	1020

Min. = 1200	Min. = 960	Min. = 930
Max. = 1680	Max. = 1120	Max. = 1160
Avg. = 1466	Avg. = 1010	Avg. = 995

NOTE: "Blocks" refers to an incremental unit as depicted on the tool load recording charts (ref. fig. 66).

Table F-4. Rough Turn tooling pressures obtained for Heat #2A - Annealed Shells.

Shell	Tool #1		Tool #2		Tool #3	
No.	Blocks	Load	Blocks	Load	Blocks	Load
308	9-1/4	1340	7	960	6	900
580	9-1/2	1370	7-1/2	980	6-1/2	960
567	9-1/2	1370	8	1000	5-1/2	840
563	10	1420	9	1060	6-1/4	930
549	10-1/2	1480	10	1110	6-1/2	960
505	10	1420	9-1/2	1080	6	900
338	10-1/2	1480	10	1110	5-3/4	870
572	10-1/4	1450	9-1/2	1080	5-1/4	820
550	9-3/4	1390	9-1/2	1080	6-1/2	960
301	9	1310	7-3/4	990	7	1020
314	9-1/2	1370	8	1000	6-3/4	990
310	9-1/4	1340	8	1000	7-1/4	1050
573	9-1/2	1370	8-3/4	1040	7-1/4	1050
408	11	1520	3	700	6	900
568	10-1/4	1450	2	600	5-3/4	870
413	10-1/4	1450	8-1/2	1030	7	1020

Tool #1	Tool #2	Tool #3
Min. = 1310	Min. = 600	Min. = 820
Max. = 1520	Max. = 1110	Max. = 1050
Avg. = 1432	Avg. = 989	Avg. = 940

NOTE: "Blocks" refers to an incremental unit as depicted on the tool load recording charts (ref. fig. 66).

APPENDIX G

INSTRUMENTATION

INSTRUMENTATION

Temperature - "Carpintec" Two-Color Pyrometer Model Hot Shot, Ratio-Scope 5.

Forging

Tool Loads - "Viatron" Pressure Transducer, Model No. 218C-Z8, 0-5000 PSI Absolute.

Ram Displacement - "Celesco" Position-Velocity Transducer, Model No. DV301-200A.

Recorder - "Gould" 2600 Flip Top Recorder with 6-Channel Vertical Presentation Oscillograph.

Rough Turn Machining

Tool Loads - "BLH Electronics" Strain Gage Type FAE-50-35-S6EL with BLH Cat. No. 5100 Strain Gage Signal Conditioner.

Recorder - Same as above.

APPENDIX H

FORGING LOADS

Table H-1. Heat #1, Data of Preform Forge Loads vs Temperatures

Temp. Range (°F):	1850-1875	1876-1900	1901-1925	1926-1950	1951-1975
Preform Load (Tons):	572.0	564.3	541.2	572.0	
	595.1	602.8	556.5	572.0	
	710.5	618.1	572.0	572.0	
		618.1	587.4	572.0	
		618.1	602.8	579.7	
		633.5	602.8	587.4	
		648.9	618.1	610.4	
		710.5	633.5	618.1	
			633.5	648.9	
			679.7	664.3	
				664.3	
Average Load:	625.9	626.8	602.8	605.6	

Table H-2. Heat #2A, Data of Preform Forge Loads vs Temperatures

Temp. Range (°F):	1850-1875	1876-1900	1901-1925	1926-1950	1951-1975
Preform Loads (Tons):		510.4	556.6	541.2	
		587.4	556.6	548.9	
		602.8	572.0	556.6	
		602.8	572.0	556.6	
		602.8	579.7	564.3	
		610.4	579.7	579.7	
		648.9	579.7	602.8	
		648.9	579.7		
			587.4		
			587.4		
			587.4		
			602.8		
			602.8		
			618.1		
			625.8		
Average Load:		610.8	585.8	564.3	

Table H-3. Heat #2B, Data of Preform Forge Loads vs Temperatures

Temp. Range (°F):	1850-1875	1876-1900	1901-1925	1926-1950	1951-1975
Preform Loads (Tons):		587.4	525.8	510.4	
		602.8	525.8	525.8	
		602.8	525.8	548.9	
			541.2	556.6	
			541.2	572.0	
			556.6	572.0	
			556.6	572.0	
			556.6	579.7	
			564.3	633.5	
			572.0	633.5	
			572.0		
			579.7		
			579.7		
			587.4		
Average Loads:		597.7	556.1	570.4	

Table H-4. Heat #1, Data of Pierce Forge Loads vs Temperatures

Temp. Range (°F):	1600-1625	1626-1650	1651-1675	1676-1700	1701-1725
Pierce Load (Tons):		699.3	699.3	606.9	668.5
		699.3	699.3	668.5	699.3
			699.3	668.5	699.3
			714.7	683.9	699.3
				683.9	699.3
				730.1	699.3
				730.1	699.3
					699.3
					714.7
Average Load:		699.3	703.2	681.7	697.6

Table H-5. Heat #2A, Data of Pierce Forge Loads vs Temperatures

Temp. Range (°F):	1626-1650	1651-1675	1676-1700	1701-1725	1726-1750
Pierce Load (Tons):	606.9	606.9	622.3	591.5	560.7
	606.9	622.3	622.3	606.9	591.5
	637.7	622.3	622.3	606.9	
	637.7	637.7	637.7	622.3	
	637.7	637.7	637.7	622.3	
	637.7	653.1	668.5		
	668.5	668.5			
	668.5	668.5			
		668.5			
Average Load:	637.7	642.8	635.1	610.0	576.1

