AD

TECHNICAL REPORT ARLCB-TR-80013

THE AUSTENITIZING BEHAVIOR OF A LOW ALLOY STEEL

P. A. Thornton

May 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENÉT WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

AMCMS No. 31110T12000

PRON No. 1A8241721A1A

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacturer(s) does not constitute an official indorsement or approval.

DISPOSITION

Destroy this report when it is no longer needed. Do not return it to the originator.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARLCB-TR-80013	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Austenitizing Behavior of a Low Alloy Steel		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Peter A. Thornton		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Armament Research and Development Command Benet Weapons Laboratory, DRDAR-LCB-TL Watervliet, N.Y. 12189		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS No. 3110T12000 DA Project. PRON No. 1A8241721A1A
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research and Development Command Large Caliber Weapon System Laboratory Dover, New Jersey 07801		12. REPORT DATE May 1980 13. NUMBER OF PAGES 27
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Austentizing Behavior
Low Alloy Steel Forgings
Chemical Segregation
Heat Treatment

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

The austenitizing behavior of a low alloy steel was examined from both the microstructual and the mechanical property standpoint. The temperature range over which austenitizing took place was accurately determined by metallographic and analytical techniques.

Metallographic evidence showed that the dissolution of carbide continues after the crystallographic transition is completed. Also, the dissolution of the preponderance of carbide coincides with a "leveling-off" trend in mechanical

20. ABSTRACT (Cont'd)

property response, viz., yield strength and Charpy impact toughness.

The data demonstrated that a minimum temperature of 774° C (1425° F) can sufficiently austenitize this steel under the appropriate conditions. However, because of chemical segregation invariably found in large forgings, it is sound practice to allow some contingency in the heat treatment parameters that will consistently provide an adequate austenitizing condition in the thickest sections of a component.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

TABLE OF CONTENTS

(Continued)

INTRODUCTION

Recently, a number of 105mm M68 gun tube forgings did not conform to the strength and impact requirements of the cannon tube forging specification MIL-S-46119A. These particular tubes were heat treated in a horizontal in-line furnace system manufactured by Selas Corporation. This type of heat treatment incorporates austenitizing, quenching and tempering, in a continuous, in-line process.

An examination of the heat treatment records for these forgings revealed that the austenitizing temperature had dropped as low as 789°C (1453°F). This measurement is taken along the surface of the forging as it exits the furnace.

Since the recommended austenitizing temperature for this steel (43xx modified with V) is approximately 843°C (1550°F),[1,2] it was suspected that the non-conforming forgings were not properly austenitized.

Examination of microstructures at the forward end of the straight breech section (Figure 1) showed that the mid-radius-to-bore regions contained excessive amounts of ferrite and ferrite-carbide aggregates (similar to laminar pearlite). These microstructural features have previously been associated

---

1. Nolan, C.J., Brassard, T.V. and DeFries, R.S., "How Microstructure Influences Mechanical Properties of Forgings", Metals Engr. Quart., May 1973.
2. Heiser, F.A. "Heat Treating Gun Steel", Watervliet Arsenal Tech. Rpt., ARLCB-TR-78006, March 1978.

with incomplete transformation to austenite in gun tubes[3]. Not only does this section of the forging contain the thickest wall, but during austenitizing in the Selas system, it experiences less heating time than any other part of the thickest wall section due to the continuous movement of the workpiece through the furnace. Hence, from a heat transfer standpoint, this is the most likely portion of the tube for incomplete austenitization to occur.

OBJECTIVE

The object of this investigation was to examine the transformation behavior of the low alloy steel under consideration for a range of "austenitizing" temperatures; including the suspected low values recorded in the manufacturing process, and then to compare the corresponding mechanical properties with their attendant transformation products as revealed by metallography.

It was also desired to obtain an accurate assessment of the temperature range over which austenitization actually takes place in this material. Data of this nature will assist the establishment of a more accurate austenitizing temperature range for the heat treatment of gun steel forgings.

THEORY

The primary step in heat treating low alloy steel

---

3. Thornton, P.A., "Rapid Heat Treatment of Cannon Tubes", Watervliet Arsenal Technical Report, ARLCB-MR-79009, August 1979.

forgings is the austenitization process. In this procedure, the steel is transformed from the ferrite and carbide phases to austenite. When a mixture of ferrite and carbide is heated into the temperature range where austenite is the stable phase, the ferrite and carbide react at their interface to form nuclei of austenite[4]. This new phase grows, eventually absorbing the ferrite and carbide. Moreover, the process being diffusion controlled, generally proceeds more rapidly at higher temperatures. However, alloy carbides are particularly slow to dissolve and may persist in steels long after the ferrite has transformed. Higher austenitizing temperatures are sometimes necessary to completely transform the material to austenite within a practical time period, especially in steels containing strong carbide formers such as chromium, molybdenum and vanadium.

On the other hand, high austenitizing temperatures lead to large austenitic grains, and this condition has been frequently associated with a degradation in impact toughness and ductility of high strength steels[5,6].

---

4. Holloman, J.H. and Jaffe, L.D., "Ferrous Metallurgical Design", John Wiley and Sons, New York 1947, P. 13.

5. Wood, W.E., Met. Trans. A., Vol. 8A, July 1977, P. 1195.

6. Ritchie, R.O., Francis, B., and Server, W.L., Met. Trans. A., Vol. 8A, July 1977, P. 1197.

The temperature and time necessary for austenitic transformation is also influenced by the prior microstructure[7-9]. Generally the coarser the distribution of ferrite and carbide, the more difficult it is to obtain complete austenitization. Even after the steel has completely transformed to austenite, alloy concentration gradients may exist. In fact, in large gun tube forgings, dendritic segregation associated with solidification of the primary ingot and large scale segregation resulting from gravitational and convective effects during freezing, have been identified throughout the steel[10].

These concentration differences may remain when the steel has transformed to austenite, and a significant amount of diffusion might be necessary to alleviate this condition. In the case of carbon, fine dendritic segregation of this element may exist only for a few seconds at typical austenitizing

---

7. Holloman, J.H. and Jaffe, L.D., "Ferrous Metallurgical Design", John Wiley and Sons, New York, 1947, P. 13.

8. Siebert, C.A., Doane, D.V. and Breen, D.A. "The Hardenability of Steels", American Society for Metals, Metals Park, Ohio, 1977, p. 133.

9. Digges, T.G. and Rosenberg, S.J., Trans. ASM, Sep 1943, p. 753.

10. Thornton, P.A. and Colangelo, V.J., Met. Trans. B, Vol. 7B, Sep. 1976, p. 425.

temperatures but coarse dendritic segregation can last considerably longer (days or weeks) depending on the temperature involved. Large scale carbon gradients are extremely persistent, and are not appreciably affected for weeks or years at ordinary austenitizing temperatures[11].

