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EFFECTS OF HUMIDITY ON THE FATIGUE CRACK GROWTH RATE IN ALUMINUM ALLOY 8090-T8771 THICK PLATE

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The purpose of this investigation was to determine the effect of relative humidity on the fatigue crack growth rate in aluminum alloy 8090 thick plate thermomechanically processed to the T8771 condition. High and low humidity fatigue crack growth rate data were generated for three load-ratios, 0.1, 0.33, and 0.7, from the near threshold through intermediate linear region. The test material showed a significant crack closure for load-ratios equaling 0.1 and 0.33. Above the near threshold region the saturated air environment caused an increased fatigue crack growth rate.

For a laboratory air environment and an R-ratio equal to 0.1, the crack growth rate leveled off to a plateau, with the growth rate increasing gradually. The slowed growth rate was related to considerable fracture surface roughness; this effect diminished when the R-ratio was 0.33 and disappeared in the absence of crack closure when the R-ratio equals 0.7.

When the load-ratio equaled 0.1 in the near threshold region, material tested in high humidity produced a larger threshold stress intensity range for fatigue crack propagation compared to laboratory air. The phenomena was attributable to additional environmental-generated debris bridging the fracture surfaces, which caused increased closure; the effect diminished with increased R-ratio where greater crack opening displacement reduced closure effects.

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FOREWORD

This technical report presents work conducted at the Materials Engineering Branch, Systems Support Division, Wright Laboratories Materials Directorate by the University of Dayton Research Institute, Dayton, Ohio under Contract F33615-90-C-5915, "Quick Reaction Evaluation of Materials and Processes." Mr. Neal Ontko serves as current contract monitor.

Testing took place over the period from October 1991 to November 1994.

The authors would like to extend recognition to Messrs. Donald Woleslagle, William Fortener, and John Eblin of the University of Dayton for conducting the tests.

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SECTION 1

INTRODUCTION

The first generation aluminum-lithium products, in the early 1980's, possessed slightly lower strength and inferior ductility and toughness when compared to then contemporary and cleaner conventional 2000 and 7000 aluminum alloy wrought products [1-3]. In the mid-1980's, these shortcomings were considerably improved upon; the most significant step was the adoption of the T851 heat treatment [1,4,5], where following solution heat treatment, a sheet or plate was stretched by 2 to 4 percent, followed by artificially aging to peak strength.

In addition to the improvement in density and modulus, Al-Li alloys show greater resistance to fatigue crack propagation than conventional high strength aluminum alloys. This behavior was primarily attributable to its unique layered microstructure which produces crack closure, where the crack remains closed and stationary for a portion of a fatigue load cycle [7,8]. Crack closure in the Al-Li alloy materials has been attributed to its anisotropic microstructure causing crack tip shielding via roughness of the crack surfaces [3,9-17]. Of the various Al-Li products, the effect has been more noticeable in thick section wrought products, like the test material, where large unrecrystallized grains possess a more anisotropic microstructure and stronger texture which result in greater fracture surface roughness induced fatigue crack closure [1,18-20]. The closure results in a reduced effective crack driving parameter, a slower fatigue crack propagation and more damage tolerance when compared to conventional aluminum products or Al-Li products [19-23] with a recrystallized grain structure.

A further increase in fatigue crack growth resistance has also been shown to occur in Al-Li alloys possessing a high Li/Cu ratio, as the test material. A high Li/Cu ratio increases fatigue crack resistance, because: (1) the coarseness of the crack surface increases with the Li/Cu ratio [24], (2) a low Cu content reduces the formation of embrittling secondary phase particles [1], and (3) in a moist environment greater oxide debris bridging of the crack occurs, since Li promotes while Cu inhibits oxide debris formation and the resulting crack closure [1,14,24-28].

SECTION 2

TEST MATERIAL

The test material, produced by ALCAN, was a 1.750-inch thick Al-Li alloy 8090 plate. The alloy was thermomechanically processed to the T8771, peak aged condition. The chemical composition, in weight percent, is shown below in Table 1. The Li/Cu ratio equals 2.0 in this Al-Li alloy.

