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SPECTRUM FATIGUE CRACK GROWTH RATE CHARACTERISTICS OF CAST ALUMINUM ALLOYS A201-T7 AND A357-T6

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The spectrum fatigue crack growth characteristics of cast aluminum alloys A201-T7 and A357-T6 were evaluated and compared with wrought aluminum 7050-T76 data. For specimens tested at three different spectrum stress levels, A357-T6 consistently possessed the longest fatigue life, nearly double that of A201-T7 and 7050-T76. At the lowest maximum spectrum stress level tested, A201-T7 had a greater FCG life than 7050-T76; at the highest maximum stress level tested 7050-T76 had a greater FCG life than A201-T7. Critical crack size of each alloy at failure varied considerably. Further analysis of the a vs. N record of each sample to obtain the crack growth rate (FCGR) vs. the corresponding stress intensity indicated that A357-T6 had the lowest crack growth rate over the range of stress intensity examined. FCGR comparisons between A201-T7 and 7050-T76 depended on the level of stress intensity. Macrofractography revealed that the alloys had distinctively different fracture topographies. Microfractography, using scanning electron microscopy, revealed little because compressive loads obliterated features typically associated with fatigue.

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SPECTRUM FATIGUE CRACK GROWTH RATE CHARACTERISTICS OF CAST ALUMINUM ALLOYS A201-T7 AND A357-T6

PREFACE

This final report was prepared by the Materials Engineering Branch (AFWAL/MLSE), Systems Support Division, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, under Project 2418, "Aerospace Structural Materials," Task 241807, "Systems Support," Work Unit 24180703, "Engineering and Design Data."

The work herein was performed during the period May 1985 - February 1986. The authors extend special recognition to Mr. Patrick Ertel of the University of Dayton Research Institute for conducting all of the testing and data reporting, and to First Lieutenant Torsten Rhode, who assisted in the development of the computer software. The final report was released March 1986.

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SECTION I

INTRODUCTION

Over the past several years, the static properties (tensile, compressive, etc.) of premium quality aluminum castings were studied extensively,[1-3] but relatively little attention was given to their dynamic properties, especially spectrum fatigue crack growth resistance. Since little, if any, data existed in 1984, a cursory test program was developed to evaluate the spectrum fatigue crack growth behavior of the two most popular premium quality casting alloys: A201-T7 and A357-T6. The program was not intended to develop large amounts of data like other programs,[4-6] but rather it was designed to simply assess the spectrum fatigue crack growth resistance of cast aluminum alloys.

Premium quality castings are an economical alternative to conventional built-up structures in airframe manufacturing. By replacing built-up structures with premium quality aluminum castings, a designer can cut component acquisition costs anywhere from 25 to 50%. Although premium quality castings are cost competitive with built-up structures, premium quality castings have not realized their full potential in airframe applications. This stems from several reasons. First, premium quality castings are limited by strength and ductility. Second there are limited design data for premium quality casting alloys, especially durability and damage tolerance data. Third, designers lack confidence in the reliability of aluminum castings. Even though these obstacles, real or imagined, prevent designers from using premium quality castings, the drive to use premium quality castings in primary structure applications has increased.

This particular program was designed to provide a cursory analysis of the spectrum fatigue crack growth resistance of premium quality casting alloys A201-T7 and A357-T6.

SECTION II

TEST PROGRAM AND PROCEDURES

A. Test Material and Specimen Geometry - Center-crack panels (CCP) were used in this study (Figure 1). The A201-T7 and A357-T6 specimens were excised from the center of the half inch thick section of step plate castings (Figure 2), while the 7050-T76 specimens were excised from 5 mm thick plate. Crack starter notches, 0.3 inches long by 0.05 inches wide, were produced using an electric discharge machine. The typical notch tip radius was 0.005 inches. The 7050-T76 specimens were oriented so that the axial loading direction paralleled the grain direction of the plate.

Nominal alloy chemistries for the cast alloys are listed in Table 1. A201-T7 is an age-hardenable, aluminum-copper-silver alloy similar to the 2000 series wrought alloys. A357-T6 is an age-hardenable, aluminum-silicon-magnesium alloy.

The step plates were cast to Military Specification MIL-A-21180C requirements, and were X-ray Grade B or better in the half-inch thick section from which the specimens were excised. The nominal tensile properties are listed in Table 2 for comparison.

B. Test Procedures - All crack growth rate testing was performed on a 15 kip capacity MTS servo-hydraulic fatigue test machine. A PDP 11-34 computer was interfaced to the machine to provide the spectrum load control. Crack length measurements were obtained using Fractomat Krak-Gages adhesively bonded to the specimen surface. Two gages were used on each specimen to monitor the surface crack length as the crack grew from each end of the starter notch. Output from the Fractomat Measurement System was fed to the computer to produce a continuous, uninterrupted record of crack length versus elapsed flights.

The spectrum applied in all of the tests was the Fighter Aircraft Loading Standard For Fatigue (FALSTAFF) which is a tension-compression load history representative of the lower

