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AEROSPACE INFORMATION REPORT

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AUS-BAY QUENCHING OF 300M STEEL

FOREWORD

The Aerospace Metals Engineering Committee (AMEC) consists of specialists in metallic materials and processes from major aerospace and government organizations. AMEC is dedicated to the objectives of solving common problems related to metallic materials and processes.

This program was initiated by AMEC and monitored by General Dynamics, Convair Division and conducted by AMEC representatives and their support personnel. Technical evaluation and review was performed by other active AMEC members.

Aus-bay quenching is a process in which the alloy is given an intermediate quench from the 1600 °F (871 °C) austenitizing temperature to an intermediate temperature, 1000 °F (538 °C), where the transformation to ferrite and carbides is sluggish and does not start for several hours, see Figure 1. The upper nose of the transformation curve is displaced to the right far enough so the quench rate is not critical and slower quench mediums, such as inert gases or vacuum, can be used without transformation occurring. The alloy is held at this temperature for a time to allow stress relief to occur and the temperature gradients to disappear and is then quenched in oil. Minimizing residual stresses in this manner results in significantly less heat treat distortion in the part. Insufficient information existed, however, to justify using the procedure, so this program was initiated to develop additional data.

The program was divided into two phases:

a. Phase 1 to determine the feasibility of the process
b. Phase 2 to fully characterize the heat treated properties

FOREWORD (Continued)

A cooperative program was initiated by the Aerospace Metals Engineering Committee to study the effect of aus-bay quenching on the mechanical properties of 300M steel heat treated to a nominal strength level of 280 ksi (1931 MPa). Aus-bay quenching may have significant economic benefits by minimizing heat treat distortion with the subsequent straightening problems and by reducing stock removal required after heat treating. Insufficient information existed, however, to justify using the procedure without additional evaluation.

Two round bars of 300M steel, 3-1/8 in (79.4 mm) and 3-1/2 in (88.9 mm) diameter were heat treated to a strength level of 280 ksi (1931 MPa) and tested in the transverse direction. The results of the tests indicated the tensile, fracture toughness, fatigue, and stress corrosion properties of the aus-bay quenched steel are equivalent to the properties obtained using the conventional oil quenching process.