Therefore, there is an empirical relationship between temperature and time, above which the austenitization process occurs satisfactorily. Just such a relationship is illustrated in Figure 2 for a plain carbon, eutectoid, steel[12]. The upper right hand portion of this figure represents the area of optimum austenitizing conditions which, in turn, produces a chemically homogeneous or uniform austenite. Below this region, transformation to austenite (recrystallization) may be essentially complete but the resulting phase is not homogeneous and can contain various amounts of ferrite and undissolved carbides. Upon cooling, these constituents may eventually appear in the quenched and tempered structure and affect the mechanical behavior of the steel. Thus, while a chemically homogeneous austenite is desirable, the problem is attaining this goal in a practical manner, on a commercial scale.

---

11. Holloman, J.H. and Jaffe, L.D., "Ferrous Metallurgical Design", John Wiley and Sons, New York 1947, p. 13.

12. Roberts, G.A. and Mehl, R.F., Trans. ASM, Vol. 31, 1943, p. 613.

Procedure

In order to evaluate the austenitizing behavior of this steel, twelve (12) coupons were sectioned from each of two (2) 105mm M68 gun tube forgings as shown in Fig. 1. Coupon dimensions were approximately 102mm x 64mm x 19mm (4" x 2-1/2" x 3/4"). The 19mm thickness was readily quenched to essentially 100% martensite, thereby eliminating variation in microstructure (austenite decomposition products) due to an insufficient quench.

Both forgings were manufactured from basic electric furnace - vacuum degassed steel, but Number 23223 was subsequently processed by electroslag refining (ESR). Their respective ladle analyses are given as follows:

Forging Number	Weight % Percent								
	C	Mn	P	S	Si	Ni	Cr	Mo	V
6303	.34	.60	.009	.004	.16	2.23	1.00	.48	.12
23223	.36	.56	.010	.009	.12	2.44	1.05	.49	.08

Twelve (12) austenitizing temperatures ranging from 690°C (1275°F) to 843°C (1550°F) in increments of 14°C (25°F) were examined. Temperatures were independently monitored by a Type K thermocouple (Chromel-Alumel) placed in contact with the coupon. The temperatures were read by both a Hewlett-Packard 7100B strip chart recorder and a Honeywell potentiometer, Model 2702.

These instruments were connected to an electronic ice point reference junction manufactured by Joseph Kaye Co. (Model RC-51). This multi-component system provided a temperature measurement at the coupon accurate to within ± 5°F. Individual specimens were "solutionized" for 45 minutes, water quenched, and then tempered at 580°C (1075°F) for one (1) hour.

Two (2) 90mm (0.357") diameter tensile specimens and two (2) standard Charpy V-notch specimens (10mm square) were machined from each coupon as illustrated in Figure 1. The tensile specimens were tested at room temperature; Charpy specimens at -40°C.

Correspondingly, a metallographic examination was performed on specimens from each austenitizing treatment to ascertain relative differences in their microstructures. This also allowed an approximate determination of the beginning of transformation (Ac_1) through grain size observations, and an estimate of complete austenitization (Ac_3) by observing the proportions of untransformed structure, such as ferrite and ferrite-carbide aggregates that remained after the thermal treatment.

Independently, a more accurate assessment of the austenitizing temperatures (Ac_1 and Ac_3) was conducted on this steel by Differential Thermal Analysis (DTA)[13]. In this

---

13. Wendlant, W., "Thermal Methods of Analysis", John Wiley and Sons, New York, 1974, p. 134.

method a small sample of forging number 6303 was heated in the DTA apparatus at 20°/min. and its temperature was recorded as a function of the system's temperature. Phase transitions such as the crystallographic change from body centered cubic (bcc) to face centered cubic (fcc) which occur during austenitization, produce an endothermic effect. Since endothermic reactions absorb heat, a temperature decrease or concavity in the DTA curve will accompany the transformation. The beginning of this drop corresponds to the start of transformation (Ac1) while the bottom of the concavity signifies the finish (Ac_3).

Discussion of Results

Mechanical Property Behavior

The results of mechanical testing are compiled in Tables 1 and 2. The yield strength and Charpy impact energy are also plotted for the respective austenitizing temperatures in Figures 3 and 4. An examination of the curves in Figure 3 (No. 6303 - Vacuum Degassed) shows the yield strength to decrease for the treatments between 690°C - 718°C (1275°F-1325°F). However, at the latter temperature, this behavior suddenly changes and the yield strength increases sharply as the austenitizing temperature is raised to about 774°C (1425°F). Then temperatures between 774°C - 843°C (1425°F-1550°F) have only a slight effect on the yield strength; which ranged from

1138-1201 MPa (165-174 ksi) for this interval. The ESR material (Forging 23223) exhibits essentially the same behavior.

Correspondingly, the Charpy impact energy for Forging 6303 displays a sharp drop, in the neighborhood of 690°C - 760°C (1275°F-1400°F). Thereafter the impact energy decreased with increasing austenitizing temperature but in a conspicuously slower manner. Impact energy behavior in Forging 23223 displayed a similar trend, but the property levels were noticeably higher than those of 6303 for a given yield strength.

This observation was most perceptible at the 774°C (1425°F) austenitizing condition, where the yield strength began to "level-off" in both forgings. At this temperature, the yield strength range for both steels was rather narrow; 1104-1152 MPa (160-167 ksi). Yet the Charpy impact level for Forging 23223 was on the order of 50J (37 ft-lb), whereas Forging 6303 exhibited about 39J (29 ft-lb), a difference of 11J or 8 ft-lbs. The apparent variation in transverse impact behavior is very likely due to differences in melting and solidification between the two types of steels; ESR exhibiting a more uniform dendritic grain structure and possibly lower nonmetallic inclusion content than the vacuum-degassed, air melted steel. Another important aspect demonstrated by this data is that increasing the austenitizing temperature above 774°C (1425°F) does not significantly affect the yield strength, but produces a continuous decrease in Charpy impact. For example, by increasing the austenitizing temperature from774°C (1425°F) to 843°C (1550°F) in Forging 23223, the Charpy impact energy decreased from 50J (37 ft-lb) to 40J (29 ft-lb).

In a mechanical property sense, this result emphasizes an important point regarding the austenitizing behavior of this steel. Once a satisfactory austenitizing temperature (condition) is attained, based on acceptable yield strength, further heating can be detrimental to the low temperature toughness properties as measured by Charpy impact. In the case of our particular samples, that temperature was 774°C (1425°F). But achieving this "satisfactory" condition in a gun tube forging or any large forging, is another matter. Since a gun tube is a long, thick-wall cylinder, most heat flows from the outside surface (OD) to the bore (ID). Therefore, the last regions to arrive at the austenitizing temperature are very likely to be close to the ID. Accordingly, with insufficient time or inadequate temperature, these areas of the forging may not properly transform to austenite.