TABLE 1

CHEMICAL COMPOSITION OF Al 8090-T8771 IN WEIGHT PERCENT

Li	Cu	Mg	Zr	Fe	Si	Al
2.23	1.12	0.72	0.115	0.103	0.059	Balance

The average of three room temperature tensile tests are listed in Table 2 [28]. The ultimate and yield strengths were comparable to other high strength aluminum alloys. As found with other Al-Li alloys, the lowest yield strength occurred for those specimens removed from the rolling plane, with their central axis 45 degrees off the rolling direction [11]. The ductility, as indicated by the permanent elongation, was acceptable for

TABLE 2

ROOM TEMPERATURE Al 8090-T8771 AVERAGE TENSILE PROPERTIES

0.2% Yield Strength		**Ultimate Strength**		**Elongation in 1 inch G.L. (%)**	**Orientation**
MPa	**(ksi)**	**MPa**	**(ksi)**		
469.8	(68.1)	536.9	(77.9)	7.07	longitudinal
419.6	(60.9)	520.8	(75.5)	9.16	transverse
386.5	(56.1)	499.4	(72.4)	10.04	45° off long.
422.9	(61.3)	520.2	(75.4)	3.51	short-trans.*

*short-transverse oriented specimens had a 0.50-inch gage length.

specimens removed from the plate's rolling plane. However, the through-the-thickness average percent elongation was low [11,26]. The lack of ductility was attributable to nonuniform, through-the-thickness, distribution of the T8 cold work dislocations [4]. Dislocations serve as nucleation sites for a finely dispersed precipitate. The absence of a dense dislocation populace at the mid-plane resulted in fewer and larger precipitates migrating to the grain boundaries. Both weakened the grain boundaries and resulted in low ductility, toughness, and reduced strength through the thickness.

Fracture toughness data for the test plate are listed in Table 3 [28]. For the (L-T) and (T-L) specimen orientations the material's fracture toughness was satisfactory. The toughness was cut in half when the material was loaded through-the-thickness for the same reasons previously discussed.

TABLE 3

ROOM TEMPERATURE FRACTURE TOUGHNESS FOR Al 8090-T8771

	Thickness	K_Q		Valid	ASTM Validity Criteria	
Orientation	**(in.)**	**MPa(m)$^{.5}$**	**KSI(in)$^{.5}$**	**K_{ic}?**	**P_{max}/P_{min}**	**$P_{fatigue}/P_{max}$**
L-T	1.500	27.16	(24.72)	No	1.17	
	1.500	29.69	(27.02)	Yes		
	1.500	26.01	(23.67)	No	1.21	
T-L	1.500	27.42	(24.95)	Yes		
	1.500	26.72	(24.32)	Yes		
	1.500	24.89	(22.65)	Yes		
S-L	0.660	13.34	(12.14)	No		0.892
	0.660	14.09	(12.82)	No		0.842
	0.660	10.82	(9.85)	No		0.777

SECTION 3

RESULTS

Constant amplitude loading fatigue crack growth rate (FCGR) data were generated in laboratory air and saturated air environments using predominately a loading frequency of 30 Hz and three R-ratios: 0.1, 0.33, and 0.7. A few of the initial laboratory air tests were run at 25 Hz. The test specimens were ASTM E647 standard compact tension specimens with (L-T) orientation. For the low humidity and R-ratio equalling 0.1 and 0.33, the laboratory's relative humidity fluctuated from 10 to 30 percent over the testing period. For R=0.7 low humidity tests, desiccant was added to an environmental test chamber to maintain the humidity below 5%. During the high humidity tests a saturated air condition was maintained. High and low humidity FCGR data results are plotted in Figures 1 through 3, for the three load-ratios. For R-ratios of 0.1 and 0.33, the results showed unusually wide scatter bands for data generated using a computer automated test control and data acquisition system. As expected, the material exhibited considerable crack closure, (R=0.1 and 0.33) attributed to the unusually coarse fracture surfaces produced by a mostly unrecrystallized grain structure. As seen in other Al-Li alloys there was a strong closure effect for low loading conditions and with shorter crack lengths. The FCGR closure data for this same test plate was covered in more detail in Reference 28. The effective stress intensity range, ΔK_{eff}, approximately equalled half the remotely applied stress intensity range, ΔK, in the near threshold region as shown in Figure 4 [28]. The closure effect diminished with increased stress intensity range [22-23, 25]. Crack velocity was greater in the high humidity environment, except in the near threshold region, for an R-ratio of 0.1 and 0.33, where closure effects were dominant.

