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STRESS CORROSION STUDIES OF AM-355 STAINLESS STEEL

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ABSTRACT

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The stress corrosion cracking susceptibility of AM-355 stainless steel alloy was studied. This alloy is used extensively for sleeves in flared tube fittings in the S-I and S-IC stages of the Saturn I and Saturn V vehicles, respectively. Various heat treated conditions were investigated and relative stress corrosion cracking susceptibility determined. Of the generally used heat treatments, the fully hardened SCT 1000 treatment was found to be superior in stress corrosion resistance. Author

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PROPULSION AND VEHICLE ENGINEERING LABORATORY
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SUMMARY

An investigation of the stress corrosion susceptibility of AM-355 stainless steel alloy was initiated because of a stress corrosion cracking problem associated with the sleeves which are used with flared tube fittings on the Saturn I. Because of the precipitation-hardening characteristics of AM-355, the heat treatment is considered the most important factor in controlling stress corrosion cracking. Therefore, the various heat treated conditions were investigated, and the relative stress corrosion cracking susceptibilities were determined.

This study indicated that the presence of a carbide network in the grain structure increases greatly the susceptibility of AM-355 to stress corrosion cracking; however, cracking can occur if no carbides are present. The tempering temperature used for this alloy is equally as important as the basic heat treatment in preventing stress corrosion cracking. To assure the greatest resistance to this type of failure, the AM-355 alloy should be given the fully hardened SCT heat treatment with a tempering temperature of at least 950°F and preferably 1000°F.

INTRODUCTION

The semi-austenitic stainless steels developed in recent years are finding increased use in space vehicle applications because of their unique properties which combine the corrosion resistance and formability characteristics of the austenitic stainless steels and the strength of the straight chromium, martensitic steels. One important but unclarified point is the stress corrosion resistance of these alloys.

The most frequently used alloy of the semi-austenitic stainless steels in the S-I and S-IC vehicles is AM-355. The major use of AM-355 in these vehicles is for sleeves used in flared tube fittings which require a material of high strength and hardness. The stress corrosion susceptibility of this alloy was studied because of a cracking problem associated with these sleeves. Although cracking problems, attributed to various reasons, have occurred through the years with this type of fitting, metallurgical analyses of these failures gave strong indications that the problem was due to stress corrosion. The cracking problem associated with these specific parts will be covered in another report.

Factors that could contribute to the stress corrosion susceptibility of AM-355 alloy are many; however, because of the precipitation hardening characteristics of this alloy, the heat treatment was considered to be the most important factor in controlling this phenomena. Thus, the purpose of the study was to determine the effect of various heat treatments on the stress corrosion susceptibility of AM-355 alloy.

EXPERIMENTAL PROCEDURE

Since the major use of AM-355 alloy in the Saturn vehicles has been confined to sleeves for flared tube fittings, all stress corrosion specimens for this study were fabricated from bar stock and from actual sleeves. The bar stock, purchased from the Allegheny-Ludlum Steel Corporation, was double consumable electrode melted, carbide solution treated, equalized, and overtempered. Table I gives the analysis of this material. The alloy was given the various heat treatments that are shown in Table II. The sleeves used in this study also were heat treated in the same manner as the bar stock; however, since they were taken from stock, they were fabricated from various lots of material. All lots conformed to MSFC Specification 145.

A "C"-ring type specimen (FIG 1) utilizing the constant deflection method explained in Appendix I was employed in this work. Specimens which were machined from one and one-half-inch bar stock were one and three-eighths inches in diameter with a wall thickness of 0.062 inch. Specimens made from sleeves were 1.6 inches in diameter and 0.048 inch in wall thickness. The specimens were degreased with acetone, stressed to the desired level, and then placed in the various corrosive environments until failure occurred or until the tests were terminated. Mechanical properties of the alloy were measured by cutting tensile specimens from each bar; minimum published values were used for specimens which were made directly from fabricated sleeves. Specimens were stressed at various levels from 25 to 100 percent of the yield strength (0.2 percent offset) of the alloy. The corrosive environments included continuous salt spray (five percent NaCl), alternate immersion (3.5 percent NaCl), and both inside and outside exposure at the George C. Marshall Space Flight Center, Huntsville, Alabama. The alternate immersion test (FIG 2) consists of 10 minutes immersion in the salt solution, followed by 50 minutes of drying each hour.

RESULTS AND DISCUSSION

The complete results of this study are summarized in Table III. It is evident that the fully hardened SCT heat treatment is vastly superior to the SCT heat treatment in reducing the susceptibility of AM-355 alloy to stress corrosion cracking. These tests also indicated that the tempering temperature influences greatly the stress corrosion susceptibility. The high tempering temperatures reduced the susceptibility of this alloy to some extent in the SCT condition and to an even greater extent in the fully hardened SCT condition. At this tempering temperature (1000°F), the alloy has less hardness and strength but greater ductility and notch strength. All of these properties tend to make most metal alloys less susceptible to stress corrosion cracking, and this study has indicated that this is true for the AM-355 alloy.

