MEMORANDUM REPORT ARLCB-MR-84006

OBSERVATIONS ON THE AUS-QUENCHING OF GUN STEEL AND RELATED PROPERTIES

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A reforged tube section was aus-quenched and tempered. Tensile and Charpy V-notch properties were determined at three locations in the forging, as well as the parent tube. No significant differences were observed in the strength, ductility, or toughness of the aus-quenched forging as compared to the conventionally heat-treated parent tube. It was further determined that a tempered martensitic microstructure was obtained in all sections for both methods of heat treatment.

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INTRODUCTION

Statement of the Problem

The importance of achieving a tempered martensitic microstructure in large gun tube forgings has been well documented (refs 1-3). However, in order to attain this microstructure, a rather drastic quench is required, generally water, due to the hardenability characteristics of the alloy. Quenching of this type invariably results in high residual tensile stresses in the tube. If the tensile stresses are of sufficient magnitude, quench cracks develop and the tube is scrapped. Obviously, this constitutes a serious scheduling problem, with an equally serious economic problem.

DISCUSSION/APPROACH TO THE PROBLEM

Figure 1 is the Time, Temperature, Transformation Diagram developed for gun steel (ref 4). Two continuous cooling curves have been superimposed on the diagram, representing conventional and aus-quenching methods of quenching.

In the conventional method of heat treating gun steel, the tube is quenched from the austenitizing temperature, at a rate fast enough to avoid the bainitic shelf. In most cases, water is used as the quenching medium. Because of the high austenitizing temperature, generally 1550°F to 1650°F,

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[1]Nolan, C. J., Brassard, T. V., and DeFries, R. S., "How Microstructure Influences the Properties of Forgings," Metals Engr. Quarterly, May 1973.
[2]Throop, J. and Miller, G., "Optimum Fatigue Crack Resistance," Technical Report WVT-7006, Watervliet Arsenal, Watervliet, NY, January 1970.
[3]Colangelo, V. J. and Heiser, F. A., Analysis of Metallurgical Failures, John Wiley & Sons, 1974.
[4]Hehemann, R. F. and Toroiand, A. R., "The Bainitic Reaction in Steel," Metals Progress, Vol. 2, 1945.

this technique generates the greatest degree of distortion, the largest amount of residual tensile stresses, and hence, the susceptibility to quench cracking.

In the aus-treating or quenching of steel (refs 5,6), cooling is done at a rate sufficiently fast to avoid the pearlitic nose. The component part is then held at temperature in the austenitic bay until thermal equilibrium has been established. It is subsequently quenched at a rate sufficiently fast to insure complete transformation to martensite.

In some early work on transformation studies in a modified 4340 alloy (ref 4), it was found that an incubation period existed before the onset of transformation to bainite, when cooling occurred from austenite, at a low temperature. This particular experiment was designed on the basis of this observation. More recent work by Cote, using a combined method of Thermo-Magnetic and Differential Thermal Analysis has confirmed that considerable suppression of the bainite transformation can occur in gun steels, especially for high vanadium concentrations.

EXPERIMENTAL PROCEDURE

The material selected represents a typical heat of gun steel. The chemical analysis is given in Table I.

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[4]Hehemann, R. F. and Toroiand, A. R., "The Bainitic Reaction in Steel," Metals Progress, Vol. 2, 1945.
[5]Pavar, M., Aus-Treating, U.S. Patent 3,567,527 (A patented process for heat treating various chromium-molybdenum alloy steel), 1968.
[6]Cote, P. J., "Determination of the Heat Treatment Characteristics of Various Gun Steels by Combined Thermomagnetic and Differential Thermal Analysis," ARDC Memorandum Report, ARLCB-MR-83039, Benet Weapons Laboratory, Watervliet, NY, November 1983.