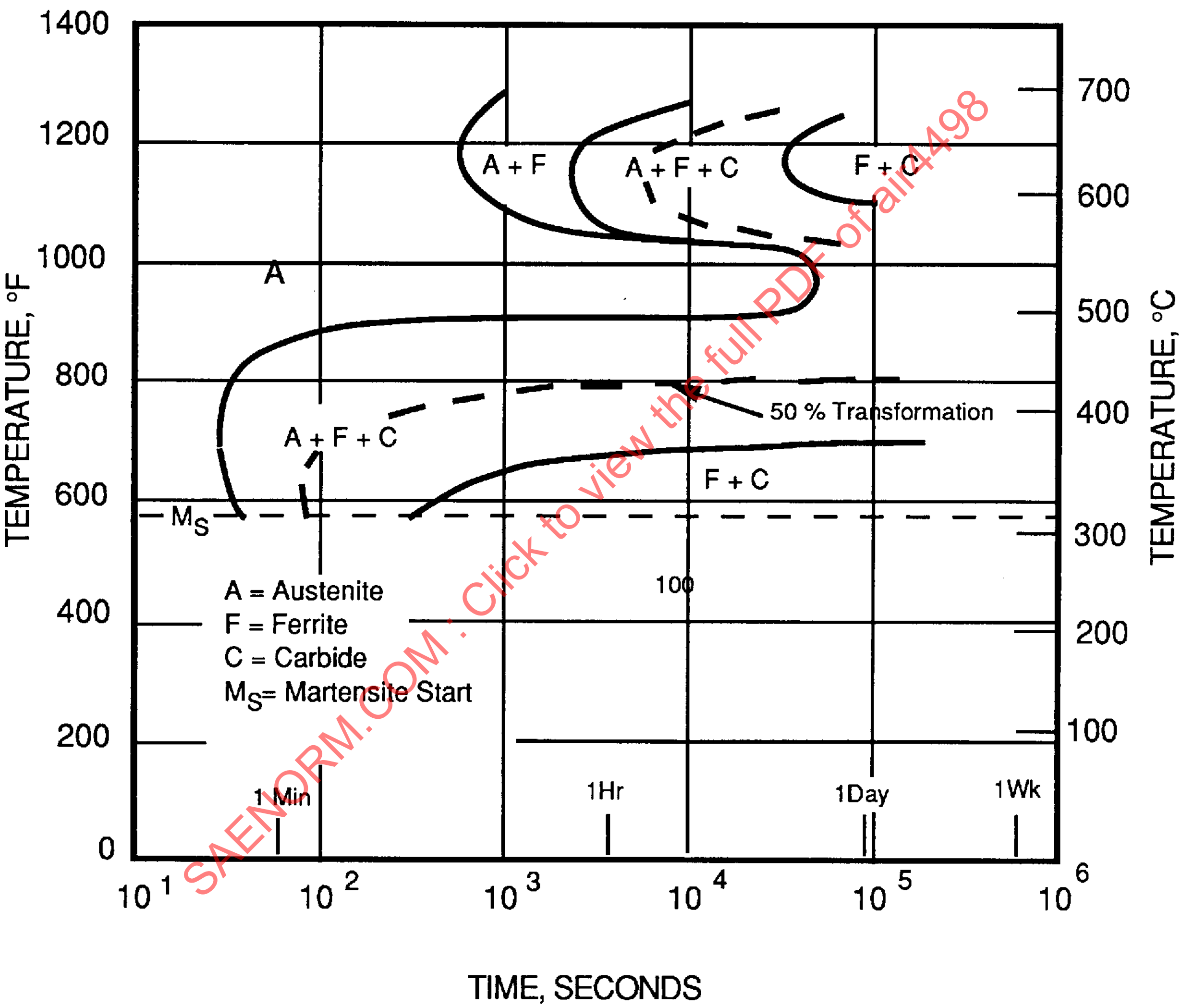

FIGURE 1 - Time-Temperature-Transformation Diagram
300M Steel

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1. SCOPE:

The objective of this program is to compare the properties of aus-bay quenched 300M steel with the properties of 300M steel oil quenched in the conventional manner.

2. REFERENCES:

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 6419 Bars, Forgings, and Tubing, 1.6Si 0.82Cr 1.8Ni 0.40Mo 0.08V (0.40-0.45C), Consumable Electrode Vacuum Remelted

2.2 ASTM Publications:

Available from ASTM, 1916 Race Street, Philadelphia, PA 19103-1187.

ASTM E 8 Testing of Metallic Materials
ASTM E 399 Plane-Strain Fracture Toughness of Metallic Materials
ASTM E 466 Constant Amplitude Axial Fatigue Tests of Metallic Materials
ASTM STP 543 (pages 64 to 73)

2.3 Military Publications:

Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-S-8844 Steel Bar, Reforging Stock, and Mechanical Tubing, Low Alloy, Premium Quality

3. MATERIAL AND HEAT TREATMENT:

3.1 Phase 1:

Material used in Phase 1 of the program was 3-1/8 in (79.3 mm) diameter bar produced to the requirements of MIL-S-8844 Class 3 (300M). Heat treatment schedules were as shown in Table 1.

TABLE 1 - Heat Treat Schedules Used on 300M Bar

	Aus-bay	Oil Quench
Normalize	1675 °F (913 °C) 3 h, nitrogen back fill to 150 °F (65 °C)	1675 °F (913 °C) 3 h, nitrogen back fill to 150 °F (65 °C)
	1200 °F (649 °C) 4 h, nitrogen back fill to R.T.	1200 °F (649 °C) 4 h, nitrogen back fill to R.T.
Austenitize	1600 °F (871 °C) 3 h	1600 °F (871 °C) 3 h
Quench	1000 °F (538 °C) Salt 20 min then into agitated oil	Agitated Oil
Double Temper	575 °F (302 °C) 4 h, Air Cool /1/	575 °F (302 °C) 4 h, Air Cool /1/

/1/ Coupons air cooled to room temperature between tempering cycles.

