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Stress Corrosion Evaluation of HP 9Ni–4Co–0.20C Steel

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National Aeronautics and
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Scientific and Technical
Information Program

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
AMS	Aerospace Material Specification
MIL	Military Specification
MSFC	Marshall Space Flight Center
ASRM	Advanced Solid Rocket Motor
IUS	Inertial Upper Stage
LTV	Ling-Tempco-Vought
HD	High Density (Conoco Grease)
NaCl	Sodium Chloride
SCC	Stress Corrosion Cracking
RH	Relative Humidity
Mag.	Magnification
UTS	Ultimate Tensile Strength
YS	Yield Strength
EL	Elongation
RA	Reduction in Area
D.P.H.	Diamond Pyramid Hardness
Rc	Rockwell C
OD	Outer Diameter
TIR	Tool Indicator Reading
R	Radius
UNC	Unified National Course
°C	Degrees Celsius or Centigrade
°F	Degrees Fahrenheit

cm	Centimeter
mm	Millimeter
in	Inch
MPa	Mega Pascal [Mega Newtons per Square Meter (1 ksi = 6.8948 MPa)]
ksi	Kilopounds per Square Inch

TECHNICAL PAPER

STRESS CORROSION EVALUATION OF HP 9Ni–4Co–0.20C STEEL

INTRODUCTION

A stress corrosion cracking (SCC) evaluation was completed on HP 9Ni–4Co–0.20C steel. This alloy is considered an alternate to HP 9Ni–4Co–0.30C steel for the Advanced Solid Rocket Motor (ASRM) case. However, the initial SCC evaluation of this alloy was performed at the request of the Air Force because this alloy was considered as a backup to Custom 455 stainless steel for the Inertial Upper Stage (IUS) spreader beams [Ref. 1 and 2]. Also, the Air Force was using this alloy in the B–1 bomber in moderately high strength applications [Ref. 1].

Current results on ring forging material as well as previous results obtained from bar [Ref. 3 and 4] and plate [Ref. 5] materials are compiled in this report. These tests were conducted by exposing tensile specimens at several stress levels to high humidity, alternate immersion in 3.5-percent sodium chloride (NaCl), and 5-percent salt spray. The extent of corrosive attack was measured in terms of weight loss and reduction in load carrying ability. The results obtained in this program provide a base to compare this alloy with other high strength steels as regards to SCC and corrosion susceptibility.

EXPERIMENTAL PROCEDURE

Ring Forging Material

HP 9Ni–4Co–0.20C steel material per Aerospace Material Specification (AMS) 6525A–89 [Ref. 6], which was produced by Ling-Tempco-Vought (LTV) Steel, was used for this evaluation. This material was subsequently formed into a 74-cm (29-in) outer diameter (OD) by 2.54-cm (1-in) thick by 25.4-cm (10-in) high hot rolled ring forging. The heat numbers, mill chemical analysis, heat treating procedure per Military Specification MIL-H-6875 [Ref. 7], and mechanical properties for the ring forging material are presented in Table 1, Section A, Table 2A, and Table 3, Section A.

After the heat treatment was performed, circumferential and longitudinal round tensile specimens [0.318-cm (1/8-in) gauge length diameter with a 5.08-cm (2-in) total length] were machined [Figures 1A (Metric Units) and 1B (English Units)]. These specimens were stressed per American Society for Testing and Materials (ASTM) G49 [Ref. 8] to 50, 75, and 90 percent of the 0.2-percent offset circumferential and longitudinal yield strengths (YS). Stressing fixtures (Figures 2 through 5B) made of PH 13–8 Mo steel (H-1000 condition) were used. The stressing device is shown in Figure 6. Stress-strain curves were used to determine the strain corresponding to the desired stress levels.

Conoco HD Calcium Grease No. 2 was used to protect the threads and the ends of the specimens. This protection helps to prevent galvanic interaction between the specimens and the frames. Specimens were cleaned with acetone and wiped with alcohol to eliminate any residue left by the acetone. Then, the specimens were exposed in quadruplicate to 5-percent salt spray at 35 °C (95 °F) (Figure 7) per ASTM B117 [Ref. 9] and high humidity [100-percent relative humidity (RH) at 38 °C (100 °F)] (Figure 8). In addition, circumferential and longitudinal unstressed specimens were exposed to each environment in triplicate.

These specimens which were exposed for 3 months were weighed before and after testing to determine weight loss. After completion of the tests, photographs were taken to evidence the extent of corrosion attack. The losses in load carrying ability (expressed in percentages) were also obtained and were used as a measure of the material's susceptibility to corrosion. Also, one of the specimens was sectioned for metallographic analysis and microhardness determinations [Diamond Pyramid Hardness (D.P.H.) readings were converted to Rockwell C (Rc) hardness].

Bar Material

The chemical analysis of the tested bar material is presented in Table 1, Section B. The specimens were machined from the transverse direction of a 17.8-cm (7-in) bar of HP 9Ni–4Co–0.20C steel. They were heat treated prior to final machining per the Marquardt Company's recommendations as specified in Table 2B. The mechanical properties obtained for the bar material are presented in Table 3, Section B.

The tensile specimens were stressed to 25, 50, and 75 percent of the yield strength and exposed in quintuplicate to 5-percent salt spray for 3 months and in quadruplicate to high humidity for 6 months.

Plate Material

The chemical analysis for the plate is presented in Table 1, Section C. The chips for this analysis were obtained from tensile specimens that had been pulled for mechanical properties. The heat treatment procedure and mechanical properties are presented in Tables 2C and 3 (Section C), respectively. The specimens were exposed to salt spray at 50, 75, and 90 percent YS and to 3.5-Percent NaCl alternate immersion (Figure 9) (ASTM G44 [Ref. 10]) at 50 and 75 percent YS. These specimens were tested in quintuplicate for 3 months in each environment. The reductions in load carrying ability were determined after completion of the SCC test for this group of samples.

The same specimen configuration was used for the forging, bar, and plate materials. The only difference in the procedure was the use of a maskant (Maskcoat No. 2 from Western Coating Company) to protect the frames when testing the plate and bar materials. This maskant, which is a cellulose acetate butyrate compound with plasticizers and stabilizers added (per MIL-P-23242B, March 22, 1982), was melted in a thermostatically controlled vessel prior to application. After immersion of the frames in the melted compound, time was allowed for hardening and cooling.

The salt spray cabinets used for these tests were manufactured by Industrial Filter and Pump Manufacturing Company (Type 411.1ACD). The plate and bar specimens were tested in a cabinet which has a serial number of S–5069. This cabinet was later replaced by cabinet S–6198 which was used to test the ring forging specimens.

RESULTS AND DISCUSSION

Ring Forging Material

The SCC results for the ring forging specimens are presented in Table 4, Section A. No failures occurred during the 3-month exposure to high humidity or salt spray. This indicates that the HP 9Ni–4Co–0.20C steel ring forging, at the strength level tested, is highly resistant to stress corrosion in humidity and salt spray.

Figures 10 through 16 show the ring forging tensile specimens after completion of the tests. The severity of the salt spray test is evidenced by the large amount of corrosion products on the specimens (Figures 10 and 11). Removal of corrosion products from the specimens (with a 50-percent lactic, 50-percent phosphoric acid solution) revealed the depth of corrosion attack (Figure 12). The ring forging specimens tested in high humidity for 3 months barely showed corrosion spots to the naked eye (Figures 13 and 14) though some pitting corrosion was observed at higher magnification (Figure 15). Severe pitting corrosion of an unstressed specimen, shown in Figure 16, resulted from 4 months of exposure to high humidity. This contrast suggests that the bare stressing frames afforded some degree of protection against pitting corrosion for the stressed samples.

The weight losses of the ring forging specimens tested in salt spray are presented in Table 5. The average weight loss for the stressed specimens was found to be 1.53 percent. The average weight loss for the unstressed specimens was 6.50 percent. During this test, the unstressed specimens were exposed entirely bare, while the stressed specimens were protected with Conoco grease at the extremes, leaving only the gauge length exposed. This would explain the difference in weight loss between the unstressed and the stressed specimens. No significant weight loss occurred on the specimens tested in high humidity for 3 months. However, the sample (Figure 16) left in the humidity cabinet for 4 months lost 3 percent of its initial weight.

No significant reductions in load carrying ability were found for the specimens tested in high humidity, although significant losses in load carrying ability were found on the specimens tested in salt spray (Table 6). These losses ranged from 11.1 percent (unstressed) to 29.0 percent (stressed at 90 percent YS).

Several photographs of the specimens that were tensile tested to failure after exposure to high humidity and salt spray are presented in Figures 17 and 18, respectively. The cup-cone fractures are indicative of ductility. Figure 19 shows the microstructure of an HP 9Ni–4Co–0.20C steel tensile specimen. The average microhardness (D.P.H. readings converted to Rockwell C) obtained was Rc 45.4.

Bar and Plate Materials

The results obtained on HP 9Ni–4Co–0.20C steel bar [Ref. 3 and 4] and plate [Ref. 5] material specimens are presented in Table 4, Sections B and C. These stress corrosion data indicate that the HP 9Ni–4Co–0.20C steel bar material specimens, tested in high humidity and salt spray and the plate material specimens tested in alternate immersion and salt spray for the specified length of time and at the specified strength levels, are highly resistant to SCC.

As was the case for the forging material, the bar and plate specimens experienced a severe corrosion attack when exposed to the 5-percent salt spray. A noticeable reduction in cross sectional area occurred under the maskant (Figure 20) on the specimens tested in salt spray, which may be attributed to pitting corrosion. The plate specimens tested in 3.5-percent NaCl alternate immersion also corroded significantly, but deteriorated less than the specimens tested in salt spray (Ref. Figure 20). Bar specimens tested in high humidity showed less corrosion attack.

The losses in load carrying ability for the plate specimens are presented in Table 7. The average loss in 5-percent salt spray was 39.7 percent. The average loss in 3.5-percent NaCl alternate immersion was 14.7 percent. These values indicate that the 5-percent salt spray medium provided a much more severe accelerated corrosion test than 3.5-percent NaCl alternate immersion.

CONCLUSIONS

There were no SCC failures in the HP 9Ni–4Co–0.20C steel bar, plate, and hot rolled ring forging specimens as tested in this evaluation. This alloy was found susceptible to general corrosion in 5-percent salt spray and 3.5-percent salt alternate immersion environments. Because of the general corrosion attack in these environments, a protective coating would be required. Although the specimens showed more tolerance to high humidity, a protective coating would also be required.

REFERENCES

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2. Memo EE41 (87–34), dated February 19, 1987, from EE41/R.W. Hughes to EH01/R.J. Schwinghamer, Subject: Stress Corrosion Testing of 9Ni–4Co–0.20C and 9Ni–4Co–0.30C Steels for IUS Spreader Beams.

3. Memo EH24 (87–22), dated July 15, 1987, from EH01/R.J. Schwinghamer to EE41/R.W. Hughes, Subject: SCC Evaluation of 9Ni–4Co–0.20C and 9Ni–4Co–0.30C Steels.

4. Memo EH24 (88–04), dated January 22, 1988, from EH01/R.J. Schwinghamer to EE41/R.W. Hughes, Subject: SCC Evaluation of 9Ni–4Co–0.20C and 9Ni–4Co–0.30C Steels.

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6. Aerospace Material Specification (AMS) 6525A–89, Steel Bars, Forgings, Tubing, and Rings 0.75Cr–9.0Ni–4.5Co–1.0Mo–0.09V (0.16–0.23C) Consumable Electrode Vacuum Melted, 1989.

7. Military Specification MIL–H–6875H, Heat Treatment of Steel, Process for, 1 March 1989.

8. American Society for Testing and Materials Specification ASTM G49–85, Standard Practice for Preparation and Use of Direct Tension Stress Corrosion Test Specimens, Issued in 1985, Reapproved in 1990.

9. ASTM B117–85, Standard Method of Salt Spray (Fog) Testing, 1985.

10. ASTM G44–75, Standard Recommended Practice for Alternate Immersion Stress Corrosion Testing in 3.5-Percent Sodium Chloride Solution, Issued in 1975, Reapproved in 1980.