TABLE I. CHEMICAL ANALYSIS OF PARENT TUBE

C	-0.35
Mn	-0.32
P	<0.01
S	0.01
Ni	2.91
Cr	0.88
Mo	0.23
Si	0.18
V	0.13

A section of the breech end was reforged to a 4-1/2 inch square and lightly machined to remove surface scale. A macrophotograph of the forged square appears in Figure 2.

The reforged section was austenitized at 1550°F for one hour and transferred to an adjacent furnace at 1000°F. The specimen was held until the temperature was equalized. It was then soaked for four hours at 1000°F and subsequently water quenched.

Tensile and Charpy V-notch impact specimens were cut and machined from the edge, mid-radius, and center locations of the forging as shown in Figure 3. After testing, the Charpy V-notch specimens were used for metallographic analysis.

RESULTS

The mechanical properties of the parent tube are presented in Table II. The 0.2 percent yield strength is 174.0 Ksi with tensile strength of 185.0 Ksi, and elongation and reduction in area of 14.5 percent and 46 percent, respectively. We obtained Charpy impact values of 24 ft.-lbs. at room temperature and 21 ft.-lbs. at -40°F.

TABLE II. MECHANICAL PROPERTIES OF CONVENTIONALLY HEAT-TREATED GUN STEEL

Direction	0.2% Y.S. (Ksi)	U.T.S. (Ksi)	% El	% RA
Transverse	175.0	187.0	15.0	45
Transverse	173.0	186.0	16.0	48
Transverse	174.0	183.0	14.0	46
Transverse	173.0	183.0	13.0	45

Charpy V-Notch Impact

Direction	Test Temp (°F)	Energy Absorbed/ft.-lbs.
Transverse	Room	21.0
Transverse	Room	27.0
Transverse	-40	20.0
Transverse	-40	22.0

TABLE III. MECHANICAL PROPERTIES OF AUS-QUENCHED AND TEMPERED GUN STEEL

Test Direction	Test Location	0.2% Y.S. (Ksi)	U.T.S. (Ksi)	% El	% RA
Transverse	Edge	170.0	182.0	16	46
Transverse	Edge	170.0	182.0	18	40
Transverse	Mid-Radius	173.0	184.0	12	40
Transverse	Mid-Radius	174.0	185.0	14	42
Transverse	Center	173.0	183.0	11	33
Transverse	Center	172.0	183.0	10	41

Charpy V-Notch Impact

Test Direction	Test Location	Test Temp (°F)	Energy Absorbed ft.-lbs.
Transverse	Edge	-40	24
Transverse	Edge	-40	26
Transverse	Mid-Radius	-40	23
Transverse	Mid-Radius	-40	24
Transverse	Center	-40	23
Transverse	Center	-40	24

Heat Treatment - 1550°F for one hour; transfer to 1000°F and hold four hours; water quench and temper at 1050°F for two hours; water quench.

TABLE IV. COMPARISON OF CHARPY V-NOTCH PROPERTIES CONVENTIONALLY HEAT TREATED AND AUS-QUENCHED FOR GUN STEEL

Direction	Location	Heat Treatment	Test Temp (°F)	Energy Absorbed ft.-lbs.
Transverse	Edge	Conventional	-40	17
Transverse	Edge	Aus-Quenched	-40	24
Transverse	Mid-Radius	Conventional	-40	18
Transverse	Mid-Radius	Aus-Quenched	-40	23
Transverse	Center	Conventional	-40	17
Transverse	Center	Aus-Quenched	-40	23

Heat treatment of the parent tube consisted of normalizing at 1750°F for one and one-half hours and air cooling, austenitizing at 1550°F for one and one-half hours and water quenching, followed by tempering at 1050°F for two hours and water quenching.

The mechanical properties reflect a typical gun tube of acceptable quality. Mechanical property data for the aus-quenched section are given in Table III. Yield and tensile strengths as well as elongation and percent reduction of area are essentially the same as the parent tube. The impact values are slightly higher than the parent tube. In Table IV the impact values are compared at similar locations, edge, mid-radius, center, and bore of the tube. Both the tube and the aus-quenched forging show a consistent toughness at all locations which indicates that hardening was achieved with both heat treatments. The aus-quenched forging shows a six ft.-lb. advantage over the parent tube, which quite possibly is due to the additional forging and slightly finer grain size.