For a load-ratio of 0.7, no closure effects and considerable reduction in the data scatter band width were observed. For this R-ratio, crack face surface roughness produced in the two environments were approximately equal.

The low humidity air data-set, for R=0.1, showed a plateau of nearly constant or gradually increasing crack velocity. The slope of the FCGR linear mid-region for most

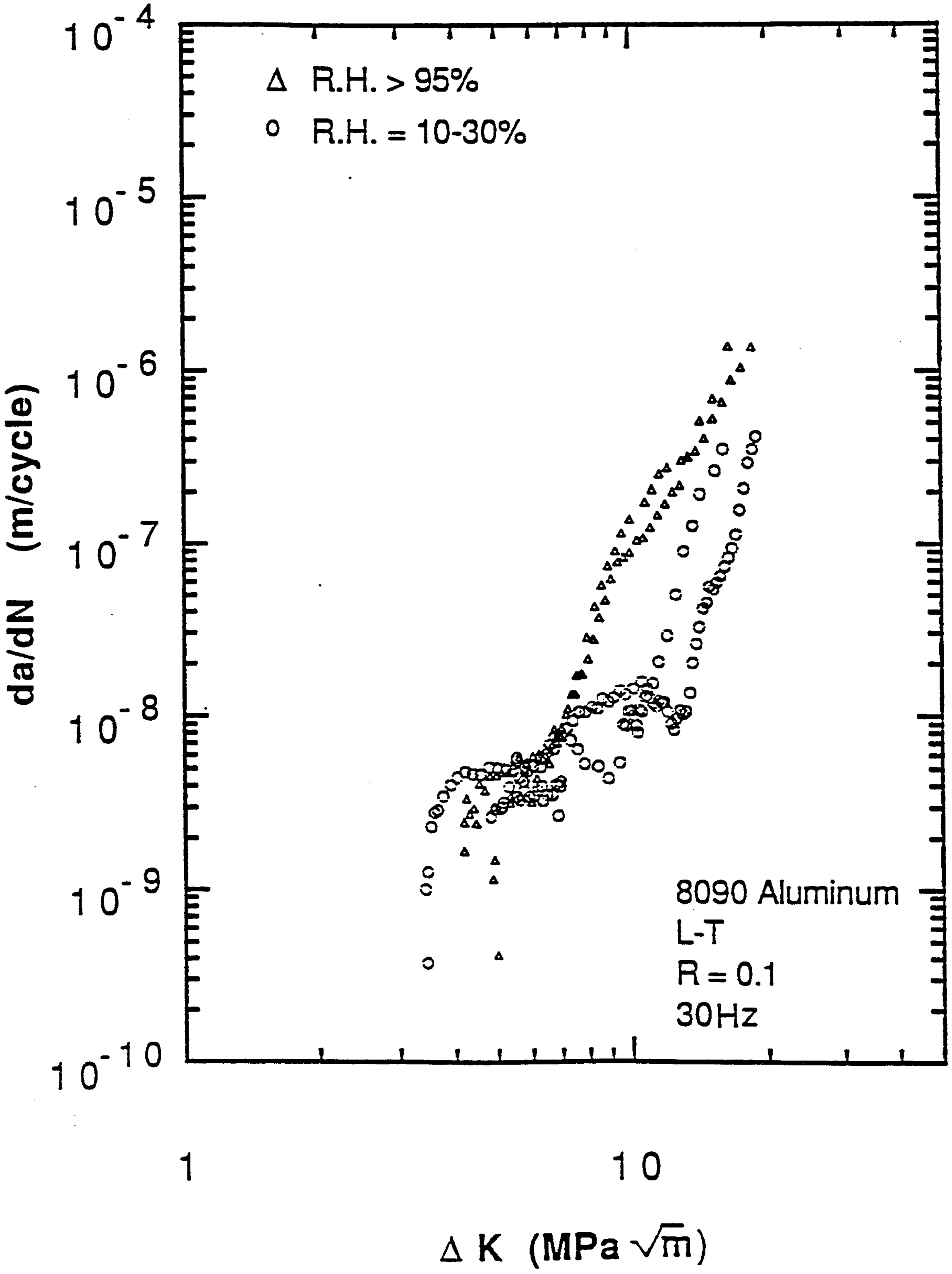

Figure 1. Laboratory Air High and Low Humidity Fatigue Crack Growth Rate for a Load-Ratio Equalling 0.1.

