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MECHANICAL AND METALLURGICAL PROPERTIES OF CARBURIZED 8620H STEEL FOR M14 RIFLE COMPONENTS

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BY

JOSEPH L. SLINEY

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7.62mm M14 RIFLE

WATERTOWN ARSENAL
WATERTOWN 72, MASS.

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ABSTRACT

Mechanical and metallurgical tests have been conducted to aid in the development of improved processes and materials for M14 rifle bolts and receivers which are currently being manufactured from carburized 8620H resulphurized steel. The investigation revealed the extreme brittleness which can occur in carburized components, especially those having small fillet radii. This brittleness is associated particularly with high core hardness and nonmartensitic microstructures which can occur in AISI 8620H steel over the allowable range of composition. The study demonstrates the importance of close control over the composition and heat treatment of this material and the advantages from a performance standpoint of employing a steel having higher hardenability and lower carbon content. The study also provides an evaluation of several important variables upon fatigue properties of 8620H steel.

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INTRODUCTION

Metallurgical studies are being conducted to aid in the development of improved processes and materials for the M14 bolts and receivers which are currently being manufactured from carburized 8620H resulphurized steel. This study has been aimed at evaluating the mechanical and metallurgical properties of the 8620H resulphurized steel as related to its use in the M14 rifle bolts with particular emphasis on the problem of cracking in the locking lug. The data and conclusions contained here are also applicable to the receiver on the same weapon. The high surface hardness has been specified to provide wear resistance and minimize deformation under concentrated loads at the locking lug surfaces.

During service testing, and also experimental proof testing, several bolts failed by fracturing in the locking lug fillet[1] after firing a relatively small number of rounds. Also, a large number of bolts which did not fail during proof firing exhibited cracks in this critically stressed area. In addition to the bolt problem several receivers manufactured from a maverick steel (SAE 1330) exhibited brittle fracture after a small number of rounds were fired in the weapons.

Upon consideration of the types of failures which occurred, it was decided that both impact properties (or notch sensitivity) and fatigue were involved. Consequently, the effects of heat treating variables and notch acuity on notched bar impact properties and rotating beam fatigue properties were assessed. Since carburized steel is a complex structure involving a large number of variables, the study has been limited mainly to the variables observed in the bolts and receivers made in the current production of M14 rifles.

MATERIAL AND PROCESSING

All materials used in this study were obtained from Springfield Armory either in the form of 15/16-inch-diameter bar stock or closed die bolt forgings (Figure 1). A chemical analysis was conducted on each lot of material procured from the Armory and these analyses are presented in Table I. The materials employed are about in the middle of the composition range for the 8620H steel.

All carburized mechanical test specimens used in this study were machined at Watertown Arsenal and heat treated at Springfield Armory. These specimens were heat treated in groups which consisted of Charpy impact specimens, notched and unnotched tensile specimens and R. R. Moore fatigue specimens with some groups consisting of Charpy impact or fatigue specimens separately. The standard carburizing cycle as obtained from Springfield Armory consisted of:

Carburize 1580F - 1-2/3 hours, Oil Quench
Temper 375F - 1 hour

This treatment was used on the majority of the fatigue specimen groups to determine the effect of notch configurations upon the fatigue properties of this carburized steel. Other heat treatments were employed to determine the effect of quenching severity and case depth.

RESULTS AND DISCUSSIONS

Although the various types of specimens were grouped for heat treatment, the subsequent results will be presented according to the type of test conducted. This will provide an opportunity to explain the factors influencing toughness and fatigue in separate discussions.

Toughness

The toughness of steel in the carburized and heat-treated conditions, as well as after a mock carburizing heat treatment, was measured by Charpy impact tests and, to a limited extent, by notched tensile tests. Charpy impact tests have been widely used and accepted as a measure of toughness in homogeneous steel but only limited information is available on the impact properties of carburized steel.

Recent studies* by C. Wells have been made using nitrided Charpy impact specimens to separate the crack initiation energy from the crack propagation energy. It was suggested by these results that the energy measured in a carburized Charpy specimen is essentially crack propagation energy. In order to verify this concept, three series of Charpy impact specimens (Series A, B and C, heat treated as indicated in Table II) were tested in the carburized condition, in the pre-cracked-carburized condition, and notched-after-carburizing condition.

The pre-cracking was accomplished by standard fatigue procedures presently being used at Watertown Arsenal Laboratories. In each test series, the energy absorbed from the pre-cracked specimens was essentially the same as the uncracked carburized specimens. These data indicate that the energy to initiate the crack in the carburized Charpy impact specimen is very low and unmeasurable.. The Charpy impact specimens that were notched after carburizing (thus eliminating the carburized notch) indicated a general increase in energy absorbed. This energy is associated with crack initiation of the uncarburized notches. These data are presented in Table III.

A variety of carburizing and/or heat-treating cycles were employed on nine groups of Charpy impact specimens. Half of the specimens in each group were notched prior to heat treatment and the other half after heat treatment. The results of these tests along with core hardness and tensile tests are summarized in Table IV. The metallographic data pertinent to these specimens are presented in Table V. A comparison of Charpy impact values obtained at -40F indicated that specimens notched before carburizing absorbed only 2.5 to 6 ft-lb except for those austenitized in neutral salt (mock carburized) which absorbed approximately 20 ft-lb. The specimens notched after

*Private communication

carburizing absorbed somewhat more energy than those mentioned previously. For the carburized specimens (notched before carburizing), there was very little variation in absorbed energy over a range of core hardnesses (Rockwell C 32 to 38), carburizing cycles (1 hour to 2-1/2 hours), and as a result of delayed quenching (about 45 percent free ferrite in the core). The use of a water quench to obtain a high core hardness (Rockwell C 45) was associated with a significantly lower absorbed energy than that of the other treatments when specimens were notched before or after carburizing. There was considerable variation between the energies absorbed by the duplicate specimens in the room temperature tests because of the presence of laminations which have a pronounced effect on the energy in these longitudinal specimens. This variability also tends to obscure the effect of heat treating variables in tests conducted at room temperature. However, the room temperature impact values of the water-quenched specimens (Rockwell C 45) were very low in comparison with the specimens quenched in oil to a hardness of less than Rockwell C 40.

It should be noted that almost all specimens which exhibited fibrous fractures possessed laminations. These laminations are attributed, at least in part, to the presence of sulphide inclusions in this resulphurized steel. Typical fracture surfaces of Charpy impact specimens are shown in Figure 2. It should be emphasized that, if Charpy impact specimens could be obtained transverse to the major working direction in this material, even lower impact resistance would result because the fracture would be progressing parallel to the laminations and not across them. The Charpy impact specimens, Figure 2, do not display the laminations at -40F because the material deforms so little during crack propagation at this test temperature. The specimen groups 4, 5 and 6 were machined from forged bolts (Figure 1), but their impact resistance and fracture appearance were essentially the same as the specimens machined from the bar stock at the same core hardness level.

The carburized layer on the Charpy impact specimens is very hard and brittle, thus preventing the formation of the shear lips on the edge of the specimens (Figure 2).

Standard 0.357-inch-diameter tensile and notched tensile specimens were heat treated with the first nine groups of impact specimens, and these data are also presented in Table IV. The percent elongation was measured with pencil scribed marks instead of the conventional prick punch marks because of the brittleness and notch sensitivity associated with carburized surfaces.

An evaluation of the notched tensile strength data is obtained by using the notched/unnotched tensile ratio. This "notch-strength ratio" is larger than unity (approximately 1.5)[2] for notch-insensitive materials by an amount which depends upon notch contour, and is unity or less for notch-sensitive materials. The uncarburized specimens exhibited a notch-strength ratio of 1.74 and the carburized specimens indicate ratios between 0.86 to 1.11 depending upon core hardness level. The water-quenched specimens, having a core hardness level of Rockwell C 45, exhibited the lowest notch-strength ratio. The theoretical stress concentration factor (K_t) used on these specimens was approximately three, a relatively mild stress concentration factor for determining this ratio.

Core hardness is a major factor affecting the toughness of carburized parts, since it is related to microstructure in this material and also because it affects energy level per se. Several groups of specimens were heat treated to obtain high, intermediate, and low core hardness. Both carburized and uncarburized specimens were evaluated at the high and intermediate hardness, and only carburized specimens were evaluated at the lowest hardness. The core hardness was varied by changing the cooling rate from the austenitizing temperature, whereas all other procedures, including austenitizing and tempering treatments, were held constant.

The impact transition curves of these groups of specimens are plotted in Figure 3, with the associated hardness and metallurgical characteristics presented in Table IV. Although the transition temperature can be defined in a number of ways, it was decided to select for listing in Table II, the temperatures at which 10 and 50 percent fibrous fractures occur. These criteria represent the minimum temperature at which some energy is absorbed and the condition at which cracking would not be expected to progress without an additional applied load, respectively. It can be observed that carburization raises the transition temperature and lowers the energy level at a given core hardness.

At a core hardness of Rockwell C 45-47 (Table II), the energy of the carburized steel is extremely low even at room temperature. At the lower hardness levels (Rockwell C 31 and 40), the transition temperature is considerably lower. The lowest temperature at which some toughness is observable, at both these latter hardness levels, is -4F. It is expected that highly stressed components, possessing sharp notches or cracks, would be very susceptible to brittle fracture at temperatures at least as high as -4F in this material.