Figure 4 represents a series of microphotographs from the Charpy impact specimens at the three locations tested. As can be seen, the microstructure in each case is tempered martensite which verifies complete transformation.

The electron-microphotograph which appears in Figure 5 shows the fine, randomly dispersed carbides which are typical of aus-quenched material. Good toughness and fatigue life are characteristic of this type of carbide dispersion in martensitic steels.

CONCLUSIONS

1. A tempered martensitic microstructure can be attained with the aus-quenching method of heat treatment.

2. Tensile strength, ductility, toughness, as well as hardness, are consistent throughout the cross-section of the forging.

3. Aus-quenching is potentially a good method for eliminating quench cracks in gun tubes while maintaining comparable mechanical properties.

REFERENCES

1. Nolan, C. J., Brassard, T. V., and DeFries, R. S., "How Microstructure Influences the Properties of Forgings," Metals Engr. Quarterly, May 1973.

2. Throop, J. and Miller, G., "Optimum Fatigue Crack Resistance," Technical Report WVT-7006, Watervliet Arsenal, Watervliet, NY, January 1970.

3. Colangelo, V. J. and Heiser, F. A., <u>Analysis of Metallurgical Failures</u>, John Wiley & Sons, 1974.

4. Hehemann, R. F. and Toroiand, A. R., "The Bainitic Reaction in Steel," Metals Progress, Vol. 2, 1945.

5. Pavar, M., Aus-Treating, U.S. Patent 3,567,527 (A patented process for heat treating various chromium-molybdenum alloy steel), 1968.

6. Cote, P. J., "Determination of the Heat Treatment Characteristics of Various Gun Steels by Combined Thermomagnetic and Differential Thermal Analysis," ARDC Memorandum Report, ARLCB-MR-83039, Benet Weapons Laboratory, Watervliet, NY, November 1983.