As shown in Table III, all specimens that were tested in the SCT 850 condition failed when exposed in the alternate immersion tester. Specimens stressed to as low as 25 percent of the yield strength (41.5 ksi) failed in 51 to 114 days. At 50 percent of the yield strength (83 ksi), the specimens failed in 11 to 35 days, and specimens stressed at 75 and 100 percent of the yield strength failed in 2 to 10 days.

Using the same basic heat treatment (SCT) but tempered at 1000°F, specimens of this alloy showed a considerable improvement in the susceptibility to stress corrosion cracking in the alternate immersion tester. None of the specimens which were stressed at 25 percent of the yield strength failed in 180 days of exposure, and only two out of six specimens failed (124 and 125 days) at a stress level of 50 percent of the yield strength. Only three of six specimens failed at 75 percent of the yield strength in 30 to 107 days, and all six specimens that were stressed at 100 percent of the yield strength failed in 37 to 156 days.

In the fully hardened SCT condition, the AM-355 alloy in the 850°F temper was somewhat less susceptible to stress corrosion cracking than in the SCT 1000 condition. As the tempering temperature in the fully hardened SCT condition increased, the resistance to stress corrosion cracking increased to a great extent. The alloy which was tempered at 950°F and 1000°F did not fail during the 180-day test.

Limited tests in other environments substantiated the results that were obtained by using the alternate immersion tester; however, the alternate immersion test proved to be the most severe of the environments used in this study. Salt spray tests, when used to compare this alloy in the fully hardened SCT 850 condition to the fully hardened SCT 1000 condition, showed only one failure in the fully hardened SCT 850 (100 percent yield strength) and no failures in the fully hardened SCT 1000 condition. In the outside atmosphere at the Marshall Space Flight Center, the high susceptibility of this alloy in the SCT 850 condition also was shown. In this rather mild environment, two of three specimens failed at stress levels of 75 and 100 percent of the yield strength; no failures occurred in the fully hardened SCT 1000 condition. Failures did not occur in any of the specimens exposed in the laboratory environment in any of the various heat treated conditions.

Metallurgical analysis of this alloy indicated the presence of grain boundary carbide networks in all specimens heat treated to the SCT condition (FIG 3 and 4). These networks apparently contributed greatly to the susceptibility of this material to stress corrosion cracking; however, the fully hardened SCT heat treatment completely eliminated the carbide networks, but stress corrosion cracking occurred when the tempering temperature was 850°F or 900°F. Figures 5 and 6 show a crack in a specimen which has a carbide network and one that is free of such a network. Both cracks are intergranular, and the mode of failure appears to be the same. Therefore, stress corrosion cracking can occur in this alloy without the presence of carbide networks in the grain structure. Both the correct heat treatment and final temper must be used to obtain the greatest resistance to stress corrosion cracking.

CONCLUSIONS AND RECOMMENDATIONS

This study has indicated that the fully hardened SCT 1000 heat treatment greatly reduces the susceptibility of AM-355 stainless steel to stress corrosion cracking under the conditions of these tests. The alloy is very susceptible in the SCT 850 and SCT 1000 conditions and moderately susceptible in the fully hardened SCT 850 and fully hardened SCT 900 condition.

The presence of a carbide network in the grain structure greatly increases the susceptibility of this alloy to stress corrosion, probably because of the increased intergranular corrosion and pitting along the grain boundary carbides; however, cracking can occur when no carbides are present. The tempering temperature used for this alloy is equally as important as the basic heat treatment process in preventing stress corrosion cracking. To assure the greatest resistance to stress corrosion cracking, the AM-355 alloy should be given the fully hardened SCT heat treatment with a tempering temperature of at least 950°F and preferably 1000°F.

APPENDIX

METHOD FOR STRESSING "C"-RING STRESS CORROSION SPECIMENS

The following is a procedure for stressing "C"-ring stress corrosion specimens:

1. Measure with a micrometer to the nearest 1/1000 of an inch the outside parallel to the stressing screw (averaging the two ends of the ring) and the wall thickness.

2. Set up a table to calculate the final diameter (OD_f) required to give the desired stress using the following equations:

$$OD_f = OD - \Delta$$

$$\Delta = \frac{f \cdot \pi \cdot D^2}{4 \cdot E \cdot t \cdot Z}$$

where

Δ = Change of OD giving desired stress, inch
f = Desired stress, psi
OD = Outside diameter, inch
t = Wall thickness, inch
D = Mean diameter (OD-t), inch
E = Modulus of elasticity
Z = Constant (function of ring D/t)

OD_f = Final outside diameter of stressed "C"-ring

3. To simplify calculations, certain terms in the above equation may be combined into a constant that will be applicable for a group of rings of the same alloy and size.