Table H-6. Heat #2B, Data of Pierce Forge Loads vs Temperatures

Temp. Range (°F):	1600-1625	1626-1650	1651-1675	1676-1700	1701-1725	1726-1750
Pierce Load (Tons):	637.7	622.3	606.9	606.9	606.9	560.7
	668.5	622.3	606.9	622.3	606.9	576.1
		637.7	606.9		637.7	591.5
		637.7	606.9			
			606.9			
			622.3			
			622.3			
			622.3			
			622.3			
			622.3			
			622.3			
			637.7			
Average Load:	653.1	630.0	617.6	614.6	617.2	576.1

Table H-7. Heat #1, Data of Draw Forge Loads vs Temperature

Temp. Range (°F):	1450-1475	1476-1500	1501-1525	1526-1550	1551-1575	1576-1600
Draw Load (Tons):	126.4	126.4		126.4	126.4	126.4
	142.1	126.4		126.4	126.4	126.4
		126.4		126.4	126.4	
				126.4	126.4	
				134.3	134.3	
				134.3		
				134.3		
				134.3		
				134.3		
				136.1		
Average Load:	134.3	126.4		131.3	128.0	126.4

Table H-8. Heat #2A, Data of Draw Forge Loads vs Temperature

Temp. Range (°F):	1450-1475	1476-1500	1501-1525	1526-1550	1551-1575
Draw Load (Tons):		126.4	126.4	110.7	110.7
		126.4	126.4	118.5	126.4
		126.4	133.5	126.4	126.4
		126.4	134.3	126.4	126.4
		126.4	134.3	126.4	
		134.3		126.4	
		134.3		134.3	
		134.3		134.3	
		134.3		134.3	
				134.3	
Average Load:		130.0	131.0	127.2	122.5

Table H-9. Heat #2B, Data of Draw Forge Loads vs Temperature

Temp. Range (°F):	1450-1475	1476-1500	1501-1525	1526-1550	1551-1575
Draw Load (Tons):		126.4	126.4	126.4	134.3
		142.1	134.3	126.4	134.3
			134.3	126.4	134.3
			141.4	126.4	134.3
			142.1	126.4	
			149.9	126.4	
				134.3	
				134.3	
				141.4	
				141.4	
				141.4	
				141.4	
				141.4	
				141.4	
Average Load:		134.3	138.0	134.0	134.3