Another method of reducing the hardness of the core is by raising the tempering temperature. Unfortunately, this type of treatment also lowers the case hardness. Groups of specimens in the carburized and uncarburized condition were warm water quenched (to obtain maximum as-quenched core hardness) and tempered at temperatures up to 1000F to assess these treatments on toughness. The results of impact tests at -40F are shown in Table VI. There is a significant drop in toughness in the tempering temperature range of 450F to 700F. This condition, which is observed in most steels when martensite is tempered in this range, is generally called "blue brittleness" and should be avoided in the heat treating of M14 rifle components. The core hardness readings indicate that a manufacturer quenching his components to martensite (Rockwell C 45 to 47) might consider tempering in this embrittling range to meet specified core hardness requirements. Consequently, a maximum tempering temperature of 450F should be specified to prevent this embrittlement since an impact test is not currently required for controlling the processing of these carburized components.

If a tempering temperature above 700F is employed, the case hardness is lowered to about 45-47 Rockwell C, which is considered to be too soft for the wear resistance required for the components.

These results indicate the desirability of investigating the use of other steels having a maximum "as-quenched" core hardness of 43-44 Rockwell C and sufficient hardenability to provide a martensitic structure. This would permit the components to be quenched to martensite having a hardness of less than Rockwell C 42 after tempering at 350 to 425F.

Fatigue

The second important factor to consider in the service of bolts and receivers is their short cycle fatigue life (10,000 to 20,000 rounds). After some consideration, it was decided to concentrate on rotating beam type (R. R. Moore) fatigue tests because of their wide acceptance and the availability of testing machines in sufficient number at Watertown Arsenal so that extensive testing could be accomplished quickly.

Both notched and unnotched rotating beam tests were conducted on specimens in the carburized and uncarburized conditions. Specimen sizes and notch configurations considered are presented in Figure 4. The notched and unnotched specimens have the same net cross sectional area at mid-span, and the stress levels plotted in the subsequent figures (5 through 8) were computed by the simple beam formula. The curves presented are the best fit curves for the data obtained.

The first series of specimens was tested at 10,000 rpm speed and these data are presented in Figure 5. Each curve has been numbered with its appropriate group number in this and subsequent figures. The metallurgical data for all sets of fatigue specimens are listed in Table V with its appropriate group number.

The effect of carburizing is clearly evident in Figure 5. The carburized case has improved the fatigue properties by a combination of residual compressive stresses and a strengthening of the outside fibers where the maximum bending stress occurs. A group of specimens polished in the longitudinal direction before carburizing is also presented in Figure 5 to demonstrate the comparison with a machined finish. The machining or tool marks are less detrimental to fatigue life at the higher stress levels (finite life region), but this condition did produce a marked effect upon the endurance limit. The slack-quenched group of specimens (Group 2) was held in air 30 seconds before quenching into oil, a procedure which produced 45-50 percent free ferrite in the core. These soft ferrite areas appeared to have a marked effect in lowering the cycles to failure at the high stress levels.

The effect of a 45 degree notch with a notch radius of 0.010 and 0.030 inch in both the carburized and uncarburized conditions, tested at a speed of 1800 rpm, is presented in Figure 6. The sharp carburized notch (0.010 inch radius) decreases the fatigue strength at a life of 10,000 cycles to a stress level equivalent to that of uncarburized notched fatigue specimens. Also presented in this figure is a curve obtained with smooth specimens which had 0.002 inch removed from the surface by using number 80 grit paper, polishing in the circumferential direction. The reduction in the fatigue properties is very slight indicating that this amount of material removal, when done with care, is not harmful to the fatigue properties.

The effect of 90 degree notches having radii of 0.002, 0.010 and 0.030 inches, is presented graphically in Figure 7. These data indicate that this variation in notch severity does not influence the finite fatigue life significantly. It has been well established[3] in the literature that notches do not exhibit their full effect in fatigue. The fatigue stress concentration factor (K_f) is less than the theoretical stress concentration factor (K_t). But, as indicated in Figure 7, there is a reduction in strength by the introduction of a notch in the finite portion and a larger reduction in the endurance limit. Therefore, the largest notch radius allowable should be used.

The effects of various metallurgical conditions upon the fatigue characteristics of carburized 8620H, when tested at 1800 RPM, are presented in Figure 8. The major detriment to fatigue was a slight decarburized layer caused by air cooling from the carburizing temperature followed by reaustenitizing in neutral salt (Group 7 specimens). Therefore, this practice should be avoided in the manufacture of the M14 rifle components. Long carburizing time increased the fatigue resistance slightly by increasing the carburized depth.

In simple bending, the maximum tensile and compressive stresses occur at the outside fibers. The carburized case not only increases the strength of the case material, but also creates a state of residual compression as a result of temperature gradients and phase transformations[4] during heat treatment. These residual compressive stresses shift the point of maximum tensile stress in bending from the surface to some point below the surface. Depending upon the strength of the case, the case depth, and the residual compressive stresses present, failure will initiate at the point where the net stresses are maximum or at the case-core junction where a discontinuity of both residual stresses and microstructure occurs. The presence of a notch results in a stress concentration at the root which raises the stress to a level several times greater than the nominal stress on the outer surface of a smooth specimen. Therefore, failure in a notched fatigue specimen initiates at the root surface of the notch.

Typical carburized fatigue specimen fractures are presented in Figures 9 and 10 for the smooth and notched specimens, respectively. It should be noted in Figure 9 that the failure initiated at the case-core junction for the smooth specimen and in Figure 10 the failure initiated evenly at the outside layer for the notched specimen.

<u>Metallographic Examination</u>

One Charpy impact specimen and one fatigue specimen from each group were examined for case depth, retained austenite, core structure, and core hardness. These data are presented in Table V. The smooth R. R. Moore fatigue specimens generally had high core hardness and martensitic microstructure, but the larger cross section, notched fatigue specimens (Fig. 4) and impact specimens which cooled slower during quenching have lower core hardnesses and higher percentages of free ferrite. In an effort to overcome the difference in core hardness and microstructure, one set of notched fatigue specimens was warm water quenched. This quenching severity was too great, and the specimens were so distorted that they could not be tested. Therefore, a small part of the decrease in fatigue properties of the notched specimens is attributed to lower core hardness.

Typical photomicrographs are presented in Figures 11 and 12. The differences in microstructure between the Charpy impact specimens and the fatigue specimens heat treated under the same conditions are due to section size and transformation rates. Consequently, it is necessary to compare specimens possessing the same hardness and microstructure rather than the same nominal heat treatment.

Surface Hardness Comparisons

Rockwell C, D, A and superficial scale 45N, 30N, 15N and 1Kg Tukon readings were conducted on the Charpy impact specimens from Group 1 through 9 and converted to Rockwell C readings for comparison. These data are presented in Table VII. One specimen from each group was sectioned so that the Tukon hardness readings could be taken 0.002 inch below the surface. The averages of these micro-hardness readings were converted to Rockwell C, and these data and core hardness data are also presented in Table VII. The major difference between the Tukon and the Rockwell C readings appear in Group 5 which was carburized only one hour. But this difference can not be associated entirely with case depth since large differences of 7.6 and 8.2 points Rockwell C were also observed in Groups 1 and 9, respectively. The maximum differences between the Rockwell D and the Tukon hardness readings were obtained in Groups 5 and 7 which are 3.1 and 3.7 points Rockwell C, respectively. Group 7 specimens had a slight decarburized layer due to the air cooling from the carburizing temperature plus austenitizing in neutral salt, while Group 5 had a shallow case. The general agreement among the readings using all the hardness scales on the uncarburized specimens (Group 3) should be noted.

All groups of carburized specimens exhibited an increase in hardness in going from the heavy 150Kg Rockwell C to the 15Kg-15N loads. It was indicated by this investigation, as well as others[5] that reliable readings of surface hardness of thin cases can only be obtained by using "superficial" hardness tests. Variables present such as case depth, decarburization, and core hardness influence the case hardness readings, but the results of the Rockwell C test alone do not provide a reliable means for identifying the cause of the low reading.

CONCLUSIONS AND RECOMMENDATIONS

1. Impact tests of M14 rifle bolt material (AISI 8620H steel) demonstrate that the current requirements limiting tempering temperature to a maximum of 425F and core hardness to 35-42 Rockwell C are extremely important in order to provide satisfactory toughness in these carburized components. The upper limit on hardness as well as the tempering temperature limit will reject components having extremely low toughness at room temperature. The lower limit on hardness is required to limit the presence of nonmartensitic microstructures which raise the transition temperature for brittle fracture and also to control fatigue which is adversely affected by low core hardness (low strength).

2. AISI 8620H steel has a borderline hardenability for the section size involved in the bolts and receivers of the M14 rifle. The steel also has a carbon content range (0.18-0.23 percent) such that an excessively high core hardness can occur during heat treatment when the carbon is on the high side of the acceptable carbon range. Consequently, an alternate alloy steel having higher hardenability and lower maximum carbon content should be established to permit more latitude in heat treatment and better uniformity in mechanical properties of the components (the large changes in section size of the receiver result in excessively high hardnesses in the rail section and low hardnesses in the muzzle end of the same component). An investigation will be required on the change in machinability and distortion which may result from the use of alternate steels.