3.2 Phase 2:

Material used in this phase of the program was a 3-1/2 in (88.9 mm) diameter bar, Heat No. 3834593, produced by LTV Steel (Republic Steel) using the consumable electrode, vacuum arc remelt process. The bar met the requirements of AMS 6419 (300M) and had the following composition as shown in Table 2:

TABLE 2

Element	Heat #3834593	AMS 6419 Min	AMS 6419 Max
Carbon	0.41	0.40	0.45
Manganese	0.72	0.60	0.90
Silicon	1.68	1.45	1.80
Phosphorus	0.01	--	0.010
Sulfur	0.003	--	0.010
Chromium	0.78	0.70	0.95
Nickel	1.74	1.65	2.00
Molybdenum	0.36	0.30	0.50
Vanadium	0.08	0.05	0.10
Copper	0.17	--	0.35
Aluminum	0.07	--	--

The 139 in (3.53 m) bar was cut into 22-1/4 in (565 mm) long coupons and heat treated as shown in Table 3.

TABLE 3 - Heat Treat Schedules Used on Phase 2 Material

Bar No.	Type of Heat Treatment	Austenitizing Atmosphere 1600 °F (871 °C)	Intermediate Quench Media 1000 °F (538 °C)	Final Quench Media Ambient	Tempering Temperature
I	Conventional	Endothermic	No intermediate quench	Oil	575 °F (302 °C) 7 h /1/
II	Salt aus-bay	Salt	Salt	Oil	575 °F (302 °C) 7 h /1/
III	Air aus-bay	Endothermic	Exothermic	Oil	575 °F (302 °C) 7 h /1/
IV	Vacuum aus-bay	Vacuum	Argon	Oil	575 °F (302 °C) 7 h /1/

/1/ Coupons double tempered and air cooled to room temperature between cycles.

4. TEST RESULTS:

4.1 Phase 1:

Five, 0.250 in (6.35 mm) diameter by 1 in (25.4 mm) gage length tensile specimens were machined from the transverse direction of bars in each heat treated condition and tested at room temperature in accordance with ASTM E 8. The ends of each bar were discarded prior to machining test specimens to eliminate heat treat end effects. The results are shown in Table 4.

TABLE 4 - Transverse Tensile Results
300M Steel Specification - MIL-S-8844, Class 3

Yield Strength Aus-bay Quench ksi	Yield Strength Aus-bay Quench MPa	Yield Strength Oil Quench ksi	Yield Strength Oil Quench MPa	Ultimate Strength Aus-bay Quench ksi	Ultimate Strength Aus-bay Quench MPa	Ultimate Strength Oil Quench ksi	Ultimate Strength Oil Quench MPa	Elongation Aus-bay %	Elongation Oil %	Reduction in Area Aus-bay %	Reduction in Area Oil %
235.1	1621	235.1	1621	285.7	1970	287.1	1979	12.9	13.0	39.4	36.2
238.6	1645	239.6	1652	285.8	1971	286.6	1976	12.0	14.4	39.3	35.8
238.1	1642	236.0	1627	286.7	1977	286.3	1974	12.1	12.7	30.0	36.0
240.0	1655	234.1	1614	287.1	1979	285.9	1971	12.5	14.0	38.9	36.1
238.5	1644	233.6	1611	286.4	1975	286.3	1974	13.8	13.5	39.0	36.4
Avg. 238.1	1642	235.7	1625	286.3	1974	286.4	1975	12.7	13.5	37.1	36.1
MIL-HNBK-5 Requirements 230.0 ksi (1586 MPa)	MIL-HNBK-5 Requirements 230.0 ksi (1586 MPa)	MIL-HNBK-5 Requirements 230.0 ksi (1586 MPa)	MIL-HNBK-5 Requirements 230.0 ksi (1586 MPa)	280.0 ksi (1931 MPa)	280.0 ksi (1931 MPa)	280.0 ksi (1931 MPa)	280.0 ksi (1931 MPa)				

4.1 (Continued):

Stress corrosion specimens were machined in the transverse direction from bars in both heat treated conditions and also in the longitudinal direction from bars in the oil quenched condition. The specimens were tested in bending in portable stainless steel fixtures in accordance with procedures discussed in ASTM STP 543, pages 64 to 73. Each specimen was stressed in bending by tightening a through bolt. The number of turns required to break a calibration specimen without any environmental exposure was used to establish the bend strength. The corrosion specimens were subjected to the various stress levels by tightening the through bolt to a percentage of the breaking load. The results of these tests are presented in Table 5.