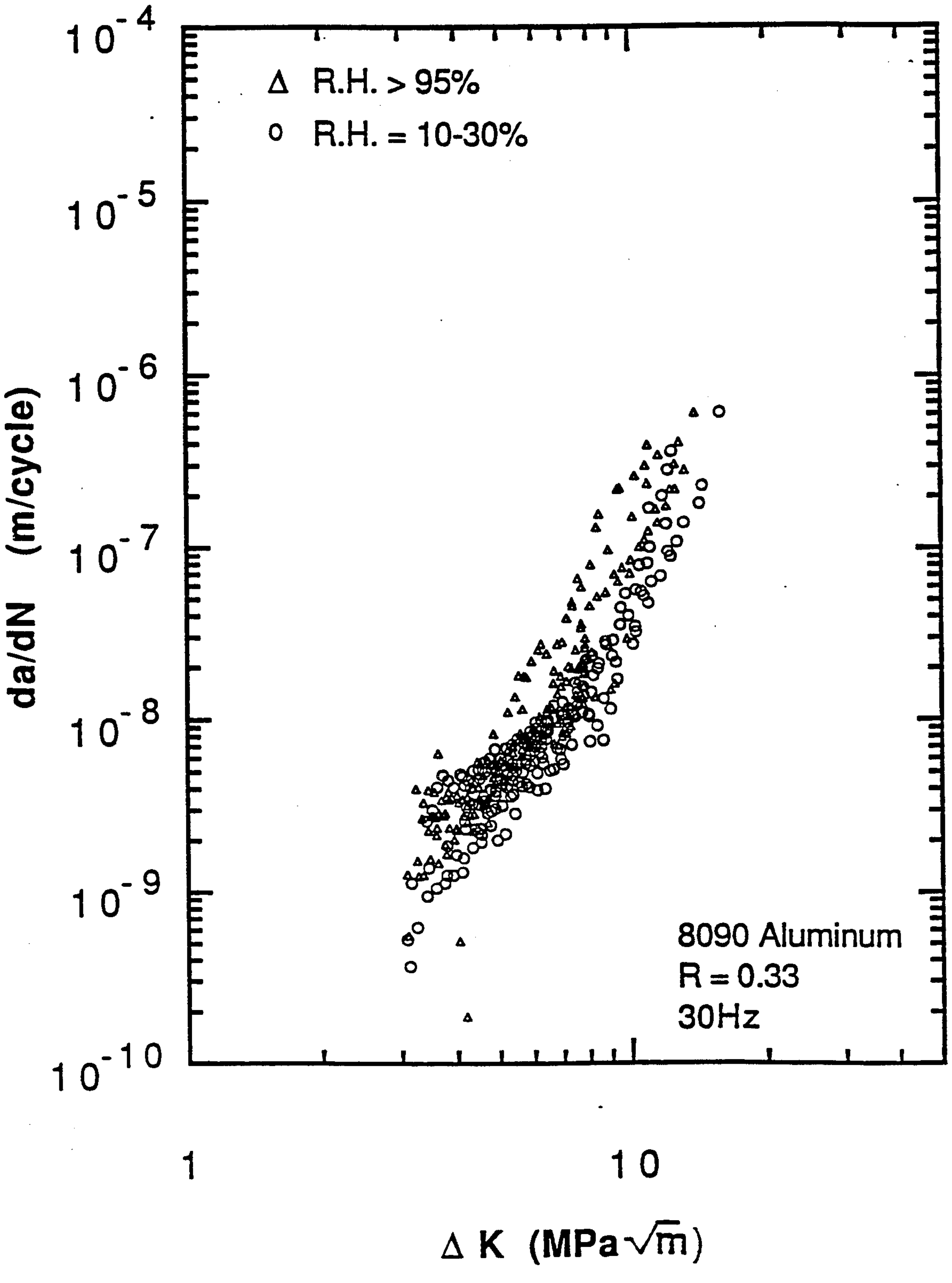

Figure 2. Laboratory Air High and Low Humidity Fatigue Crack Growth Rate for a Load-Ratio Equalling 0.33.