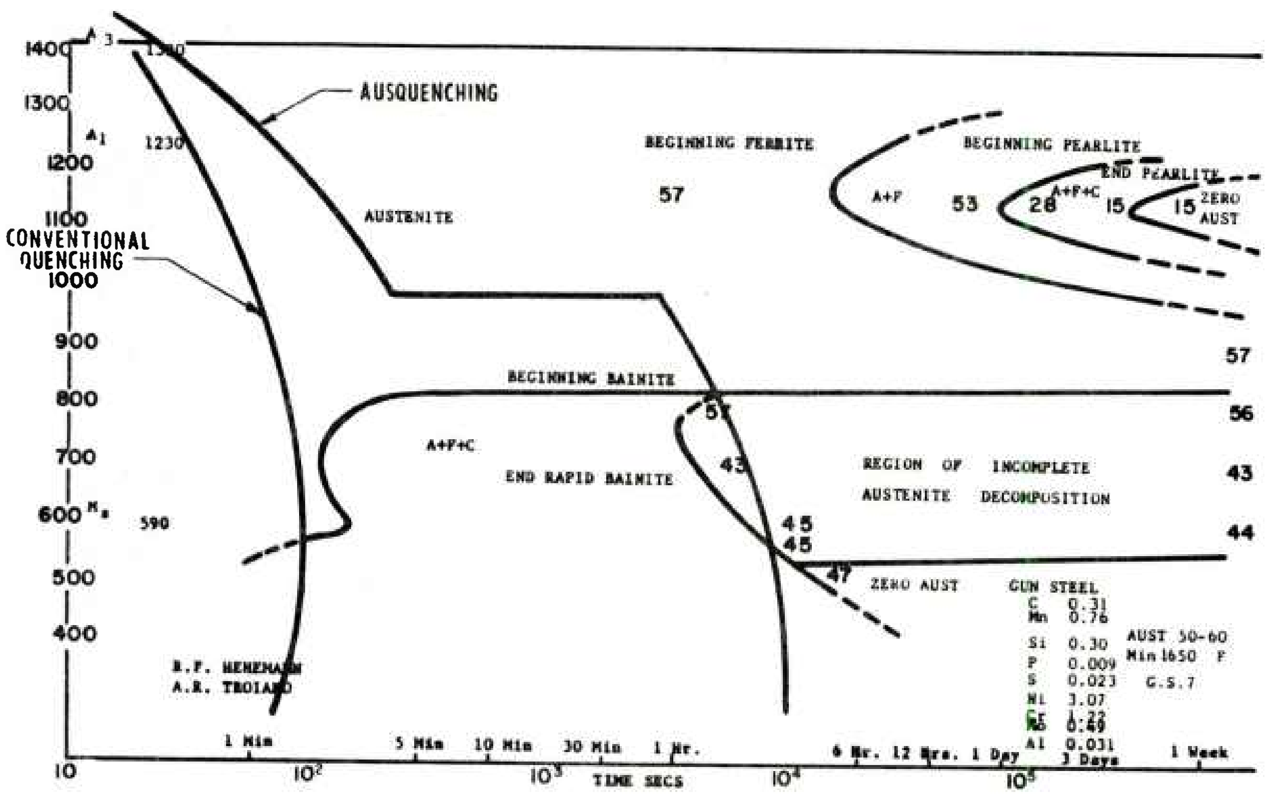


Figure 1. Time-Temperature-Transformation Diagram for Gun Steel With Superimposed Cooling Curves.

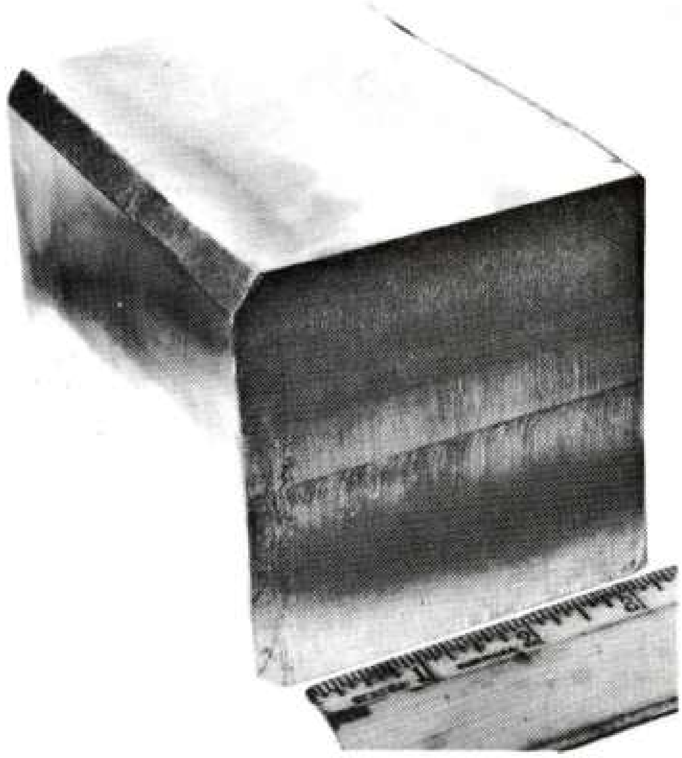


Figure 2. Reforged Section of Gun Tube - 4-1/2 Inches Square.