APPENDIX I

I.T.T. CURVE

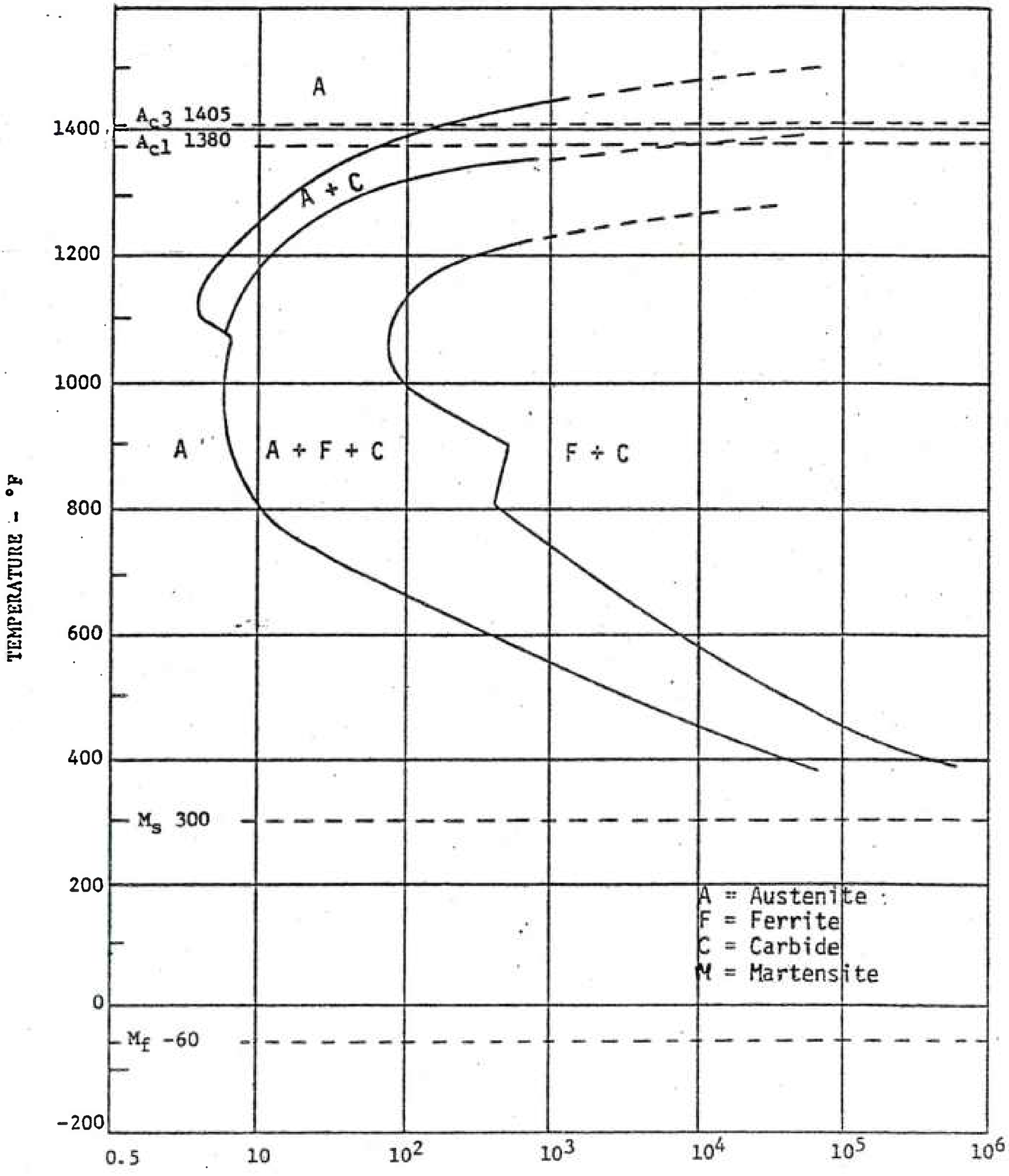


Figure I-1. I.T.T. Curve

APPENDIX J

