22-15 WOL S1
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~~American Air Express~~
MATERIALS MEMORANDUM

To: J. L. Watkins 8 April 1971
PPD:mc:N4350:0009

From: P. P. Dessau

Subject: LN₂ and LH₂ Fracture Toughness of ARMC0 Alloy 22-13-5

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MASTERI. INTRODUCTION

Fracture toughness tests were performed in order to enable ductile/brittle classification of the nozzle candidate material, ARMC0 22-13-5. One inch thick precracked compact tension specimens were fabricated from a 1 1/4 inch thick plate. A total of six specimens were tested to determine critical stress intensity parameters, KIC, in LN₂ and LH₂. Results of these tests indicated that the material was tough (ductile) at both temperatures according to the ductility criterion specified in SNPO-C-1.

II. CONCLUSIONS

a. Fracture toughness, KIC, decreased from 84 KSI-in^{1/2} at 140°R to 63 KSI-in^{1/2} at 40°R, or exactly 25%.

b. The material was classified as tough, according to the criterion in SNPO-C-1, since the critical stress, σ_c , exceeded the material's yield strength at both 140°R and 40°R.

III. DISCUSSION

The material used was produced by ARMC0 Steel Company and is described in Appendix 1. After rolling to the final plate thickness, the material was heat treated to simulate the NERVA nozzle tube brazing process (Appendix 1).

Chevron notched compact tension specimens corresponding to P/N 1138365-115 were machined such that the notch plane was lined-up with the plate rolling direction, as shown in Figure 1. This specimen orientation has been designated as "TS" by fracture toughness investigators and is expected to be the lowest fracture toughness direction that can be tested.

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Following machining and inspection of critical specimen dimensions, the six specimens were precracked in an axial (Baldwin) fatigue machine at 1800 cycles per minute. Precracking was conducted at room temperature. The high room temperature toughness of this material prevented fatigue crack initiation at the very low stress intensities required in Reference 3 specification. However, the specification requirements designed to restrict the plastic zone size at the crack tip in order to maintain plane strain, linear elastic conditions were adhered to, as follows:

a. $K_f (\text{max})/E < 1.2 \times 10^{-3}$ in $1/2$

and, b. $K_f \text{ max} < K_Q/2$

Following testing of the specimens, macroscopic examination of the precracks indicated that the crack-front requirements of Reference 3 were also met, as shown by the photographs of failed specimens shown in Figure 2.

Specimens were tested in LN_2 and LH_2 after 15 minutes soak at temperature. Specimens were loaded at a rate conforming to Reference 3 requirements, i.e., from 30 - 150 KSI-in $^{1/2}$ per minute.

Results of testing, shown in Table 1 and summarized in Table 2 indicated that the material had high fracture toughness at both testing temperatures, 140 and 40°R. High, in this context, means that material containing a flaw will deform plastically (yield) rather than fail catastrophically when loaded to stresses as high as the materials yield strength. In SNPO-C-1, this criterion for toughness (or ductility) is expressed as follows:

$\sigma_{TY} \leq \sigma_c$, where σ_c is the critical stress derived from surface or sub-surface flaw equations cited in SNPO-C-1.

The critical flaw diameters $(2C)_{cr}$, required to cause failure at stress levels equal to the yield strengths at each temperature is also shown in Table 2. Spherically shaped flaws approximately 3/4 in. and 1/2 in. in diameter at 140 and 40°R, respectively, would be required for unstable flaw propagation. This compares with the 5/64 inch flaw diameter used to compute σ_c , the 3/64 in. flaw size to which the ARMCO alloy should be produced to and the 1/64 inch maximum flaw size currently being attempted by titanium forgers producing forgings for TPA applications.

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Materials Section

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REFERENCES

1. Memorandum N4350:MM70-448, H. W. Spaletta to J. L. Watkins, ARMC0 22-13-5 Alloy Preliminary Screening Evaluation Results, 22 Decem ber 1970
2. Data Release Memorandum No. M38, August 7, 1970, Design Allowables for Alloy 22-13-5 Stainless Steel Bar (C data)
3. ASTM-E399, Method of Test for Plane-Strain Fracture Toughness of Metallic Materials.

FIGURE 1

LOCATION OF FRACTURE TOUGHNESS
SPECIMENS FROM ARMCO 22-13-5 PLATE

S-75

(E-14)

1 1/4 x

S-76

(E-15)

1 1/4 x

FIGURE 2

Post-test appearance of specimen E-14, (left) tested in LN₂, and E-15, tested in LH₂, showing flat fracture, characteristic of valid plane strain fracture toughness tests. Specimen preparation and test zones are shown at left, as follows:

- Zone 1 - Machined chevron notch zone.
- Zone 2 - High-load fatigue precrack zone.
- Zone 3 - Low-load fatigue precrack zone.
- Zone 4 - Static tensile fracture zone.