3. Fatigue tests using rotating beam specimens provided quantitative information on the effect of the most important variables introduced in the processing of M14 rifle bolts and receivers made from AISI 8620H steel. The results support and expand previous work on fatigue with regard to the detrimental effects of sharp notches, decarburized surfaces, quality of machined finish, low core hardness, and nonuniform microstructures (patchy ferrite in the core).

4. A non-resulphurized material should be employed for bolts and receivers because segregations of nonmetallic inclusions of the type observed in the current steel cause laminations which can result in catastrophic failure in critically stressed areas.

TABLE I

CHEMICAL ANALYSIS OF THREE LOTS OF 8620H STEEL BAR STOCK

Description	C	Mn	Si	Ni	Mo	P	S	Cr
AISI 8620H	0.18 0.23	0.70 0.90	0.20 0.35	0.40 0.70	0.15 0.60	-----	0.035 0.050	0.40 0.60
Lot 1	0.20	0.83	0.31	0.50	0.22	0.014	0.045	0.52
Lot 2	0.20	0.83	0.32	0.52	0.18	0.014	0.046	0.54
Lot 3	0.21	0.83	0.30	0.51	0.20	0.015	0.041	0.52

TABLE II

METALLURGICAL PROPERTIES OF CHARPY IMPACT SPECIMENS

Series	Heat Treatment	Case Hardness			Core Hardness R_c	Core Microstructure			Case Depth (inches)	Temperature (°F)	
		R_c	R_c (from R_A)	R_c (from R_D)		F	HTB	M		10 Fib.	50 Fib.
A	Carburize 1-2/3 hr Warm Water Quench Temper, 375 F 1 hr	59.5	61.2	60.8	47.0	0	0	100	0.018	40	57
B	Carburize 1-2/3 hr Agitated Oil Quench Temper, 375 F 1 hr	56.9	61.4	59.1	40.5	5	80	15	0.017	- 4	50
C	Carburize 1-2/3 hr Agitated Oil Quench Reheat, 1580 F Neutral Salt Quench into 400 F Salt 1/4 hr, Oil Quench, Temper 375 F 1 hr	55.5	59.0	58.3	31.5	18	67	15	0.015	- 4	46
D	Austenitize (Neutral Salt) (1/4 hr, Warm Water Quench, Temper, 375 F 1 hr	----	----	----	45.0	0	0	100	None	-112	+14
E	Austenitize (Neutral Salt) 1/4 hr, Oil Quench Temper, 375 F 1 hr	----	----	----	39.5	3	52	45	None	-184	-40

Note: F - Free Ferrite
HTB - High Temperature Bainite
M - Low Carbon Tempered Martensite
Fib. - Fibrosity in percent

TABLE III

CHARPY IMPACT DATA ON CARBURIZED 8620H STEEL

Temperature (°F)	ENERGY ABSORBED (FT-LB) Carburized	Pre-Cracked Carburized	Notched after Carburized
Series A			
+32	4.0	4.0 3.7	9.2 8.6
- 4 -40	4.2 4.2	--- ---	--- ---
Series B			
+32	7.5	6.2 10.3	15.8 16.5
- 4 -40	5.0 3.7	--- ---	--- ---
Series C			
32	15.8	14.2 15.8	20.5 20.8
- 4 -40	12.1 6.7	--- ---	--- ---

TABLE IV

MECHANICAL PROPERTIES OF 8620H CARBURIZED SPECIMENS

Speci-men Group	Heat Treatment	Charpy Notched Before H.T. -40 F	Charpy Notched Before H.T. -76 F	Room Temp.	Impact Energy Absorbed (ft-lb) Notched After H.T. -40 F	Impact Energy Absorbed (ft-lb) Notched After H.T. -76 F	Room Temp.	YS 0.2% (ksi)	UTS (ksi)	Notch Strength (ksi) K_t=3	$\frac{NTS}{UTS}$	Elon. (%)	RA (%)	Core Hardness Rockwell C
1	Carburize 1580 F 1-2/3 hr Oil Quench Temper 375 F 1hr	5.7 6.2	[illegible].4	21.1 25.4	7.5 7.5	7.0	25.4 37.7	130.0 119.0 121.0	149.0 148.0 148.2	165.8 170.0 160.6	1.11	1.4 1.4 0.7	3.8 4.9 3.8	32.6
2	Carburize 1580 F 1-2/3 hr Hold in Air 30 Seconds, Oil Quench, Temper 375 F 1hr	3.4 3.0	2.5	16.2 20.8	7.0 7.0	5.0	15.8 14.2	148.0 142.0 158.5	156.4 156.3 161.5	155.8 164.5 144.4	0.98	0.7 0.7 0.7	3.8 3.8 1.3	35.4
3	Austenitize 1580 F ¼ hr Oil Quench, Temper 375 F 1hr	20.8 18.8	12.4	31.8	21.1 18.1	16.2	18.4	118.5 138.5	172.0 177.3	297.9 310.7	1.74	4.3 5.7	47.8 47.4	32.7
4	Carburize 1580 F 1-2/3 1hr Oil Quench, Temper 375 F 1hr	3.7 3.7		21.9	6.7 7.5		19.4	142.5 140.0	177.0 172.5			0.7 0.7	1.1 2.7	36.0
5	Carburize 1580 F 1hr Oil Quench, Temper 375 F 1hr	4.7 4.2		19.7	7.5 15.2		35.7	131.0 107.0	165.0 149.5			1.4 2.1	7.6 8.7	34.5
6	Carburize 1580 F 2¼ hr Oil Quench, Temper 375 F 1hr	3.2 3.2		17.8	6.7		20.5	127.0 133.0	176.0 186.5			2.1 0.7	2.2 3.3	36.8
7	Carburize 1580 F 1-2/3 hr Air Cool, Heat to 1550 F ¼ hr, Oil Quench, Temper 375 F 1 hr	4.0 4.0		10.6 15.8	6.4 7.5		19.1 21.5	147.5 152.5	179.0 180.0	182.5 175.7	1.0	0.7 0.7	3.8 2.7	38.6
8	Carburize 1580 F 1-2/3 hr Warm Water Quench Temper 375 F 1 hr	2.3 2.5		4.7 3.7	3.4 5.4		4.0 17.8	169.5 175.0	196.0 208.5	162.0 187.0 170.8	0.86	0.7 0.7	3.3 2.2	45.4
9	Carburize 1580 F 1-2/3 hr Oil Quench, No Temper	4.0 3.4		12.4 17.8	7.0 7.3		16.2 31.4	104.0 96.0	145.5 136.0	145.3 148.3	1.04	2.1 1.4	5.5 6.0	33.7

Note:
1. Groups 4, 5 and 6 were machined from forged bolts and notched perpendicular to the longitudinal axis.
2. Core hardness values were obtained on Charpy impact specimens.
3. 0.357" diameter tensile specimens were used.
4. The notched tensile specimens were 0.357" diameter tensile specimens with circumferential 0.79" deep 0.010" radius 45° notches.

TABLE V

METALLURGICAL PROPERTIES OF 8620H MECHANICAL TEST SPECIMENS

Specimen Group	Heat Treatment	Case Depth (inches)	Free Ferrite (%)	High Temperature Bainite (%)	Low Carbon Tempered Martensite (%)	Retained Ausenite (%)	Core Hardness Rockwell C
CHARPY IMPACT SPECIMENS							
1	Carburize 1-2/3 hr. Oil Quench Temper	0.011	8	84	8	---	32.6
2	Carburize 1-2/3 hr. Hold 30 sec. in air. Oil Quench Temper	0.013	8	85	7	---	35.6
3	Austenitize (Neutral Salt) ¼ hr. Oil Quench Temper	-----	8	90	2	---	32.7
4	Carburize 1-2/3 hr. Oil Quench Temper	0.013	3	70	27	---	36.0
5	Carburize 1 hr. Oil Quench Temper	0.005	15	77	8	---	34.5
6	Carburize 2¼ hrs. Oil Quench Temper	0.016	5	60	35	---	36.8
7	Carburize 1-2/3 hr. Air cool Austenitize 1550 F ¼ hr. Oil Quench Temper	0.011	10	50	40	---	38.6
8	Carburize 1-2/3 hr. Warm Water Quench, Temper	0.012	5	18	77	---	45.4
9	Carburize 1-2/3 hr. Oil Quench. No Temper	0.011	6	70	24	---	33.7
R. R. MOORE FATIGUE SPECIMENS							
1	Carburize 1-2/3 hr. Oil Quench Temper	0.015	0	18	82	2	43.9
2	Carburize 1-2/3 hr. Hold 30 sec. in air. Oil Quench Temper	0.013	45	--	55	5	3[illegible].7
3	Austenitize (Neutral Salt) ¼ hr. Oil Quench Temper	-----	1	--	99	---	44.5
4	Carburize 1-2/3 hr. Oil Quench Temper	0.018	2	28	70	35	41.1
5	Carburize 1 hr. Oil Quench Temper	0.014	2	78	20	5	4[illegible]
6	Carburize 2¼ hr. Oil Quench Temper	0.021	0	18	82	20	45.2
7	Carburize 1-2/3 hr. Air cool Austenitize 1550 F ¼ hr Oil Quench Temper	0.017	1	3	96	1	44.8

(Continued)

TABLE V (Continued)