Let $\frac{4 \cdot E}{\pi} = K$, a constant

Then $\Delta = \frac{f \cdot D^2}{K \cdot t}$

TABLE I

CHEMICAL COMPOSITION AND CERTIFICATION TESTS CONDUCTED ON AM-355 BAR STOCK, HEAT NUMBER 24497-5

Constituents	Percent
C	0.103
Mn	1.060
P	0.017
S	0.007
Si	0.28
Cr	15.22
Ni	4.20
Mo	2.74
N	0.077
H_2	7 ppm
O_2	24 ppm

TABLE II

HEAT TREATMENTS AND PHYSICAL PROPERTIES
OF AM-355 STAINLESS STEEL ALLOY

SCT 850

1 hour at 1900°F, WQ*
10 minutes at 1710°F, WQ
3 hours at -100°F
3 hours at 850°F, air cooled

Mechanical Properties

U.T.S.	Y.S.	Elong.	Hardness
216,000	182,000	19%	46-47

SCT 1000

1 hour at 1900°F, WQ
10 minutes at 1710°F, WQ
3 hours at -100°F
3 hours at 850°F, air cooled

Mechanical Properties

U.T.S.	Y.S.	Elong.	Hardness
173,000	148,000	18%	Rc 37-40

FH SCT 850

1 hour at 1900°F, WQ
3 hours at -100°F
15 minutes at 1750°F, WQ
3 hours at -100°F
3 hours at 850°F, air cooled

Mechanical Properties

U.T.S.	Y.S.	Elong.	Hardness
215,000	182,000	20.9%	46-47

FH SCT 900

1 hour at 1900°F, WQ
3 hours at -100°F
15 minutes at 1750°F, WQ
3 hours at -100°F
3 hours at 900°F, air cooled

Mechanical Properties

U.T.S.	Y.S.	Elong.	Hardness
210,000	182,000	19.6%	45-46

*Water quenched

TABLE II (Concluded)

FH SCT 950

1 hour at 1900°F, WQ
3 hours at -100°F
15 minutes at 1750°F
3 hours at -100°F
3 hours at 950°F

Mechanical Properties

U.T.S.	Y.S.	Elong.	Hardness
186,000	174,000	18%	Rc 42

FH SCT 1000

1 hour at 1900°F, WQ
3 hours at -100°F
15 minutes at 1750°F
3 hours at -100°F
3 hours at 1000°F

Mechanical Properties

U.T.S.	Y.S.	Elong.	Hardness
176,000	163,000	20.6%	Rc 38-40

TABLE III

STRESS CORROSION CRACKING OF AM-355 STAINLESS STEEL ALLOY

Heat Treat-ment	Stress % Y.S.	Alternate Immersion Test			Salt Spray Exposure			Outside Exposure, MSFC		
		Speci-mens in Test	No. Fail-ures	Days to Failure	Speci-mens in Test*	No. Fail-ures	Days to Failure	Speci-mens in Test	No. Fail-ures	Days to Failure
SCT	25	3	3	51,53,114						
850	50	3	3	11,13,35						
	75	3	3	3,6,6				3	2	199,199
	100	3	3	2,6,10				3	2	108,199
SCT	25	6		124,125						
1000	50	6	2	30,33,107				3		
	75	6	3	37,41,72						
	100	6	6	79,104,156				3		
FH SCT	25	6			3					
850	50	6	2	152,152	3					
	75	6	3	151,151,151	3					
	100	6	2	151,152	3	1	151			
FH SCT	25	3								
900	50	3								
	75	3	1	156						
	100	3	2	97,152						
FH SCT	25	3								
950	50	3								
	75	3								
	100	3								

*Heat treated from overtempered condition

TABLE III (Concluded)

Heat Treatment	Stress % Y.S.	Alternate Immersion Test: Specimens in Test	No. Failures	Days to Failure	Salt Spray Exposure: Specimens in Test	No. Failures	Days to Failure	Outside Exposure, MSFC: Specimens in Test	No. Failures	Days to Failure
FH SCT 1000	25	6			3					
	50	6			3					
	75	6			3			3		
	1000	6			3			3		