Metallurgical

The metallographic examination of our test samples vividly demonstrates the microstructural features of inadequate austenitizing conditions. For example, in the coupons austenitized between 690°C-718°C (1275°F-1325°F), the quenched and tempered microstructure contains relatively large amounts of previously untransformed ferrite and ferrite-carbide aggregates. Such typical features are shown in Figure 5. Microstructural evidence of recrystallization was observed in specimens from the austenitizing treatment at 732°C (1350°F). Figure 6 reveals the new austenite grains growing predominantly from sites associated with prior austenitic grain boundaries. These most recent grains present a chain-like appearance against the as-yet untransformed matrix.

In the vicinity of 788°C-802°C (1450°F-1475°F), the preponderance of previously untransformed structure (ferrite and carbide) has vanished and the quenched and tempered microstructure consists of lath-like martensite as shown in Figure 7.

Differential Thermal Analysis

The results of the DTA for Forging 6303 are illustrated in Figure 8. The concave portion of the temperature differential curve (number 3) represents the endothermic reaction associated with transformation to austenite in this steel. Based on a heating rate of 20°C/min., recrystallization starts at approximately 723°F (1333°F) and ends on the upward side of the endothermic "peak" (minima), at approximately 758°C (1396°F). A comparison of the transformation temperatures determined by DTA and by mechanical response is made in the following table:

Transformation Temperature °C (°F)

Method	Ac_1	Ac_3
DTA	723 (1333)	758 (1396)
Mech. Prop.	718 (1325)	774 (1425)
Temp. Diff.	5 (8)	16 (29)

Compared to the austenitizing temperature value responsible for effecting a noticeable change in mechanical property behavior, the transformation start temperature (Ac_1) of 723°C (1333°F) via the DTA technique is only 5°C higher than the temperature corresponding to the yield strength minimum. However, this only amounts to a temperature differential of 2%. Conversely, the recrystallization finish temperature (Ac_3) indicated by DTA at approximately 758°C (1396°F) is roughly 16°C lower than the temperature conditions where the yield strength began to "level off" (approx. 774°C). Thus, the analytical data shows that recrystallization was essentially complete at about 758°C (1396°F) but the corresponding mechanical property responses continued to change with increasing austenitizing temperature. As the austenitizing temperature was increased from 758°C to 843°C (1550°F), the yield strength improved and the Charpy impact response decreased.

As previously discussed, the dissolution of carbides in this steel, particularly alloy carbides, can be difficult to achieve[14,15]. Nevertheless, dissolution of carbides is very important to the homogeniety of the austenite and the resultant quenched and tempered properties. The additional improvement in yield strength after recrystallization is complete [approx. 758°C-774°C (1400°F-1425°F)] is very likely due to further dissolution of carbides. Unfortunately, segregation of carbon in this steel is difficult to prevent during solidification of the ingot. This chemically inhomogeneous condition is not eliminated during subsequent heating and forging operations but merely altered[16]. Thus, during the final heat treatment, segregated regions of the material respond differently to austenitization because they have different carbon concentrations. These regions or

---

14. Griffin, R., "Rapid Austenitization of a Modified 4340 Alloy", Watervliet Arsenal Technical Report, WVT-TR-75029, June 1975.

15. Bain, E.C. and Paxton, H.W., "Alloying Elements in Steel", American Society for Metals, Metals Park, Ohio, 1961, p. 113.

16. Thornton, P.A. and Colangelo, V.J., "Variation of Mechanical Properties in Large Steel Forgings", Met. Trans. B, Vol 7B, Sep 1976, p. 425

bands of higher carbon content will be difficult to solutionize thereby producing a relatively inhomogeneous austenite.

In summary, our results underscore the problem of adequately austenitizing large gun tube forgings produced from low alloy steel. A temperature sufficient to effect both recrystallization and dissolution of the carbide phase must be attained in the thickest section of the forging. This temperature depends not only on heating rate and the nominal chemistry (ladle analysis) of the steel, but also on the prior degree of alloy segregation; especially carbon. The greater the uniformity of carbon distribution in the forging, the easier it will be to produce a sufficient austenitizing condition. From a practical standpoint, this is very important because it allows lower austenitizing temperatures and/or less furnace time to achieve a satisfactory austenitic condition; which in turn will yield an acceptable combination of yield strength and impact toughness in the quenched and tempered product.

Conclusions

The austenitizing behavior of this steel has been analyzed by two methods. An analytical technique (DTA), showed the recrystallization temperature range, A_{c1} - A_{c3}, to be on the order of 723°C-758°C (1333°F - 1396°F). This temperature interval represents the crystallographic transformation to austenite. However, it does not specifically separate the dissolution of carbide from this crystallographic transformation.

The mechanical property evaluation in conjunction with metallography demonstrates a noticeable change in yield strength and Charpy impact behavior between 718°C-774°C (1325°F-1425°F). This temperature interval encompasses the recrystallization event as determined by DTA. The metallographic evidence shows that the dissolution of carbide continues after the crystallographic transition is completed. Furthermore, the dissolution of the preponderance of carbide is roughly coincident with the"leveling-off" trend observed in the mechanical properties.

This information clearly establishes that a minimum temerature of 774°C (1425°F) can sufficiently austenitize this steel under certain conditions. These conditions include: heating rate - the faster the heating rate, the higher the minimum austenitizing temperature; chemical homogeneity - the more uniform the carbon distribution in the steel, the easier it is to obtain a reasonably homogeneous austenite; section size - the heavier the section size of the workpiece, the longer the time required to attain the minimum austenitizing temperature throughout the thickest section.

Therefore, the practical considerations of austenitizing large, low alloy steel forgings must be integrated with the experimental evidence. Because of the material variations invariably encountered in such forgings, it is sound practice to allow some contingency in the heat treatment parameters that will consistently provide an adequate austenitizing condition in the heavy sections of the work. Past experience with this material shows that 843°C (1550°F) consistently produces acceptable mechanical properties. However, from the results of this present study, we can conclude that temperatures as much as 69°C or 125°F lower than the optimum value, can produce acceptable properties and microstructure. The important aspects of this deviation from 843°C (1550°F) are: the accuracy of temperature measurement; the degree of process control (heating rate) and the inherent variability (chemical segregation) of the material being processed.