METALLURGICAL PROPERTIES OF 8620H MECHANICAL TEST SPECIMENS

	Specimen Group	Heat Treatment	Case Depth (inches)	Free Ferrite (%)	High Temperature Bainite (%)	Low Carbon Tempered Martensite (%)	Retained Austenite (%)	Core Hardness Rockwell C
		R. R. MOORE FATIGUE SPECIMENS (Continued)						
	8	Carburize 1-2/3 hr, Warm Water Quench, Temper	0.018	0	1	99	10	46.4
	9	Carburize 1-2/3 hr, Oil Quench, No Temper	0.019	2	92	6	0	44.4
Polished 1800RPM Test Speed	10	Carburize 1-2/3 hr, Oil Quench Temper	0.018	1	15	84	1	43.6
Polished 10,000RPM	11	Carburize 1-2/3 hr, Oil Quench Temper	0.014	3	20	77	2	43.1
45° Notch 0.010" Rad. Uncarburize	12	Austenitize (Neutral Salt) ¼ hr Oil Quench Temper	-----	2	18	80	--	41.7
45° Notch 0.030" Rad. Uncarburize	13	Austenitize (Neutral Salt) ¼ hr, Oil Quench Temper	-----	12	12	76	--	42.8
45° Notch 0.016" Rad. Carburize	14	Carburize 1-2/3 hr, Oil Quench Temper	0.014	15	50	35	1	36.5
45° Notch 0.030" Rad. Carburize	15	Carburize 1-2/3 hr, Oil Quench Temper	0.011	15	40	45	0	36.3
90° Notch 0.030" Rad.	16	Carburize 1-2/3 hr, Oil Quench Temper	0.012	18	15	67	1	36.7
90° Notch 0.010" Rad.	17	Carburize 1-2/3 hr, Oil Quench Temper	0.017	15	60	25	2	32.5
45° Notch 0.002" Rad.	18	Carburize 1-2/3 hr, Oil Quench Temper	0.015	8	67	25	5	33.9
90° Notch 0.002" Rad.	19	Carburize 1-2/3 hr, Oil Quench Temper	0.015	8	70	25	5	31.8
Polished 0.002" Removed on Rad.	20	Carburize 1-2/3 hr, Oil Quench Temper	0.014	2	13	85	3	44.8

Notes:
1. All specimens were carburized or austenitized at 1580 F.
2. All tempering was performed at 375 F for one hour.
3. Percent retained austenite was not determined on Charpy impact specimens in Groups 1 to 9.
4. Case depth was determined by Tukon hardness surveys on Groups 1 to 9.

TABLE VI

TEMPERING CHARACTERISTICS

OF 8620H STEEL

Tempering Temperature °F	Uncarburized			Carburized			
	Energy Absorbed (ft-lb)	Fracture (%) Fibrous	Core Hardness Rockwell C	Energy Absorbed (ft-lb)	Fracture (%) Fibrous	Hardness Rockwell C Core	Hardness Rockwell C Case
As-quench	17.5	20	47.0	2.5	0	46.6	64.8
200	15.8	15	47.4	2.5	0	45.6	64.4
300	18.1	25	47.0	3.4	0	45.6	61.7
400	18.8	35	45.9	3.4	0	45.9	58.6
500	15.5	20	43.7	1.8	0	42.6	55.6
600	9.5	10	42.0	1.8	0	41.0	53.4
700	15.8	15	40.7	2.3	0	41.8	50.6
800	31.4	75	38.2	9.7	0	38.8	46.7
900	47.8	100	33.8	30.2	100	34.6	43.9
1000	67.9	100	30.4	37.7	100	30.6	39.7

Notes: 1. All specimens quenched from 1580 into warm water; 85TM, 12 HTB, 3FF carburized; 100TM, uncarburized.

2. All specimens tested at -40 F

TABLE VII

HARDNESS SURVEYS ON 8620H

CARBURIZED CHARPY IMPACT SPECIMENS

Specimen Group	Heat Treatment	Core R_C 150KG	Case						
			R_C 150KG	R_D-R_C 100KG	R_A-R_C 60KG	45N-R_C 45KG	30N-R_C 30KG	15N-R_C 15KG	Tukon-R_C 1KG
1	Carburize 1580 F 1-2/3 hr, Oil Quench, Temper 375 F 1 hr	32.6	51.7	56.5	61.5	62.3	62.7	61.9	59.3
2	Carburize 1580 F 1-2/3 hr, hold in air 30 seconds Oil Quench Temper 375 F 1 hr	35.6	53.3	56.8	61.2	62.3	61.7	62.4	57.3
3	Austenitize ¼ hr Oil Quench Temper 375 F 1 hr	32.7	35.7	36.6	39.3	36.8	37.1	37.0	34.0
4	Carburize 1580 F 1-2/3 hr, Oil Quench, Temper 375 F 1 hr	36.0	53.9	58.2	61.4	61.8	62.1	62.8	58.0
5	Carburize 1580 F 1 hr, Oil Quench, Temper 375 F 1 hr	34.5	45.5	51.2	56.3	56.7	59.5	60.5	54.3
6	Carburize 1580 F 2-½ hr, Oil Quench, Temper 375 F 1 hr	36.8	57.3	60.1	61.2	60.7	60.7	62.1	59.3

(Continued)

TABLE VII (Continued)

HARDNESS SURVEYS ON 8620H

CARBURIZED CHARPY IMPACT SPECIMENS

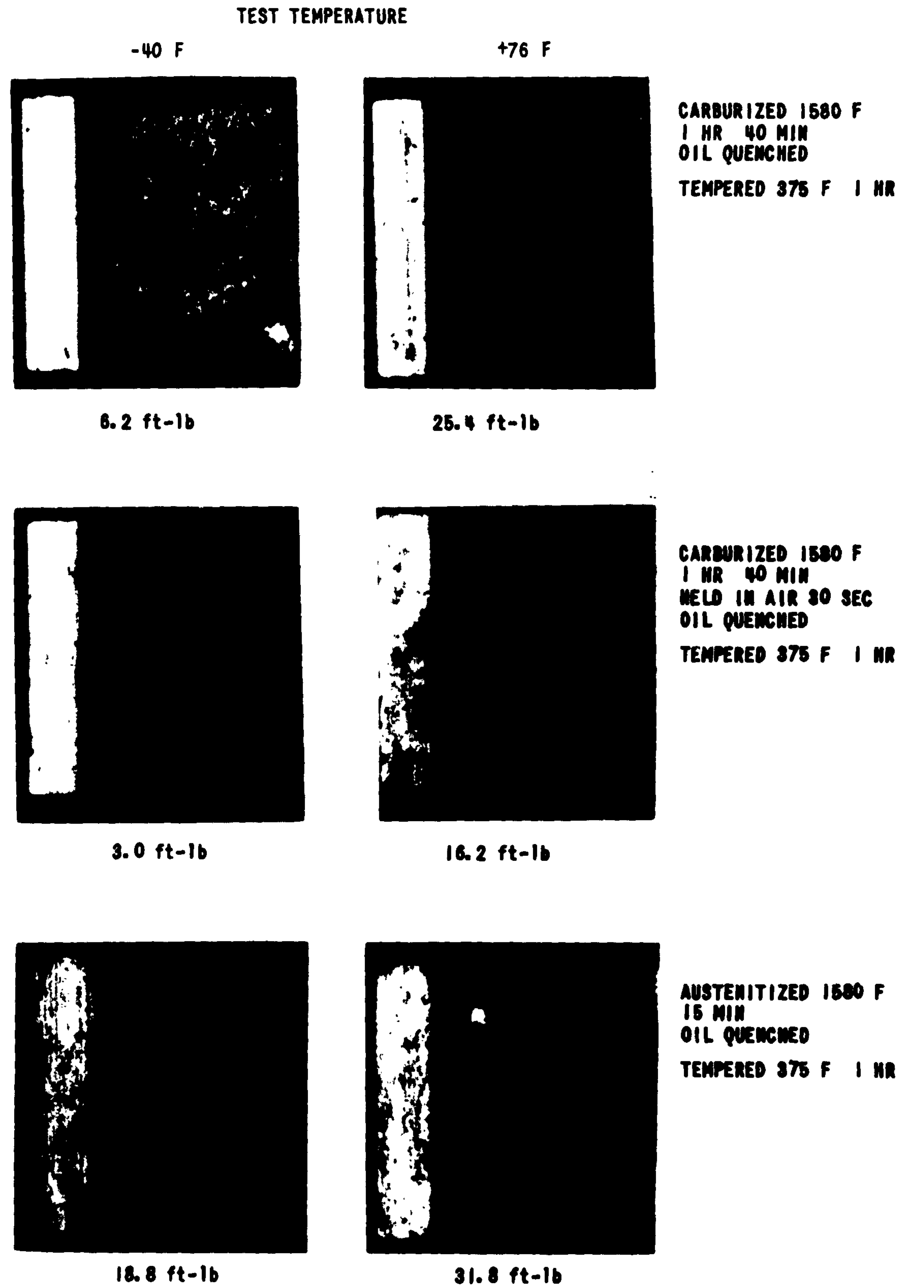
Specimen Group	Heat Treatment	Core R_c 150KG	Case R_c 150KG	R_D-R_c 100KG	R_A-R_c 60KG	45N-R_c 45KG	30N-R_c 30KG	15N-R_c 15KG	Tukon-R_c 1KG
7	Carburize 1580 F 1-2/3 hr Air Cool Austenitize 1550 F ¼ hr - Oil Quench Temper 375 F 1 hr	38.6	55.6	57.3	57.9	55.7	57.8	55.3	54.0
8	Carburize 1580 F 1-2/3 hr Warm Water Quench Temper 375 F 1 hr	45.4	55.2	58.1	60.6	61.2	61.3	62.0	58.0
9	Carburize 1580 F 1-2/3 hr Oil Quench No Temper	33.7	55.3	62.6	65.8	66.0	55.2	66.3	63.5

Notes:

1. The above hardness surveys are all Rockwell C readings converted from the indicated scale.
2. The Tukon readings are an average of two readings taken 0.002 inch below surface on opposite faces.
3. Each reading (except Tukon) represents an average of surveys (4 or more readings) taken on two or more samples from each group.