TENSILE GRAPHS

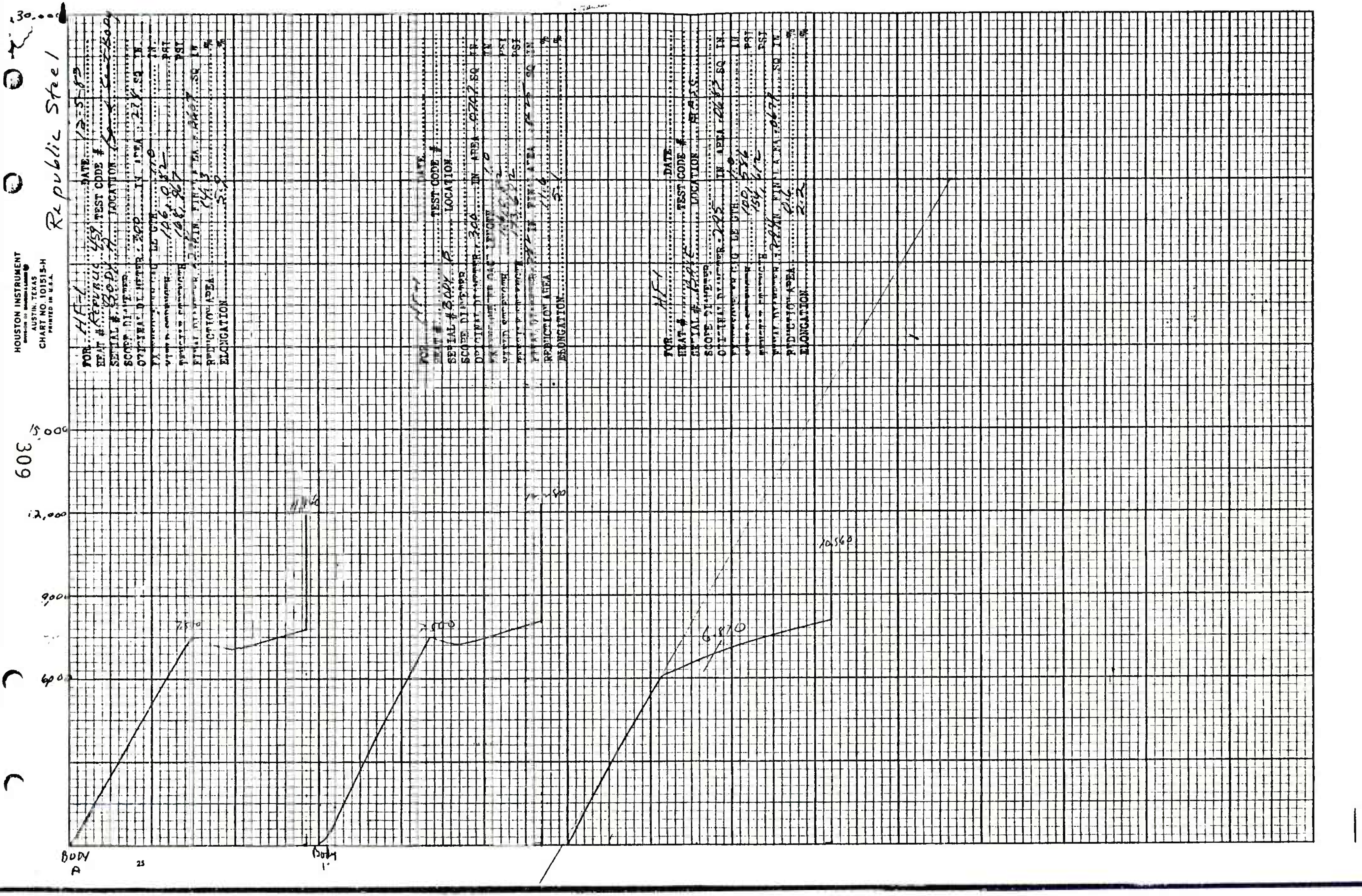
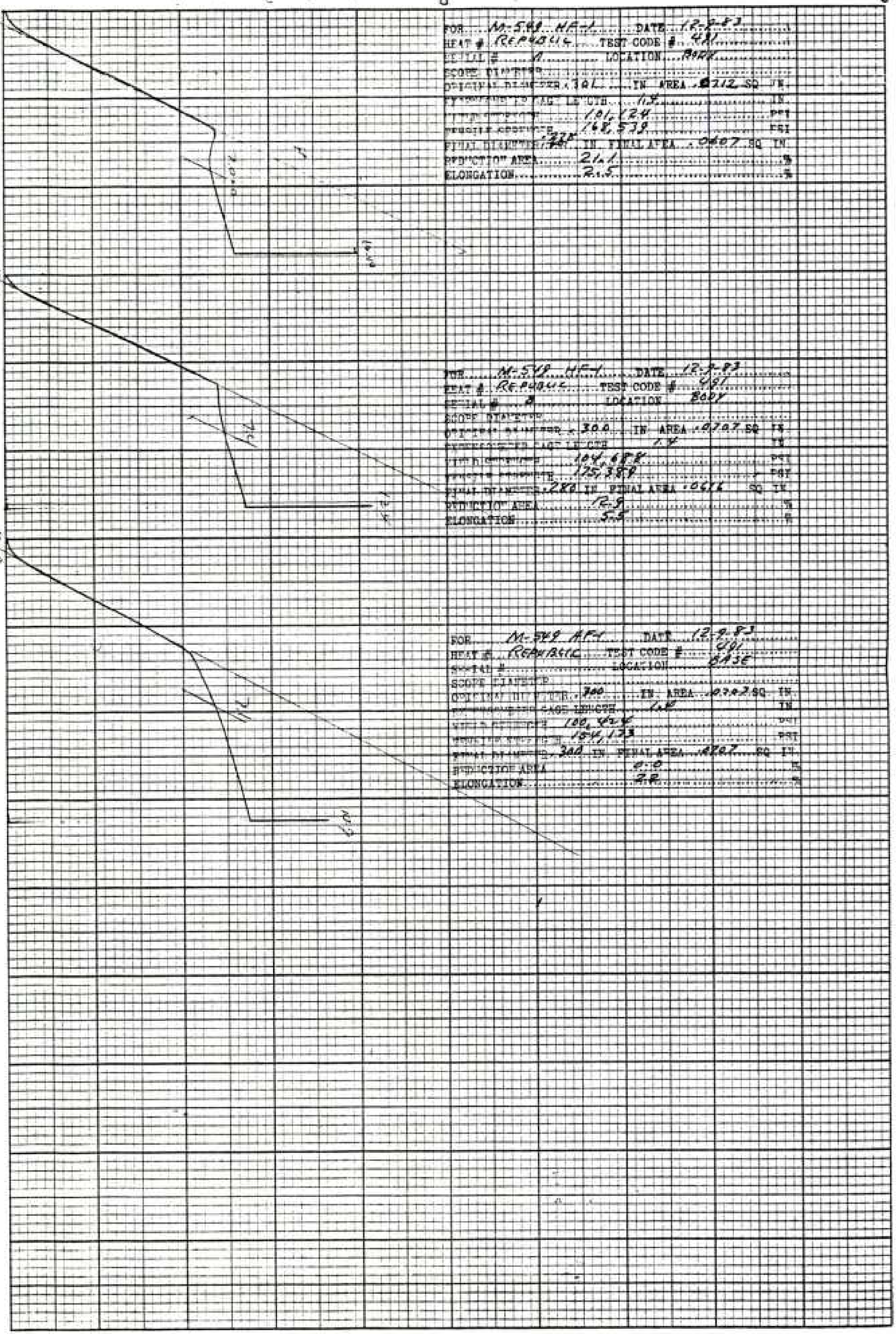