TABLE I - MECHANICAL PROPERTIES FORGING 6303

Austenitizing Temperature		Y.S.		UTS				-40° Charpy Impact		Hardness
°C	°F	MPa	ksi	MPa	ksi	%El	%RA	J	Ft-lb	R_c
690	1275	769	111.5	893	129.6	19	51	62	46	28
		748	108.5	886	128.6	20	58	73	54	
704	1300	707	102.5	859	124.6	20	58	57	42	26
		665	96.4	817	118.5	*	57	53	39	
718	1325	694	100.7	859	124.6	20	58	52	38	25
		665	96.4	845	122.6	20	58	54	40	
732	1350	717	104.0	893	129.6	19	50	46	34	
		696	101.0	893	129.6	18	52	49	36	28
746	1375	832	120.6	980	142.2	18	49	61	45	31
		810	117.5	970	140.7	19	51	60	44	
760	1400	998	144.7	1098	159.3	15	45	43	32	35
		956	138.7	1084	157.2	16	49	46	34	
774	1425	1149	166.7	1212	175.8	14	40	34	25	38
		1122	162.8	1212	175.8	14	43	35	26	
789	1450	1164	168.8	1217	176.3	14	38	39	29	39
		1158	167.9	1217	176.3	15	43	38	28	
802	1475	1195	173.3	1254	181.9	14	39	32	24	40
		1205	174.8	1261	182.9	16	45	38	28	
816	1500	1174	170.3	1240	179.9	15	43	38	28	40
		-	-	"Missing"	-	-	-	39	29	
829	1525	1180	171.2	1254	181.9	15	43	37	27	
		1164	168.8	1254	181.9	15	45	35	26	41
843	1550	1164	168.8	1247	180.9	15	49	32	24	39
		1176	170.6	1247	180.9	16	50	34	25	

*Specimen failed outside gage length.

TABLE II - MECHANICAL PROPERTIES FORGING 23223

Austenitizing Temperature		Y.S.		UTS				-40° Charpy Impact		Hardness
°C	°F.	MPa	ksi	MPa	ksi	%El	%RA	J	Ft-lb.	R_c
690	1275		107.0		127.1	20	53	76	56	26
			112.1		129.2	22	58	Missing		
704	1300		106.0		126.2	21	58	76	56	24
			103.0		124.2	21	55	84	62	
718	1325		103.0		126.2	20	53	72	53	26
			103.0		128.2	21	58	79	58	
732	1350		115.1		137.3	17	49	64	47	30
			111.2		137.3	19	51	68	50	
746	1375		127.5		149.2	17	49	53	39	32
			124.8		146.7	17	50	60	44	
760	1400		145.4		159.8	14	49	52	38	36
			141.7		159.8	16	47	57	42	
774	1425		-		Missing	-	-	43	32	38
			167.3		179.9	16	45	58	43	
789	1450		162.2		173.8	14	43	46	34	38
			163.7		176.8	16	47	43	32	
802	1475		165.9		175.2	14	42	45	33	39
			165.8		177.8	16	49	46	34	
816	1500		166.7		177.8	16	46	41	30	39
			164.3		177.8	16	47	46	34	
829	1525		173.3		187.3	14	45	38	28	41
			169.7		185.4	14	45	38	28	
843	1550		169.0		181.3	14	41	41	30	40
			169.7		182.8	16	48	38	28	

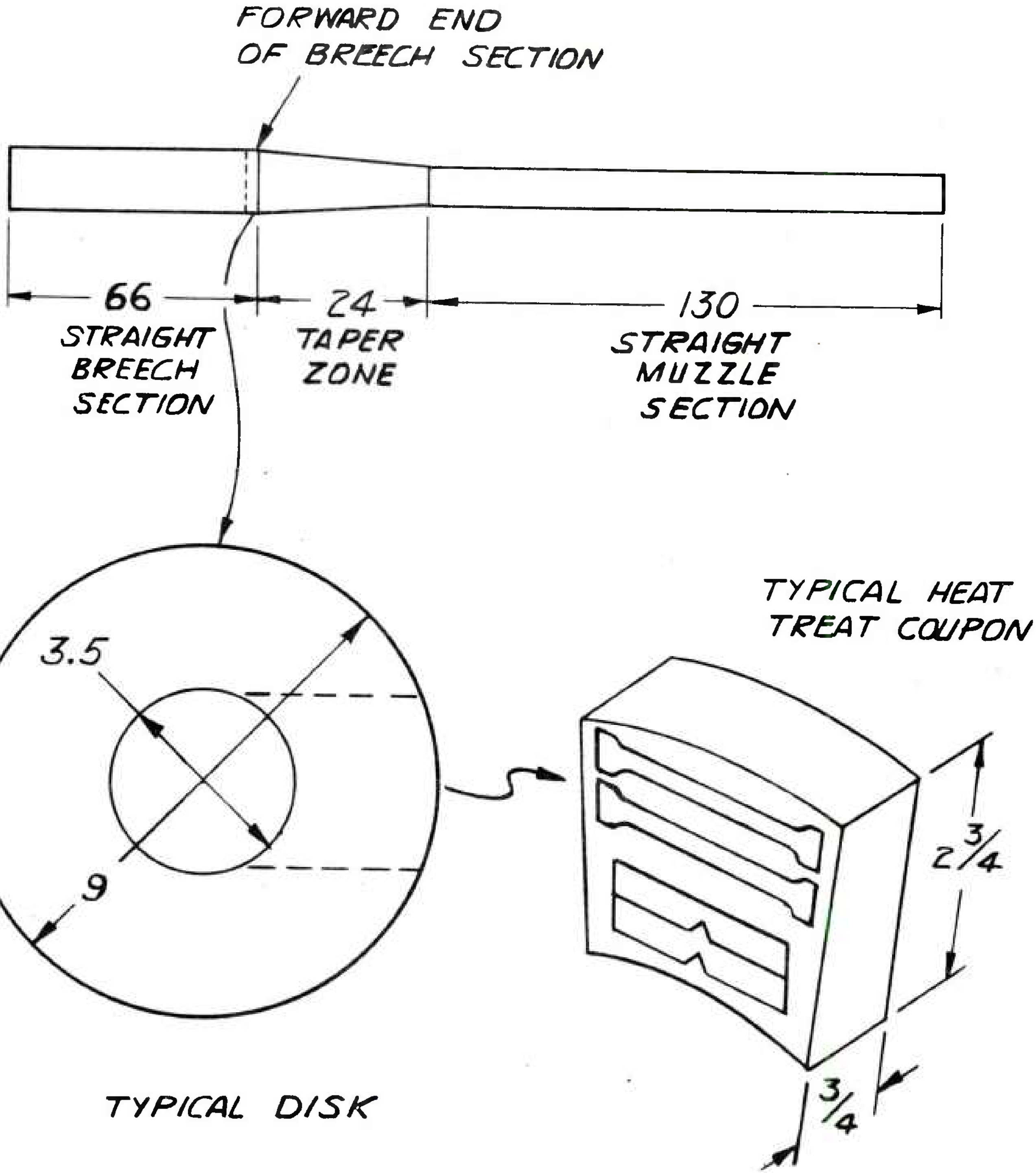


FIG. 1 - Schematic showing 105mm M68 gun tube forging with layout for heat treat specimens. Dimensions in inches.