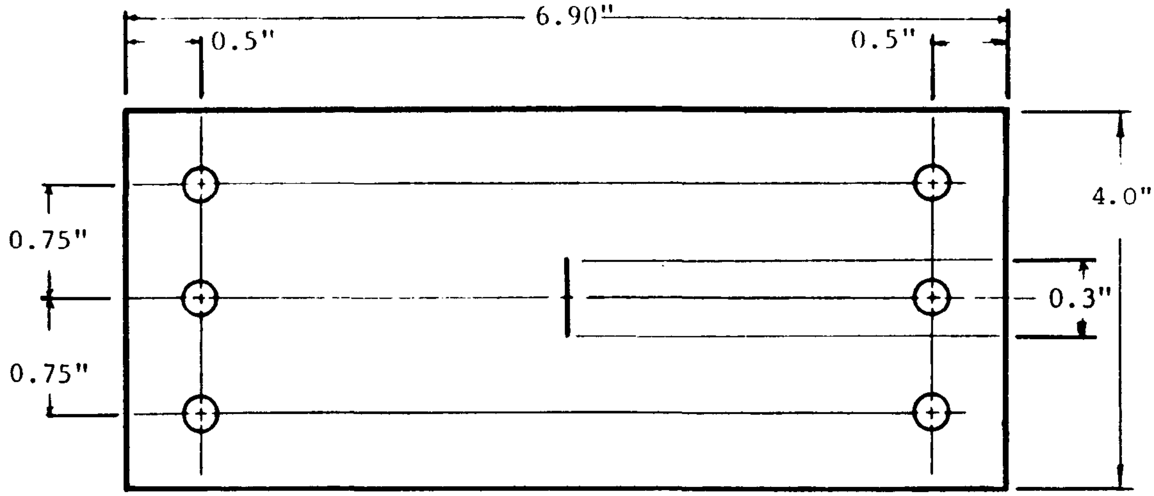

Figure 1. Center-Crack Panel (CCP) Used for Spectrum Crack Growth Tests. Thickness 0.2 Inches.

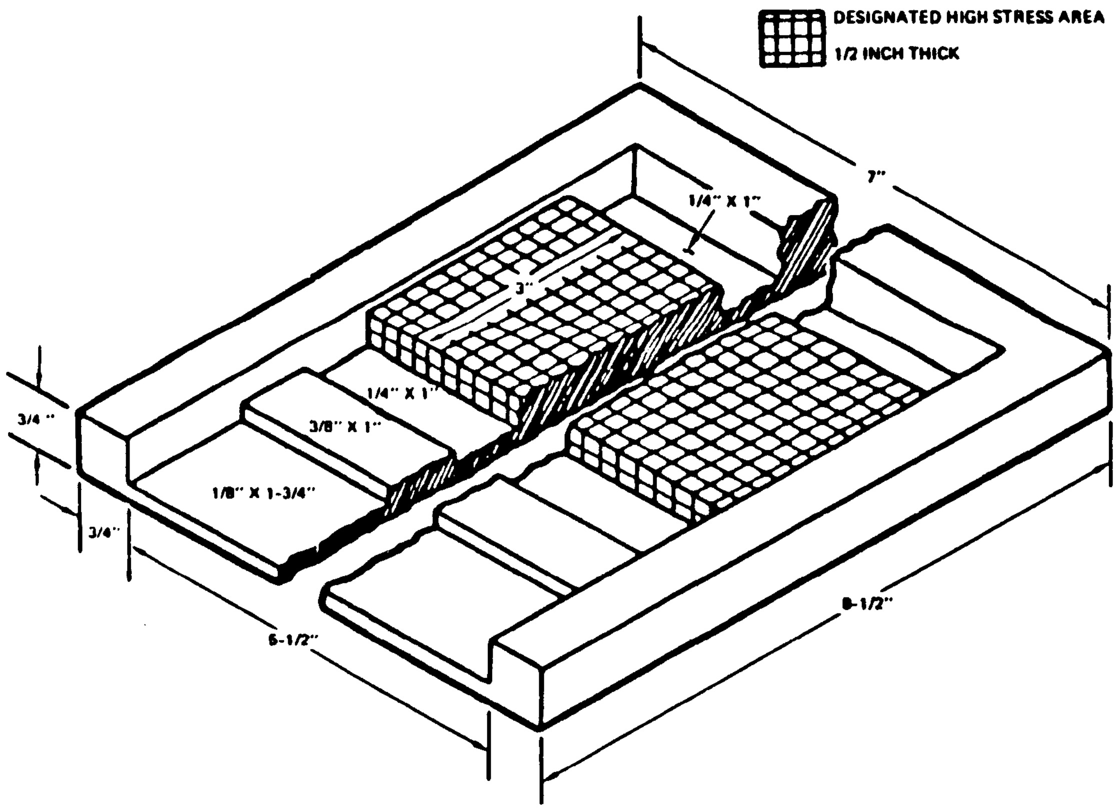

Figure 2. Step Plate From Which A201-T7 and A357-T6 Center-Crack Panel Specimens Were Excised.

TABLE 1

ALLOY CHEMISTRY COMPOSITIONS BY WEIGHT PERCENT ACCORDING TO MIL-A-21180C, HIGH-STRENGTH ALUMINUM-ALLOY CASTINGS[7]

	A201-T7	A357-T6
Copper	4.0-5.0	0.20 max
Silicon	0.05 max	6.5-7.5
Iron	0.10 max	0.20 max
Manganese	0.20-0.40	0.10 max
Zinc	---	0.10 max
Magnesium	0.15-0.35	0.40-0.70
Titanium	0.15-0.35	0.10-0.20
Beryllium	---	0.04-0.07
Silver	0.40-1.00	---
Others, each	0.03	0.05
Others, total	0.10	0.15

TABLE 2

AVERAGE TENSILE PROPERTIES OF A201-T7[8], A357-T6[8], AND 7050-T76

Material	Yield Strength (ksi)	Ultimate Tensile Str. (ksi)	% Elongation in 1-inch Gage Length
A201-T7	60	65	4.8
A357-T6	41	49	5.6
7050-T76	80	84	14

tension-compression load history representative of the lower wing location of a fighter-type aircraft. The spectrum represents 200 random length flights ranging from tranquil to severe flight conditions. Three maximum stress conditions were used: 15, 20, and 25 ksi. These stress levels were selected for the purpose of investigating stress level effects within a reasonable test period.

All testing was conducted under ambient conditions at a loading frequency of approximately 5 Hz. In all tests, spectrum loading conditions were applied from the as-machined notch up to the specimen failure, i.e. separate precracking procedures were not applied. To eliminate any notch effects and to compare the different alloys on an equal basis, crack length records and flights to failure were referenced to an initial crack size, 2a, of 0.4 inches.