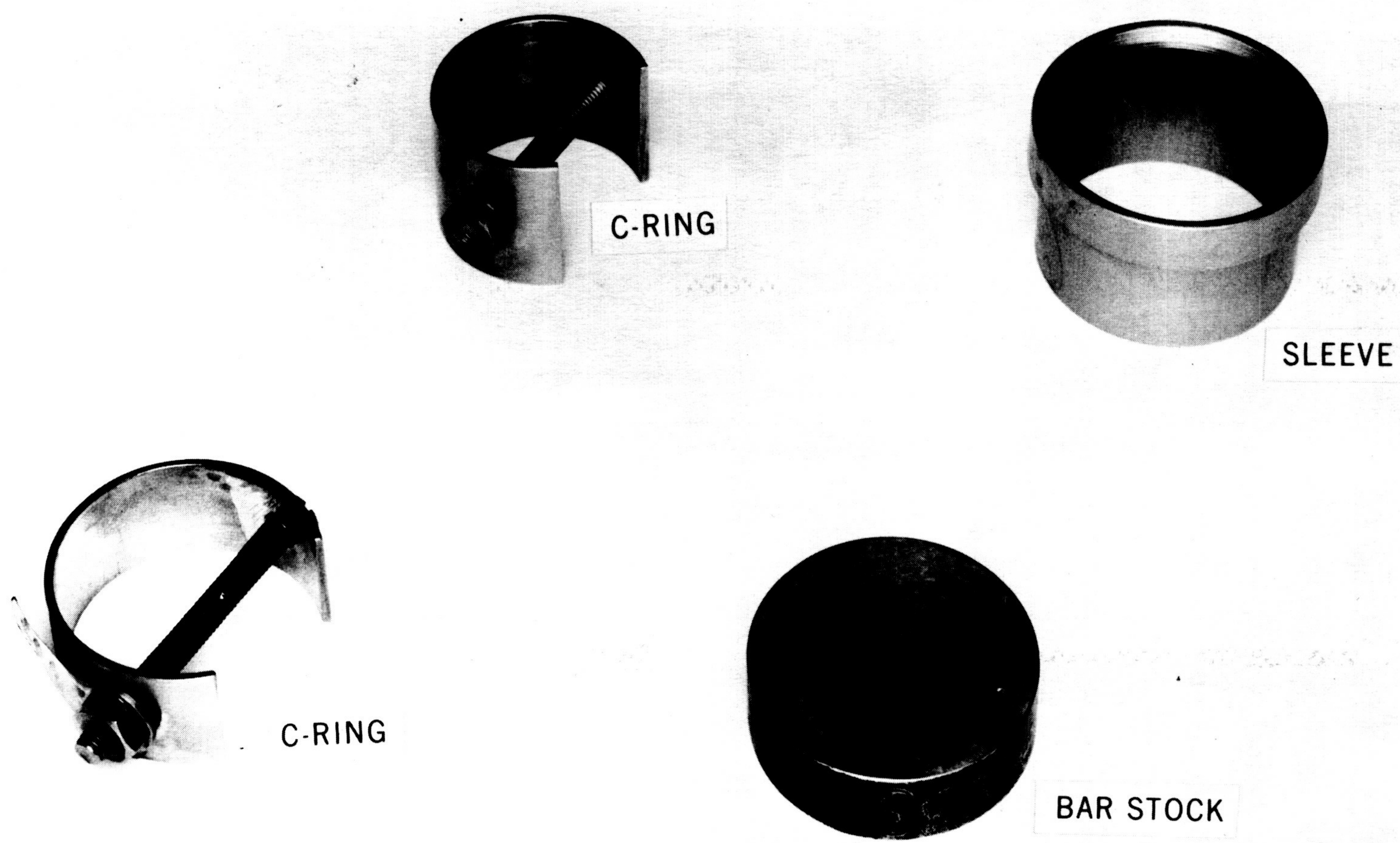

FIGURE 1. - STRESS CORROSION SPECIMENS MADE FROM AM-355 BAR AND SLEEVE MATERIAL

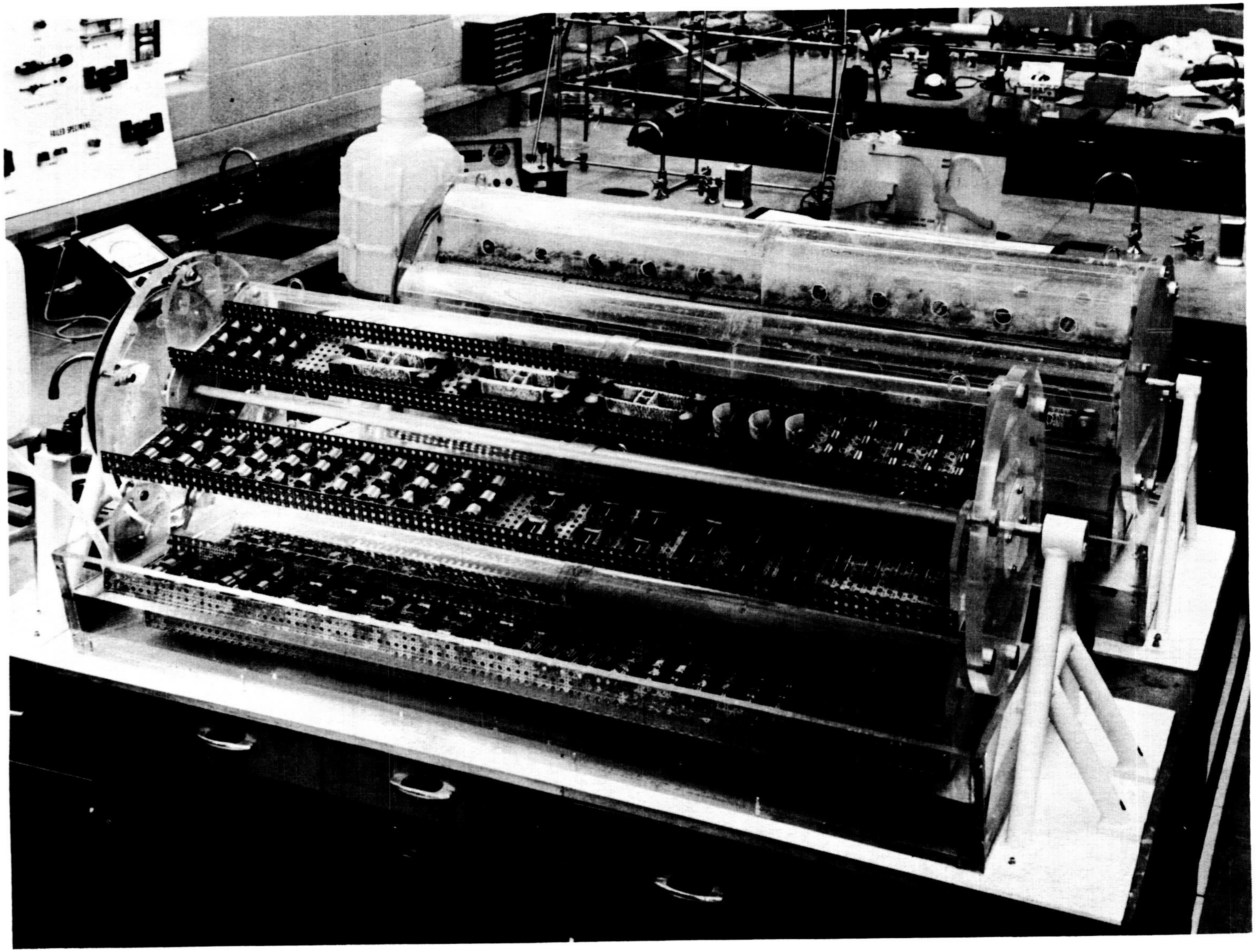