Table 1
HP 9Ni–4Co–0.20C Steel Chemical Analysis

A. Ring Forging

Vacuum Melt Heat No. 3827006
Airmelt Heat No. 8644939-7

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Co	Fe
LTV Analysis	0.21	0.27	0.004	0.001	0.06	0.16	8.79	0.72	0.92	0.09	4.33	Balance
MSFC Analysis	0.2106	0.23	0.004	0.00194	0.04	0.10	8.47	0.76	0.86	0.07	4.25	Balance
MSFC Analysis	0.2043	0.23	0.003	0.0017	0.03	0.10	8.60	0.77	0.87	0.07	4.22	Balance
MSFC Analysis	0.2072	0.23	0.0003	0.00175	0.12	0.10	8.53	0.76	0.84*	0.07	4.26	Balance
MSFC Analysis	0.2055	0.23	0.003	0.00208	0.01	0.13	8.38*	0.76	0.84*	0.07	4.24	Balance

B. Bar Material [Ref. 3]

C	Mn	Si	Cu	Ni	Cr	Mo	V	Co
0.19	0.28	0.06	0.23	9.05	0.70	0.94	0.07	4.28

C. Plate Material (MSFC Analysis)

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Co	Fe
0.2156	0.24	ND†	0.0008	0.04	0.08	9.26	0.71	0.94	0.07	4.47	Balance

AMS 6525A [Ref. 6]

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Co	Fe
Min	0.17	0.20	—	—	—	—	8.50	0.65	0.90	0.06	4.25	Balance
Max	0.23	0.40	0.010	0.010	0.20	0.35	9.50	0.85	1.10	0.12	4.75	

The chemical composition at MSFC was determined by using inductively coupled plasma (ICP) emission spectroscopy and LECO combustion analyses. Four tensile specimens from the ring forging were analyzed and some values for Ni, Mo, and Co content were under the minimum specified in AMS 6525A. However, several of these values are acceptable per AMS 2248D for chemical check analysis limits.

* Represents values less than those specified in AMS 2248D.

† ND = None Detected.

Table 2A

Heat Treatment Procedure Followed for HP 9Ni–4Co–0.20C Steel Ring Forging

Ladish Company, Inc.:

Normalize at 899 °C (1,650 °F) for 1 hour, air cool after forging.

Lindberg Heat Treating Company:

1. Harden at 843 °C (1,550 °F) for 1 hour and 5 minutes at temperature, oil quench, and subzero cool at –73°C (–100 °F) for 90 minutes.
2. Temper at 538 °C (1,000 °F) for 3 hours at heat, still air cool.
3. Retemper at 538 °C (1,000 °F) for 3 hours at heat, still air cool.

Table 2B

Heat Treatment Procedure Followed for HP 9Ni–4Co–0.20C Steel Bar Material [Ref. 3]

(Marquardt Company's Recommended Procedure)

1. Normalize at 899 ± 14 °C (1,650 ± 25 °F) for 2 hours, air cool.
2. Austenitize at 829 ± 14 °C (1,525 ± 25 °F) for 2 hours, air cool.
3. Within 2 hours, cool to –73 °C (–100 °F) for 2 hours at temperature.
4. Temper at 552 ± 6 °C (1,025 ± 10 °F) for 2 hours, air cool.
5. Retemper at 552 ± 6 °C (1,025 ± 10 °F) for 2 hours, air cool.

Table 2C

Heat Treatment Procedure Followed for HP 9Ni–4Co–0.20C Steel Plate Material [Ref. 5]

(MSFC Thermal Treatment)

Heat treat per MIL–H–6875 except for the following:

1. Normalize at 885 to 913 °C (1,625 to 1,675 °F) for 60 to 75 minutes at temperature.
2. Austenitize at 829 to 857 °C (1,525 to 1,575 °F) for 60 to 75 minutes at temperature.
3. Quench in oil per MIL–H–6875. Air cool to 38 °C (100 °F) maximum.
4. Subzero cool to –73 ± 6 °C (–100 ± 10 °F) for 60 to 75 minutes at temperature. Air warm to 16 °C (60 °F) minimum.
5. Snap temper at 149 to 177 °C (300 to 350 °F) for 3 hours at temperature. Air cool to 38 °C (100 °F) maximum.
6. Temper at 538 to 549 °C (1,000 to 1,020 °F) for 3 to 3 1/4 hours at temperature. Air cool to 38 °C (100 °F) maximum. Repeat temper as above. Air cool.

Table 3
Mechanical Properties of HP 9Ni–4Co–0.20C Steel

A. Ring Forging

	UTS		YS		EL	RA	Modulus of Elasticity	
	MPa	ksi	MPa	ksi	(%)	(%)	(MPa×10^{-3})	(psi×10^{-6})
Circumferential	1,413	205	1,276	185	14.1	62.8	197	28.5
Longitudinal	1,407	204	1,269	184	14.5	63.3	190	27.6

B. Bar Material [Ref. 3]

	UTS		YS		EL
	MPa	ksi	MPa	ksi	(%)
Transverse	1,427	207	1,276	185	17.3

C. Plate Material [Ref. 5]

UTS		YS		EL	RA
MPa	ksi	MPa	ksi	(%)	(%)
1,489	216	1,358	197	15.9	62.7

Table 4
SCC Test Results of HP 9Ni–4Co–0.20C Steel

A. Ring Forging

Stress Level			High Humidity (3 Months)				5-Percent Salt Spray (3 Months)			
			Circumferential		Longitudinal		Circumferential		Longitudinal	
% YS	MPa	ksi	F/N	Time To Failure	F/N	Time To Failure	F/N	Time To Failure	F/N	Time To Failure
50	641	93	0/4	NF	0/4	NF	0/4	NF	0/4	NF
75	958	139	0/4	NF	0/4	NF	0/4	NF	0/4	NF
90	1,151	167	0/4	NF	0/4	NF	0/4	NF	0/4	NF

B. Bar Material

Stress Level			High Humidity (6 Months)		5-Percent Salt Spray (3 Months)	
% YS	MPa	ksi	F/N	Time To Failure	F/N	Time To Failure
25	319	46.2	0/4	NF	0/5	NF
50	638	92.5	0/4	NF	0/5	NF
75	956	138.7	0/4	NF	0/5	NF

C. Plate Material

Stress Level			3.5-Percent NaCl Alternate Immersion (3 Months)		5-Percent Salt Spray (3 Months)	
% YS	MPa	ksi	F/N	Time To Failure	F/N	Time To Failure
50	676	98	0/5	NF	0/5	NF
75	1,020	148	0/5	NF	0/5	NF
90	1,220	177	Not Tested		0/5	NF

NOTES: 1. F/N denotes failure ratio (failures divided by number of specimens tested).
2. NF denotes no failures.

Table 5
Weight Reduction of HP 9Ni–4Co–0.20C Steel Ring Forging Specimens After a 3-Month Exposure to 5-Percent Salt Spray

Stress Level (Percent YS)	Weight Reduction (Percent) Circumferential	Longitudinal
0	6.49	5.66
0	5.24	8.77
0	6.62	6.22
	Average = 6.12	Average = 6.88
50	1.15	0.99
50	1.12	1.62
50	1.69	1.06
50	1.20	0.84
	Average = 1.29	Average = 1.13
75	1.79	2.22
75	1.51	1.38
75	1.50	1.67
75	1.94	1.67
	Average = 1.68	Average = 1.74
90	1.11	1.40
90	1.92	1.67
90	1.43	1.80
90	1.30	2.63
	Average = 1.44	Average = 1.88

NOTE: During this test, the unstressed specimens were exposed entirely bare; however, only the gauge length sections of the stressed specimens were exposed bare. This may explain the significant differences in weight losses between the unstressed and the stressed specimens.

Table 6
Reduction in Load Carrying Ability of HP 9Ni–4Co–0.20C Steel Ring Forging Specimens After a 3-Month Exposure to 5-Percent Salt Spray

Stress Level (Percent YS)	Reduction in Load Carrying Ability (Percent) Circumferential	Longitudinal
0	11.3	17.9
0	17.3	12.7
0	11.1	14.0
	Average = 13.2	Average = 14.9
50	23.6	20.9
50	26.8	19.7
50	18.1	25.3
50	17.7	20.1
	Average = 21.6	Average = 21.5
75	18.5	27.7
75	23.7	20.9
75	19.7	18.3
75	27.6	20.9
	Average = 22.4	Average = 22.0
90	24.8	27.4
90	22.5	18.1
90	27.4	24.5
90	25.2	29.0
	Average = 25.0	Average = 24.8

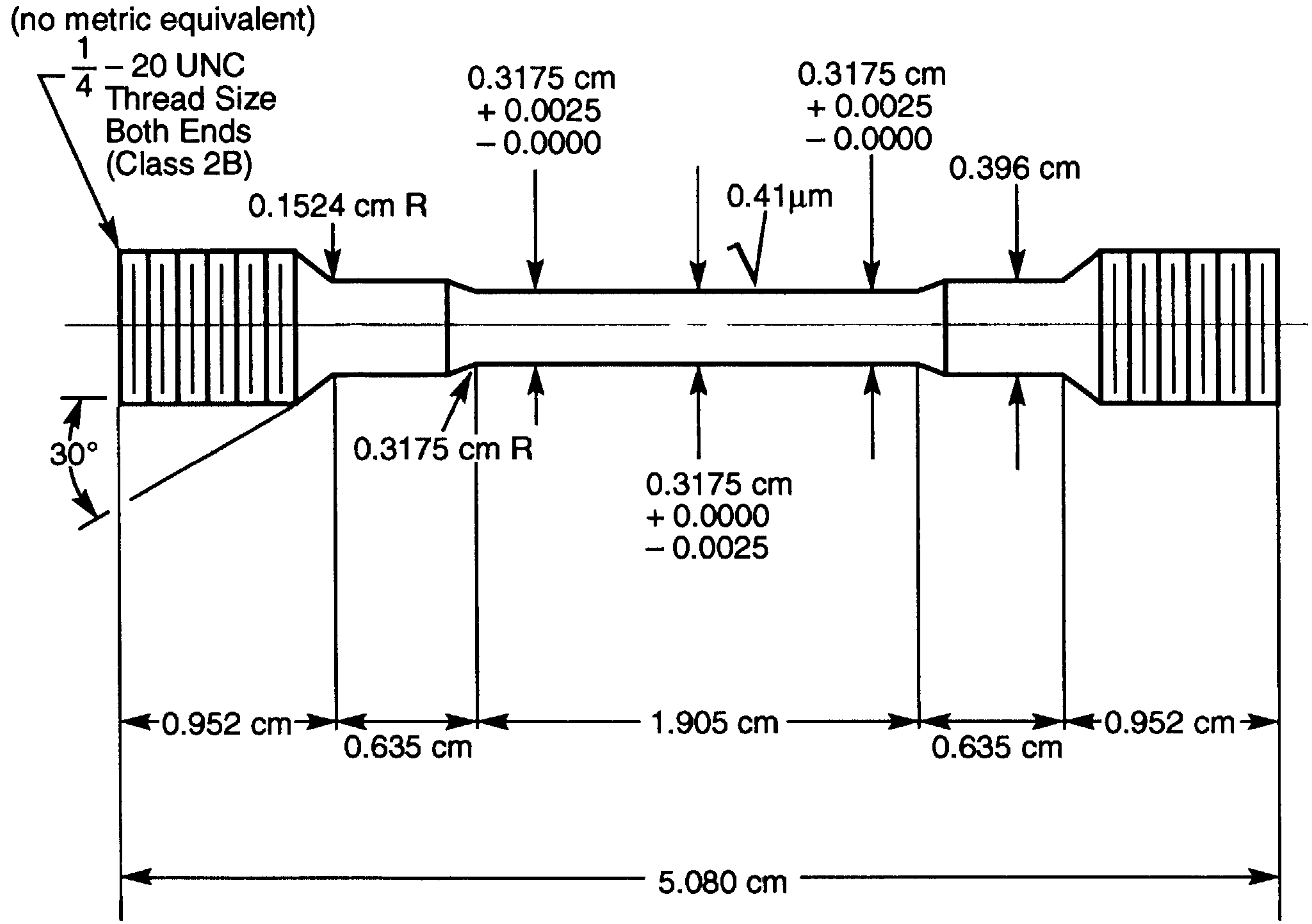
Overall Average for all the Stressed Specimens = 22.9.
Overall Average for all the Unstressed Specimens = 14.0.