SECTION III
RESULTS AND DISCUSSION

A. Fatigue Crack Growth Life - Results of the spectrum fatigue testing are shown as plots of total crack length, 2a, versus flights in Figure 3. Shown in each plot are the results of a single specimen of each alloy tested under similar stress conditions. Fatigue crack growth (FCG) life of each specimen is also listed in Table 3. At each stress level examined, A357-T6 had the greatest FCG life; nearly double the FCG life of the 7050-T76 plate at the low (15 ksi) and the intermediate (20 ksi) stress conditions. At the highest maximum stress (25 ksi), the A357-T6 FCG life was approximately 40% greater than 7050-T76.

The fatigue performance of A201-T7 relative to the 7050-T76 plate was dependent on the stress level. At the lowest stress level, A201-T7 had slightly greater FCG life (15%) than the 7050-T76, while at the higher stress levels, 7050-T76 outlived A201-T7 by approximately 20%. FCG life of A201-T7 was typically 50-60% of A357-T6.

In terms of critical crack size, the ranking of each alloy system depends on spectrum stress level. At the lowest stress level, the final crack length at failure of each alloy was approximately the same, which suggests that the fracture toughnesses of the alloys were similar. At the intermediate stress level, however, the critical crack length of A201-T7 was considerably less than the crack lengths of A357-T6 and 7050-T76. At the highest stress level, A357-T6 had the shortest critical crack length, A201-T7 had the next shortest, and 7050-T76 had the longest critical crack length. These inconsistent critical crack lengths, or indications of fracture toughness, were not explained by the subsequent fractographic examinations. This same variability of fracture toughness of the aluminum castings was documented in other fracture toughness studies.[4,5,8]

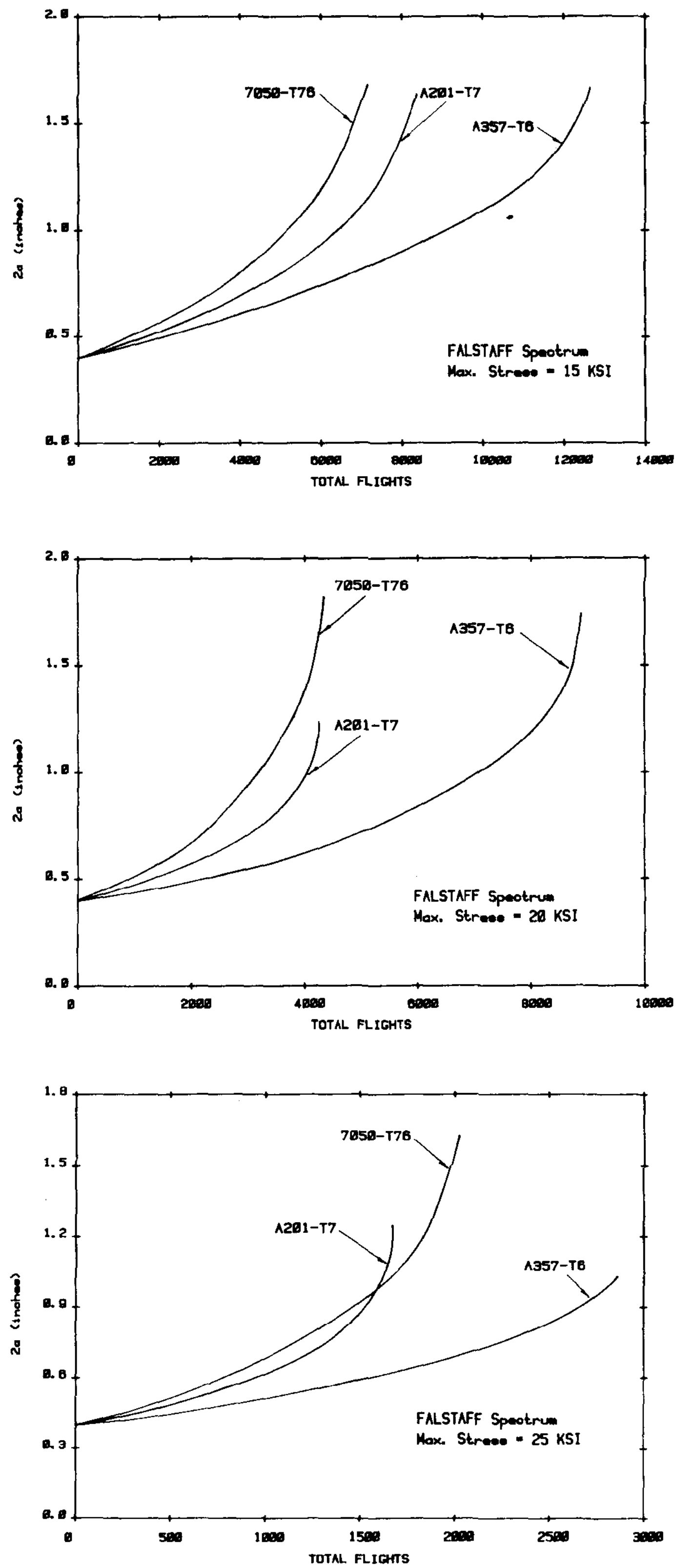

Figure 3. Fatigue Crack Growth Life Plots at Three Different Maximum Stress Levels: (a) 15 ksi, (b) 20 ksi, (c) 25 ksi.

TABLE 3

SPECTRUM LIFE DATA AT THREE MAXIMUM SPECTRUM STRESS LEVELS FOR A201-T7, A357-T6, AND 7050-T76

Alloy	Specimen ID	Flights to Failure*	Crack Size at Failure (inches)
		Maximum Stress = 15 ksi	
A201-T7	23	8351	1.632
A357-T6	31	12634	1.665
7050-T76	73	7240	1.678
		Maximum Stress = 20 ksi	
A201-T7	31	4231	1.235
A357-T6	33	8858	1.738
7050-T76	71	4324	1.823
		Maximum Stress = 25 ksi	
A201-T7	22	1668	1.244
A357-T6	32	2860	1.034
7050-T76	72	2025	1.624

* Based on initial crack size (2a) of 0.40 inches, W = 4.0 inches.