Figure J-1. Tensile Graph - Heat #1 (Republic)

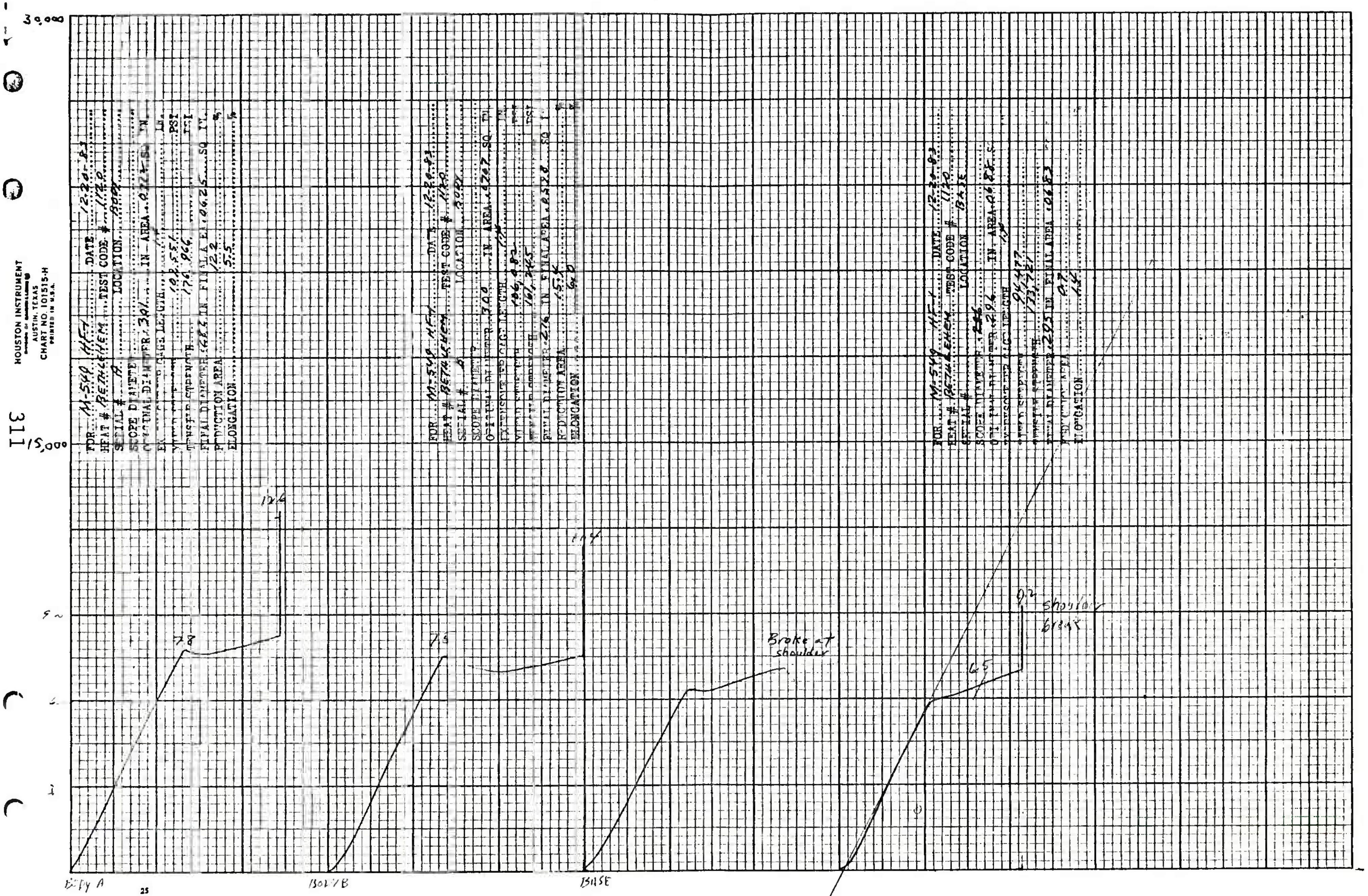


FOR M-549 HF-1 DATE 12-9-83
HEAT # REPUBLIC TEST CODE # 411
SERIAL # A LOCATION BODY
SCOPE DIAMETER
ORIGINAL DIAMETER .164 IN AREA .0212 SQ IN
EXTENSOMETER GAGE LENGTH 1.4 IN
YIELD STRENGTH 101,124 PSI
TENSILE STRENGTH 168,539 PSI
FINAL DIAMETER .228 IN FINAL AREA .0407 SQ IN
REDUCTION AREA 21.1 %
ELONGATION 2.5 %

FOR M-549 HF-1 DATE 12-9-83
HEAT # REPUBLIC TEST CODE # 411
SERIAL # B LOCATION BODY
SCOPE DIAMETER
ORIGINAL DIAMETER .300 IN AREA .0707 SQ IN
EXTENSOMETER GAGE LENGTH 1.4 IN
YIELD STRENGTH 104,688 PSI
TENSILE STRENGTH 175,389 PSI
FINAL DIAMETER .280 IN FINAL AREA .0616 SQ IN
REDUCTION AREA 12.9 %
ELONGATION 5.5 %

FOR M-549 AF-1 DATE 12-9-83
HEAT # REPUBLIC TEST CODE # 411
SERIAL # LOCATION BASE
SCOPE DIAMETER
ORIGINAL DIAMETER .300 IN AREA .0707 SQ IN
EXTENSOMETER GAGE LENGTH 1.4 IN
YIELD STRENGTH 100,424 PSI
TENSILE STRENGTH 154,173 PSI
FINAL DIAMETER .300 IN FINAL AREA .0707 SQ IN
REDUCTION AREA 0.0 %
ELONGATION 2.2 %

Figure J-2. Tensile Graph - Heat #1 (Republic)



FOR M-540 HF-1 DATE 12-20-83
HEAT # BETHLEHEM TEST CODE # 1120
SERIAL # A LOCATION BODY
SCOPE DIAMETER
ORIGINAL DIAMETER .301 IN AREA .0724 SQ IN
EXTENSOMETER GAGE LENGTH 1" IN
YIELD STRENGTH 102,551 PSI
TENSILE STRENGTH 126,966 PSI
FINAL DIAMETER .282 IN FINAL AREA .0625 SQ IN
REDUCTION AREA 12.2 %
ELONGATION 5.5 %

FOR M-549 HF-1 DATE 12-20-83
HEAT # BETHLEHEM TEST CODE # 1120
SERIAL # B LOCATION BODY
SCOPE DIAMETER
ORIGINAL DIAMETER .300 IN AREA .0707 SQ IN
EXTENSOMETER GAGE LENGTH 1" IN
YIELD STRENGTH 106,082 PSI
TENSILE STRENGTH 161,245 PSI
FINAL DIAMETER .276 IN FINAL AREA .0598 SQ IN
REDUCTION AREA 15.4 %
ELONGATION 6.0 %

FOR M-549 HF-1 DATE 12-20-83
HEAT # BETHLEHEM TEST CODE # 1120
SERIAL # LOCATION BASE
SCOPE DIAMETER .296
ORIGINAL DIAMETER .296 IN AREA .0688 SQ IN
EXTENSOMETER GAGE LENGTH 1" IN
YIELD STRENGTH 94,477 PSI
TENSILE STRENGTH 133,721 PSI
FINAL DIAMETER .295 IN FINAL AREA .0683 SQ IN
REDUCTION AREA 0.7 %
ELONGATION 1.5 %