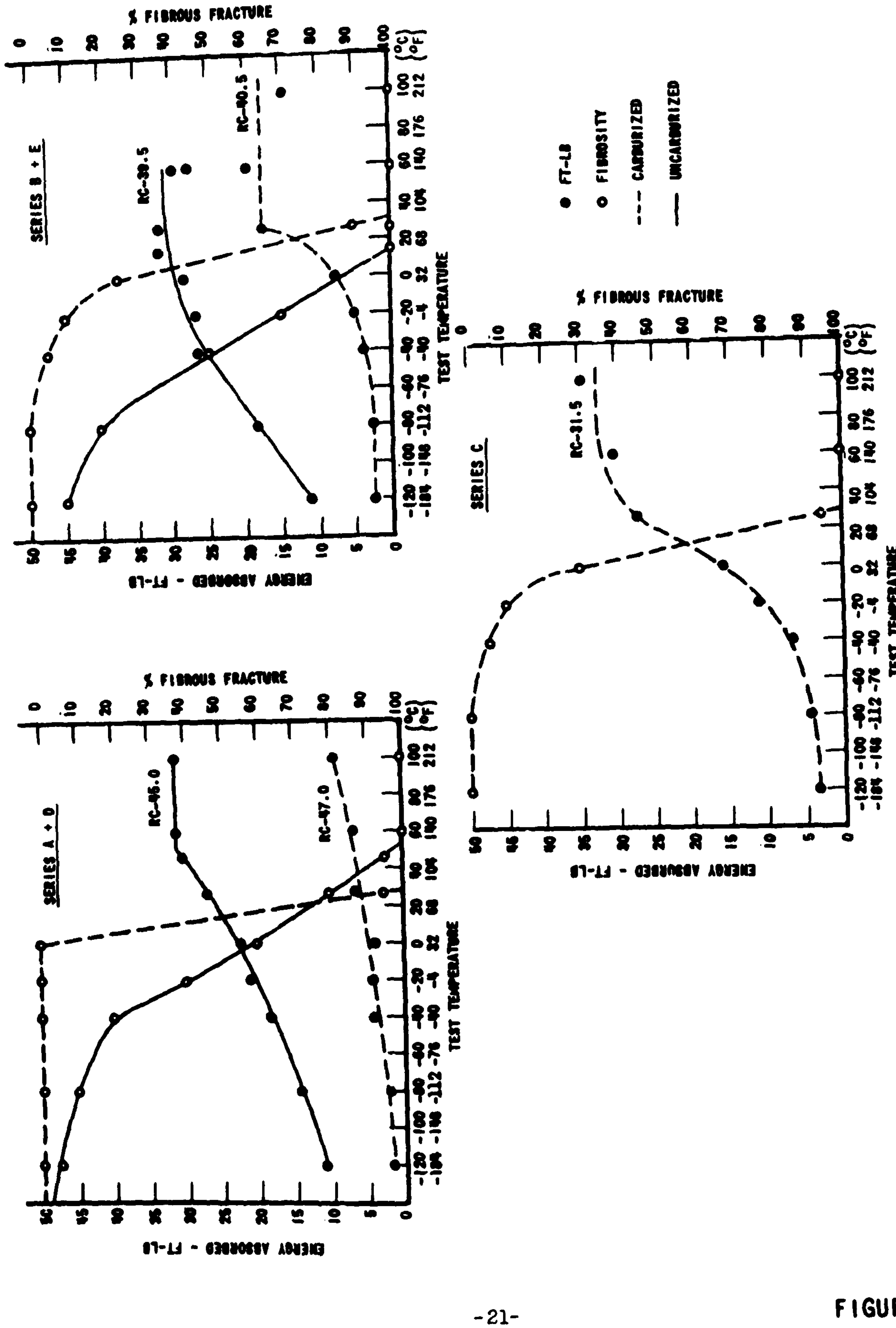
**MACROPHOTOGRAPH OF M14
CLOSED DIE BOLT FORGING**

FIGURE 1



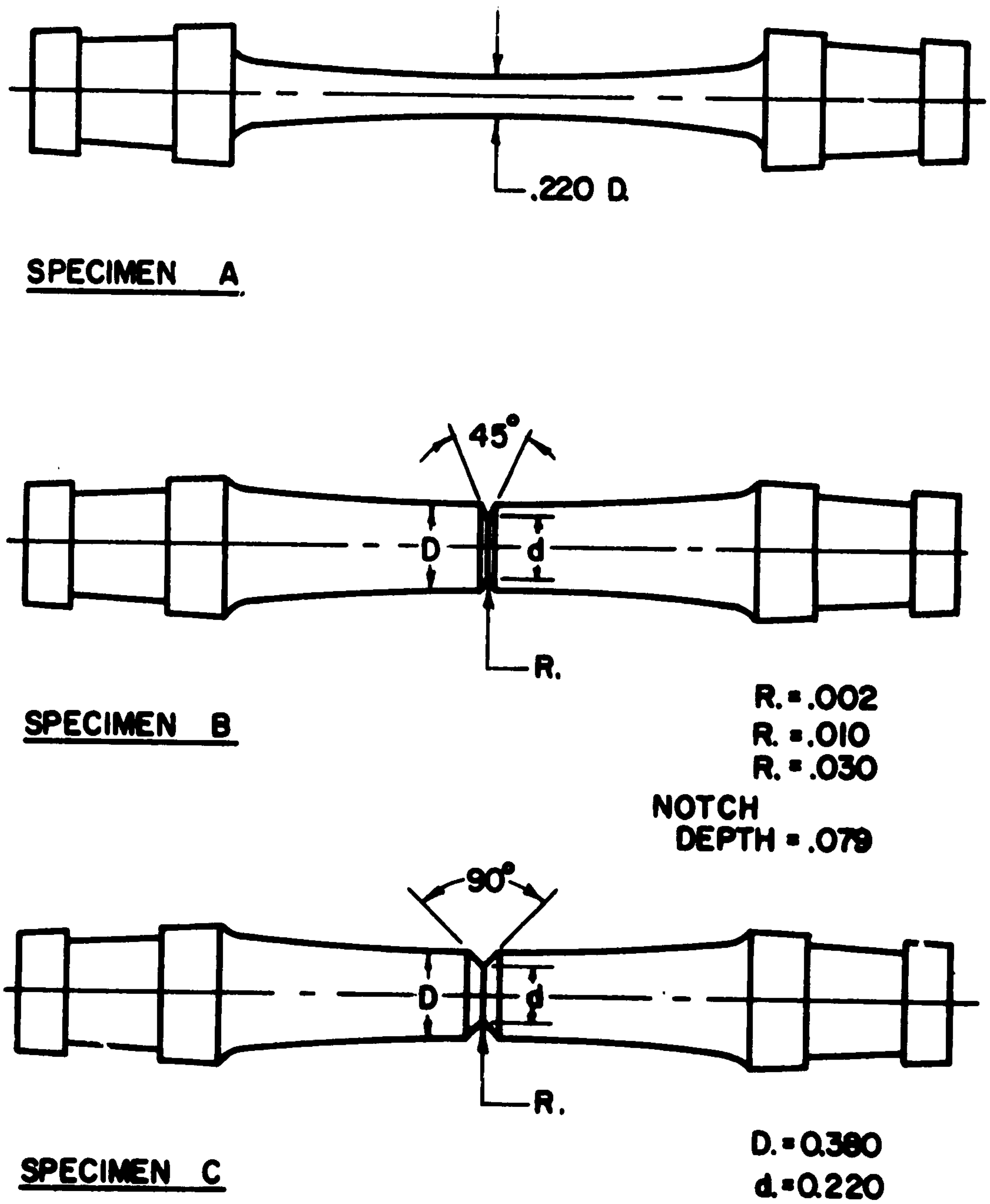
COMPARISON OF CARBURIZED AND UNCARBURIZED
8620H STEEL CHARPY IMPACT SPECIMENS

FIGURE 2



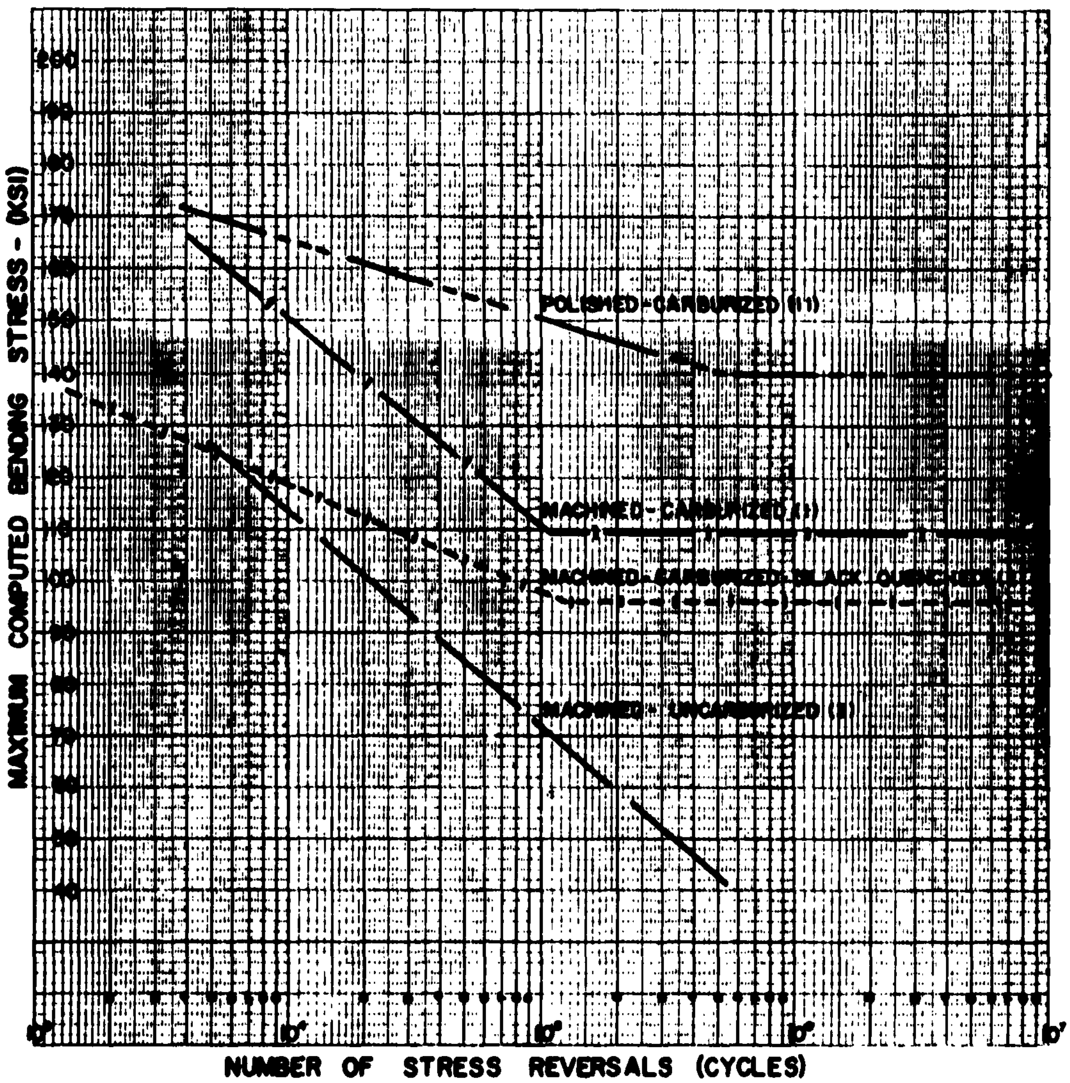
IMPACT TRANSITION FOR CARBURIZED AND UNCARBURIZED 8620H STEEL

FIGURE 3



ROTATING BEAM FATIGUE SPECIMENS

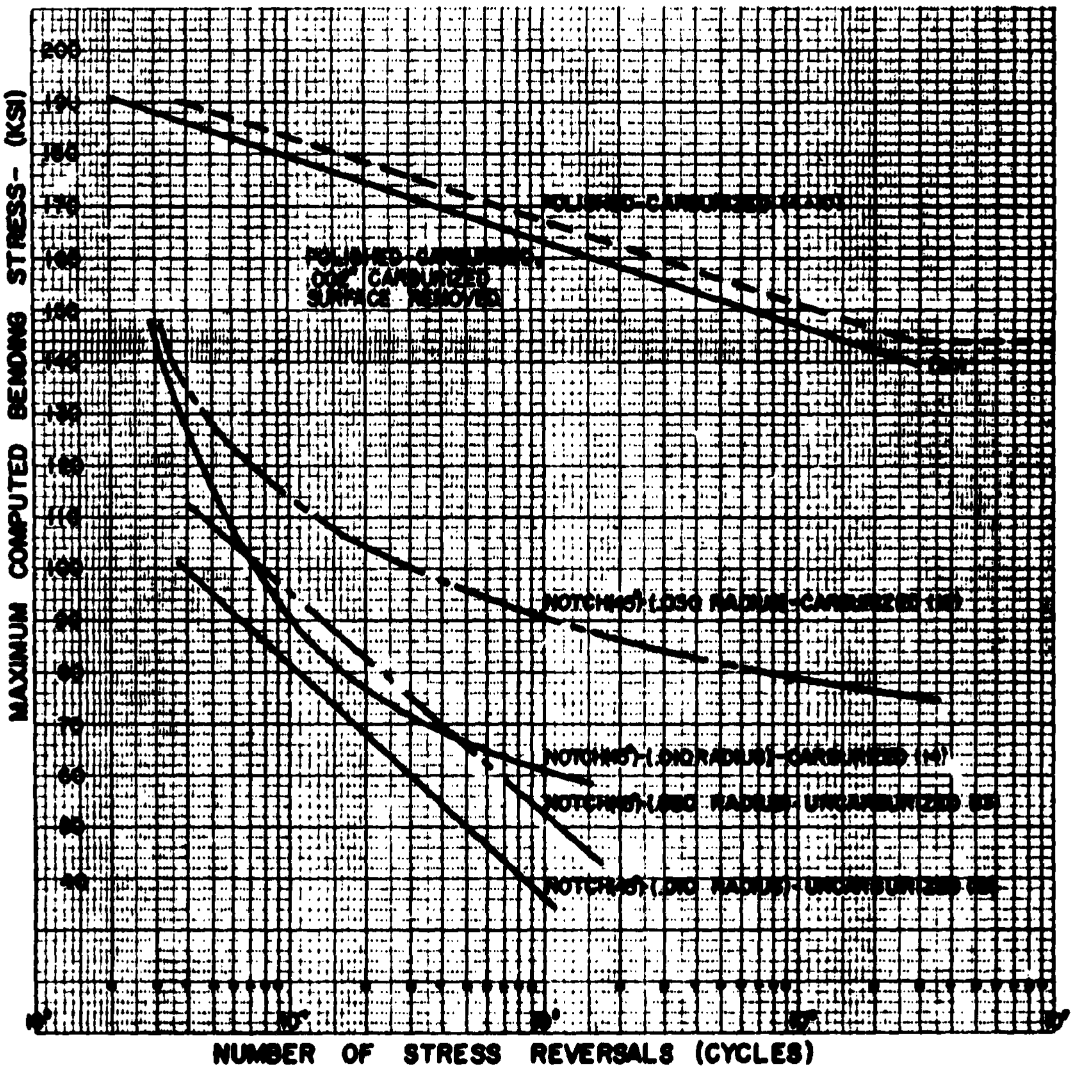
FIGURE 4



ROTATING BEAM FATIGUE
PROPERTIES OF 8620H STEEL

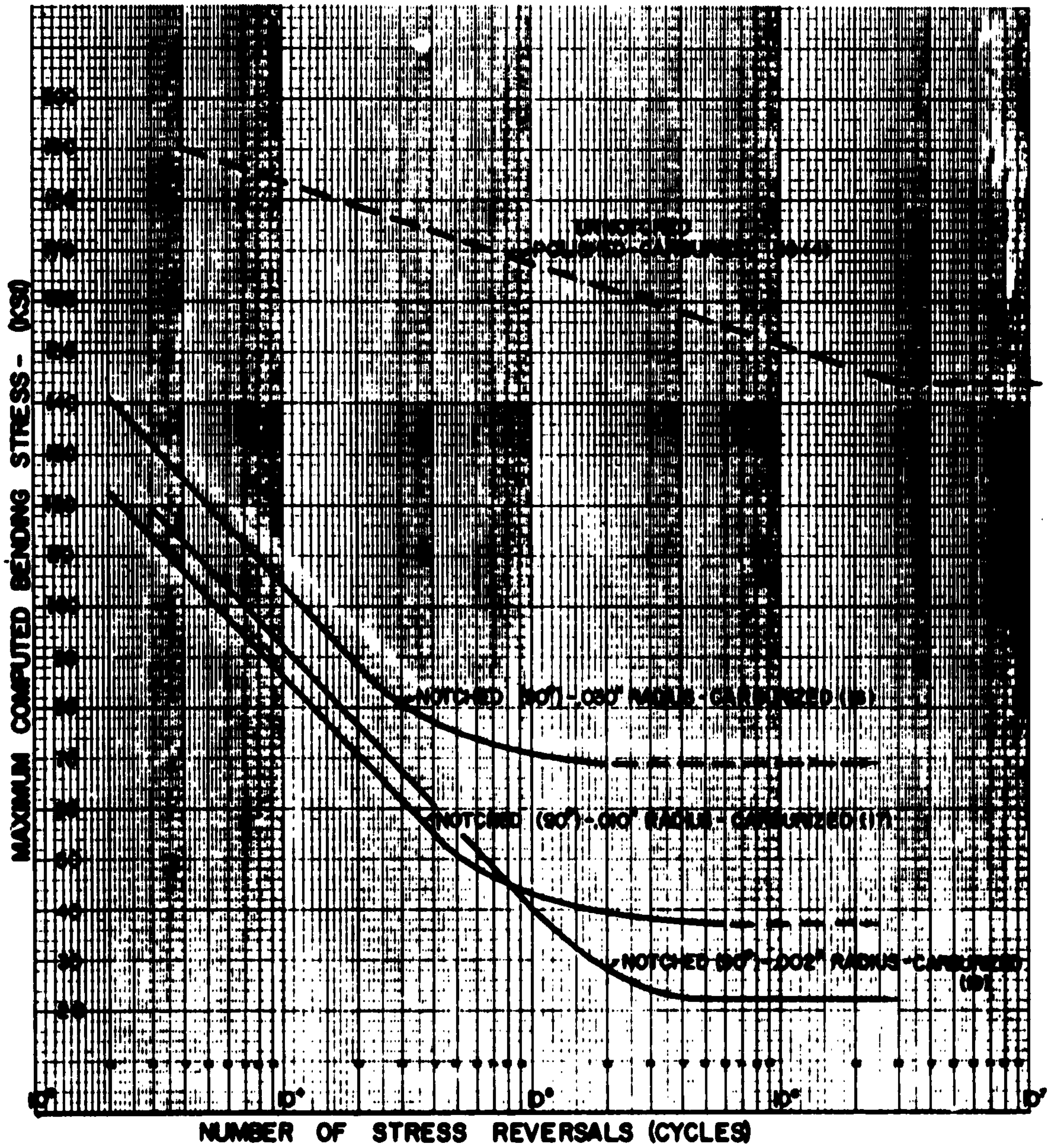
Testing Speed 10000 RPM

FIGURE 5



**ROTATING BEAM FATIGUE
PROPERTIES OF 8620H STEEL**

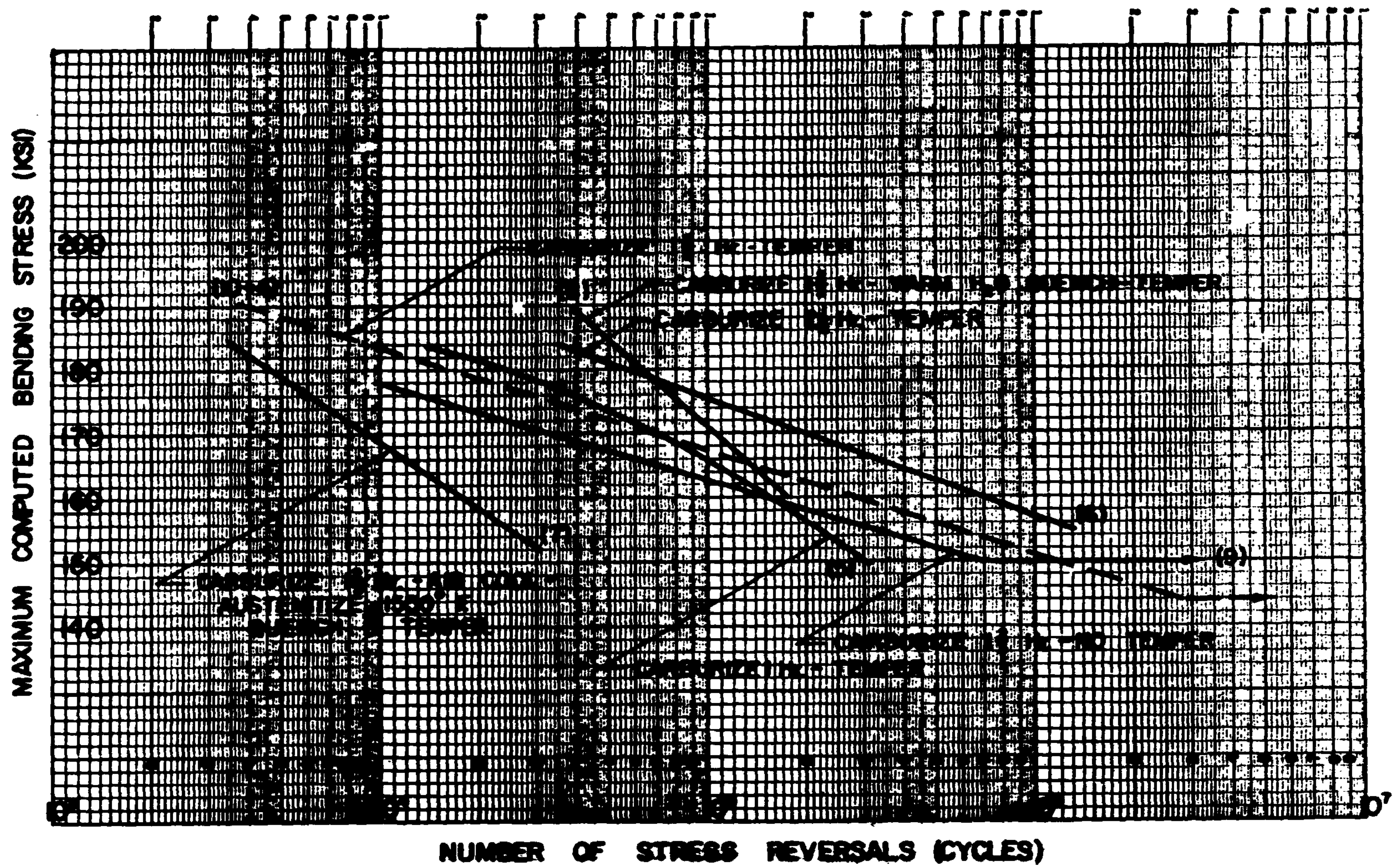
Testing Speed 1800 RPM



ROTATING BEAM FATIGUE PROPERTIES OF 8620H STEEL

Testing Speed 1800 RPM

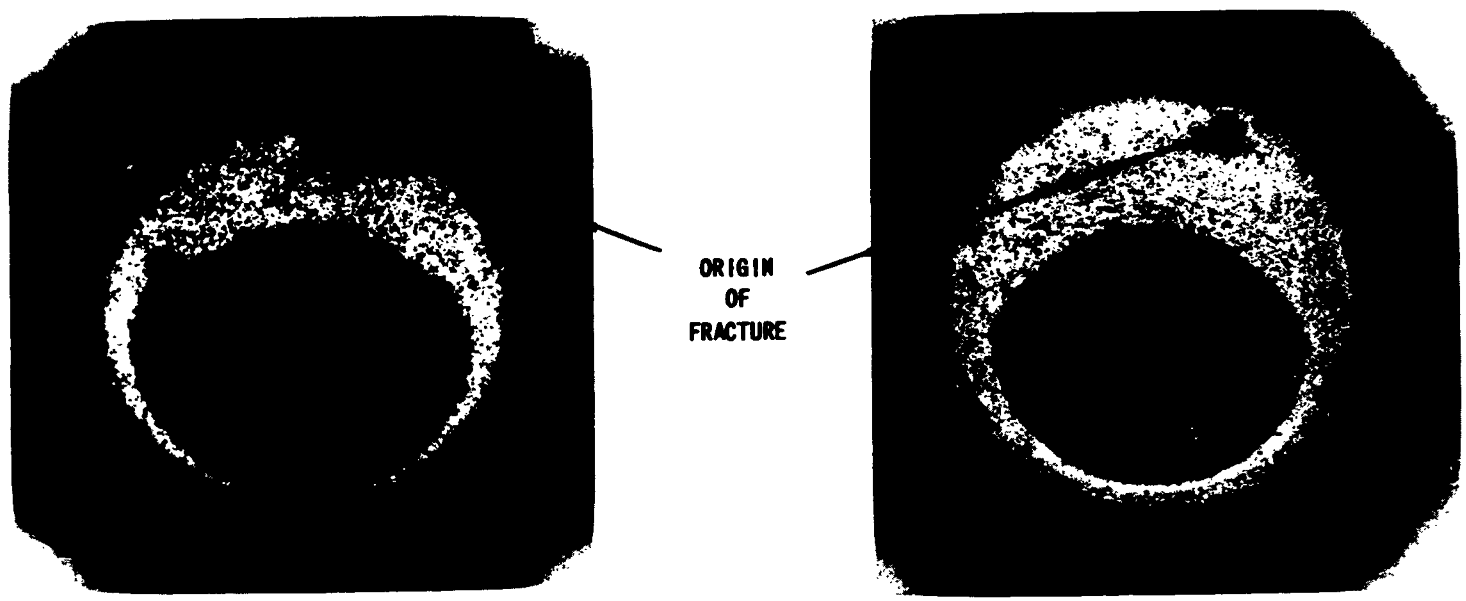
FIGURE 7



**ROTATING BEAM FATIGUE
PROPERTIES OF 8620H STEEL**