Notice that the averaged reductions in load carrying ability were higher for the stressed specimens.

Table 7
Reduction in Load Carrying Ability of HP 9Ni–4Co–0.20C Steel Plate Specimens After a 3-Month Exposure to 5-Percent Salt Spray and a 3-Month Exposure to 3.5-Percent NaCl Alternate Immersion

	Reduction in Load Carrying Ability (Percent)	
Stress Level (Percent)	Salt Spray (3 Months)	Alternate Immersion (3 Months)
50	42.3	26.2
50	40.4	7.6
50	32.8	26.6
50	41.5	4.9
50	48.3	10.2
	Average = 41.1	Average = 15.1
75	37.7	6.8
75	50.9	8.3
75	47.6	20.4
75	25.7	20.6
75	37.4	15.4
	Average = 39.9	Average = 14.3
90	35.4	
90	42.6	
90	35.8	
90	37.4	
90	38.9	
	Average = 38.0	

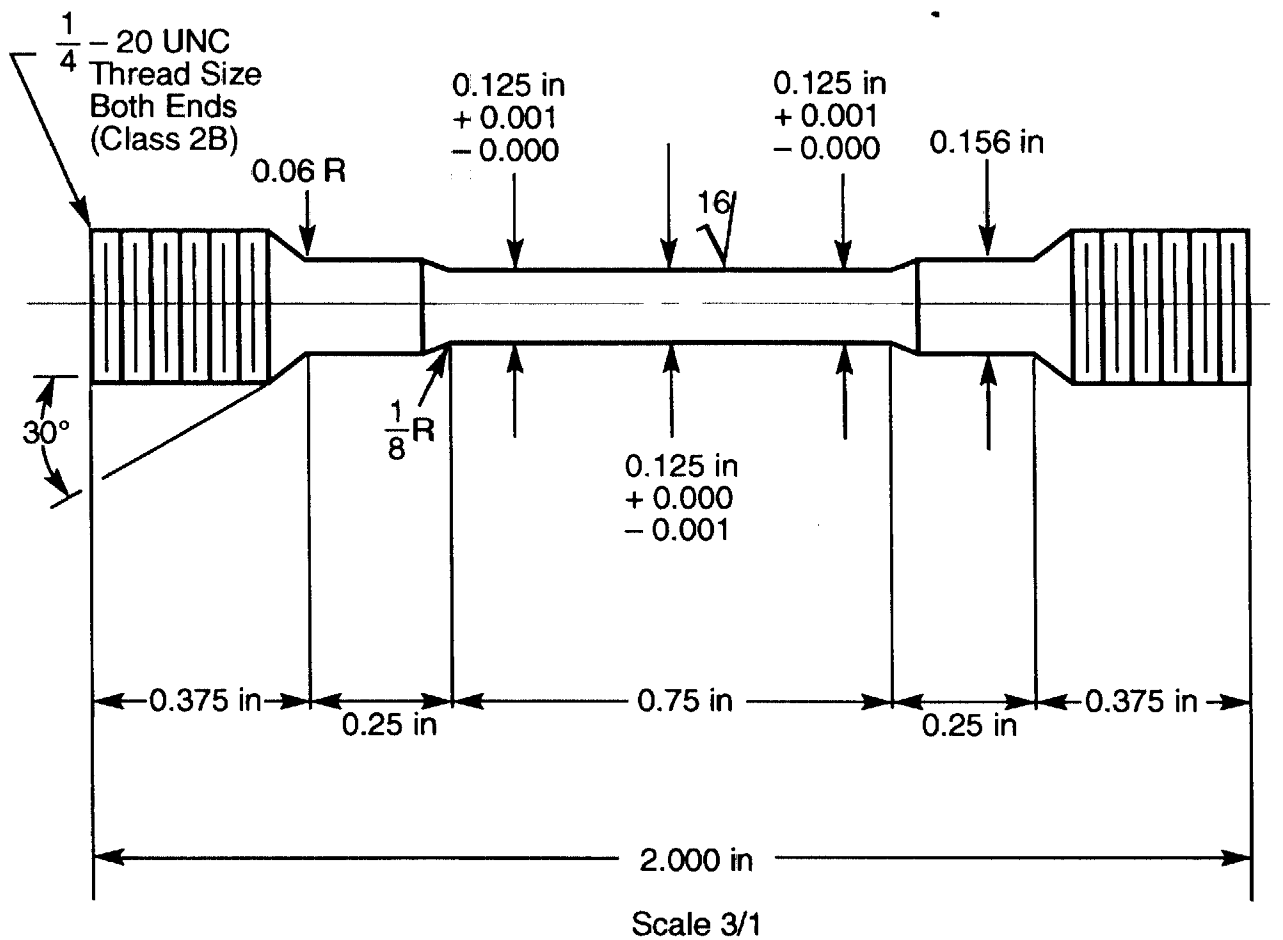
Average in Salt Spray = 39.7.
Average in Alternate Immersion = 14.7.



Scale 3/1

Notes:
(1) Thread dimensions must be as specified (measurement by fabricator is mandatory).
(2) No undercutting of radii permitted.
(3) Taper gauge length to center of specimen.
(4) Gauge section to be concentric with axis within 0.005 cm TIR and parallel.
(5) No file marks or nicks permitted within gauge section.

Figure 1A. Round Tensile Specimen With a 0.3175-cm Gauge Length Diameter (Metric Units).



Notes: (1) Thread dimensions must be as specified (measurement by fabricator is mandatory).
(2) No undercutting of radii permitted.
(3) Taper gauge length to center of specimen.
(4) Gauge section to be concentric with axis within 0.002 in TIR and parallel.
(5) No file marks or nicks permitted within gauge section.

Figure 1B. Round Tensile Specimen With a 0.125-in Gauge Length Diameter (English Units).

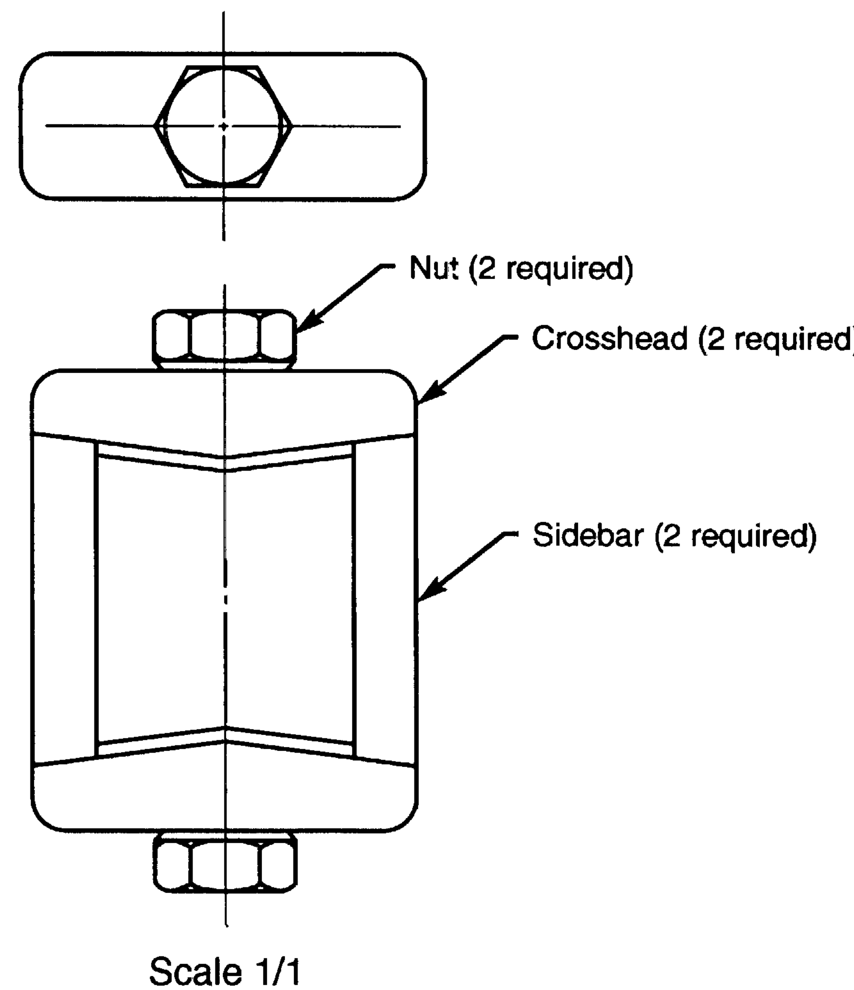


Figure 2. Frame Assembly for Round Tensile Specimens.

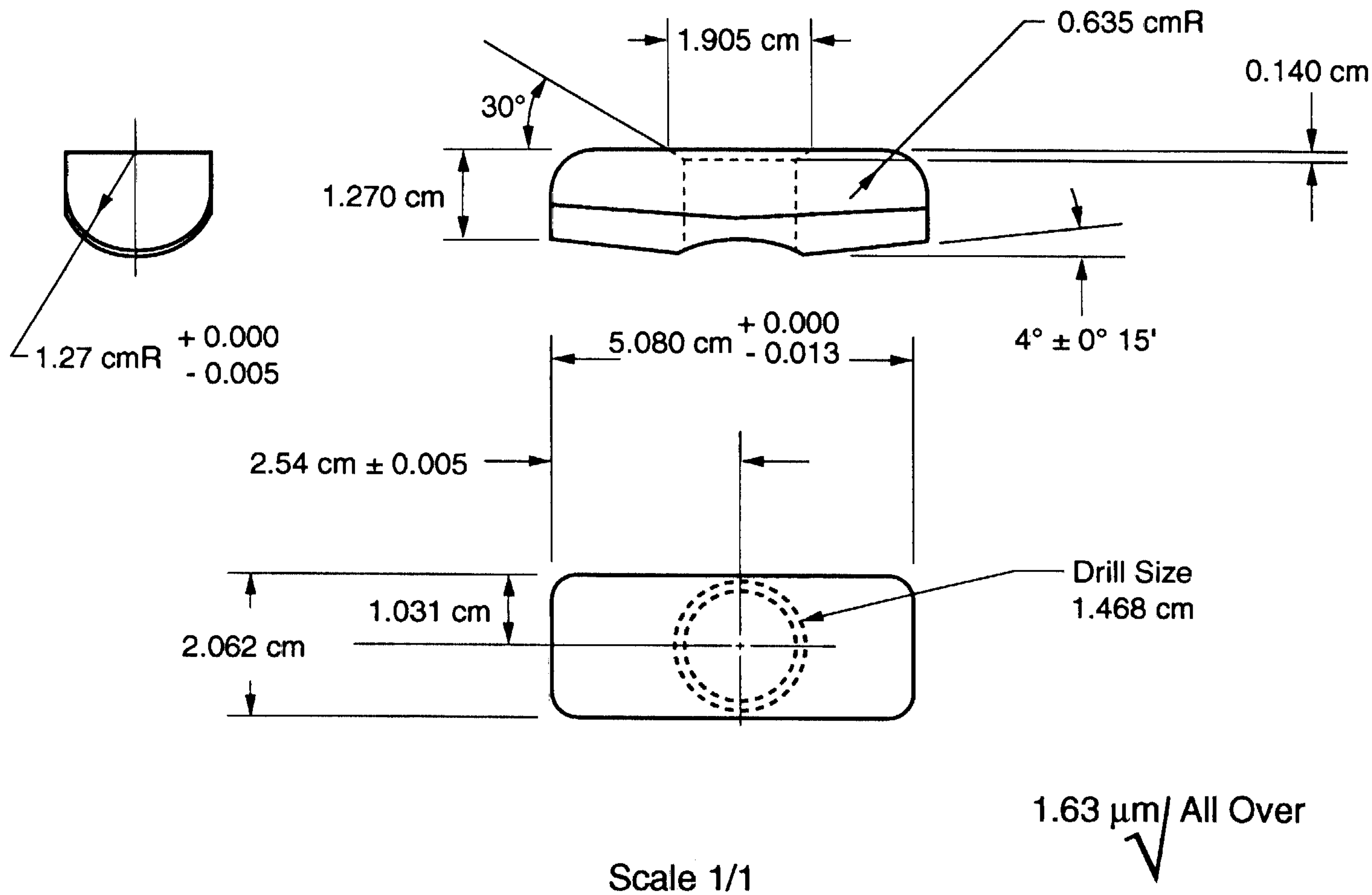


Figure 3A. Stress Corrosion Frame Crosshead (Metric Units).