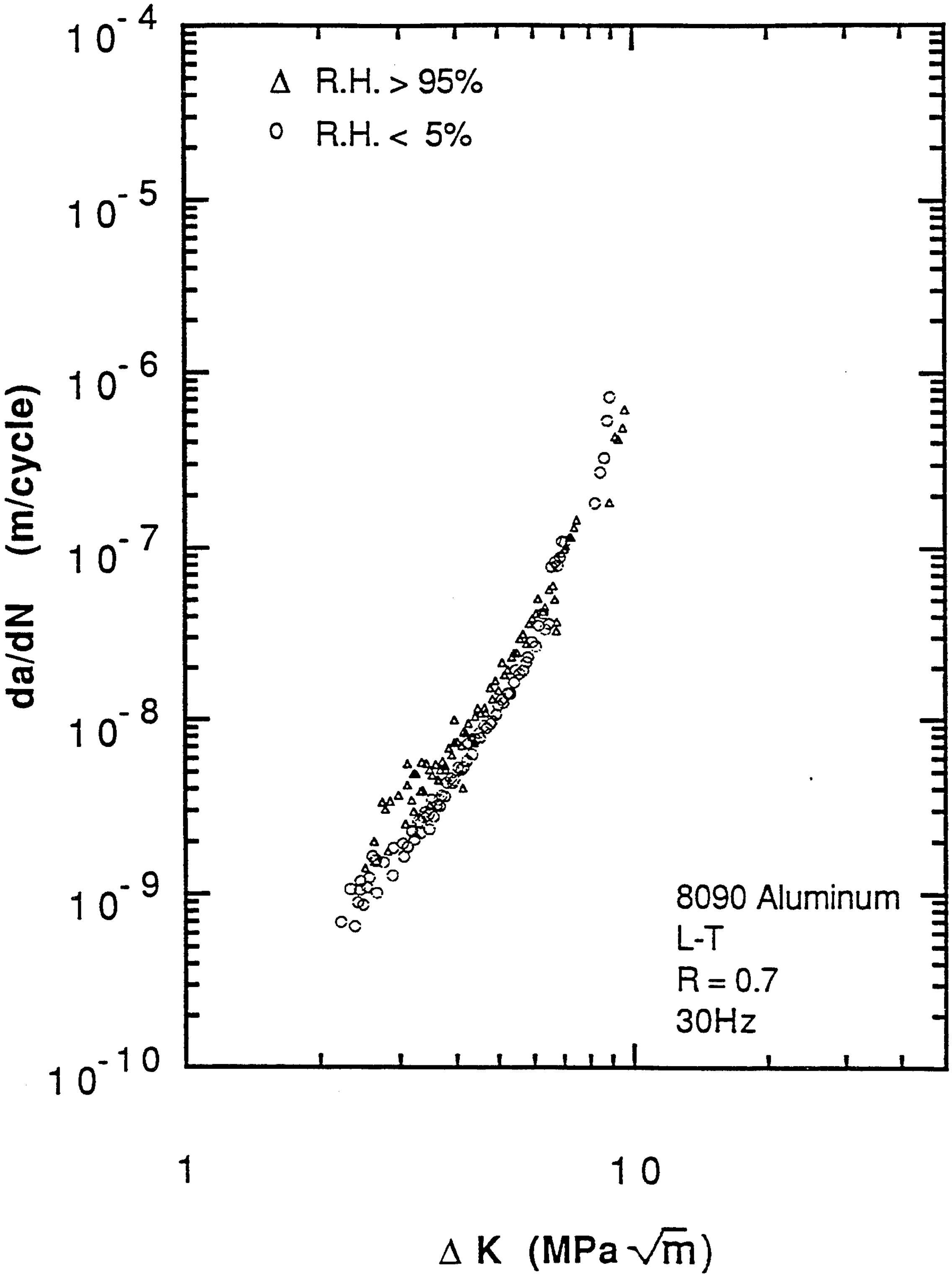

Figure 3. Laboratory Air High and Low Humidity Fatigue Crack Growth Rate for a Load-Ratio Equalling 0.7.