**Testing Speed 1800 RPM
All Specimens Polished**

FIGURE 8

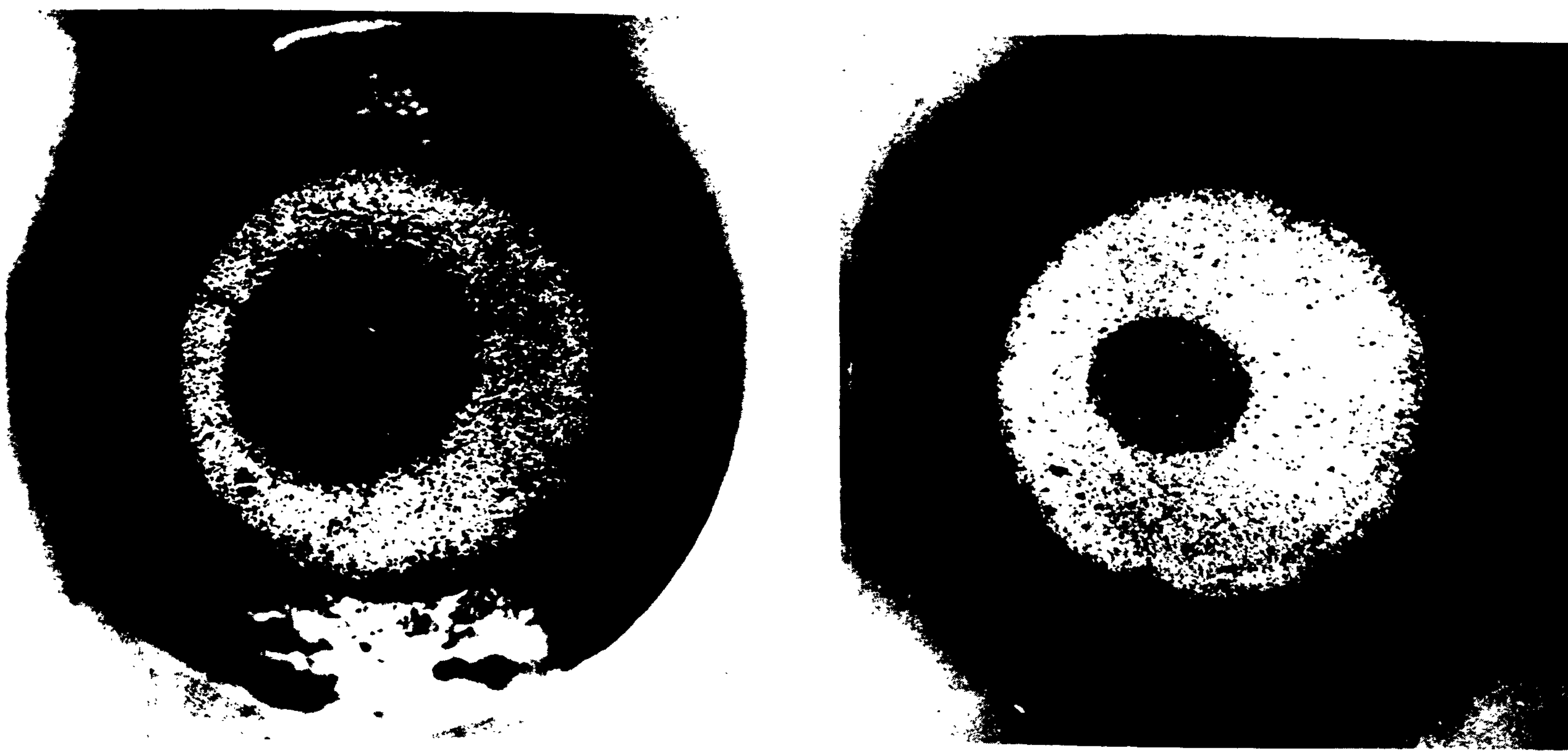


COMPUTED BENDING STRESS 170 ksi
CYCLES TO FAILURE 1.7×10^5

COMPUTED BENDING STRESS 165 ksi
CYCLES TO FAILURE 2.13×10^5

FRACTURE SURFACES OF SMOOTH ROTATING BEAM FATIGUE SPECIMENS
(Testing Speed 1800 RPM)
(Magnification 10X)

FIGURE 9

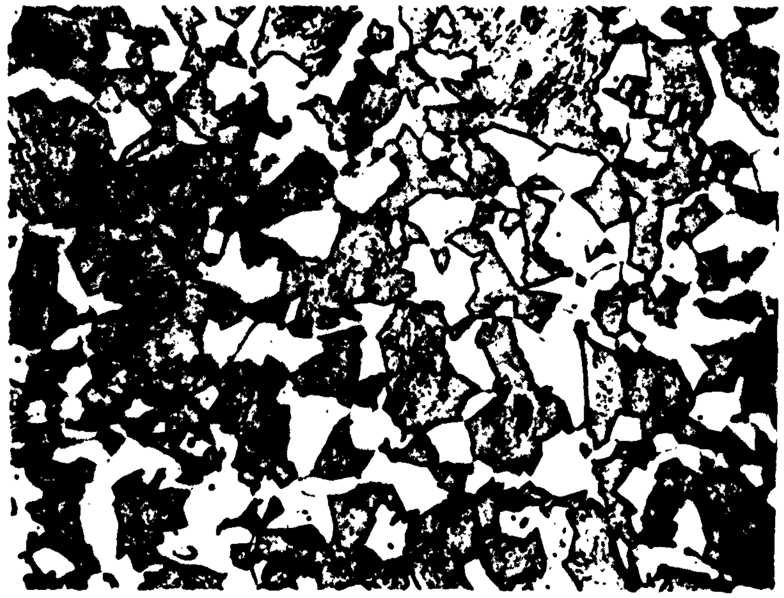


COMPUTED BENDING STRESS 110 ksi
CYCLES TO FAILURE 7×10^3

COMPUTED BENDING STRESS 75 ksi
CYCLES TO FAILURE 47×10^3

FRACTURE SURFACES OF 90° NOTCHED 0.030 RADIUS ROTATING BEAM FATIGUE SPECIMENS
(Testing Speed 1800 RPM)
(Magnification 10X)

FIGURE 10



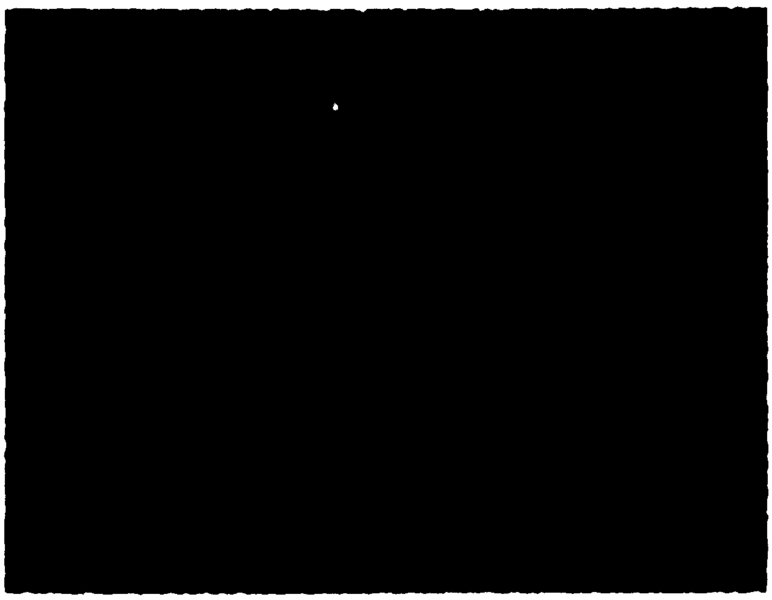
FATIGUE SPECIMEN
50% Free Ferrite
50% Low Carbon Tempered Martensite
Rockwell C 31.7

CHARPY IMPACT SPECIMEN
10% Free Ferrite