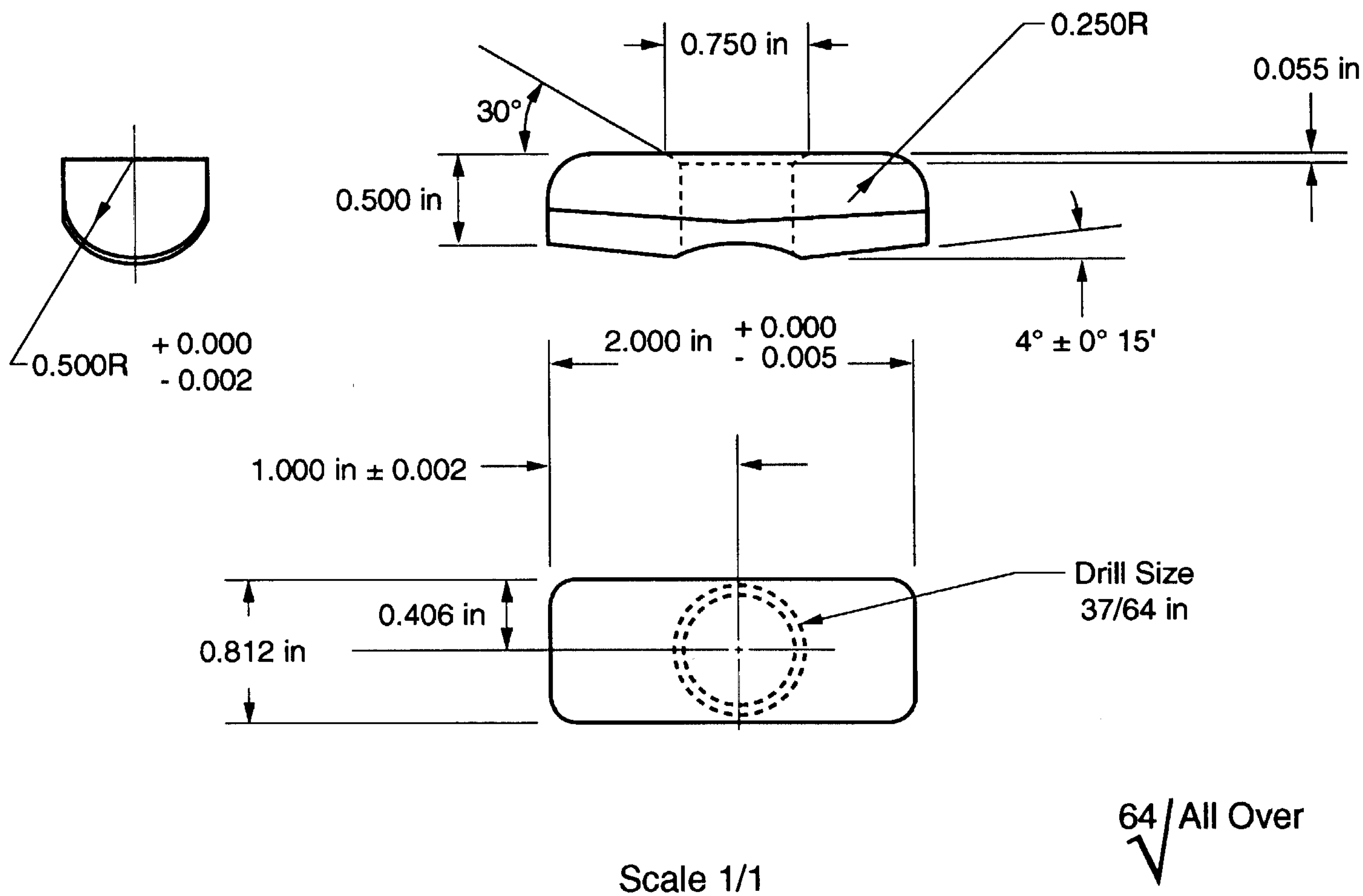


Figure 3B. Stress Corrosion Frame Crosshead (English Units).

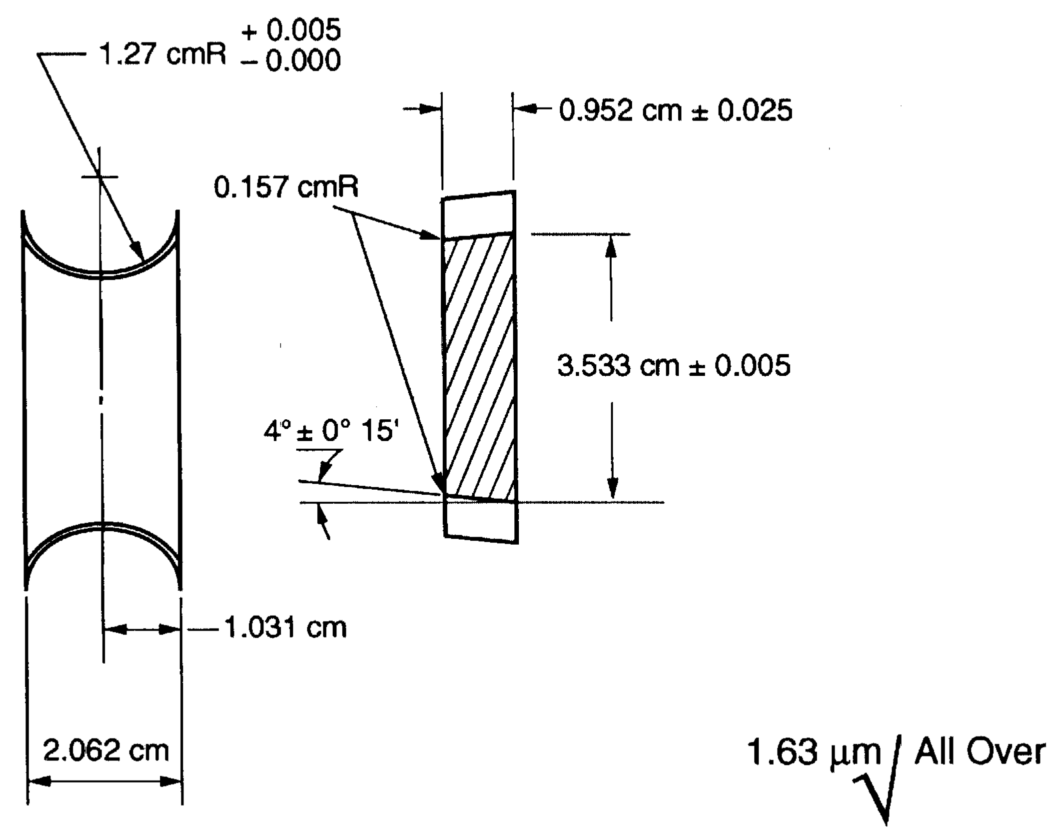


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Figure 4A. Stress Corrosion Frame Side Bar (Metric Units).

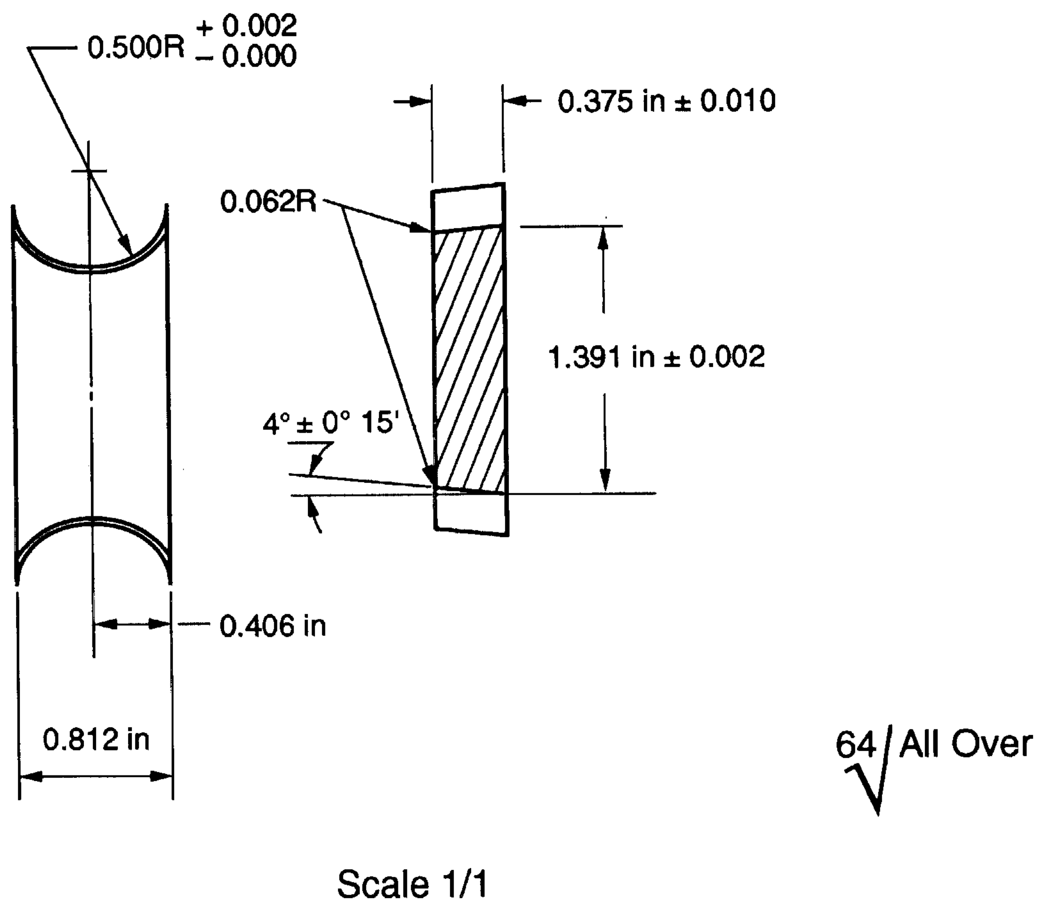
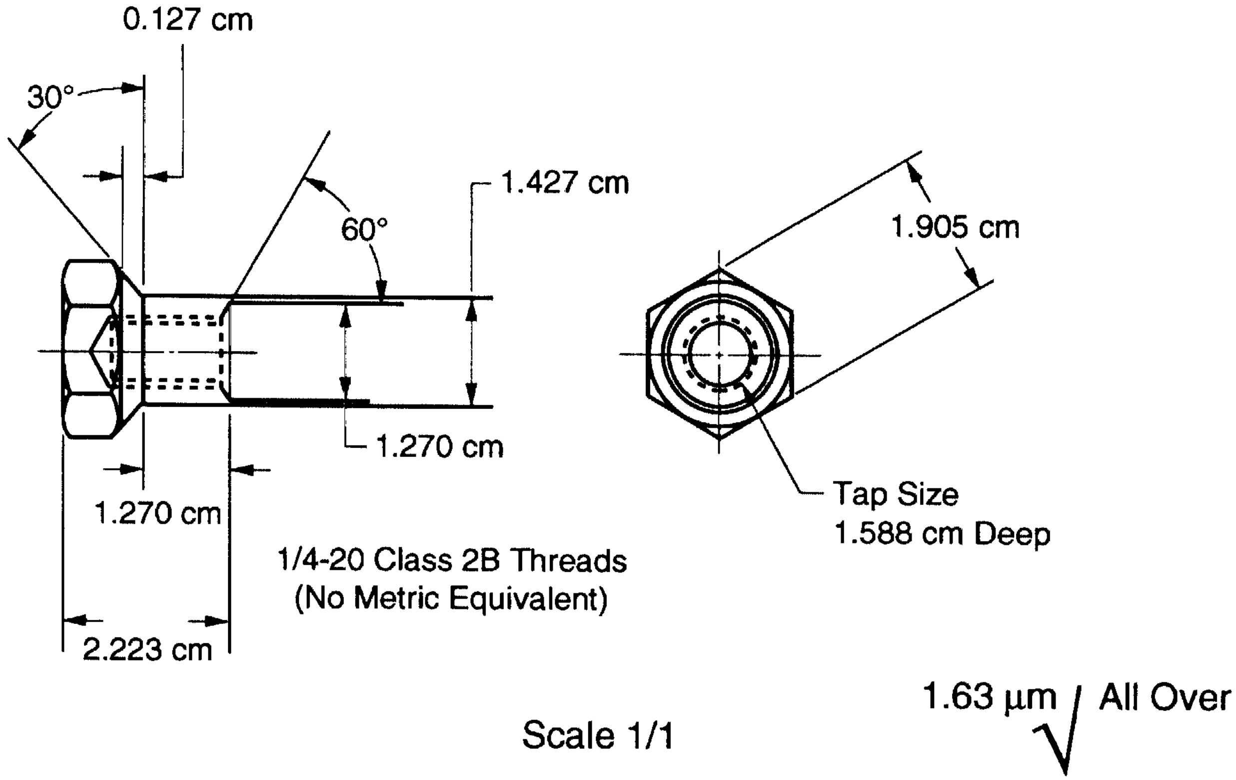