FIGURE 2. - ALTERNATE IMMERSION TESTER

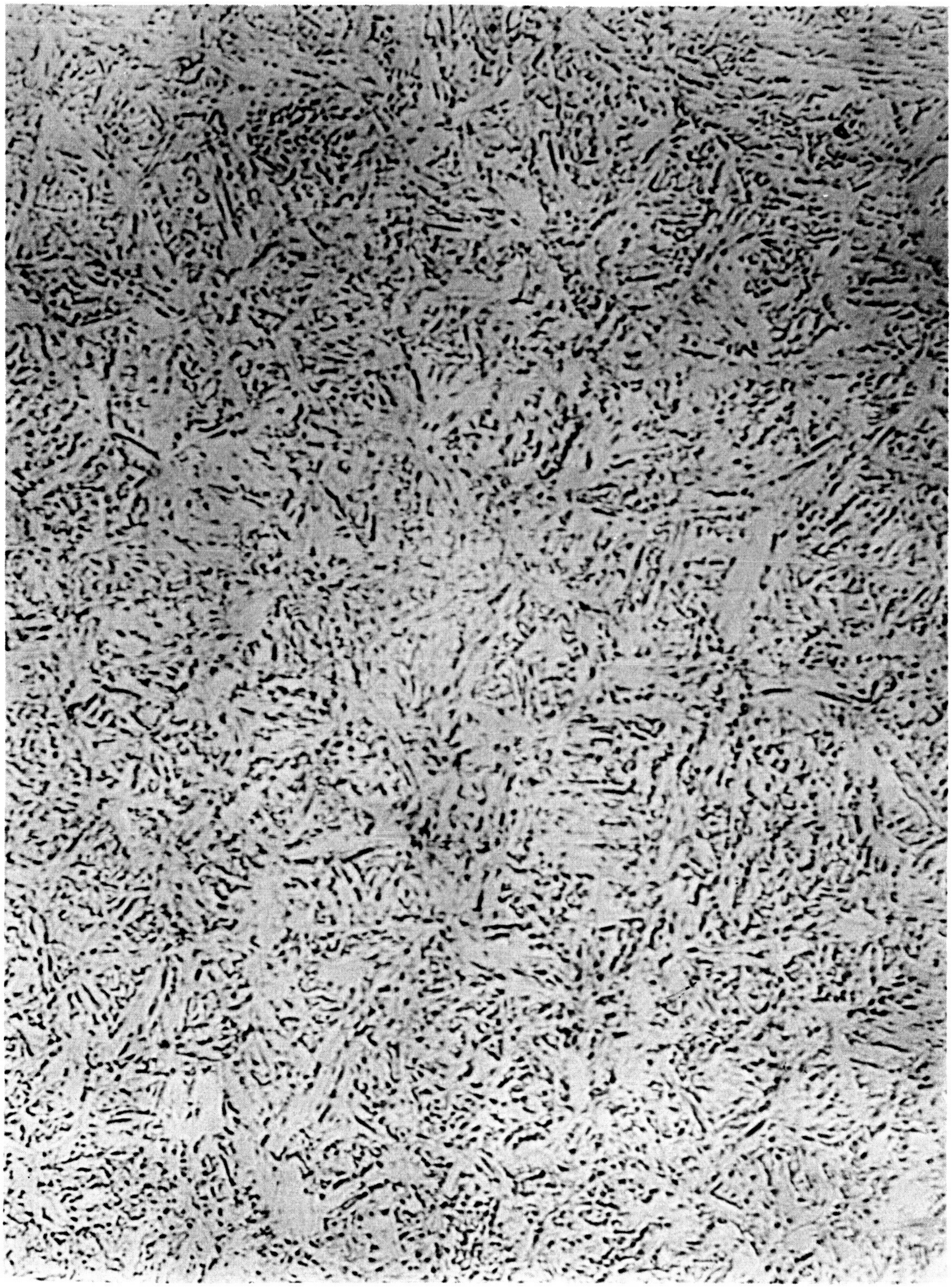

FIGURE 3. - NORMAL GRAIN STRUCTURE OF AM-355 STEEL IN FULLY HARDENED SCT-1000 CONDITION

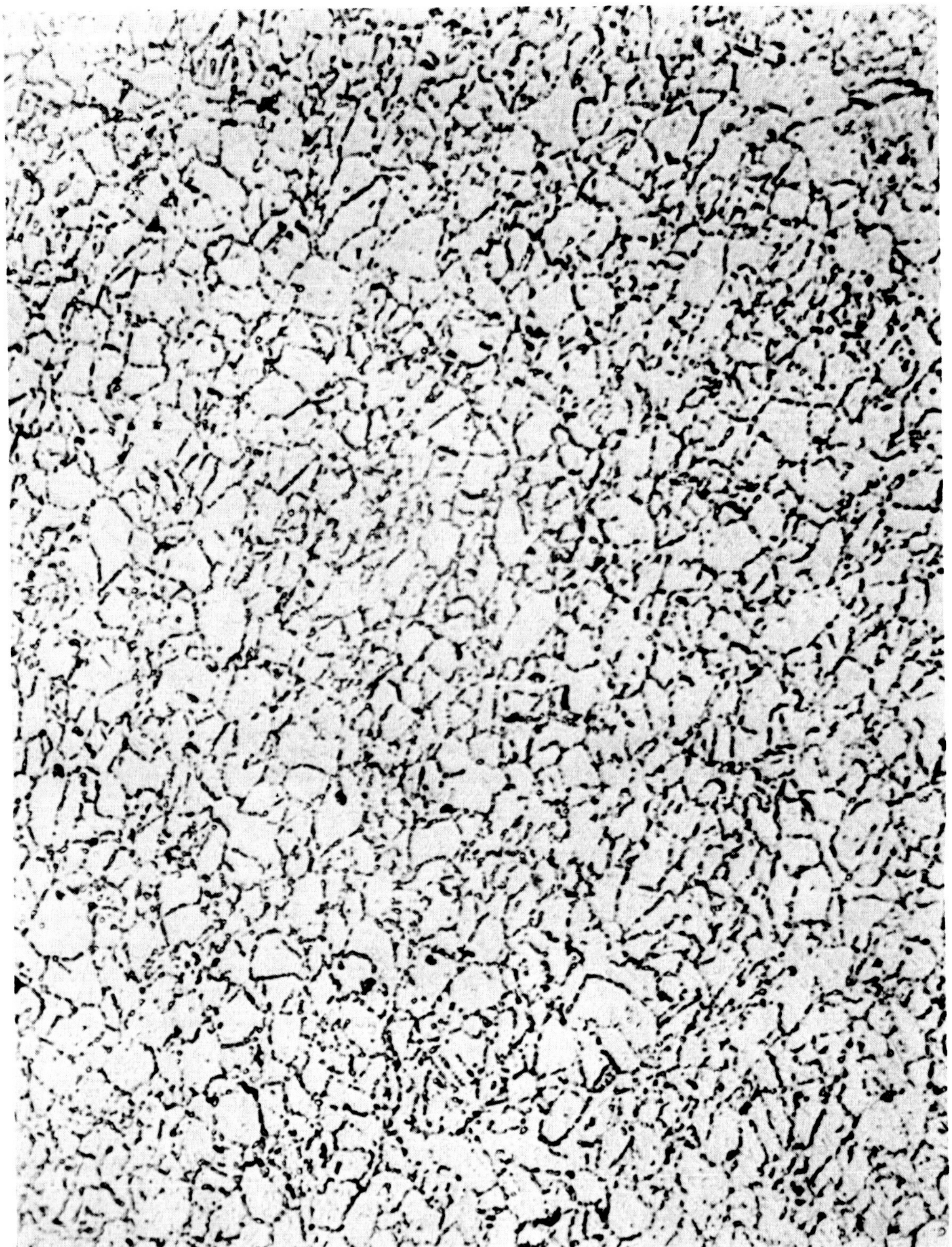