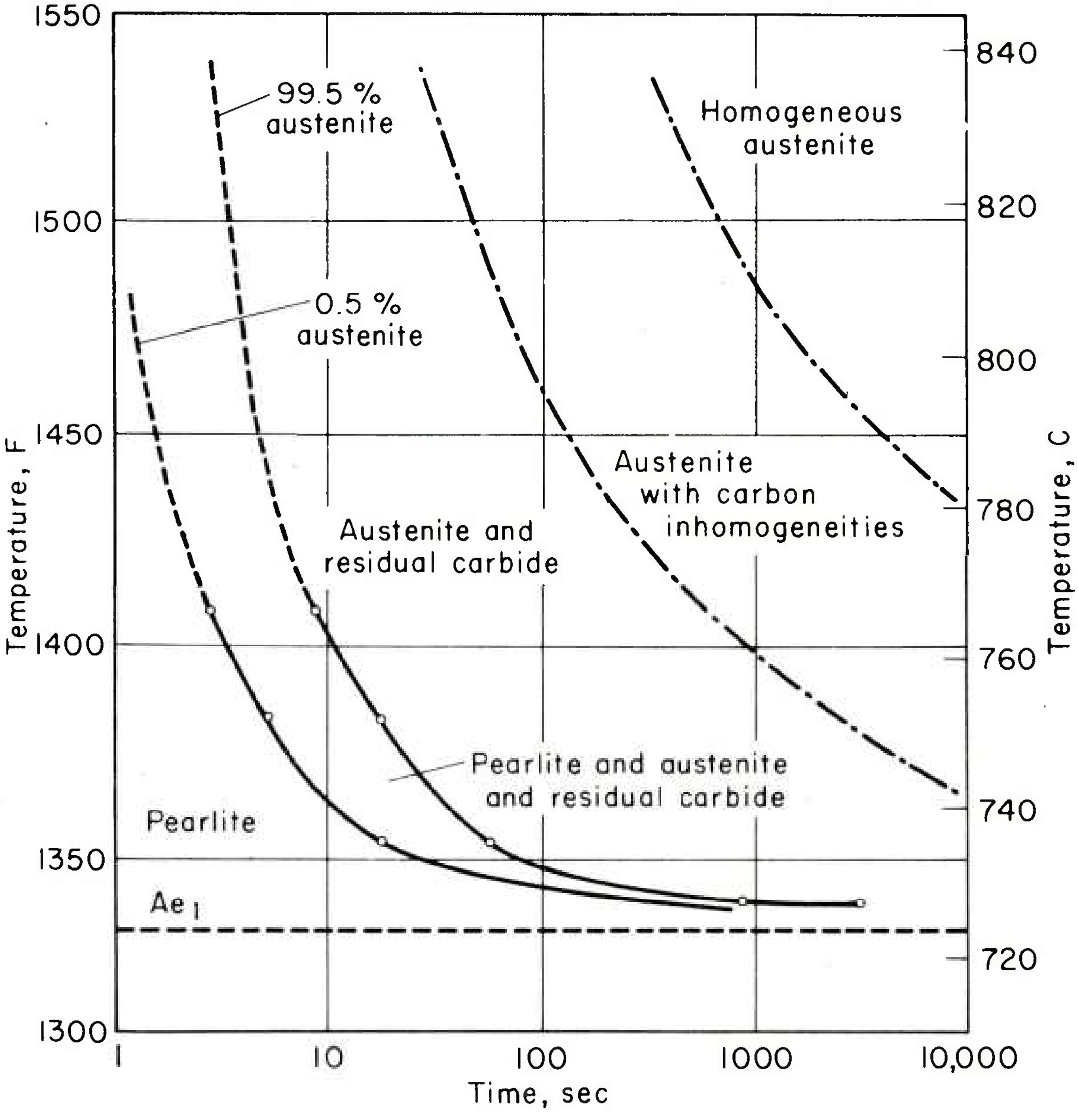
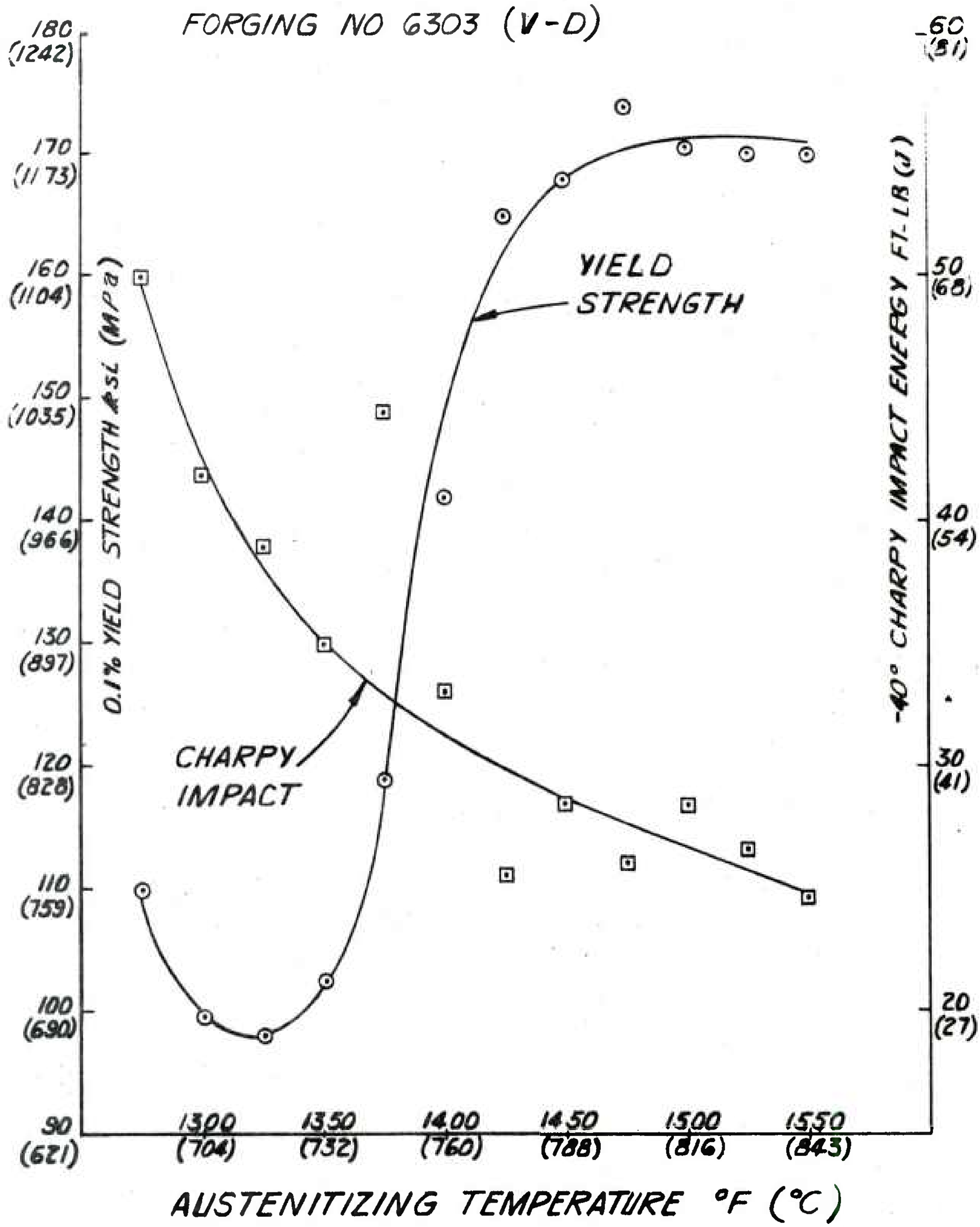
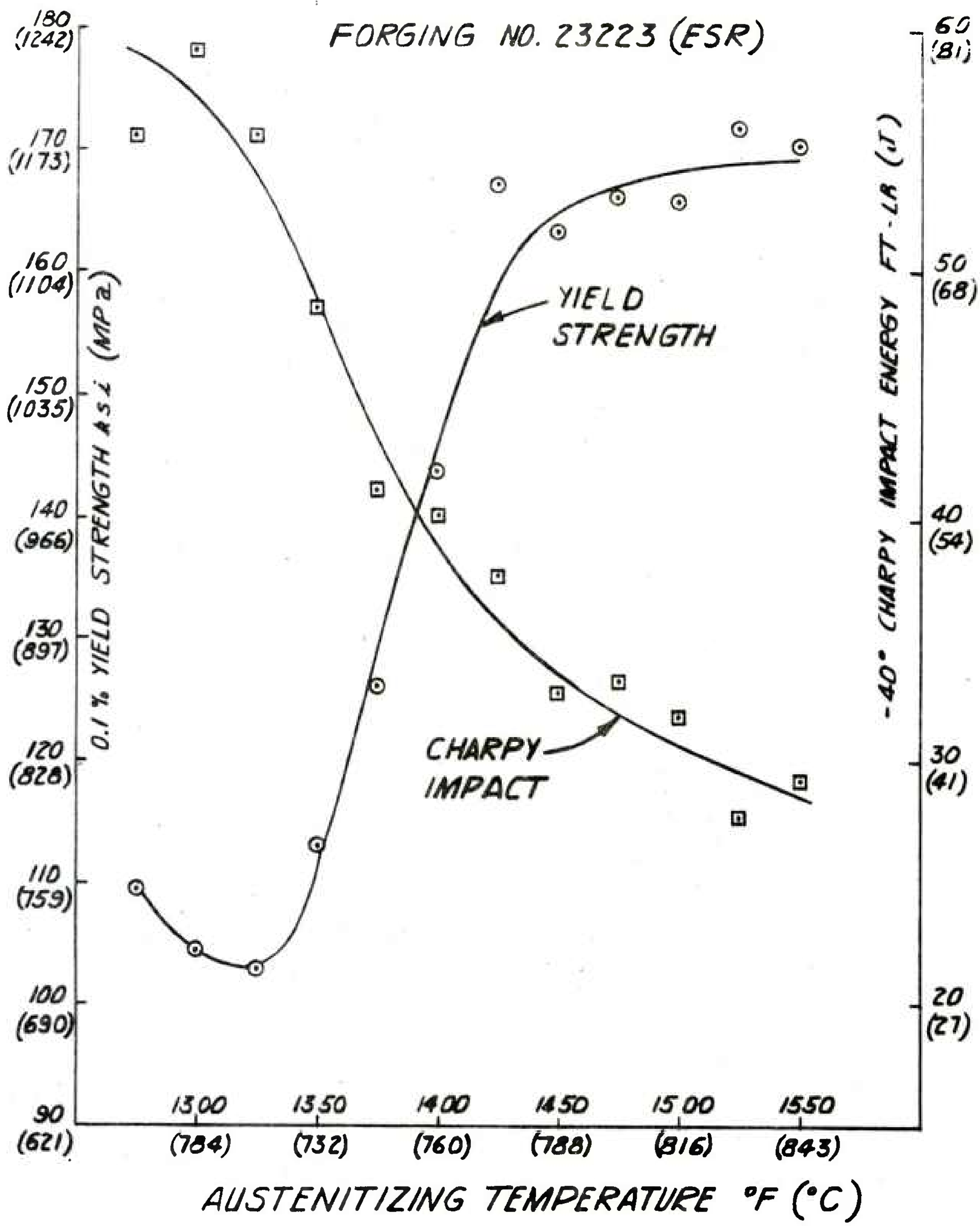