B. Fatigue Crack Growth Rate - Fatigue crack growth rate data for each alloy were also determined to compare the spectrum crack growth rate characteristics of the alloys (Figure 4). Crack growth rates were based on the crack extension occurring for each 200 flight spectrum pass. Corresponding maximum stress intensity were based on the mean crack length during the 200 flight interval and the maximum spectrum stress. Best-fit third degree polynomial curves, relating log stress intensity to log crack growth rate, are also presented in Figure 4. Both of the cast alloys had more scatter than the 7050-T76, particularly at the lower stress intensity ranges (less than 20 ksi$\sqrt{in}$). Based on the best-fit curves shown in the composite plot, A357-T6 data clearly possessed the lowest fatigue crack growth rate (FCGR) over the range of stress intensities shown. The A357-T6 FCGR was typically 50% lower than the 7050-T76 over the stress intensities evaluated. Below a maximum stress intensity range of about 23 ksi$\sqrt{in}$, A201-T7's crack growth rate was lower than the crack growth rate of 7050-T76; above this value, A201-T7 had a faster crack growth rate than 7050-T76.

C. Fractography - Since the FALSTAFF spectrum includes compressive loads which obliterate features on fracture faces, only limited fractographic analysis was performed on the failed test specimens; therefore, most of the effort was macrographic and not micrographic.

The alloy fracture faces are compared side by side for a given stress level in Figures 5-7. The cast alloys possessed coarser features than the wrought 7050-T76 with A357-T6 having the coarsest texture of the two casting alloys. Only the critical crack length changed with the change in maximum stress level applied. For the most part, the fracture features of a given alloy appeared the same regardless of the stress level (Figures 8-9). Beach marks were noticed on the cast alloys just before the overload region, but these were not captured in these macrophotographs. Also black oxide deposits resulting from fretting were noticed on all three of the alloys.

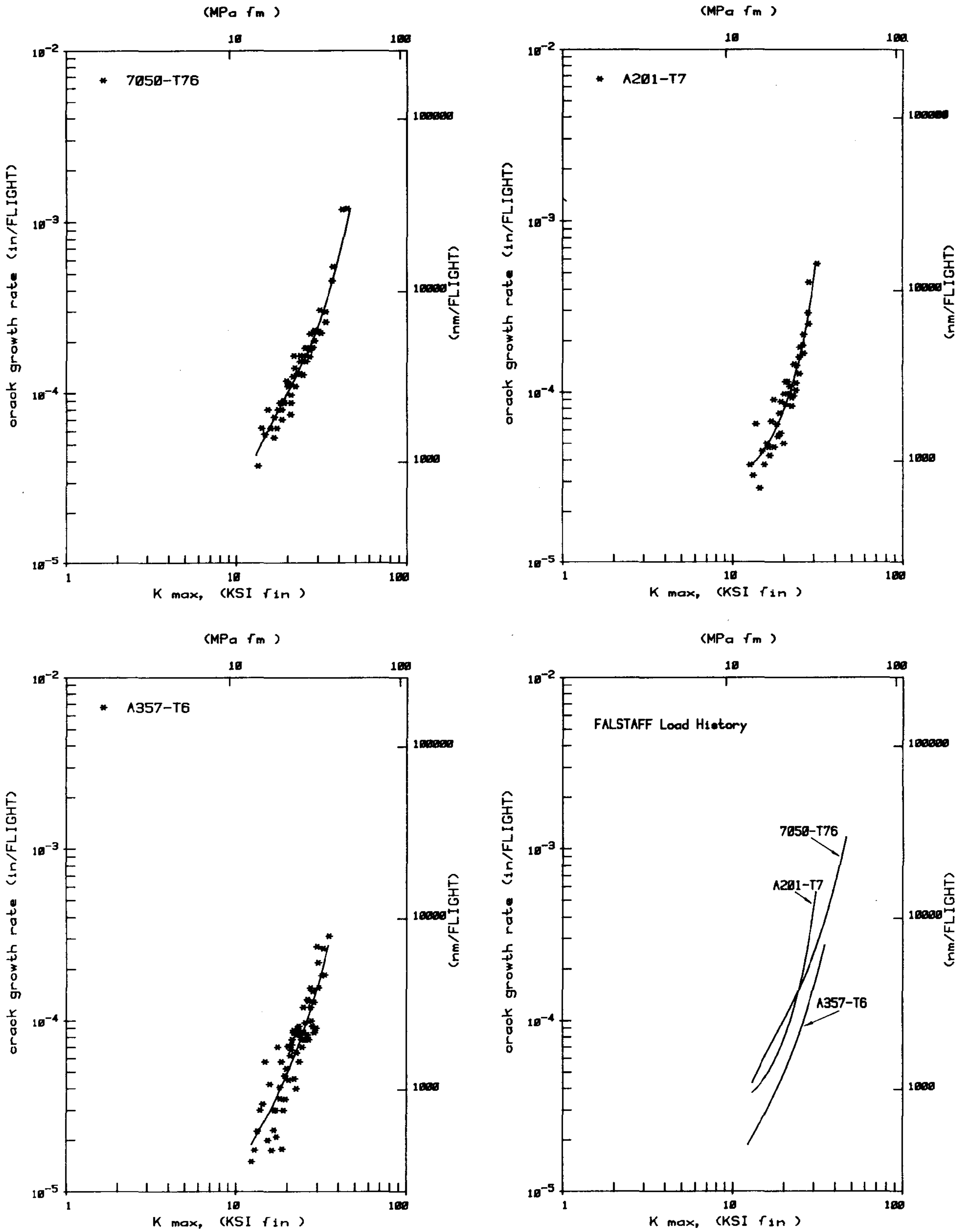

Figure 4. Fatigue Crack Growth Rate Plots of the Alloys Tested: (a) 7050-T76, (b) A201-T7, (c) A357-T6, (d) Best-Fit Curves.