FIGURE 4. - GRAIN STRUCTURE OF AM-355 STEEL SHOWING CARBIDE NETWORK

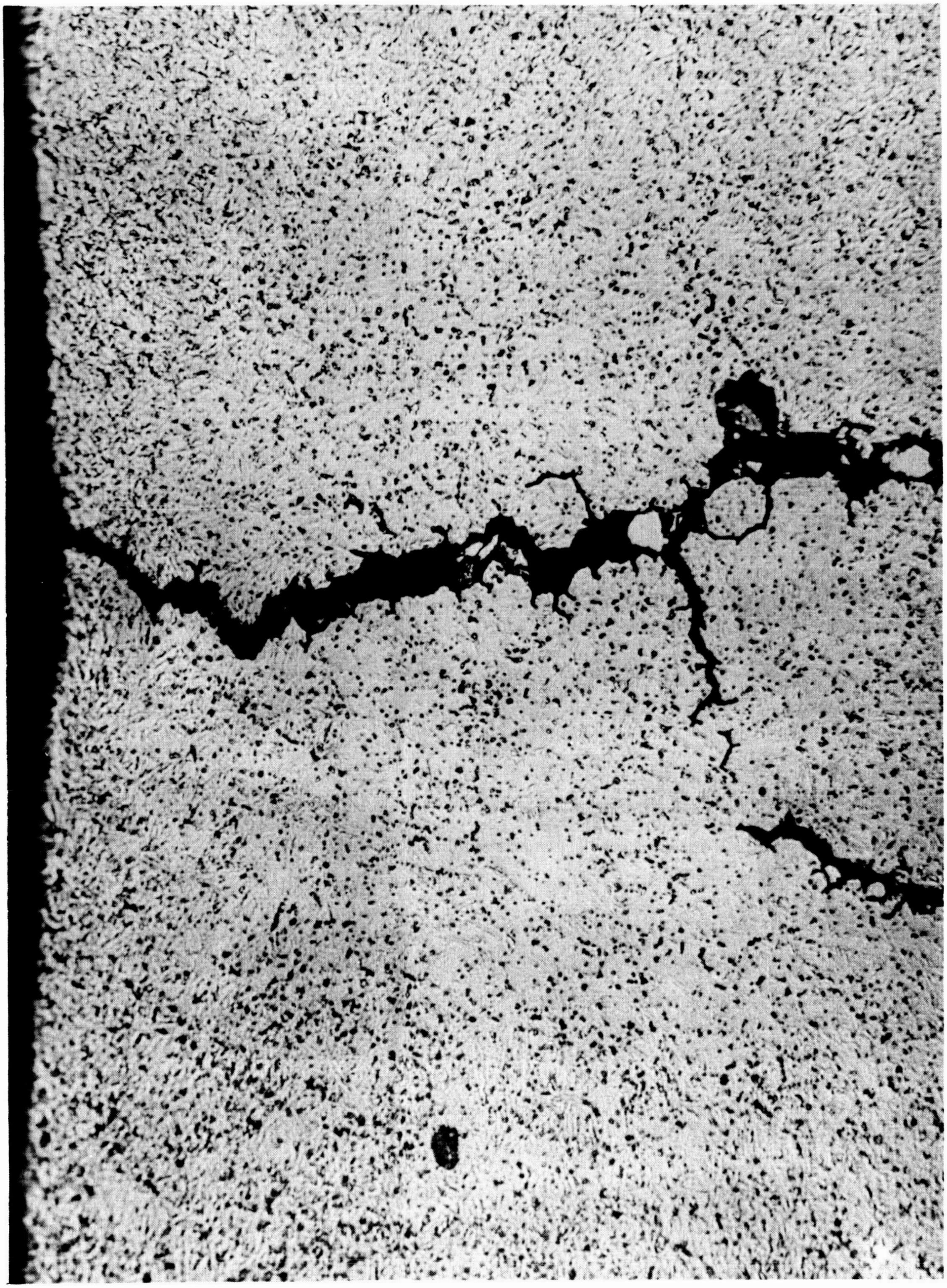

FIGURE 5. - CRACK IN AM-355 ALLOY WITHOUT CARBIDE NETWORK