FIG. 2 - Temperature-time relationship for austenitizing plain carbon steel. (After Roberts and Mehl)



FLG. 3. Mechanical Property Behavior vs. Austenitizing Temperature in Forging #6303.



4

FIG. 4. Mechanical Property Behavior vs. Austenitizing Temperature in Forging #23223.

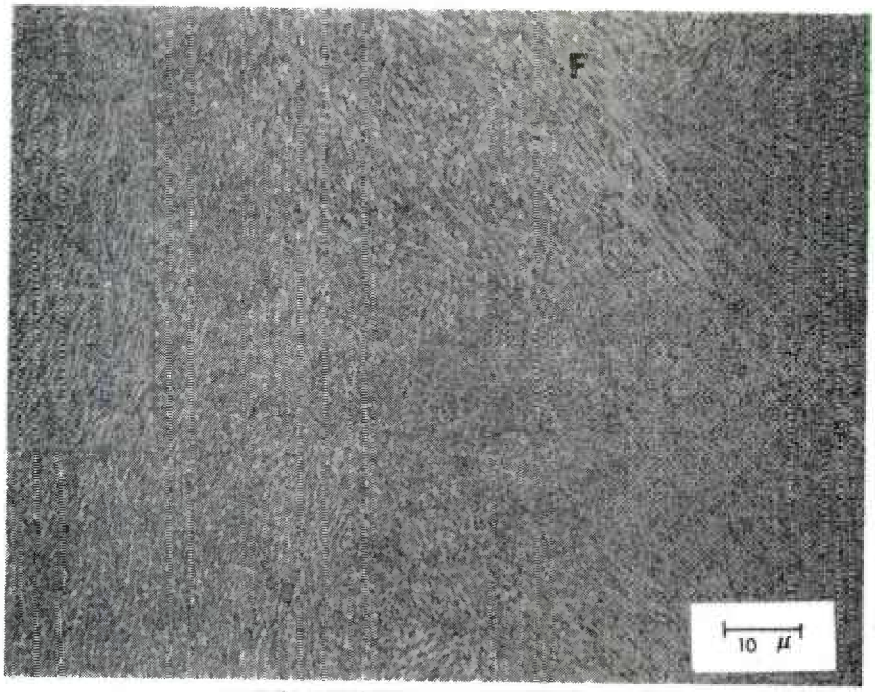


FIG. 5 - Photomicrograph showing untransformed structure in Forging #23223 for the 690°C (1275°F) austenitizing condition. F denotes ferritic regions.