TABLE 5 - Stress Corrosion Test Results
Aus-bay and Oil Quenched 300M Steel

Specimen Condition	Bending Stress, % of Ultimate Time to Failure, Hours 10	Bending Stress, % of Ultimate Time to Failure, Hours 15	Bending Stress, % of Ultimate Time to Failure, Hours 20	Bending Stress, % of Ultimate Time to Failure, Hours 25	Bending Stress, % of Ultimate Time to Failure, Hours 30	Bending Stress, % of Ultimate Time to Failure, Hours 40
Longitudinal, Oil Quenched	N.F.	N.F. N.F. N.F.	N.F. N.F. N.F. 580		N.F. N.F.	222
Transverse, Oil Quenched	N.F. N.F.	N.F. N.F. N.F.	N.F. N.F. 668 288	344	278	
Transverse, Aus-bay Quenched	N.F. N.F.	N.F. N.F. N.F. N.F.	N.F. N.F. 755 280		634	207

NOTES:
1. Tested at 120 °F (49 °C) in 95% relative humidity
2. N.F. - No failure after 1000 h of exposure

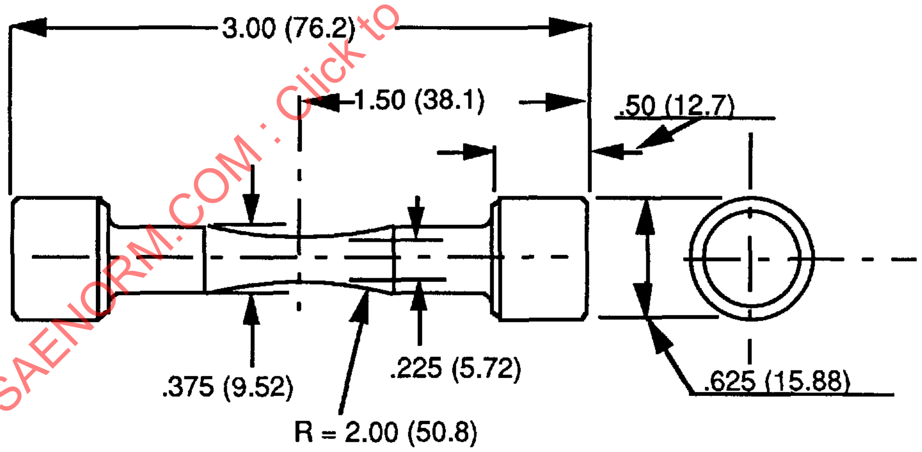
4.1 (Continued):

Fracture toughness testing was performed in accordance with ASTM E 399 using compact fracture toughness specimens oriented in the T-L direction. Data obtained from these tests are given in Table 6.

TABLE 6 - Fracture Toughness Data
T-L Direction Aus-bay and Oil Quenched
300M

ksi $(in)^{0.5}$ (MPa $(m)^{0.5}$) Aus-bay Quenched	ksi $(in)^{0.5}$ (MPa $(m)^{0.5}$) Conventional Quench
61.7 (67.8)	62.7 (68.9)
64.1 (70.4)	62.1 (68.2)
61.5 (67.6)	61.2 (67.2)
Avg. 62.4 (68.6)	62.0 (68.1)

Tension-tension fatigue tests were run in accordance with ASTM E 466 on unnotched specimens in both heat treated conditions. The gage sections of the specimens were shot peened to induce compressive stresses in the surface to force the fatigue crack to initiate sub-surface and not be initiated by surface imperfections. The gage section was not polished after shot peening. Specimen configuration is shown in Figure 2. The tests were run at R = 0.2 with a maximum stress level of 190 ksi (1310 MPa). The results of these tests are given in Table 7.



NOTE: Dimensions in inches (mm)

FIGURE 2 - Smooth Fatigue Specimen

TABLE 7 - Results of Transverse Fatigue Tests
Aus-bay and Oil Quenched 300M Steel
R = +0.2
Maximum Stress = 190 ksi (1310 MPa)

N_f, Cycles Aus-bay Quench	N_f, Cycles Oil Quench
215 000	403 000
267 000	312 000
538 000	316 000
	578 000
Avg. 340 000	402 000

4.2 Phase 2:

Each of the four heat treated pieces were cut into specimen blanks for metallographic examination, hardness, fracture toughness, and tensile testing. The ends of each bar were discarded prior to machining test specimens to eliminate heat treat end effects. All test specimens machined from the blanks were oriented in the transverse direction.