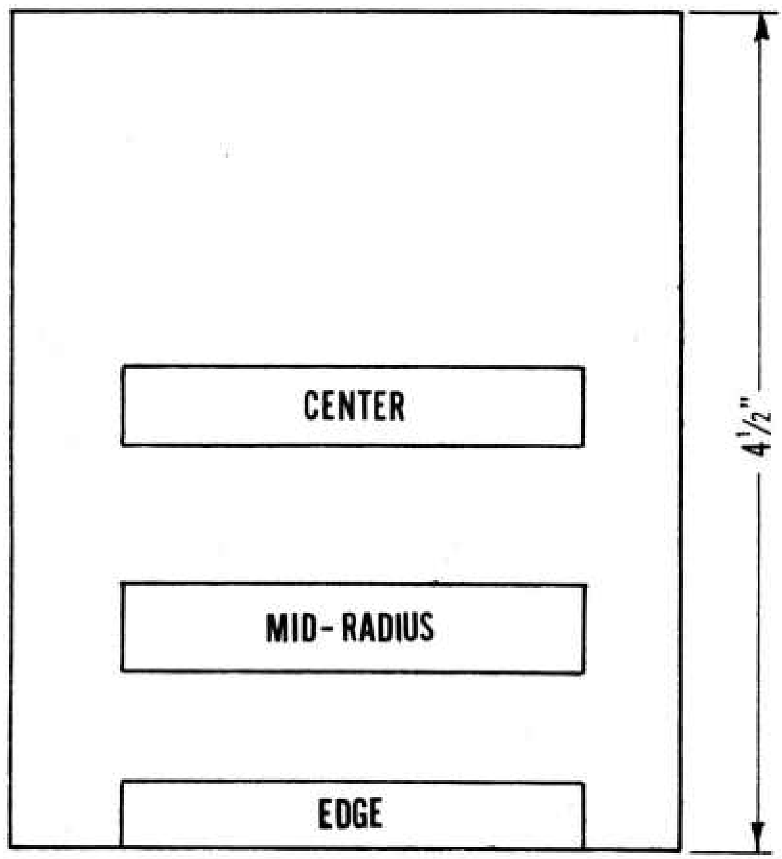
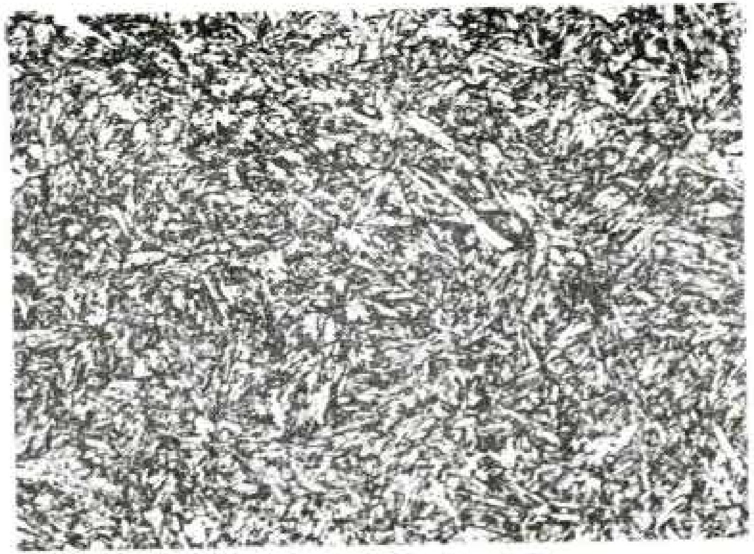
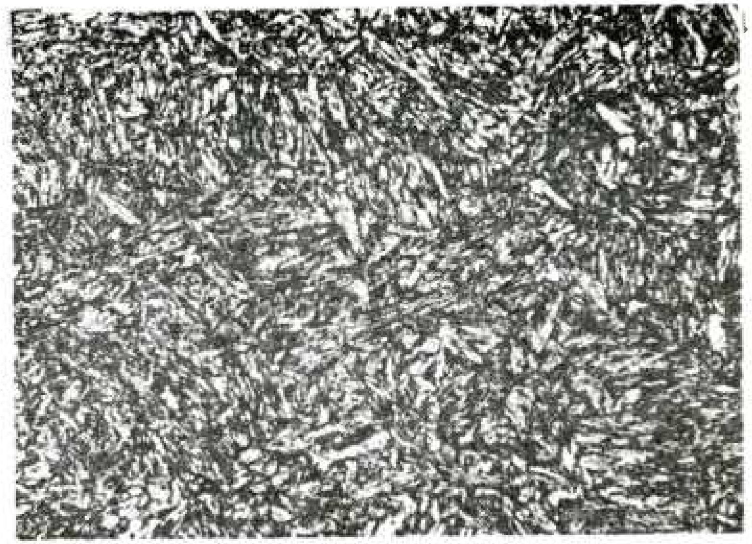