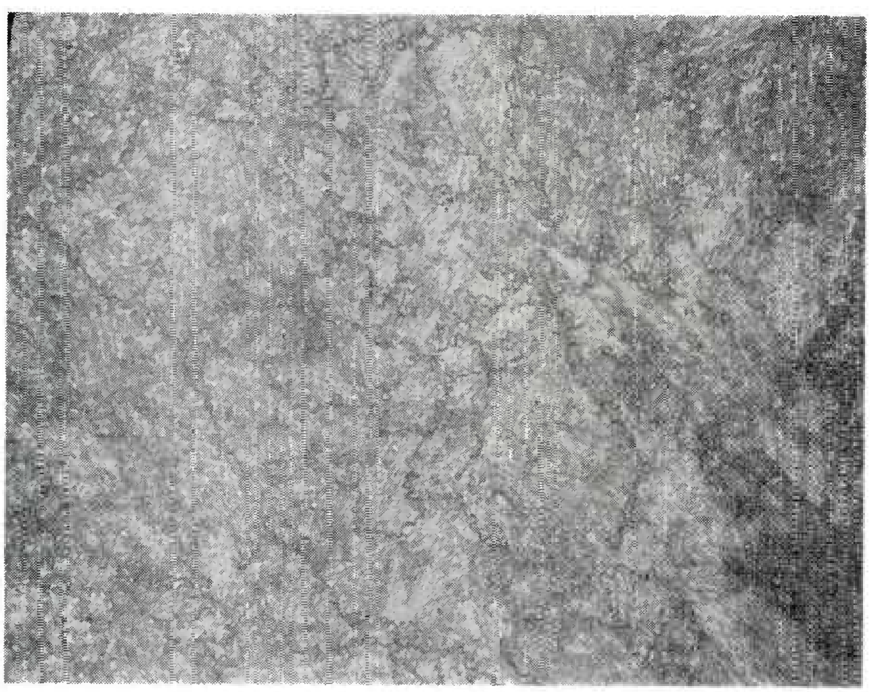


FIG. 6 - Photomicrograph showing recrystallization at the prior austenitic grain boundaries in Forging 6303 for the 732°C (1350°F) treatment.

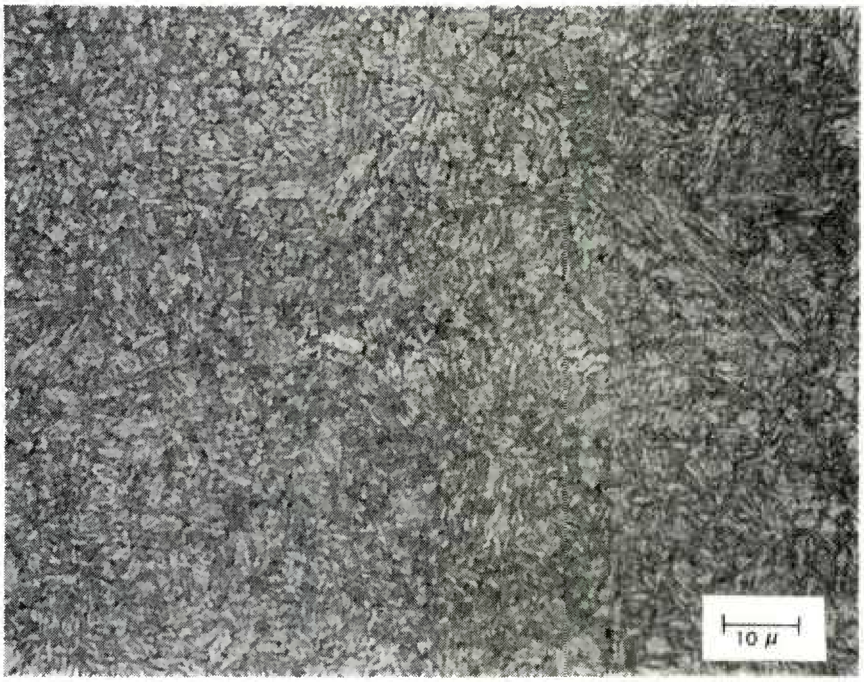


FIG. 7 - Photomicrograph showing tempered martensitic microstructure in Forging #6303 for the 802°C (1475°F) austenitizing treatment.