Figure J-3. Tensile Graph - Heat #2A (Bethlehem)

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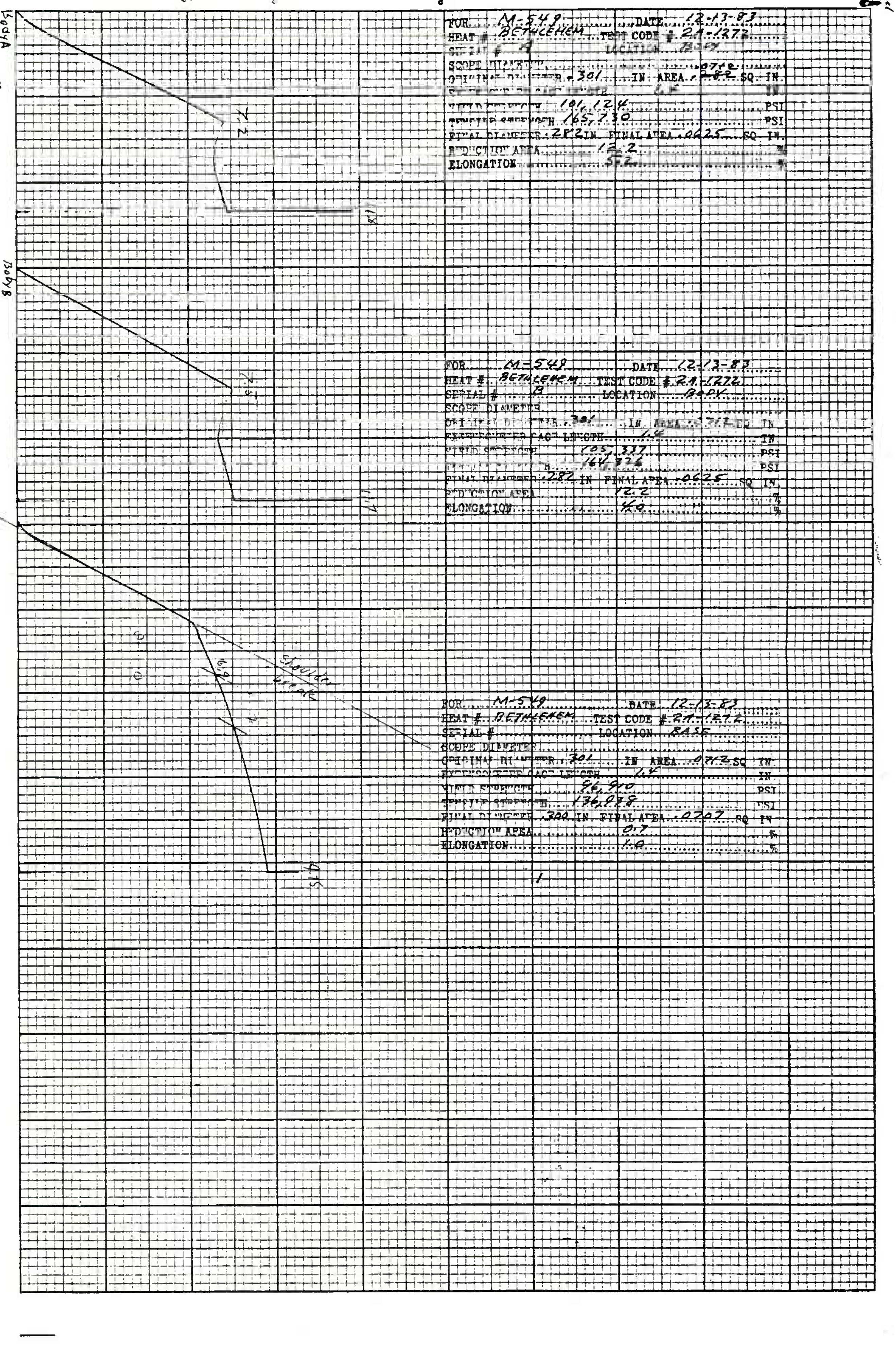
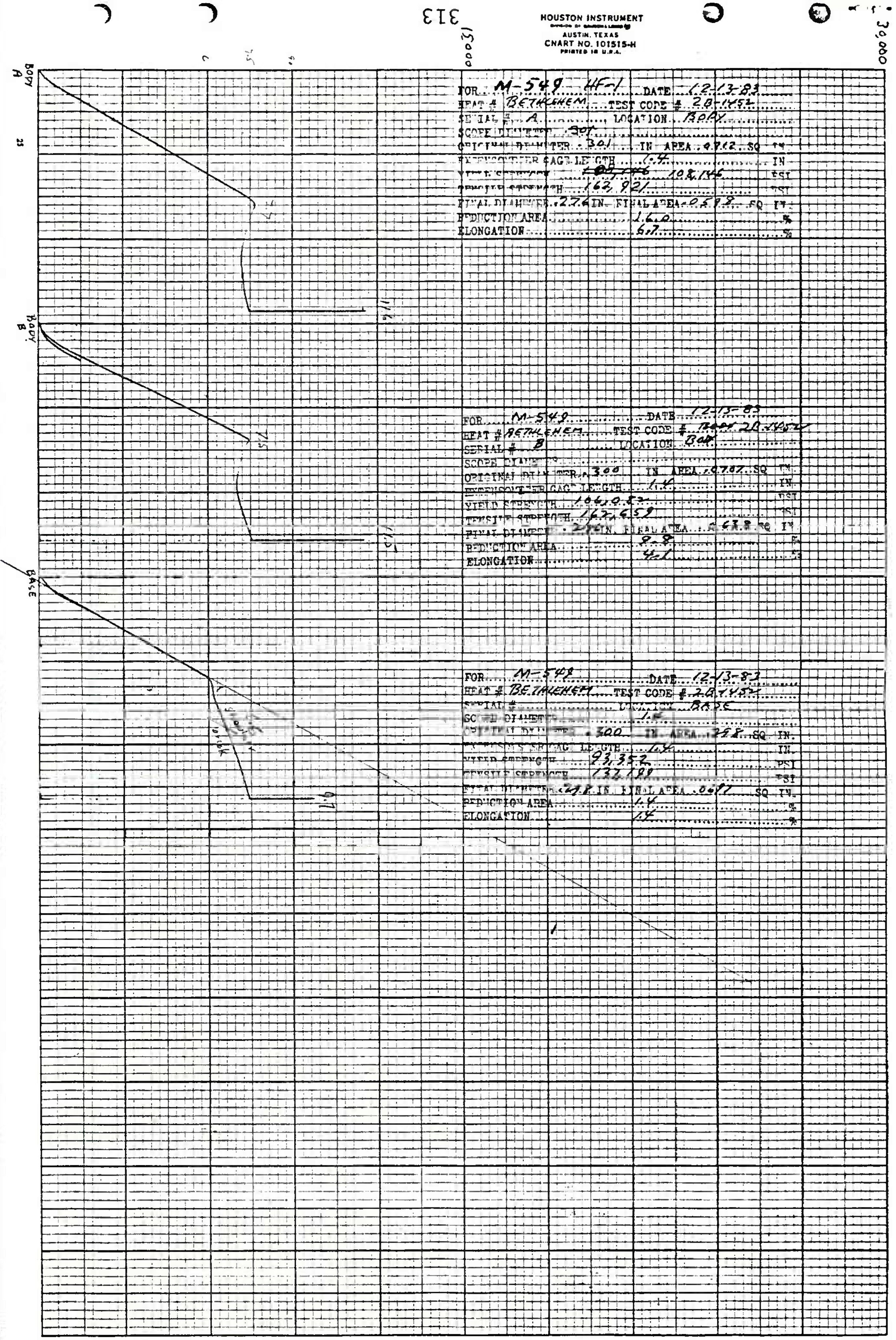