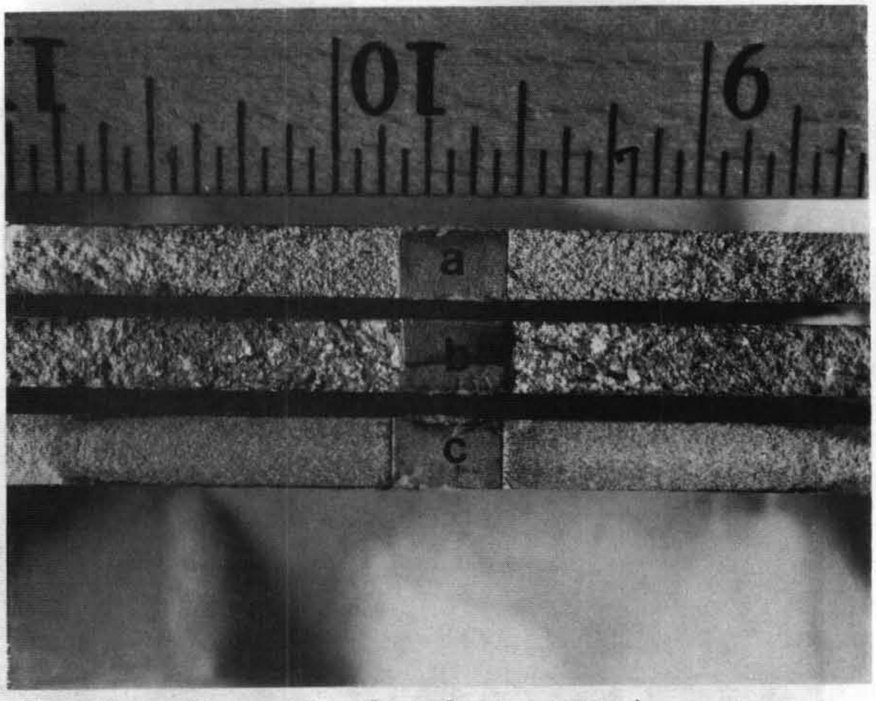

Figure 5. Fracture Faces Produced at a Maximum Stress of 15 ksi: (a) A201-T7, (b) A357-T6, (c) 7050-T76. Magnification 2X.

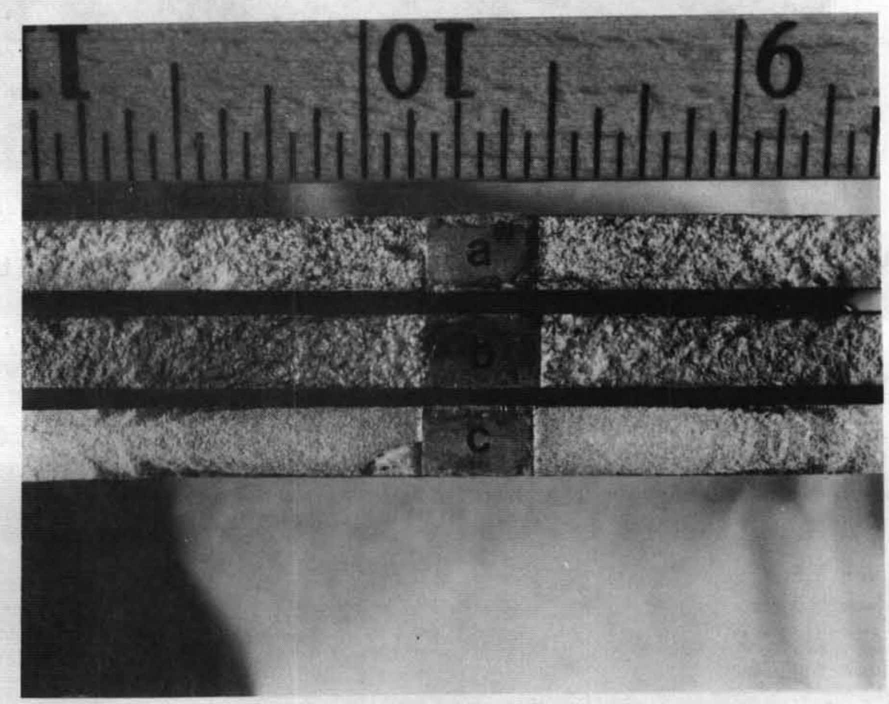

Figure 6. Fracture Faces Produced at a Maximum Stress of 20 ksi: (a) A201-T7, (b) A357-T6, (c) 7050-T76. Magnification 2X.