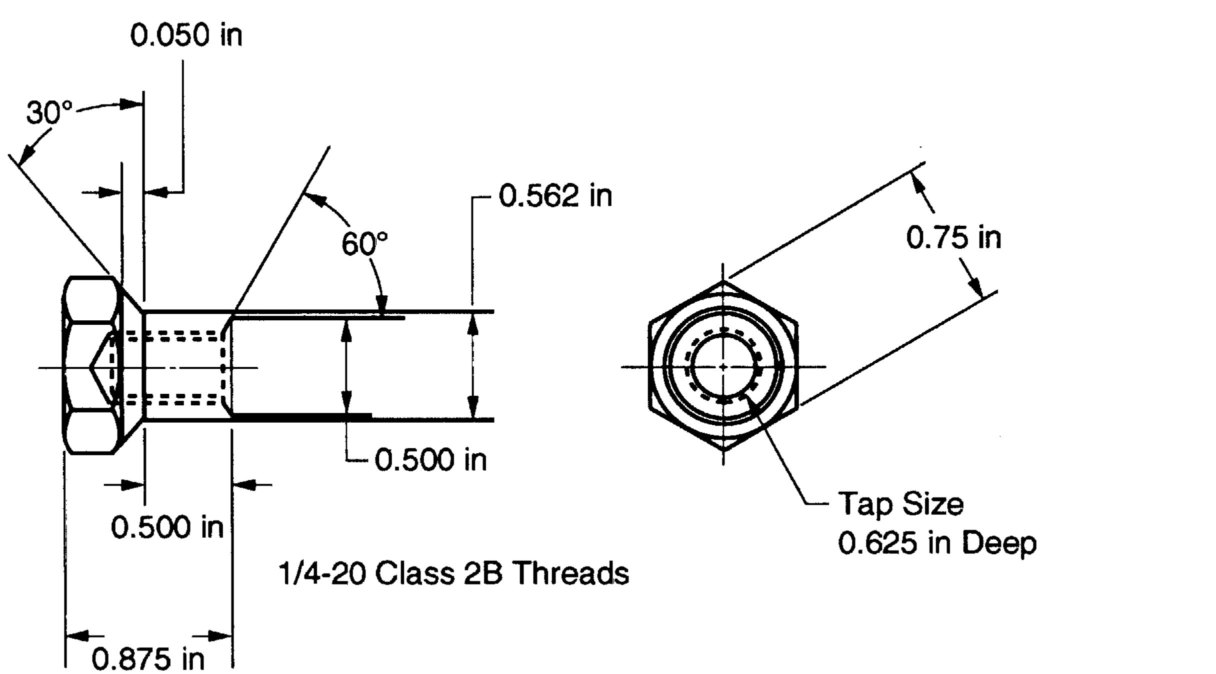
Figure 4B. Stress Corrosion Frame Side Bar (English Units).



Tolerances on ± 0.0127 cm

Note: Thread dimensions must be as specified (measurement by fabricator is mandatory).

Figure 5A. Stress Corrosion Frame Nut (Metric Units).



Scale 1/1

64 / All Over

Tolerances on ± 0.005

Note: Thread dimensions must be as specified (measurement by fabricator is mandatory).

Figure 5B. Stress Corrosion Frame Nut (English Units).

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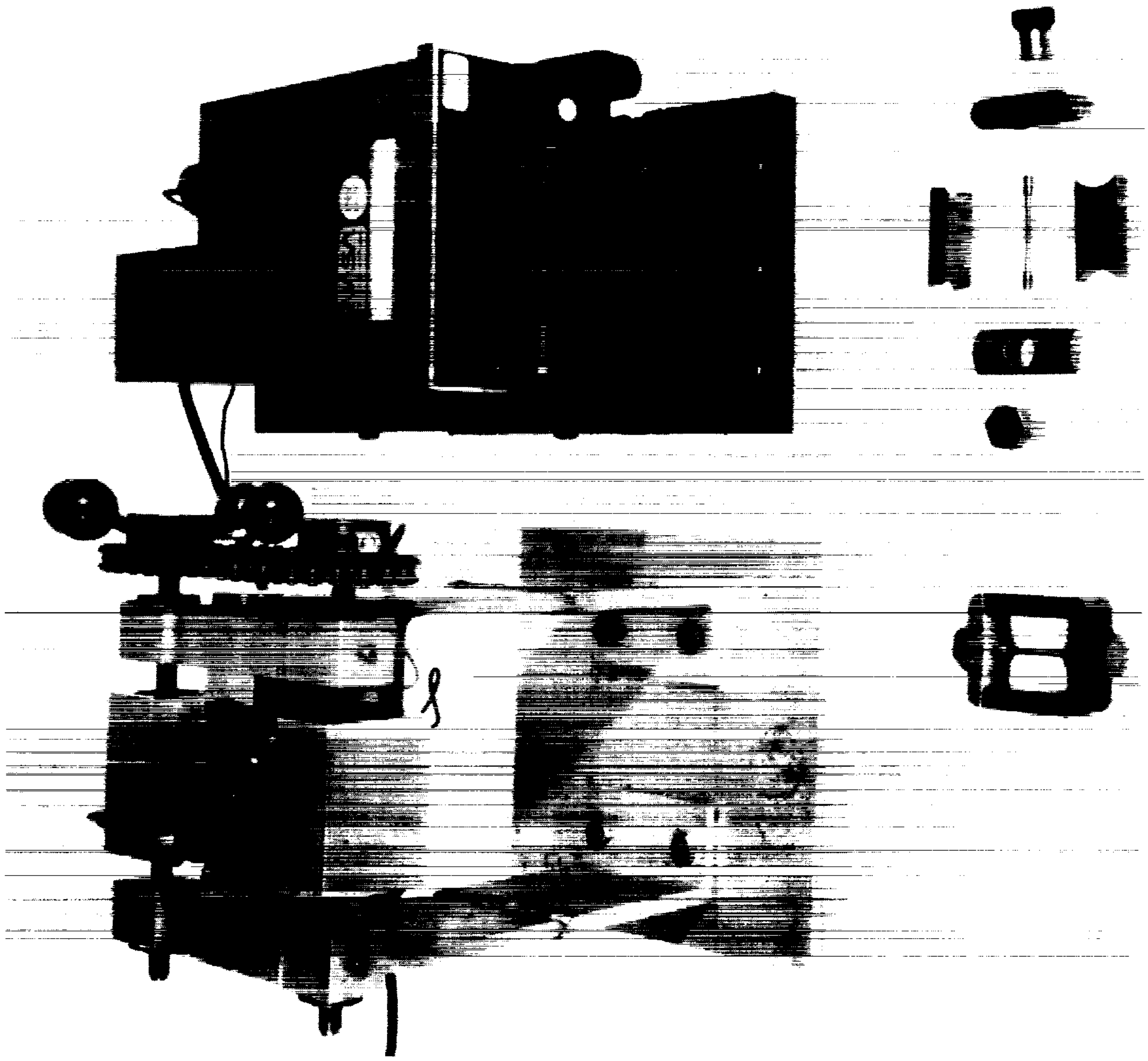

Figure 6. Device and Frames Used to Stress Round Tensile Specimens.

Figure 7. Salt Spray Apparatus.

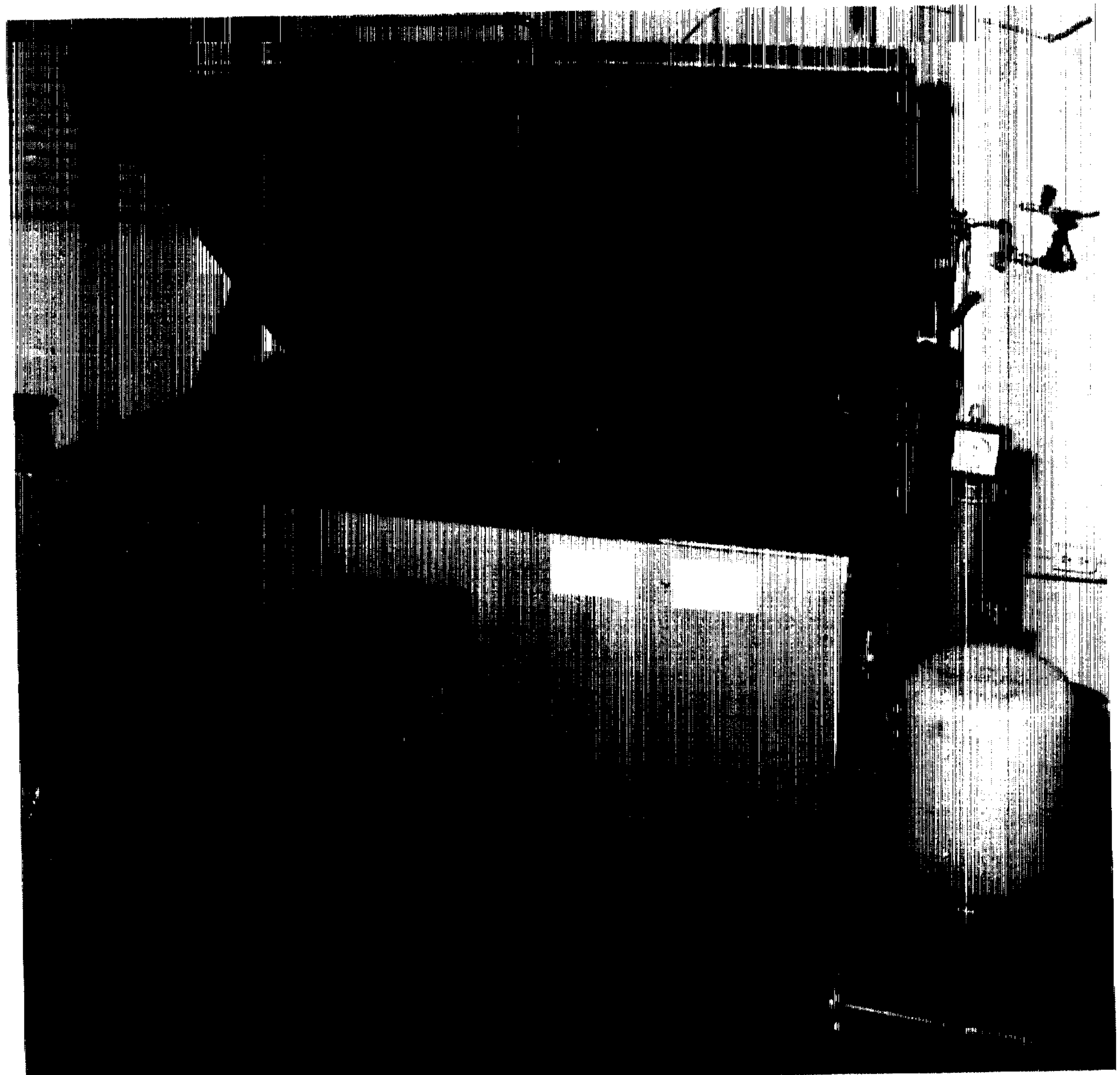

Figure 8. High Humidity Cabinet.