Tensile testing was conducted in accordance with ASTM E 8 using 0.250 in (6.35 mm) diameter by 1 in (25.4 mm) gage length specimens. Transverse tensile test results for the four heat treat conditions used in Phase 2 are given in Table 8.

TABLE 8 - Transverse Tensile Results
Four Heat Treated Conditions
300M Steel
Specification - AMS 6419

Bar No.	Sample No.	Yield Strength ksi	Yield Strength MPa	Ultimate Strength ksi	Ultimate Strength MPa	Elong. %	R. of A. %	HRC
I /1/	1-T-A	244.4	1685	295.3	2036	10	25.6	54
I	1-T-B	235.8	1626	296.2	2042	10	26.4	54
I	1-T-C	254.0	1751	296.7	2046	10	26.4	55
	Avg.	244.7	1687	296.1	2042			
II	2-T-A	248.9	1716	299.8	2067	10	26.4	
II	2-T-B	244.4	1685	295.3	2036	11	32.1	
II	2-T-C	249.0	1717	299.8	2067	10	26.0	
	Avg.	247.4	1706	298.3	2057			
III	4-T-A	240.9	1661	286.6	1976	10	28	54
III	4-T-B	247.0	1703	293.7	2025	10	30.8	54
III	4-T-C	239.3	1650	288.1	1986	10	32.1	54
	Avg.	242.4	1671	289.5	1996			
IV	5-T-A	248.0	1710	293.7	2025	10	30.8	
IV	5-T-B	243.9	1682	293.3	2022	10	30.0	
IV	5-T-C	243.9	1682	296.3	2043	10	33.4	
	Avg.	245.3	1691	294.4	2030			
MIL-HNBK-5 Req'ts.		230.0	1586	280.0	1931			

/1/ I Conventional heat treatment
II Salt aus-bay
III Air aus-bay
IV Vacuum aus-bay

4.2 (Continued):

Fracture toughness testing was conducted in accordance with ASTM E 399 using compact tension specimens. Cracks were induced in the specimens by using three descending precracking loads as shown in Table 9:

TABLE 9

Load No.	Max Load at R = 0.1 lb	Max Load at R = 0.1 Kg	Crack Growth in	Crack Growth mm	Number of Cycles, N
1	2400	1087	0.05	1.27	45 000
2	1500	680	0.03	0.76	24 000
3	1200	544	0.02	0.51	25 000

Static testing of the compact tension specimens was conducted in a 2000 lb Instron TT-D test machine using a calibrated double cantilever compliance gage to measure crack opening displacement. Flat bottom hole fixtures and undersize pins were used to minimize frictional load effects as the crack propagated. The K_{IC} results are presented in Table 10. All validity requirements of ASTM E 399 were met.

TABLE 10 - Fracture Toughness Results, 300M Steel, Compact Tension Specimen
230 ksi (1586 MPa) Yield Strength
A/W = 0.6
Load Ratio = 1.00
T-L Direction

Spec. No.	B in	B mm	W in	W mm	A in	A mm	PQ lb	PQ Kg	K_{IC} ksi $(in)^{.5}$	K_{IC} MPa $(m)^{.5}$
1	0.809	20.5	1.598	40.59	0.843	21.4	5700	2585	58.7	64.5
2	0.809	20.5	1.606	40.79	0.845	21.5	6200	2812	63.5	69.8
3	0.809	20.5	1.604	40.74	0.830	21.1	5950	2699	59.3	65.2
4	0.809	20.5	1.607	40.82	0.847	21.5	6275	2846	64.4	70.8
							Avg.		61.5	67.6

Specimens for metallographic examination were cut from the gage section and the threaded end of a tensile specimen in each heat treated condition. The microstructure of all the specimens consisted of 100% tempered martensite with little difference in appearance between any of the heat treated conditions. Photomicrographs of the structures at 800X are shown in Figures 3 through 6.

Microhardness tests made on the metallographic specimens showed little difference in hardness between the four heat treatments. Hardness values obtained on the specimens are given in Table 11.