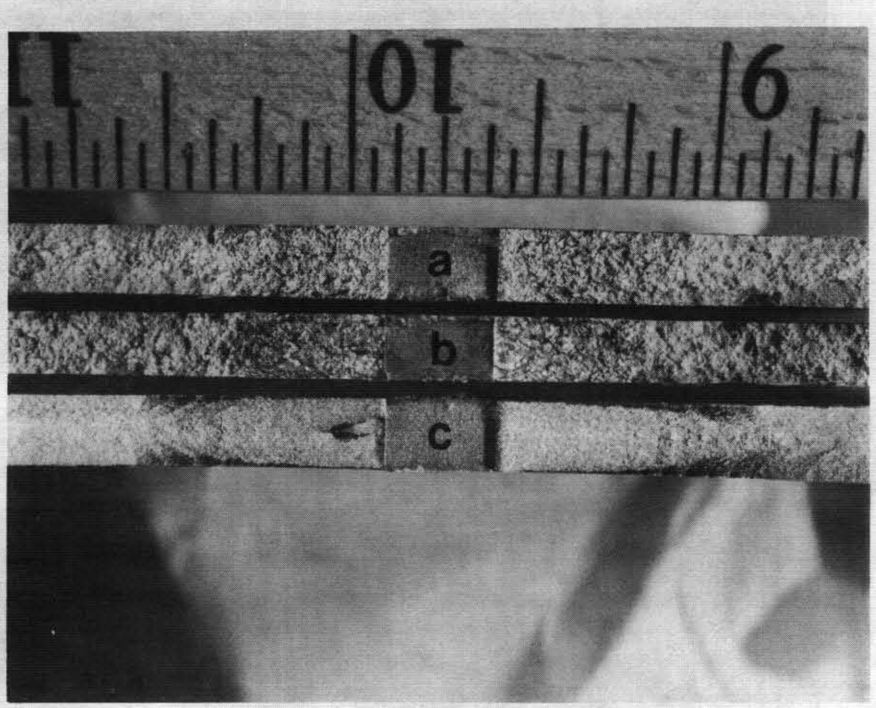

Figure 7. Fracture Faces Produced at a Maximum Stress of 25 ksi: (a) A201-T7, (b) A357-T6, (c) 7050-T76. Magnification 2X.

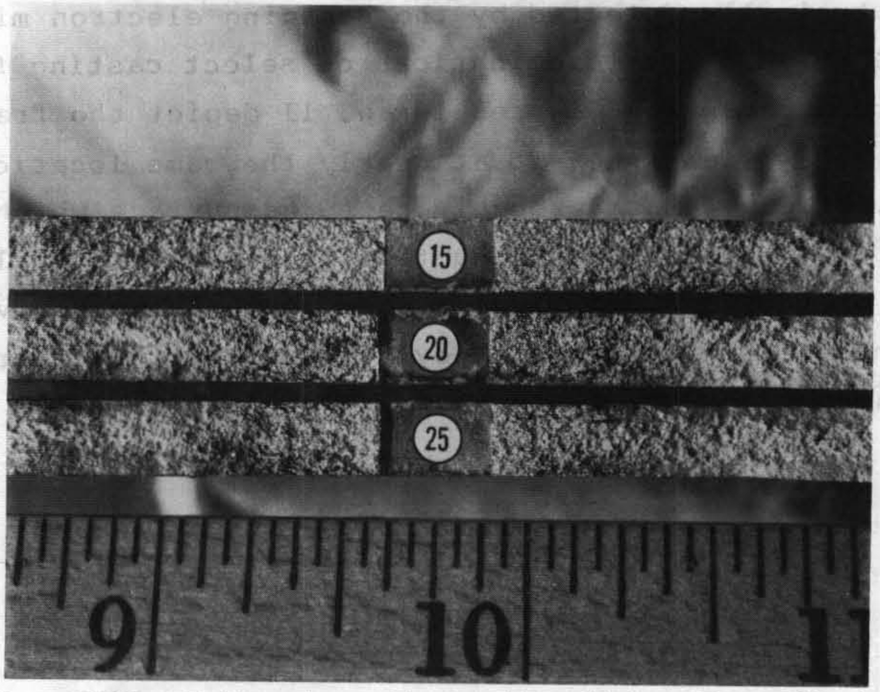

Figure 8. A201-T7 Fracture Faces Resulting From Maximum Stress Levels of 15, 20, and 25 ksi. Magnification 2X.

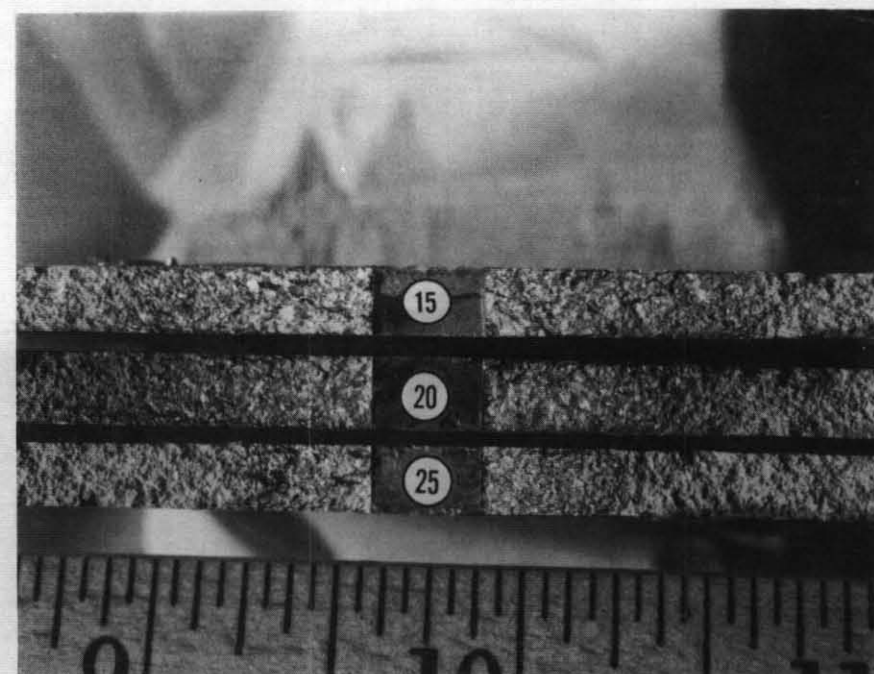

Figure 9. A357-T6 Fracture Faces Resulting From Maximum Stress Levels of 15, 20, and 25 ksi. Magnification 2X.

As predicted, the compressive loads wiped out many of the features typically detected by the scanning electron microscope, therefore only cursory examinations of select casting fracture faces were performed. Figures 10 and 11 depict the fracture faces of A201-T7 and A357-T6 at nearly the same location on each specimen. A201-T7 has a roughly textured surface which appears ductile. A357-T6 also has a ductile appearance, but also shows smearing of the fracture face because of the compressive loads. For the most part, the cast alloys offered little information in the scanning electron microscope.