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Figure 9. Alternate Immersion Tester.

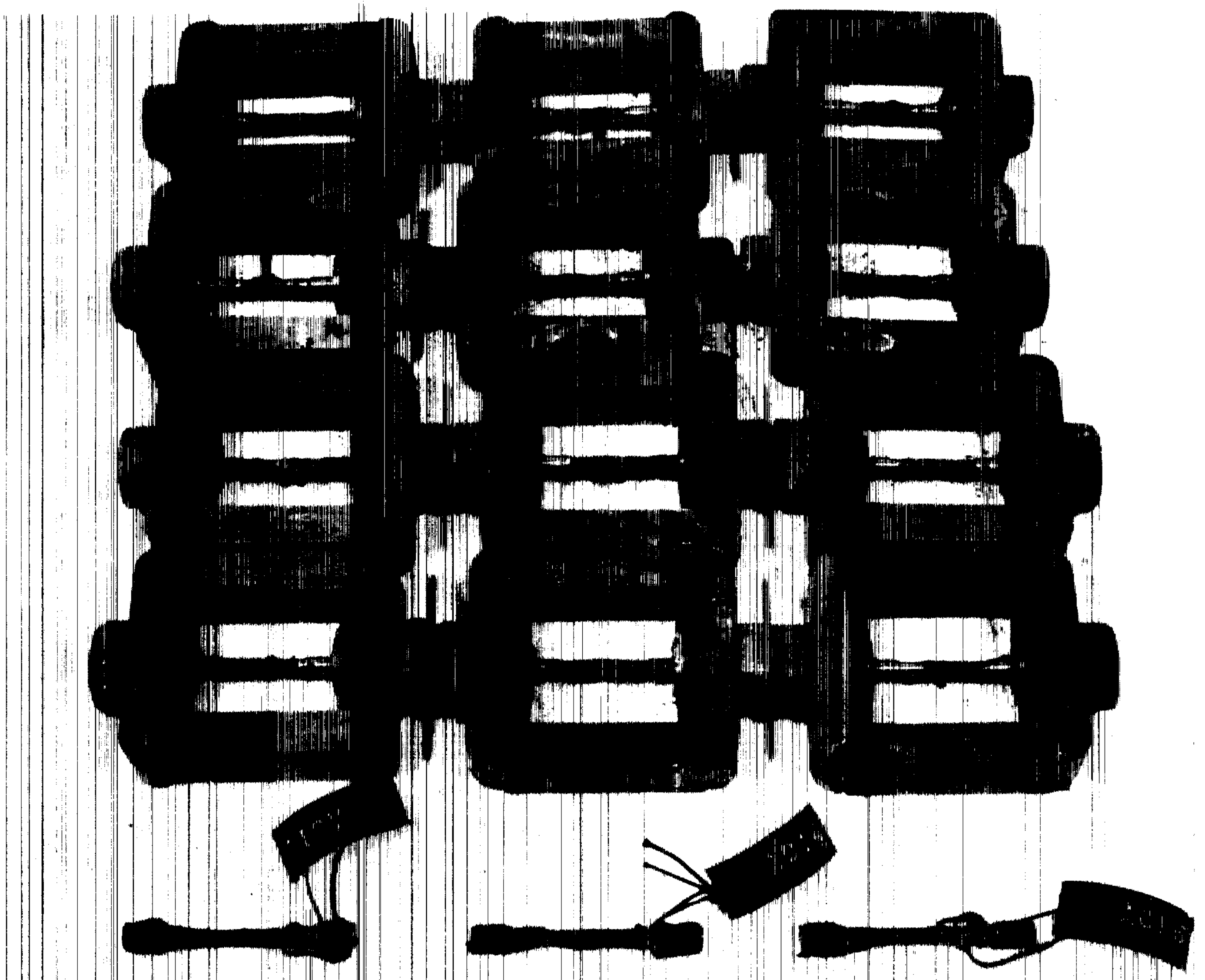

Figure 10. HP 9Ni–4Co–0.20C Steel Ring Forging Circumferential Tensile Specimens Exposed to 3 Months of 5-Percent Salt Spray.

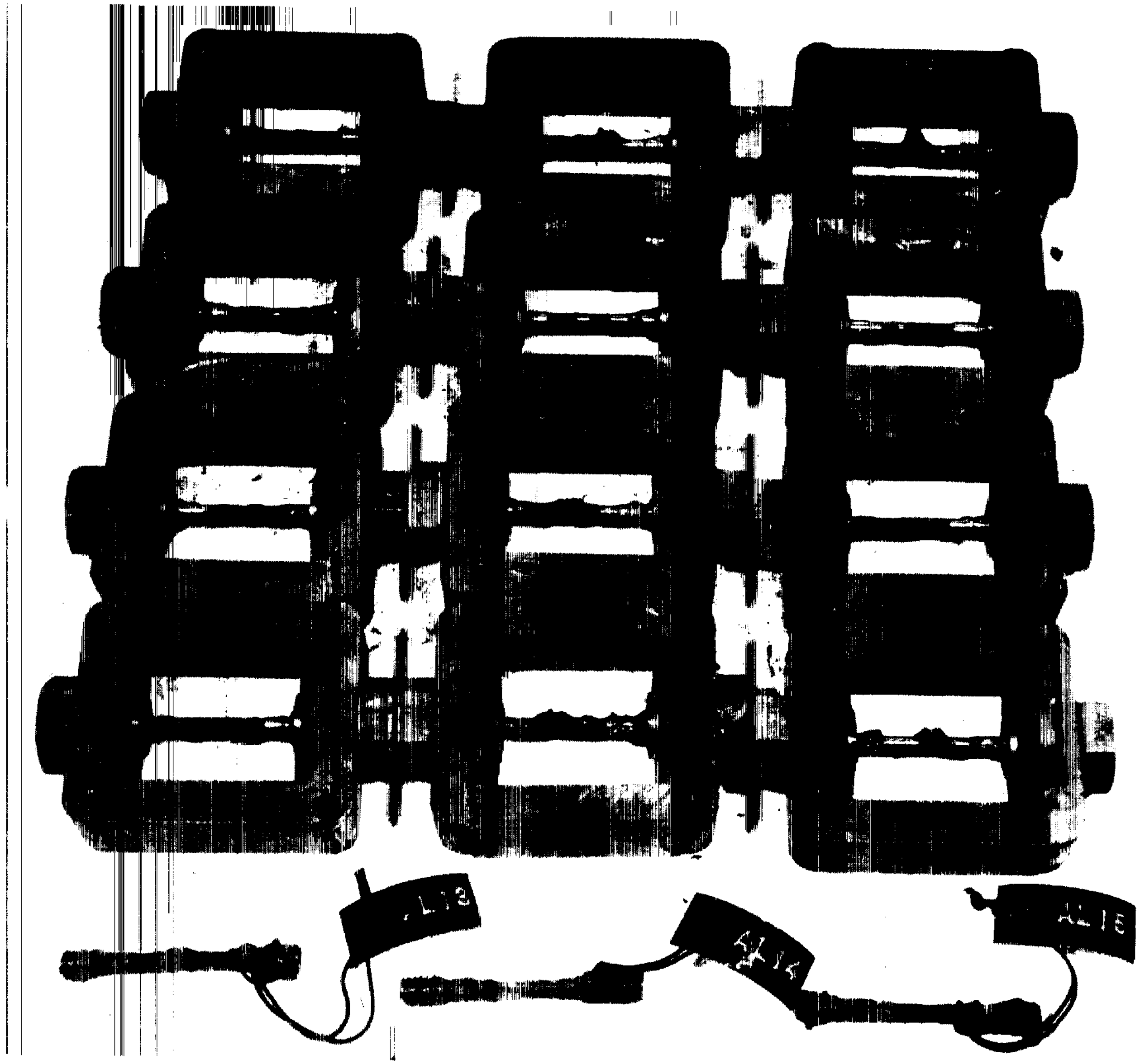

Figure 11. HP 9Ni–4Co–0.20C Steel Ring Forging Longitudinal Tensile Specimens Exposed to 3 Months of 5-Percent Salt Spray.

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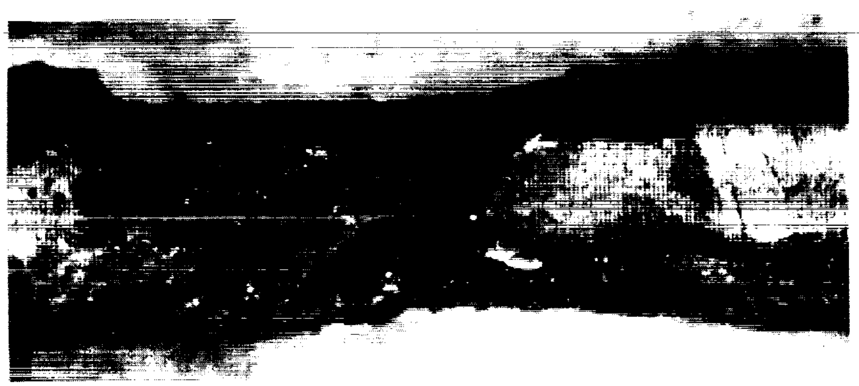
1.6X Mag.



12X Mag.

Figure 12. HP 9Ni–4Co–0.20C Steel Ring Forging Longitudinal Tensile Specimen Stressed to 75-Percent of YS and Exposed to 3 Months of 5-Percent Salt Spray.