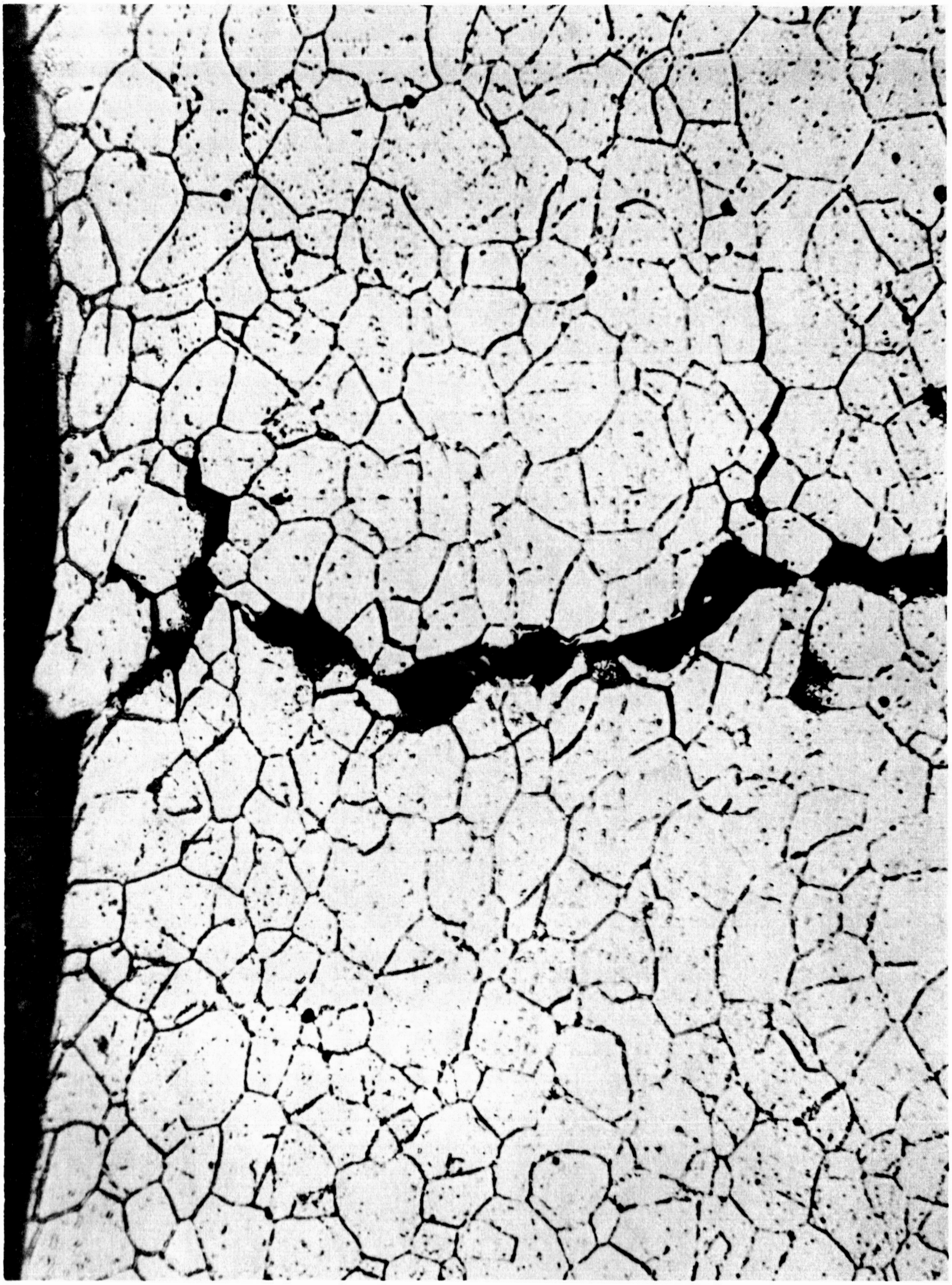

FIGURE 6. - CRACK IN AM-355 ALLOY CONTAINING CARBIDE NETWORK

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By J. G. Williamson

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document also has been reviewed and approved for technical accuracy.

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