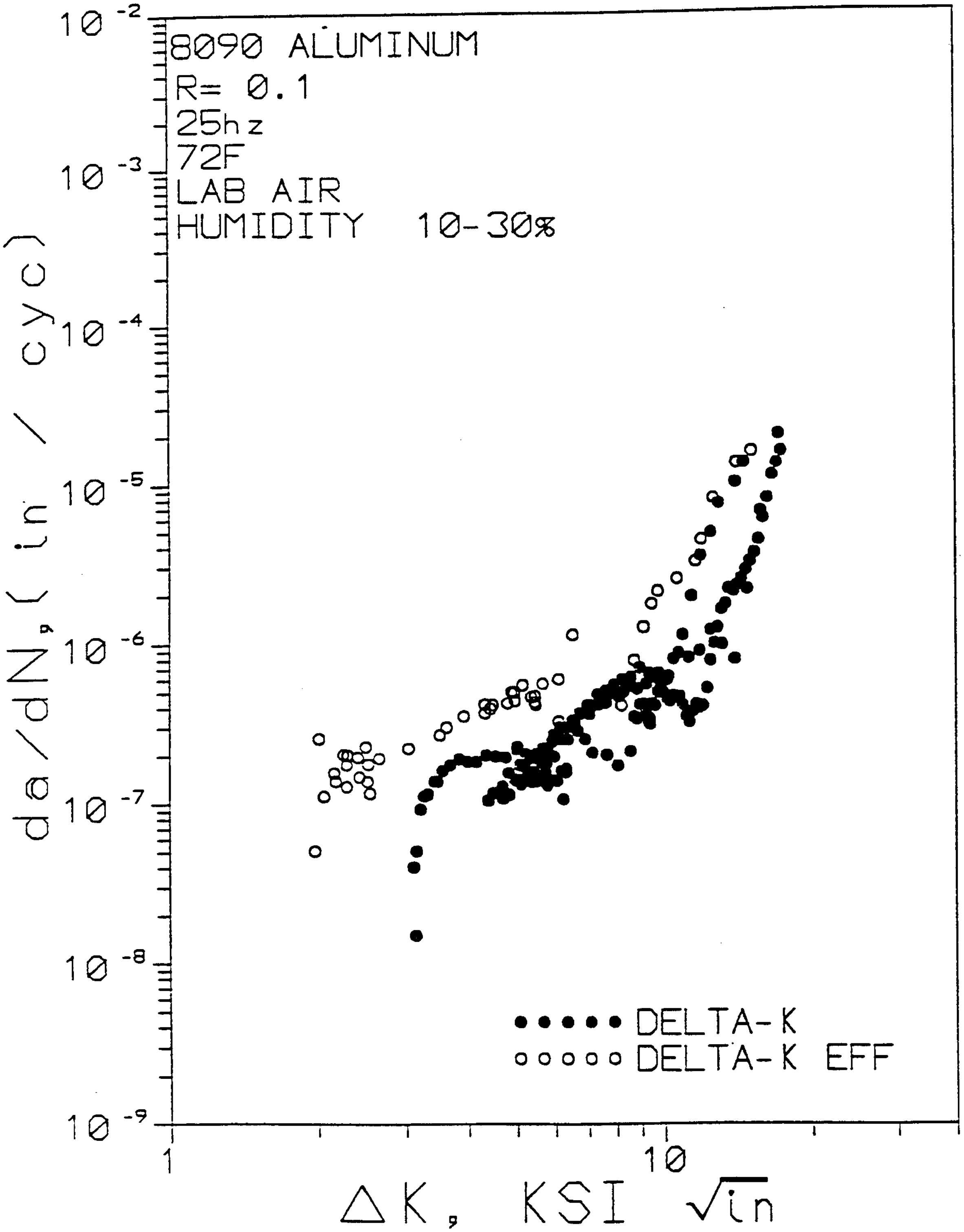

Figure 4. Remotely Applied and Effective Stress Intensity Range Versus the Fatigue Crack Growth Rate Test Results for a Laboratory Air Environment.

high strength aluminum alloys has been shown to be in the range of 3.0 to 4.0. If a line was fitted to the test data mid-range (Figure 1), the slope would approximately equal 1.0. The plateau has been previously observed for Al-Li alloys thermomechanically processed to the T8 condition [14, 18, 26] and tested in a laboratory air environment. There, the plateau was attributed to surface roughness induced closure caused by the unusually coarse fracture surface found in Al-Li thick section products with a T8 thermomechanical processing. Closure and the plateau were reduced when the R-ratio was increased to equal 0.33 and disappears when the R-ratio equalled 0.7.

For load-ratios of 0.1 and 0.33, the fracture surfaces generated in the saturated air environment appear smoother than those for the data generated in low relative humidity air. Reference literature for Al-Li thick plate tested in a NaCl solution and for growth rates above the threshold region, has shown environmental corrosion [14] or the combination of corrosion and fretting debris [29] to be responsible for smoothing the crack faces and resulting in reduced crack closure relative to that seen in dry air. The same effect was seen here; the saturated air environment produced a smoother fracture face when crack velocity exceeded 10^{-7} inch per cycle. For an R-ratio of 0.1, in the near threshold region, the high humidity data