25% Low Carbon Tempered Martensite
65% High Temperature Bainite
Rockwell C 35.4

CORE STRUCTURES OF DELAYED OIL QUENCHED SPECIMENS
(Picral - HCl Etch - Mag. X1000)

FIGURE 11

FATIGUE SPECIMEN
100% Low Carbon Tempered Martensite
Rockwell C 43.4



CHARPY IMPACT SPECIMEN
15% Free Ferrite
8% Low Carbon Tempered Martensite
77% High Temperature Bainite
Rockwell C 34.5

CORE STRUCTURES OF OIL QUENCHED SPECIMENS
(Picral - HCl Etch - Mag. X1000)

FIGURE 12

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Report No. WAL TR 739.1/3, Nov 1961, 31 pp - tables - illus, OMS Code 4010.25.0005.2.28, Unclassified Report

Mechanical and metallurgical tests have been conducted to aid in the development of improved processes and materials for M14 rifle bolts and receivers which are currently being manufactured from carburized 8620H resulphurized steel. The investigation revealed the extreme brittleness which can occur in carburized components, especially those having small fillet radii. This brittleness is associated particularly with high core hardness and nonmartensitic microstructures which can occur in AISI 8620H steel over the allowable range of composition. The study demonstrates the importance of close control over the composition and heat treatment of this material and the advantages from a performance standpoint of employing a steel having higher hardenability and lower carbon content. The study also provides an evaluation of several important variables upon fatigue properties of 8620H steel.

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2. Materials evaluation, carburized
3. Steel, 8620H

I. Sliney, Joseph L.

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