TABLE 1

COMPACT TENSION FRACTURE TOUGHNESS TESTS

LWR 7556 Engineer: Spalletta
 IDO 961339
 GWA Material: ARMCO 22-13-5 SS

Technician: Abrahams
 Date: 26 February 1971
 W/O: 7318-51-711

Specimen Number	Thick. B (in)	Width W (in)	Machined Notch a (in)	Flaw Length Q _o (in)	(a)		Deviation from ASTM Recommended Practices				Load Rate (KSI-in ^{1/2}) per Min	P _Q (Lbs.)	a/W	Stress Intensity K _{IC} (KSI-in ^{1/2})	Yield Strength (KSI)	Theoretical Thickness (IN.)	Ratio P _Q /P _f	Test Temp. (°F)
					Fatigue K _i initial (b) (KSI-in ^{1/2})	Cracking K _f final (c) (KSI-in ^{1/2})	(d)	(e)	(f)	(g)								
E-10	.9975	1.9994	.8548	1.028	30.2	28.4	OK	OK	OK	OK	42.6	12000	.5142	85.	154.0	.76	1.00	-320
E-11	.9976	2.0006	.8543	1.021	30.1	21.0	OK	OK	-.008	OK	42.0	11340	.5103	80.	154.0	.67	1.00	-320
E-14	.9976	1.9995	.8538	1.022	30.1	21.1	OK	OK	-.001	OK	42.3	12300	.5111	87.	154.0	.79	1.00	-320
E-15	.9960	2.0004	.8514	1.074	30.1	21.9	OK	OK	OK	OK	45.4	8400	.5369	64.	Unknown	Unknown	1.00	-423
E-13	.9975	2.0006	.8546	1.057	30.0	21.5	OK	OK	OK	OK	44.6	8380	.5283	62.	"	"	1.00	-423
E-12	.9977	2.0006	.8505	1.019	30.0	20.3	OK	OK	OK	OK	42.0	8980	.5093	63.	"	"	1.00	-423

NOTES:

- (a) $K_{f(max)}/E$ shall not exceed 1.2×10^{-3} in^{1/2}
- (b) $K_{f(max)}$ must not exceed $K_Q/2$
- (c) $K_{f(max)}$ must not exceed $(\sigma_{ys1}/2\sigma_{ys2}) K_Q$. All specimens fail to meet this requirement.
- (d) The difference between the 3 crack measurements at 1/4, 1/2, and 3/4 to be less than $0.05a_0$
- (e) All portions of the fatigue crack front to be greater than $0.05a_0$ or $0.050"$, which ever is greater.
- (f) The fatigue crack at the free surfaces of the specimen to be greater than $0.9a_0$.
- (g) The plane of the fatigue crack deviates from the plane of the machined notch by less than 10%.

TABLE 2

PLANE STRAIN FRACTURE TOUGHNESS OF ARMCO ALLOY
22-13-5 PLATE (1 1/4 IN.) IN LN₂ AND LH₂

<u>Temp °R</u>	<u>K_{IC} Ksi-in^{1/2}</u>	<u>Minimum ^① Critical Stress σ_c, Ksi</u>	<u>F_{ty} KSI</u>	<u>(2C)Cr, in</u>
140	85			
	80			
	<u>87</u>			
Avg	84	310	102	0.78
<hr/>				
40	64			
	62			
	<u>63</u>			
Avg	63	239	120 ^②	0.57

① Based on a minimum detectable flaw size, 2c, of 5/64 in., flaw shape factor, Q, of 2.2 and the minimum K_{IC}.

② Extrapolated from Reference 2.

APPENDIX 1

Procurement Information 22-13-5

1. P. O. N-00231
2. Vendor: ARMCO Steel Corporation.
3. Material Form: Plate - 48 in. x 8 in. x 1 1/4

Rolled by G. O. Carlson, Inc.

4. Chemistry

	Heat No. <u>300321-1C</u>	Specification <u>Range</u>
Carbon	0.042	0.06 max
Manganese	4.68	4.0 - 6.0
Phosphorus	0.021	0.04 max
Sulfur	0.010	0.03 max
Silicon	0.41	1.0 max
Chromium	21.19	20.5 - 23.5
Nickel	12.42	11.5 - 13.5
Molybdenum	2.22	1.5 - 3.0
Vanadium	0.21	0.1 - 0.3
Nitrogen	0.32	0.20 - 0.40
Columbium	0.16	0.1 - 0.3

5. Heat Treatment (per P. O. N-00952)

a. Anneal at $1950 \pm 10^{\circ}\text{F}$ and retort cool. Heating and cooling rates are to duplicate the heating and cooling rates of the Phoebus II A nozzle.

b. Simulated Braze cycle 1:

 $1950 \pm 10^{\circ}\text{F}$

Simulated Braze Cycle 2:

 $1825 \pm 10^{\circ}\text{F}$

Simulated Braze Cycle 3:

 $1775 \pm 10^{\circ}\text{F.}$

Heating and cooling rates shall duplicate the heating and cooling rates of Technology nozzle S/N 27.

6. R.T. Mechanical Properties:

For 1 1/4 in. plate:

	<u>UTS</u> <u>(KSI)</u>	<u>TYS</u> <u>(KSI)</u>	<u>% ELONG</u> <u>in 2 in</u>	<u>% R. of</u> <u>Area</u>
Tangential -	121.1	73.4	41.0	59.0
Longitudinal -	123.8	70.6	41.0	62.0

7. Fracture Toughness Testing Documentation

a. IDO 961339, February 1971

b. LWR 7556, February 1971