FOR M-549 DATE 12-13-83
HEAT # BETHLEHEM TEST CODE # 21-1272
SERIAL # A LOCATION BODY
SCOPE DIAMETER .0712
ORIGINAL DIAMETER .301 IN AREA ~~.282~~ SQ. IN.
EXTENSOMETER GAGE LENGTH 1.4 IN.
YIELD STRENGTH 101,124 PSI
TENSILE STRENGTH 165,730 PSI
FINAL DIAMETER .282 IN FINAL AREA .0625 SQ. IN.
REDUCTION AREA 12.2 %
ELONGATION 5.2 %

FOR M-549 DATE 12-13-83
HEAT # BETHLEHEM TEST CODE # 21-1272
SERIAL # B LOCATION BODY
SCOPE DIAMETER
ORIGINAL DIAMETER .301 IN AREA .0712 SQ IN
EXTENSOMETER GAGE LENGTH 1.4 IN
YIELD STRENGTH 105,337 PSI
TENSILE STRENGTH 164,336 PSI
FINAL DIAMETER .282 IN FINAL AREA .0625 SQ IN.
REDUCTION AREA 12.2 %
ELONGATION 4.0 %

FOR M-549 DATE 12-13-83
HEAT # BETHLEHEM TEST CODE # 21-1272
SERIAL #
LOCATION BASE
SCOPE DIAMETER
ORIGINAL DIAMETER .301 IN AREA .0712 SQ IN.
EXTENSOMETER GAGE LENGTH 1.4 IN.
YIELD STRENGTH 96,910 PSI
TENSILE STRENGTH 136,878 PSI
FINAL DIAMETER .300 IN FINAL AREA .0707 SQ IN
REDUCTION AREA 0.7 %
ELONGATION 1.0 %



FOR M-549 HF-1 DATE 12-13-83
HEAT # BETHLEHEM TEST CODE # 2B-1452
SERIAL # A LOCATION BODY
SCOPE DIAMETER .301
ORIGINAL DIAMETER .301 IN AREA .0712 SQ IN
EXTENSOMETER GAGE LENGTH 1.4 IN
YIELD STRENGTH ~~108,146~~ 108,146 PSI
TENSILE STRENGTH 162,921 PSI
FINAL DIAMETER .276 IN FINAL AREA .0598 SQ IN
REDUCTION AREA 16.0 %
ELONGATION 6.7 %

FOR M-549 DATE 12-13-83
HEAT # BETHLEHEM TEST CODE # ~~Body~~ 2B-1452
SERIAL # B LOCATION Body
SCOPE DIAMETER
ORIGINAL DIAMETER .300 IN AREA .0707 SQ IN
EXTENSOMETER GAGE LENGTH 1.4 IN
YIELD STRENGTH 106,082 PSI
TENSILE STRENGTH 167,659 PSI
FINAL DIAMETER .2[illegible] IN FINAL AREA .0638 SQ IN
REDUCTION AREA 9.8 %
ELONGATION 4.1 %