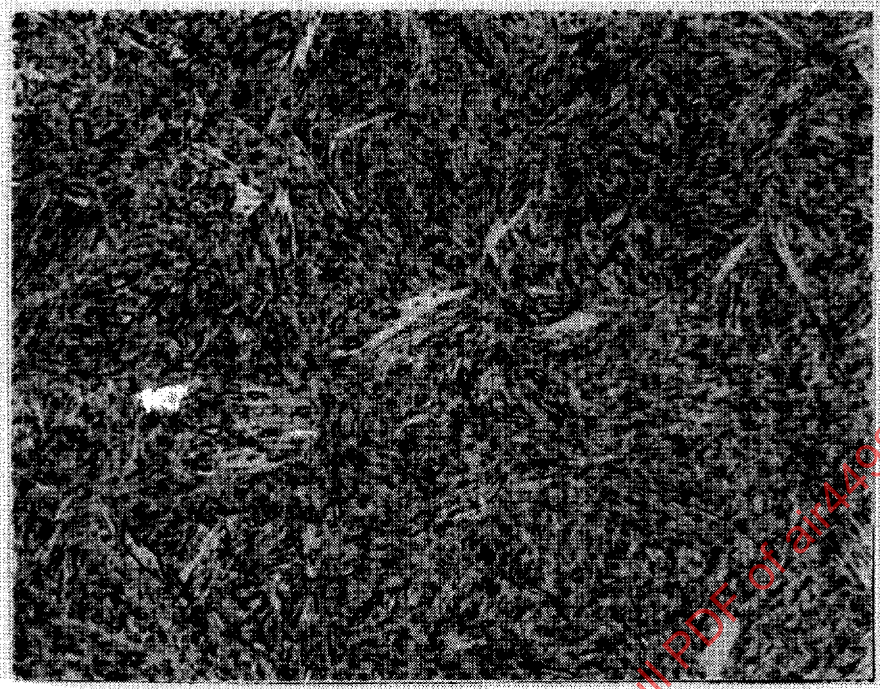


FIGURE 3 - Photomicrograph, Conventional Oil Quench
300M Steel
800X
Specimen No. 1-T-A

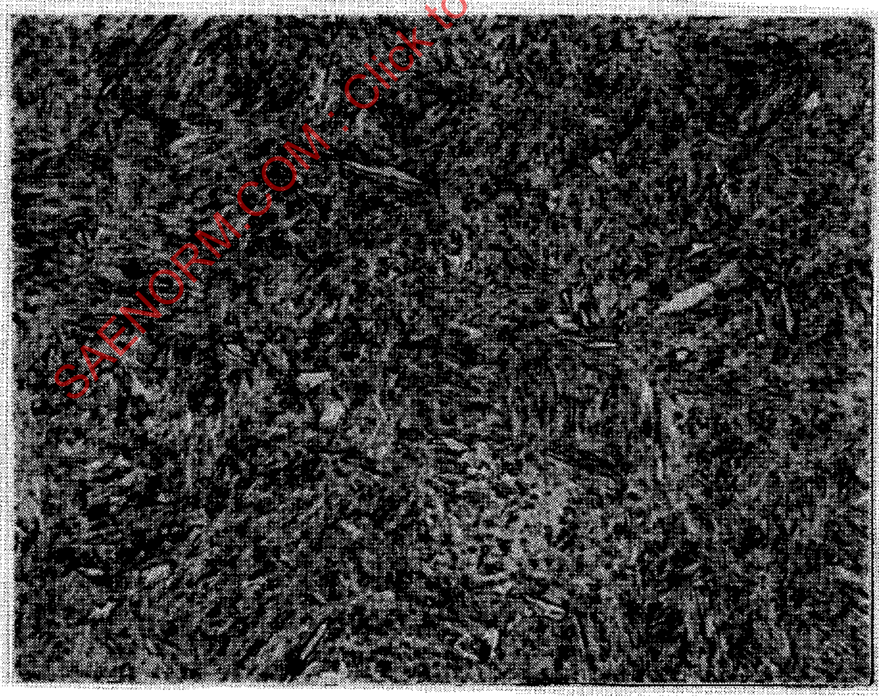


FIGURE 4 - Photomicrograph, Salt Aus-bay Quench
300M Steel
800X
Specimen No. 2-T-A