crossed the low humidity plateau and presented a higher threshold stress intensity range. For R=0.33 the two data sets were collocated in the near threshold region. Previous published work [13,24] for Al-Li thick plate data generated in a 3.5 weight percent NaCl solution has showed this same crossing of the data-set generated in a laboratory air environment. There, the phenomenon was attributed to additional corrosion debris, generated by the NaCl solution, bridging the crack at low load and crack-opening-displacement conditions and producing added closure. A reduced FCGR was the result. The same effect was likely seen here; when the relative humidity was raised to saturation, oxidation debris and associated closure increased, resulting in a reduced FCGR and a larger threshold stress intensity range.

After observing this unusual crossing of the low and high humidity data-sets (R=0.1) in the near threshold region, duplicate FCGR tests were undertaken with the frequency decreased to 1 Hz to confirm the findings. It was anticipated that the lower frequency would accentuate the crossover phenomena observed at 30 Hz. As with the data generated at R=0.7, desiccant was added to keep the humidity in the environmental chamber below 5% for the dry air tests. These test results are presented in Figure 5. As with the previously presented data there were unusually wide data scatter bands. Here, as at the higher frequency, the saturated air data crossed the plateau in the dry air data-set in the near threshold region, thus rendering a larger FCGR threshold stress intensity range.