FOR M-549 DATE 12-13-83
HEAT # BETHLEHEM TEST CODE # 2B-1452
SERIAL # LOCATION BASE
SCOPE DIAMETER 1.4
ORIGINAL DIAMETER .300 IN AREA .[illegible] SQ IN
EXTENSOMETER GAGE LENGTH 1.4 IN
YIELD STRENGTH 93,352 PSI
TENSILE STRENGTH 132,188 PSI
FINAL DIAMETER .298 IN FINAL AREA .0697 SQ IN
REDUCTION AREA 1.4 %
ELONGATION 1.4 %

Figure J-5. Tensile Graph - Heat #2B (Bethlehem)

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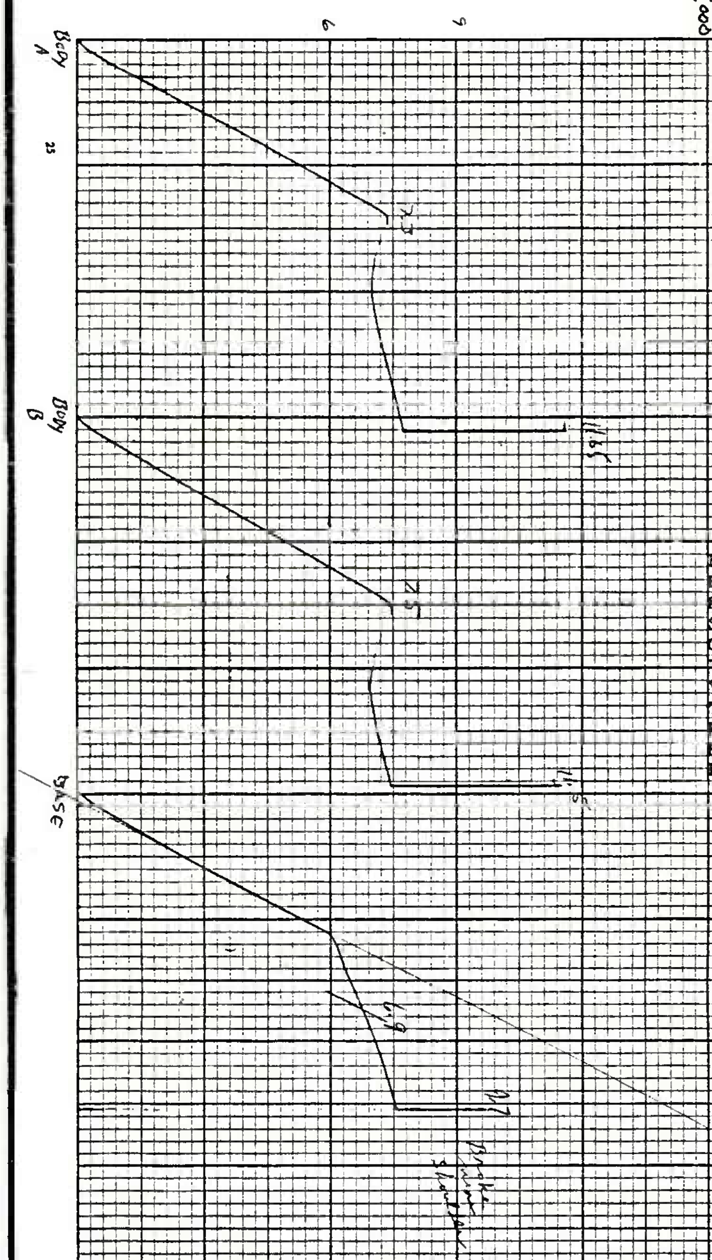
HF-1 Steel
300



FOR M-549 HF1 DATE 12-9-83
HEAT # BETHLEHEM TEST CODE # 2B-1464
SERIAL # A LOCATION BODY
SCOPE DIAMETER
ORIGINAL DIAMETER .301 IN. AREA .0712 SQ. IN.
EXTENSOMETER GAGE LENGTH 1.4 IN.
YIELD STRENGTH 102,528 PSI
TENSILE STRENGTH 163,624 PSI
FINAL DIAMETER .289 IN. FINAL AREA .0656 SQ. IN.
REDUCTION AREA 13.5 %
ELONGATION 5.5 %

FOR M-549 HF1 DATE 12-9-83
HEAT # BETHLEHEM TEST CODE # 25-1464
SERIAL # B LOCATION BODY
SCOPE DIAMETER
ORIGINAL DIAMETER .344 IN AREA .0707 SQ IN.
EXTENSOMETER GAGE LENGTH 1.4 IN.
YIELD STRENGTH 106,082 PSI
TENSILE STRENGTH 163,657 PSI
FINAL DIAMETER .278 IN FINAL AREA .0607 SQ IN.
REDUCTION AREA 14.1 %
ELONGATION 5.4 %

FOR M-549 HF-1 DATE 12-9-83
HEAT # BETHLEHEM TEST CODE # 2G-1464
SERIAL # LOCATION BASE
SCOPE DIAMETER
ORIGINAL DIAMETER .301 IN. AREA .0712 SQ. IN.
EXTENSOMETER GAGE LENGTH 1.4 IN
YIELD STRENGTH 96,910 PSI
TENSILE STRENGTH 137,199 PSI
FINAL DIAMETER .300 IN FINAL AREA .0707 SQ IN.
REDUCTION AREA 0.7 %
ELONGATION 1.0 %

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