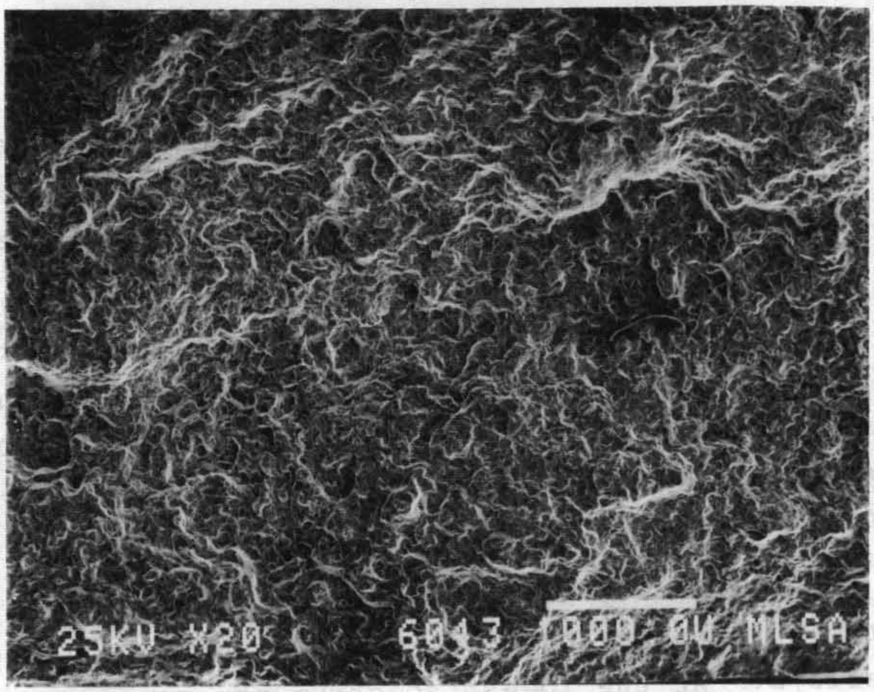

Figure 10. Fractograph of A201-T7 Tested at a Maximum Stress of 25 ksi. Magnification 20X.

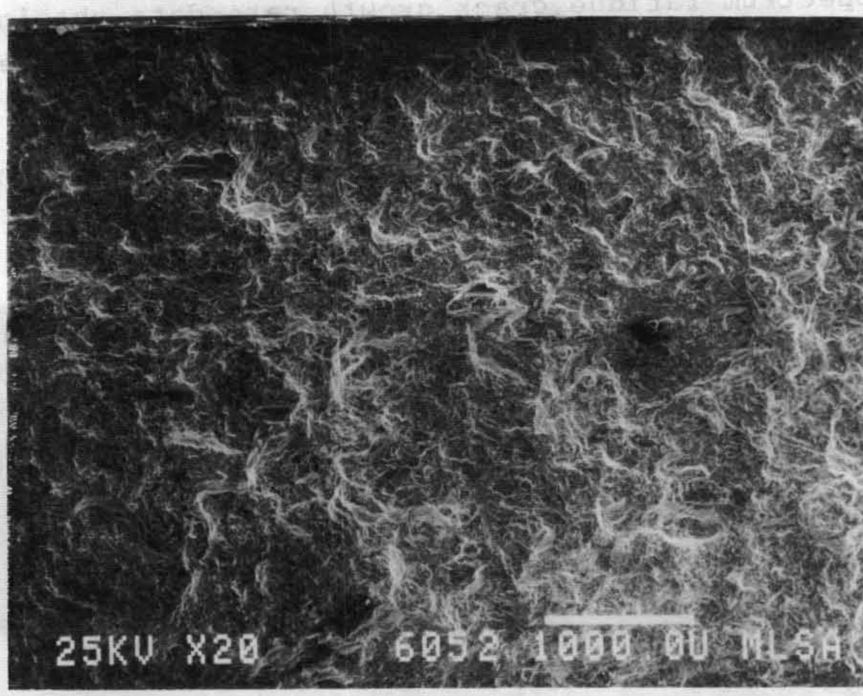

Figure 11. Fractograph of A357-T6 Tested at a Maximum Stress of 25 ksi. Magnification 20X.

SECTION IV
CONCLUSIONS

The following conclusions are based on the limited data for each alloy tested and could be altered if more data were generated to provide a more statistically sound data base.

1. Fatigue testing under a tension-compression load spectrum indicates that A357-T6 possesses fatigue crack growth life nearly double that of A201-T7 and 7050-T76. At the lowest spectrum stress level tested, A201-T7 outperformed 7050-T76; at the highest spectrum stress level tested the 7050-T76 outperformed A201-T7.

2. The ranking of toughness levels of the three alloys, based on the critical crack size, varies considerably for the two cast alloys. At the lowest spectrum stress range tested (15 ksi), toughness levels appear equal for each alloy. At the intermediate stress range (20 ksi) A201-T7 was lowest, while at the highest stress range (25 ksi) A357-T6 was lowest.

3. Spectrum fatigue crack growth rate data obtained for each alloy show A357-T6 had the lowest crack growth rates over the range of stress intensities tested.

4. The fracture faces of A201-T7, A357-T6, and 7050-T76 resulting from spectrum fatigue loading are distinctively different when examined macroscopically.