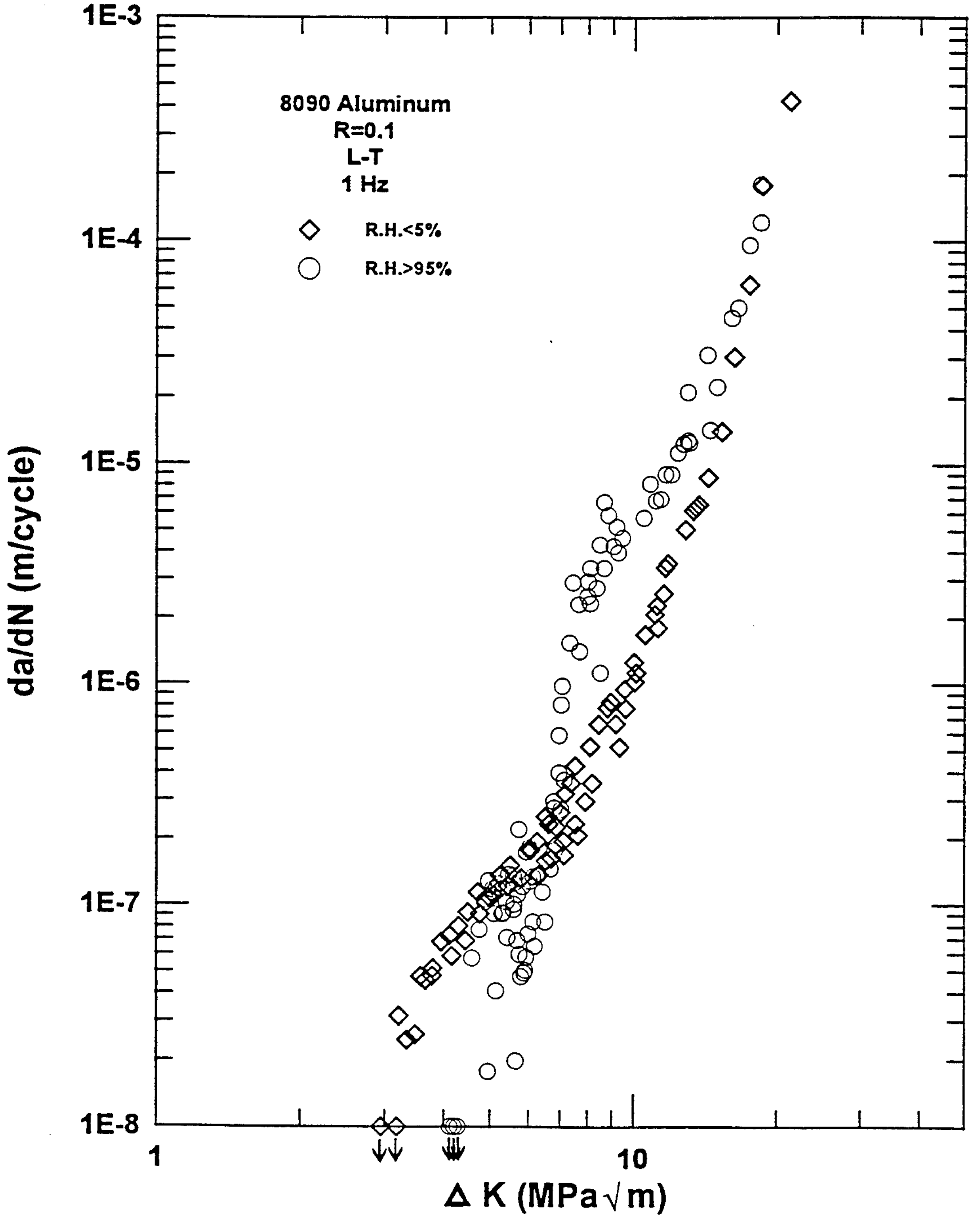

Figure 5. Laboratory Air High and Low Humidity Fatigue Crack Growth Rate for R=0.1 and a Loading Frequency of 1.0 Hz.

SECTION 4

CONCLUSIONS

1. The test material showed a great deal of fatigue crack closure. Closure diminished with increased crack length and R-ratio.

2. Above the threshold region the high humidity environment increased crack growth rate.

3. For the laboratory air environment and R=0.1, there was a plateau of nearly constant crack velocity in the FCGR data mid-range, attributable to surface roughness induced crack closure; the plateau diminished with increased R-ratio.

4. In the near threshold region where R=0.1, material tested in high humidity produced a higher threshold stress intensity range compared to laboratory air. This can be attributed to environmental generated debris on the crack faces bridging the crack at low loading and crack-opening-displacement conditions.

5. At higher R-ratios the effects of closure were reduced; however, the material tested in high humidity continued to have the higher growth rates.

6. Specimens tested at 1 Hz and R=0.1 showed similar fatigue crack growth behavior to specimens tested at 30 Hz.

SECTION 5

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