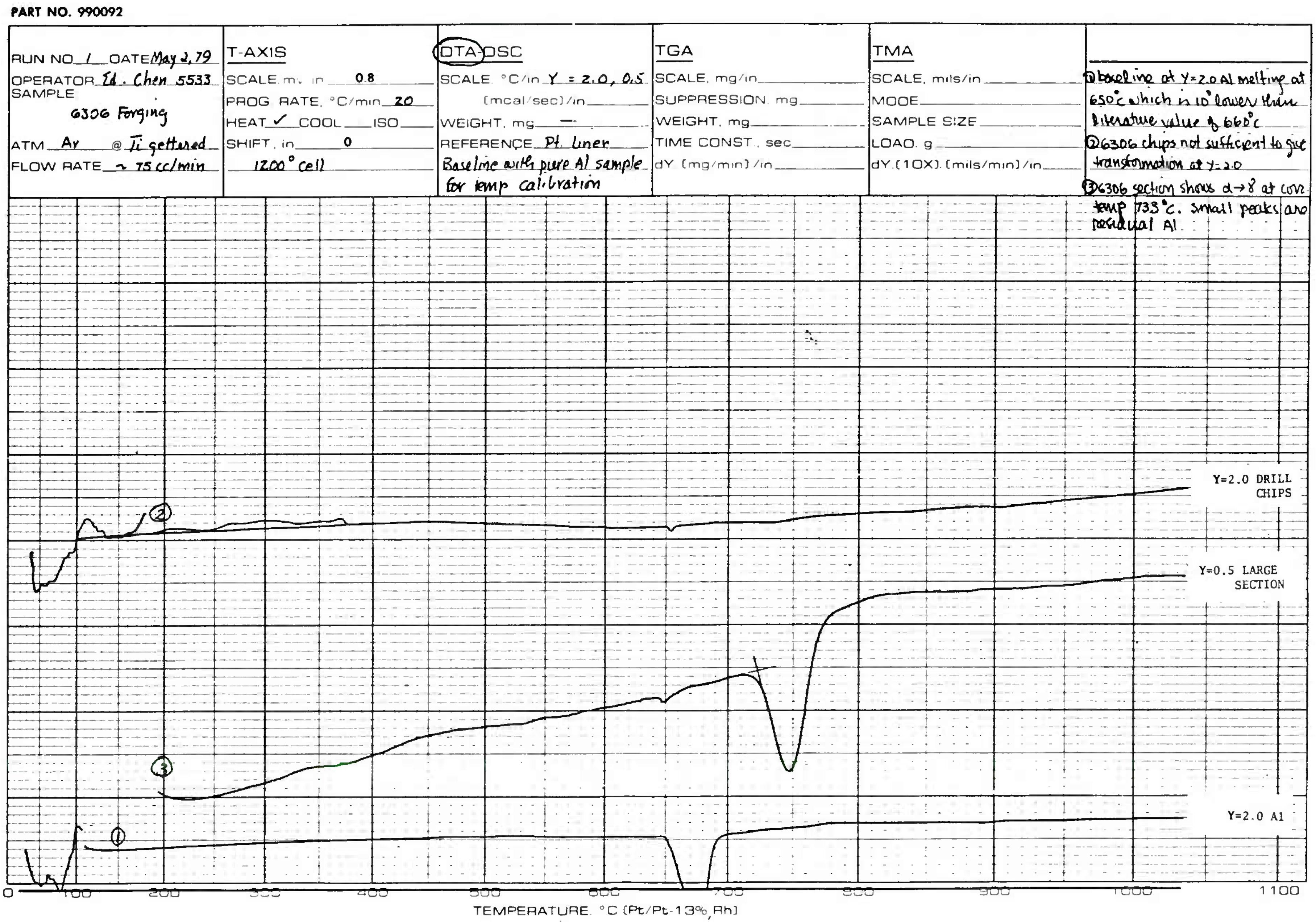


FIGURE C. DTA Curve for Specimen #6303. Curve #3 Illustrates the endothermic reaction associated with Austenitic transformation. Temperature correction +10°C

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
COMMANDER	1
CHIEF, DEVELOPMENT ENGINEERING BRANCH	1
ATTN: DRDAR-LCB-DA	1
-DM	1
-DP	1
-DR	1
-DS	1
-DC	1
CHIEF, ENGINEERING SUPPORT BRANCH	1
ATTN: DRDAR-LCB-SE	1
-SA	1
CHIEF, RESEARCH BRANCH	2
ATTN: DRDAR-LCB-RA	1
-RC	1
-RM	1
-RP	1
CHIEF, LWC MORTAR SYS. OFC.	1
ATTN: DRDAR-LCB-M	1
CHIEF, IMP. 81MM MORTAR OFC.	1
ATTN: DRDAR-LCB-I	1
TECHNICAL LIBRARY ATTN: DRDAR-LCB-TL	5
TECHNICAL PUBLICATIONS & EDITING UNIT ATTN: DRDAR-LCB-TL	2
DIRECTOR, OPERATIONS DIRECTORATE	1
DIRECTOR, PROCUREMENT DIRECTORATE	1
DIRECTOR, PRODUCE ASSURANCE DIRECTORATE	1

NOTE: PLEASE NOTIFY ASSOC. DIRECTOR, BENET WEAPONS LABORATORY, ATTN: DRDAR-LCB-TL, OF ANY REQUIRED CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH & DEVELOPMENT ATTN: DEP FOR SCI & TECH THE PENTAGON WASHINGTON, D.C. 20315	1
COMMANDER US ARMY MAT DEV & READ. COMD ATTN: DRCDE 5001 EISENHOWER AVE ALEXANDRIA, VA 22333	1
COMMANDER US ARMY ARRADCOM ATTN: DRDAR-LC	1
-LCA (PLASTICS TECH EVAL CEN)	1
-LCE	1
-LCM	1
-LCS	1
-LCW	1
-TSS(STINFO) DOVER, NJ 07801	2
COMMANDER US ARMY ARRCOM ATTN: DRSAR-LEP-L ROCK ISLAND ARSENAL ROCK ISLAND, IL 61299	1
DIRECTOR US Army Ballistic Research Laboratory ATTN: DRDAR-TSB-S (STINFO) ABERDEEN PROVING GROUND, MD 21005	1
COMMANDER US ARMY ELECTRONICS COMD ATTN: TECH LIB FT MONMOUTH, NJ 07703	1
COMMANDER US ARMY MOBILITY EQUIP R&D COMD ATTN: TECH LIB FT BELVOIR, VA 22060	1
COMMANDER US ARMY TANK-AUTMV R&D COMD ATTN: TECH LIB - DRDTA-UL	1
MAT LAB - DRDTA-RK WARREN MICHIGAN 48090	1
COMMANDER US MILITARY ACADEMY ATTN: CHMN, MECH ENGR DEPT WEST POINT, NY 10996	1
COMMANDER REDSTONE ARSENAL ATTN: DRSMI-RB	2
-RRS	1
-RSM ALABAMA 35809	1
COMMANDER ROCK ISLAND ARSENAL ATTN: SARRI-ENM (MAT SCI DIV) ROCK ISLAND, IL 61202	1
COMMANDER HQ, US ARMY AVN SCH ATTN: OFC OF THE LIBRARIAN FT RUCKER, ALABAMA 36362	1
COMMANDER US ARMY FGN SCIENCE & TECH CEN ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1
COMMANDER US ARMY MATERIALS & MECHANICS RESEARCH CENTER ATTN: TECH LIB - DRXMR-PL WATERTOWN, MASS 02172	2

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST (CONT)

	NO. OF COPIES		NO. OF COPIES
COMMANDER US ARMY RESEARCH OFFICE P.O. BOX 12211 RESEARCH TRIANGLE PARK, NC 27709	1	COMMANDER DEFENSE TECHNICAL INFO CENTER ATTN: DTIA-TCA CAMERON STATION ALEXANDRIA, VA 22314	12
COMMANDER US ARMY HARRY DIAMOND LAB ATTN: TECH LIB 2800 POWDER MILL ROAD ADELPHIA, MD 20783	1	METALS & CERAMICS INFO CEN BATTELLE COLUMBUS LAB 505 KING AVE COLUMBUS, OHIO 43201	1
DIRECTOR US ARMY INDUSTRIAL BASE ENG ACT ATTN: DRXPE-MT ROCK ISLAND, IL 61201	1	MECHANICAL PROPERTIES DATA CTR BATTELLE COLUMBUS LAB 505 KING AVE COLUMBUS, OHIO 43201	1
CHIEF, MATERIALS BRANCH US ARMY R&S GROUP, EUR BOX 65, FPO N.Y. 09510	1	MATERIEL SYSTEMS ANALYSIS ACTV ATTN: DRXSY-MP ABERDEEN PROVING GROUND MARYLAND 21005	1
COMMANDER NAVAL SURFACE WEAPONS CEN ATTN: CHIEF, MAT SCIENCE DIV DAHLGREN, VA 22448	1		
DIRECTOR US NAVAL RESEARCH LAB ATTN: DIR, MECH DIV CODE 26-27 (DOC LIB) WASHINGTON, D. C. 20375	1 1		
NASA SCIENTIFIC & TECH INFO FAC P. O. BOX 8757, ATTN: ACQ BR BALTIMORE/WASHINGTON INTL AIRPORT MARYLAND 21240	1		

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.