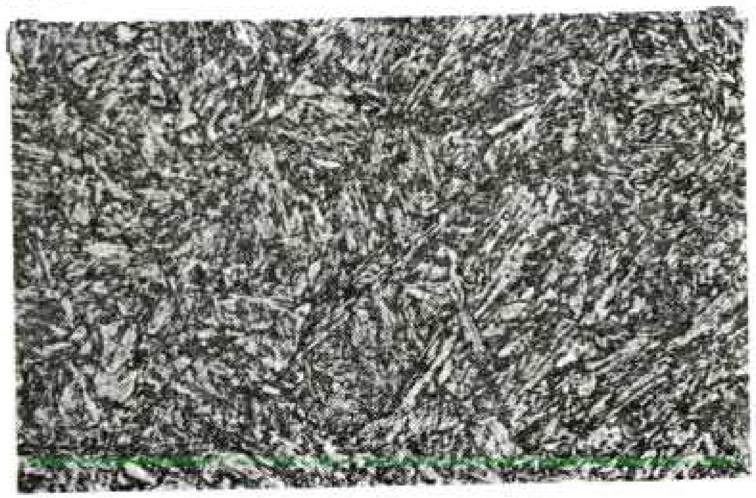
Figure 3. Schematic of Test Specimen Location - Aus-Quenched Gun Steel.



Edge - Rc 39-39.5



Mid-Radius - Rc 39-39.8



Center Rc 39-39.5

Figure 4. Microstructure of Aus-Quenched Forging at Various Locations. Magnification 1000X, Etchant Two Percent Picral.