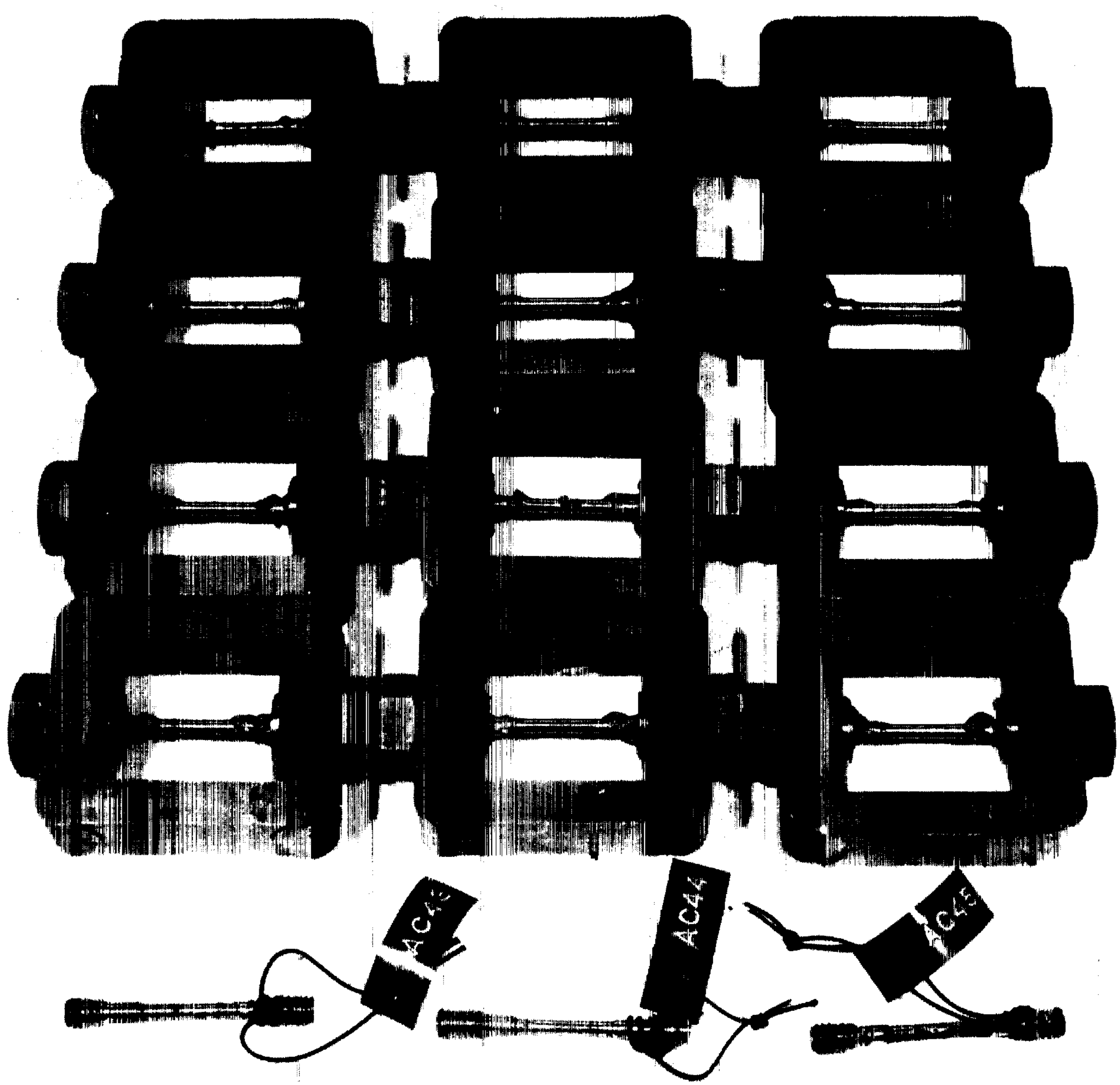


Figure 13. HP 9Ni–4Co–0.20C Steel Ring Forging Circumferential Tensile Specimens Exposed to 3 Months of High Humidity.

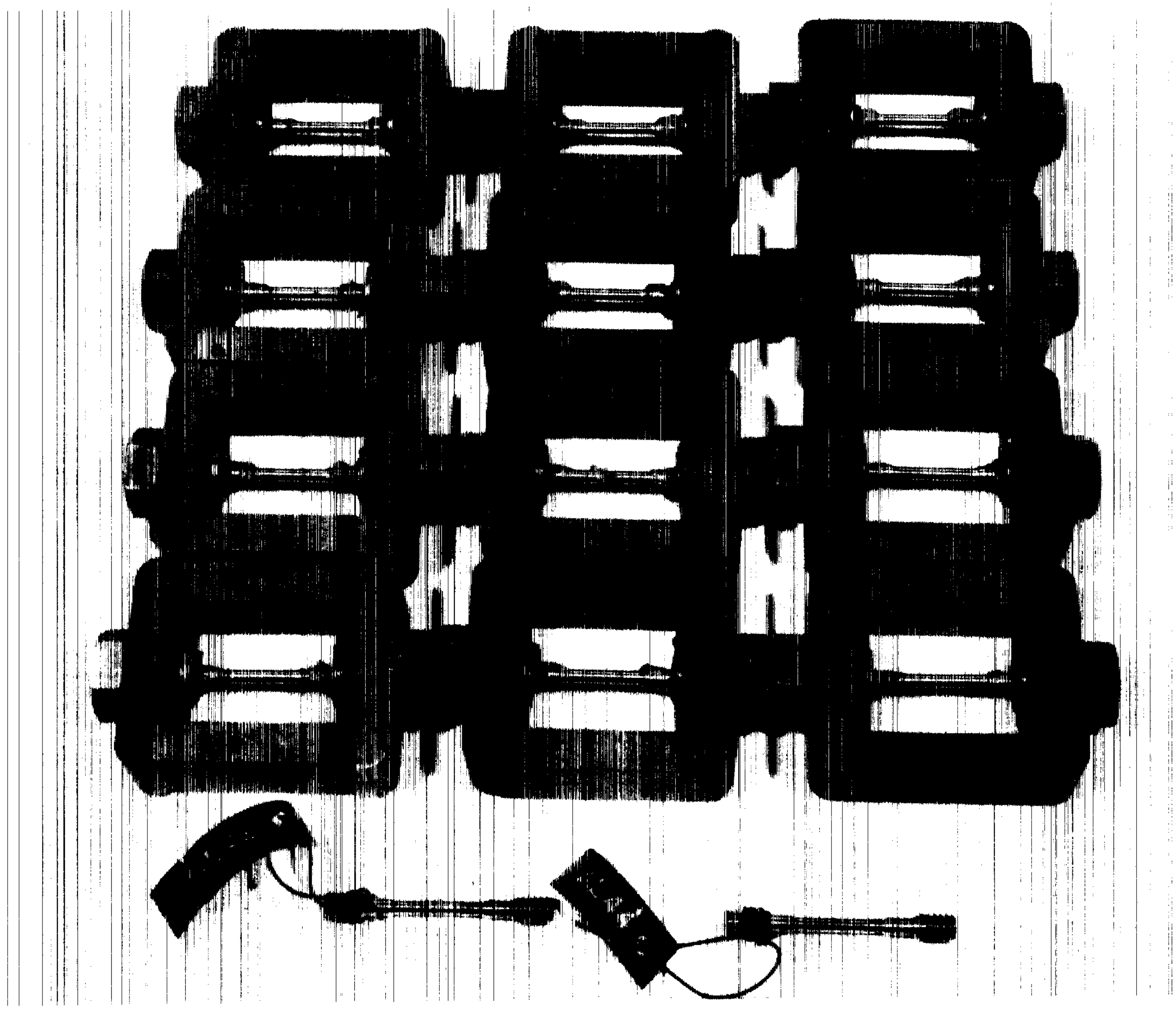
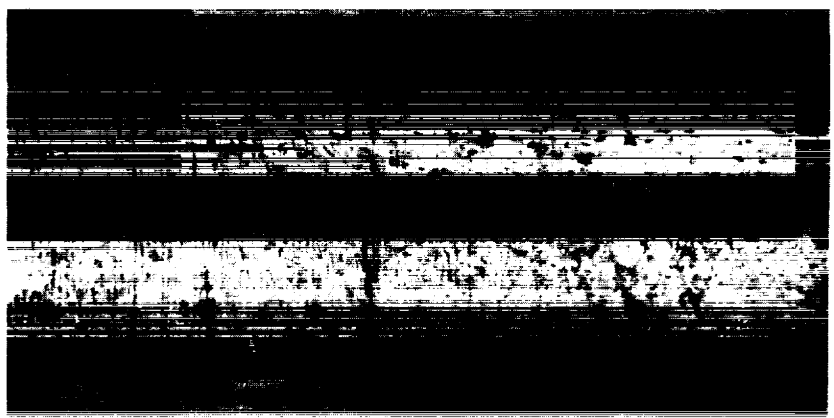


Figure 14. HP 9Ni–4Co–0.20C Steel Ring Forging Longitudinal Tensile Specimens Exposed to 3 Months of High Humidity.

1.6X Mag.



16X Mag.

Figure 15. HP 9Ni–4Co–0.20C Steel Ring Forging Longitudinal Tensile Specimen Stressed to 90-Percent of YS and Exposed to 3 Months of High Humidity.

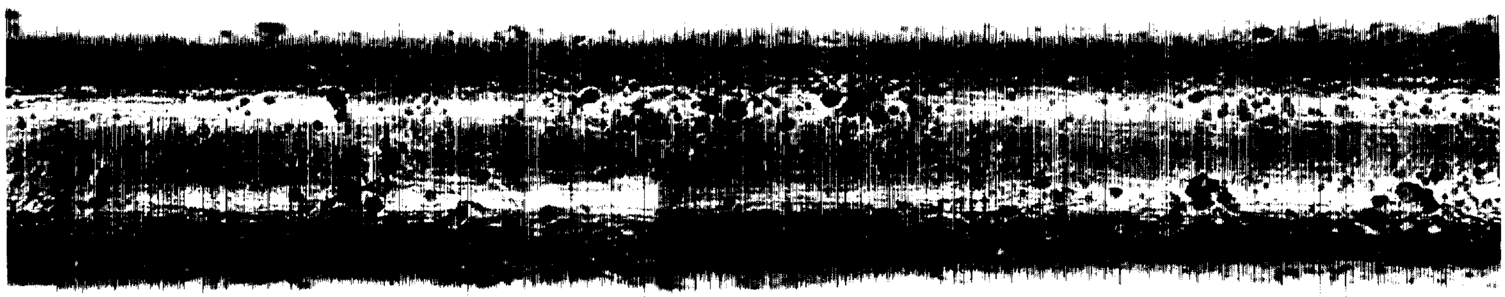
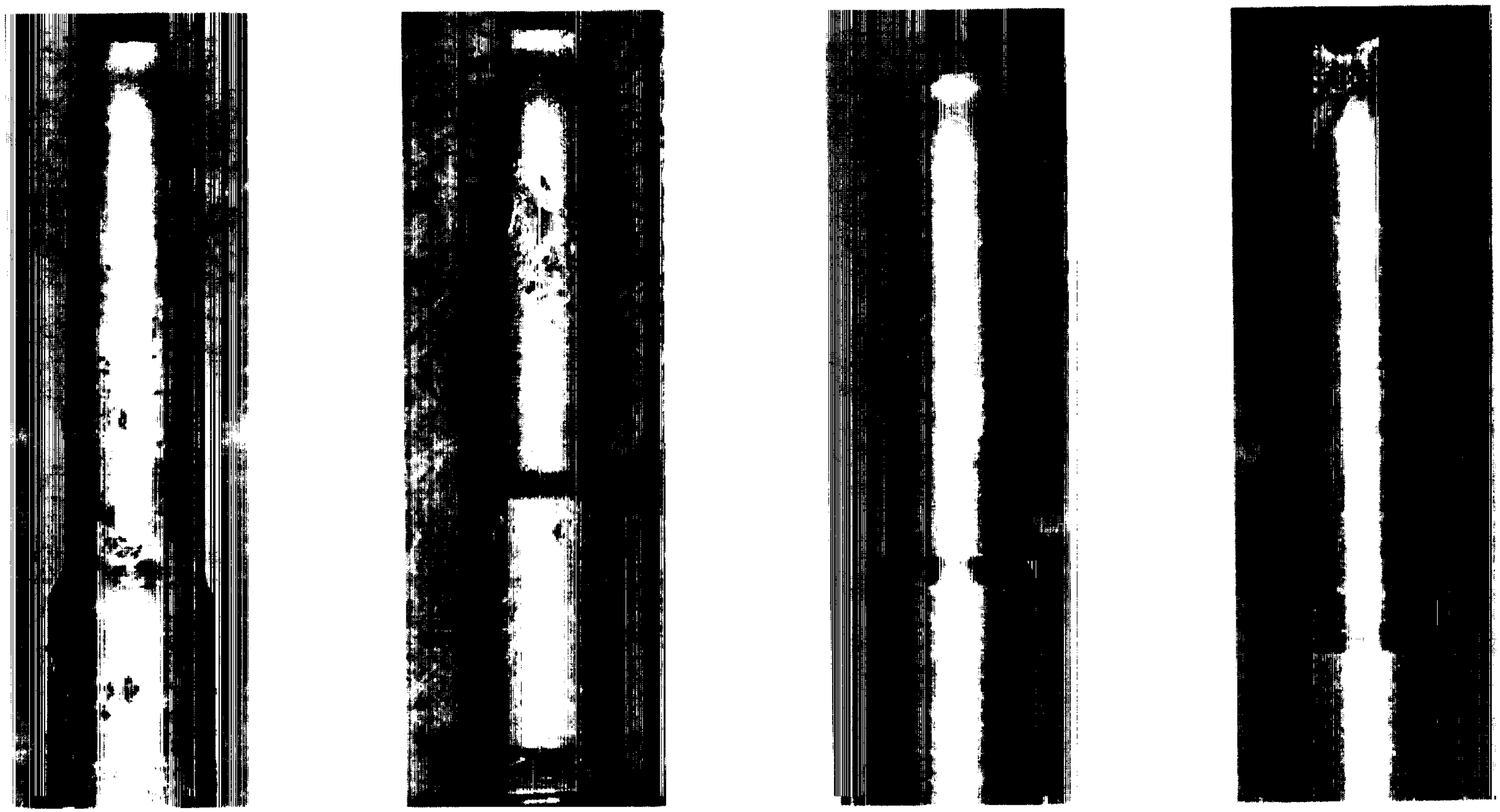


Figure 16. HP 9Ni–4Co–0.20C Steel Ring Forging Longitudinal Tensile Specimen Exposed Unstressed to 4 Months of High Humidity (Montage).