5. Compressive loads obliterate the fracture faces of test specimens leaving little classical microscopic information.

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APPENDIX

FATIGUE CRACK GROWTH DATA

TABLE A.1

FALSTAFF SPECTRUM DATA FOR A MAXIMUM STRESS OF 15 KSI

A201-T7		A357-T6		7050-T76	
Total Flights	Crack Length (2a,in)	Total Flights	Crack Length (2a,in)	Total Flights	Crack Length (2a,in)
0	0.400	0	0.400	0	0.400
25	0.401	20	0.402	140	0.409
325	0.413	234	0.408	540	0.442
725	0.427	634	0.418	340	0.419
925	0.435	834	0.424	740	0.459
325	0.413	1034	0.437	940	0.468
525	0.419	1234	0.449	1140	0.480
925	0.435	1434	0.456	1340	0.496
1125	0.455	1634	0.471	1540	0.512
1325	0.472	1834	0.483	1740	0.533
1525	0.482	2034	0.492	1940	0.553
1725	0.490	2234	0.497	2140	0.573
1925	0.510	2434	0.510	2340	0.594
2125	0.532	2634	0.522	2540	0.618
2325	0.544	2834	0.545	2740	0.639
2525	0.554	3034	0.558	2940	0.661
2725	0.572	3234	0.565	3140	0.686
2925	0.593	3434	0.575	3340	0.715
3125	0.612	3634	0.598	3540	0.731
3325	0.620	3834	0.614	3740	0.763
3525	0.645	4034	0.625	3940	0.787
3725	0.666	4234	0.633	4140	0.826
3925	0.683	4434	0.646	4340	0.853
4125	0.698	4634	0.663	4540	0.883
4325	0.720	4834	0.677	4740	0.916
4525	0.745	5034	0.686	4940	0.954
4725	0.770	5234	0.693	5140	0.992
4925	0.790	5434	0.704	5340	1.042
5125	0.813	5634	0.721	5540	1.080
5325	0.845	5834	0.733	5740	1.131
5525	0.866	6034	0.744	5940	1.190
5725	0.895	6234	0.752	6140	1.243
5925	0.928	6434	0.764	6340	1.303
6125	0.952	6634	0.778	6540	1.377
6325	0.990	6834	0.806	6740	1.461
6525	1.019	7034	0.826	6940	1.546
6725	1.060	7234	0.840	7140	1.670
6925	1.095	7434	0.852	7240	1.678
7125	1.146	7634	0.875		
7325	1.195	7834	0.894		
7525	1.246	8034	0.906		
7725	1.316	8234	0.917		
7925	1.396	8434	0.936		
8125	1.511	8634	0.952		
8325	1.604	8834	0.973		
8351	1.632	9034	0.996		

TABLE A.1 (Concluded)

FALSTAFF SPECTRUM DATA FOR A MAXIMUM STRESS OF 15 KSI

A357-T6	
Total Flights	Crack Length (2a,in)
9234	1.014
9434	1.026
9634	1.051
9834	1.062
10034	1.093
10234	1.127
10434	1.149
10634	1.165
10834	1.199
11034	1.236
11234	1.269
11434	1.296
11634	1.344
11834	1.383
12034	1.436
12234	1.489
12434	1.557
12634	1.665

TABLE A.2

FALSTAFF SPECTRUM DATA FOR A MAXIMUM STRESS OF 20 KSI

A201-T7		A357-T6		7050-T76	
Total Flights	Crack Length (2a,in)	Total Flights	Crack Length (2a,in)	Total Flights	Crack Length (2a,in)
0	0.400	0	0.400	0	0.400
400	0.424	99	0.404	20	0.401
800	0.453	295	0.412	220	0.419
1000	0.462	909	0.432	420	0.448
1200	0.498	1237	0.447	620	0.463
1400	0.522	1587	0.463	820	0.495
1600	0.544	1970	0.479	1020	0.517
1800	0.557	2126	0.486	1220	0.545
2000	0.580	2318	0.503	1420	0.580
2200	0.602	2502	0.518	1620	0.597
2400	0.622	2740	0.532	1820	0.641
2600	0.656	3251	0.552	2020	0.671
2800	0.683	3374	0.564	2220	0.737
3000	0.722	3573	0.573	2420	0.792
3200	0.755	3904	0.596	2620	0.844
3400	0.793	4119	0.611	2820	0.895
3600	0.838	4187	0.632	3020	0.956
3800	0.902	4387	0.649	3220	1.021
4000	0.977	4587	0.667	3420	1.095
4200	1.153	4781	0.695	3620	1.187
4231	1.253	4951	0.716	3820	1.277
		5137	0.733	4020	1.396
		5342	0.749	4220	1.578
		5542	0.775	4255	1.700
		5742	0.801	4284	1.773
		5942	0.824	4317	1.808
		6142	0.853	4324	1.823
		6342	0.881		
		6542	0.915		
		6742	0.944		
		6942	0.977		
		7142	1.008		
		7342	1.056		
		7542	1.093		
		7742	1.127		
		7942	1.163		
		8142	1.225		
		8342	1.298		
		8542	1.372		
		8742	1.496		
		8775	1.623		
		8810	1.675		
		8824	1.713		
		8858	1.738		

TABLE A.3

FALSTAFF SPECTRUM DATA FOR A MAXIMUM STRESS OF 25 KSI

A201-T7		A357-T6		7050-T76	
Total Flights	Crack Length (2a,in)	Total Flights	Crack Length (2a,in)	Total Flights	Crack Length (2a,in)
0	0.400	0	0.400	0	0.400
88	0.419	85	0.407	63	0.412
288	0.457	288	0.420	163	0.429
188	0.441	488	0.436	263	0.447
388	0.480	688	0.475	363	0.471
488	0.503	888	0.504	463	0.503
588	0.518	1088	0.541	563	0.529
688	0.543	1288	0.566	663	0.569
788	0.559	1488	0.602	763	0.603
888	0.589	1688	0.632	863	0.642
988	0.610	1888	0.674	963	0.680
1088	0.647	2088	0.711	1063	0.713
1188	0.677	2288	0.772	1163	0.756
1288	0.732	2488	0.841	1263	0.794
1388	0.777	2688	0.918	1363	0.844
1488	0.885	2860	1.034	1463	0.916
1529	0.972			1563	0.958
1588	1.002			1663	1.020
1621	1.045			1763	1.099
1529	0.972			1863	1.239
1668	1.244			1963	1.452
1655	1.119			1896	1.316
1668	1.244			2003	1.568
				2025	1.624

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