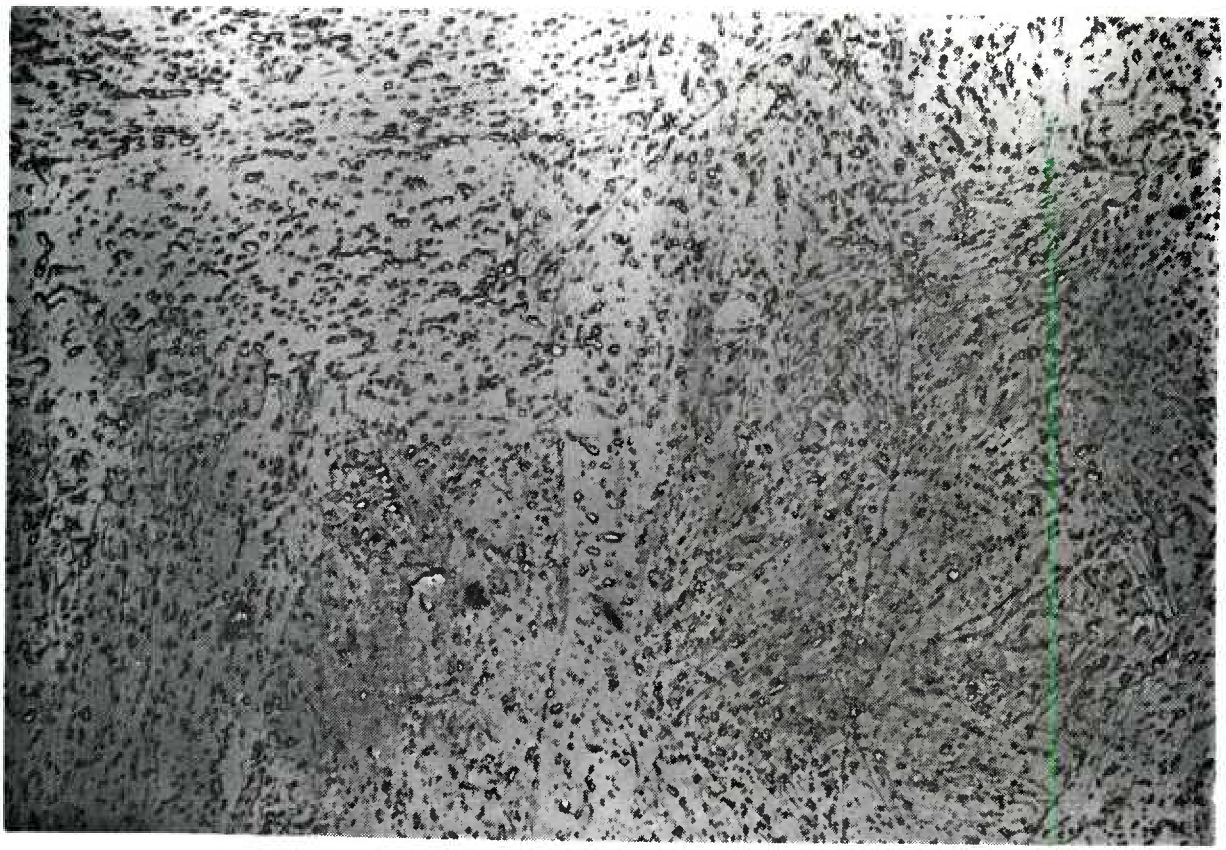


Figure 5. Typical Microstructure of Aus-Quenched and Tempered Gun Steel. Electron Microphotograph. Magnification 7500X.

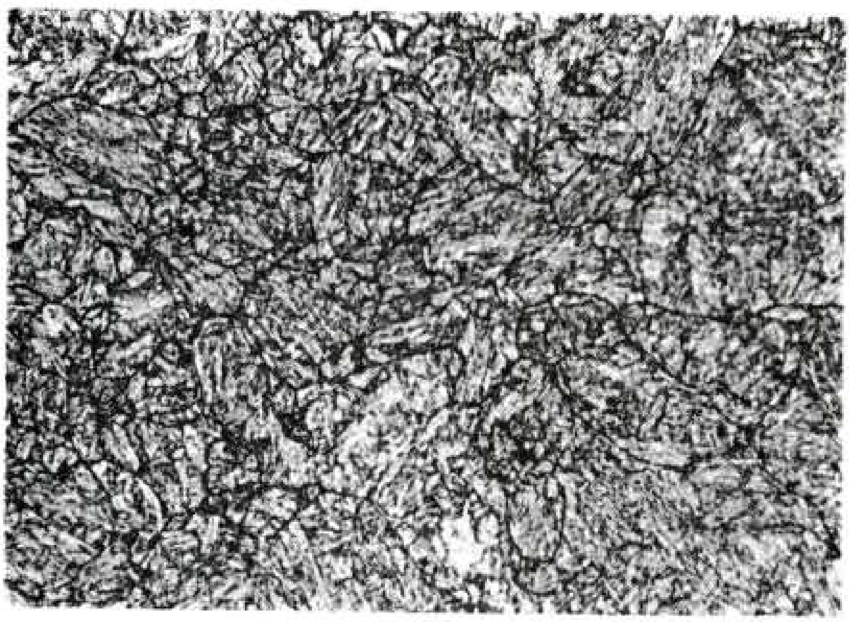


Figure 6. Representative Grain Structure of Aus-Quenched and Tempered Gun Steel. A.S.T.M. Grain Size 10-11, Magnification 1000X, Etchant-Grain Boundary Reagent.

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