Circumferential Unstressed — Longitudinal Unstressed — Circumferential 75% YS — Longitudinal 75% YS

Figure 17. HP 9Ni–4Co–0.20C Steel Ring Forging Specimens Tensile Tested to Fracture After 3-Month Exposure to High Humidity. (6× Mag.)

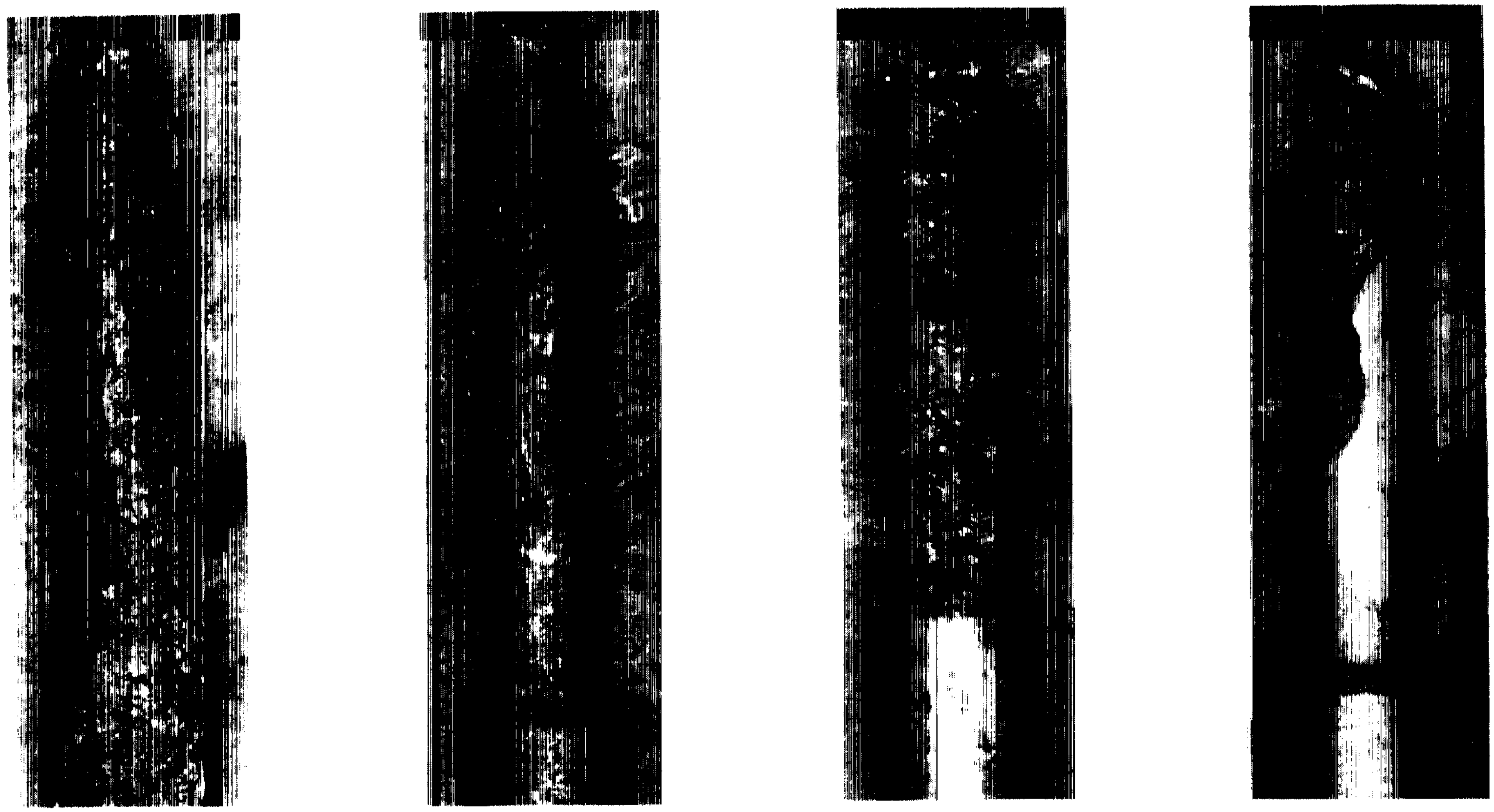


Figure18. HP 9Ni–4Co–0.20C Steel Ring Forging Specimens Tensile Tested to Fracture After a 3-Month Exposure to 5-Percent Salt Spray. (6× Mag.)

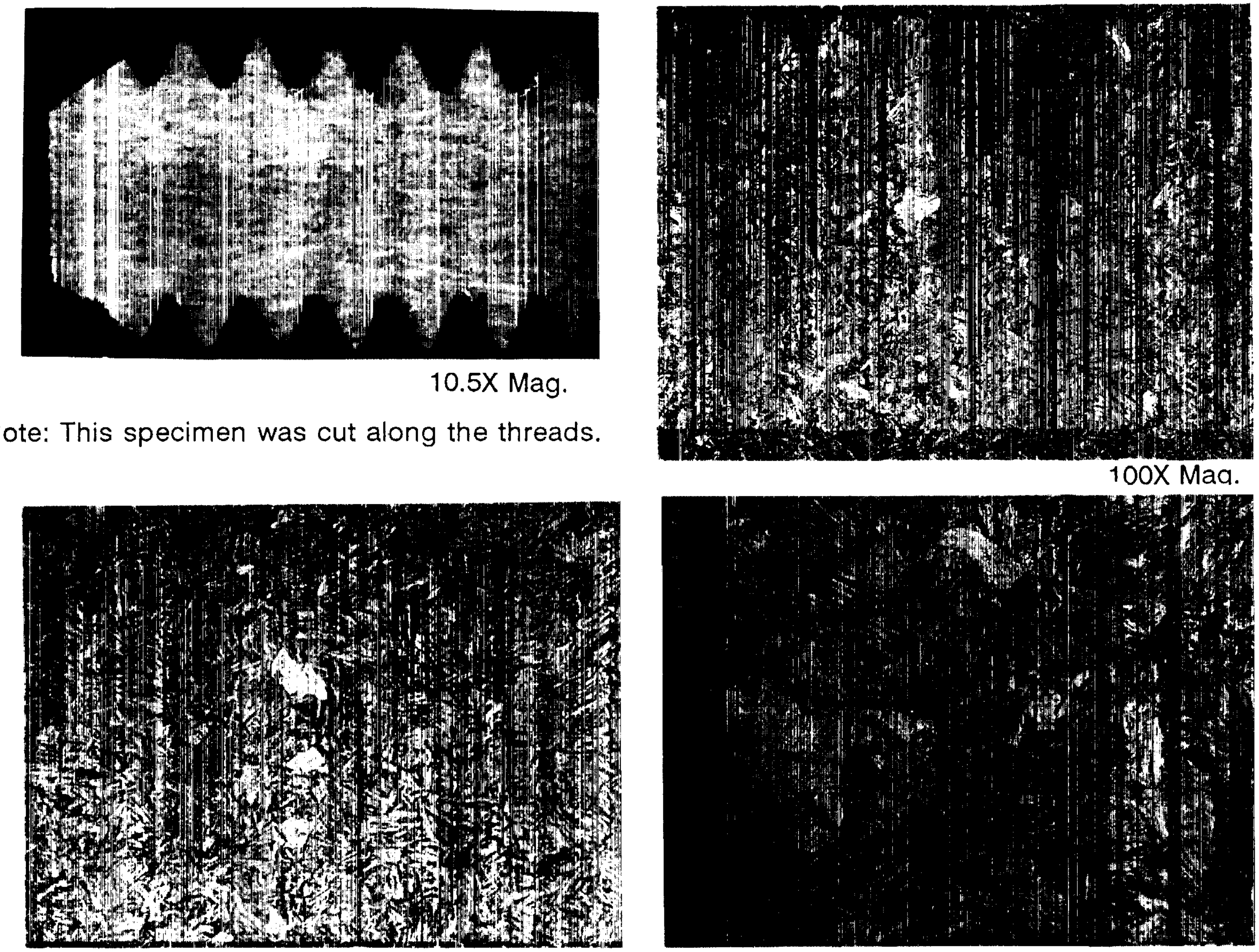
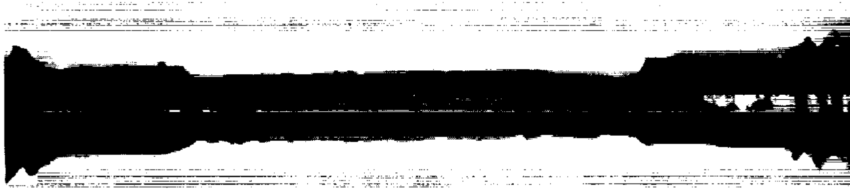


Figure 19. Microstructure of an HP 9Ni–4Co–0.20C Steel Ring Forging Tensile Specimen. (Etchant: Kallings)

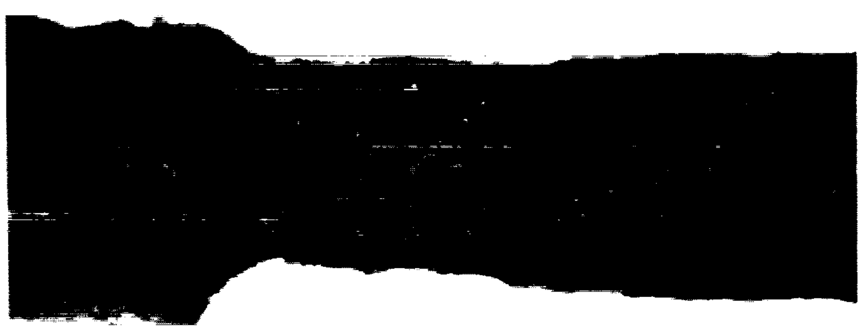
3X Mag.

10.4X Mag.

90 Days in 3.5% NaCl Alternate Immersion



3X Mag.



10.4X Mag.

90 Days in 5% Salt Spray

Figure 20. HP 9Ni–4CO–0.20C Steel Plate Tensile Specimens Stressed to 75 Percent of YS and Exposed to Various Corrosive Environments.

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13. ABSTRACT *(Maximum 200 words)*

A stress corrosion cracking (SCC) evaluation was undertaken on HP 9Ni–4Co–0.20C steel in support of the Advanced Solid Rocket Motor (ASRM) program. This alloy was tested in the forms of plate, bar, and ring forging. Several heat treating procedures yielded ultimate tensile strengths ranging from 1,407 to 1,489 MPa (204 to 216 ksi). The test environments were high humidity, alternate immersion in 3.5-percent NaCl, and 5-percent salt spray. Stress levels ranged from 25 to 90 percent of the yield strengths. The majority of the tests were conducted for 90 days. Even though the specimens rusted significantly in salt spray and alternate immersion, no failures occurred. Therefore, it can be concluded that this alloy, in the forms and at the strength levels tested, is highly resistant to SCC in salt and high humidity environments.

14. SUBJECT TERMS
Advanced Solid Rocket Motor (ASRM), Alternate Immersion, High Humidity, HP 9Ni–4Co–0.20C Steel, Salt Spray, Stress Corrosion Cracking (SCC)

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