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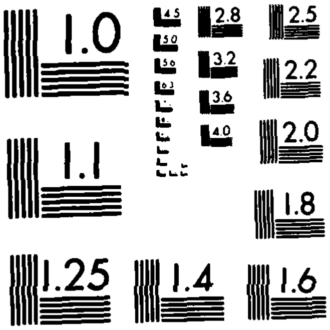

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Materials Report 82-C

FRACTURE MECHANICS AND ACOUSTIC EMISSION RESPONSE OF RETROGRESSION-REAGED 7075-T6 ALUMINUM ALLOY

K.I. McRae

July 1982

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13. ABSTRACT

Stress corrosion cracking of high strength, structural aluminum alloys, such as 7075 in the T6 temper, is a commonly encountered problem. Recently, an alternative heat treatment, known as retrogression and reaging, has been proposed. It is purported that this heat treatment imparts a stress corrosion cracking resistance for 7075-T6 equal to that of the T73 temper, with only a negligible decrease in yield strength. In order to fully characterize this heat treatment, the plane strain fracture toughness, K_{Ic}, and the resistance to fatigue crack growth were compared to those of the same alloy in the normal T6 condition. Small increases in each of these mechanical properties were detected.

The acoustic emission (AE) response to crack growth during testing was also investigated. It was determined that the number of AE signals is proportional to the crack length or total crack area. This response is consistent with proposed mechanisms for acoustic emission in this material. It is further noted that no significant difference exists in the AE response of 7075-T6 in the normal and retrogression-reaged conditions.

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FRACTURE MECHANICS AND ACOUSTIC EMISSION RESPONSE OF RETROGRESSION-REAGED 7075-T6 ALUMINUM ALLOY

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July 1982

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Abstract

Stress corrosion cracking of high strength, structural aluminum alloys, such as 7075 in the T6 temper, is a commonly encountered problem. Recently, an alternative heat treatment, known as retrogression and reaging, has been proposed. It is purported that this heat treatment imparts a stress corrosion cracking resistance for 7075-T6 equal to that of the T73 temper, with only a negligible decrease in yield strength. In order to fully characterize this heat treatment, the plane strain fracture toughness, K_{Ic}, and the resistance to fatigue crack growth were compared to those of the same alloy in the normal T6 condition. Small increases in each of these mechanical properties were detected.

The acoustic emission (AE) response to crack growth during testing was also investigated. It was determined that the number of AE signals is proportional to the crack length or total crack area. This response is consistent with proposed mechanisms for acoustic emission in this material. It is further noted that no significant difference exists in the AE response of 7075-T6 in the normal and retrogression-reaged conditions.

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Introduction

High strength aluminum alloys, such as 7075, have been employed for some time in applications for which maximum yield strength is necessary. This alloy is in common use in the aerospace industry for the manufacture of aircraft components such as the outer wing skin. Usually tempered to the T6 condition, this alloy possesses a superior yield strength (73 ksi), but suffers from poor stress corrosion cracking (SCC) resistance. Subsequent over-aging of this alloy to the T73 temper increases the SCC resistance, but results in a significantly decreased yield strength. Recently, a further heat treatment of the T6 temper, known as retrogression and reaging (RRA), has been proposed as a possible solution to this problem.[1,2] It has been demonstrated elsewhere that the heat treatment is capable of attaining a conductivity and SCC resistance equivalent to that of the T73 temper accompanied by only a 6% decrease in yield strength from the minimum T6 value, provided longer retrogression times are used to allow the heat treatment of thick sections.

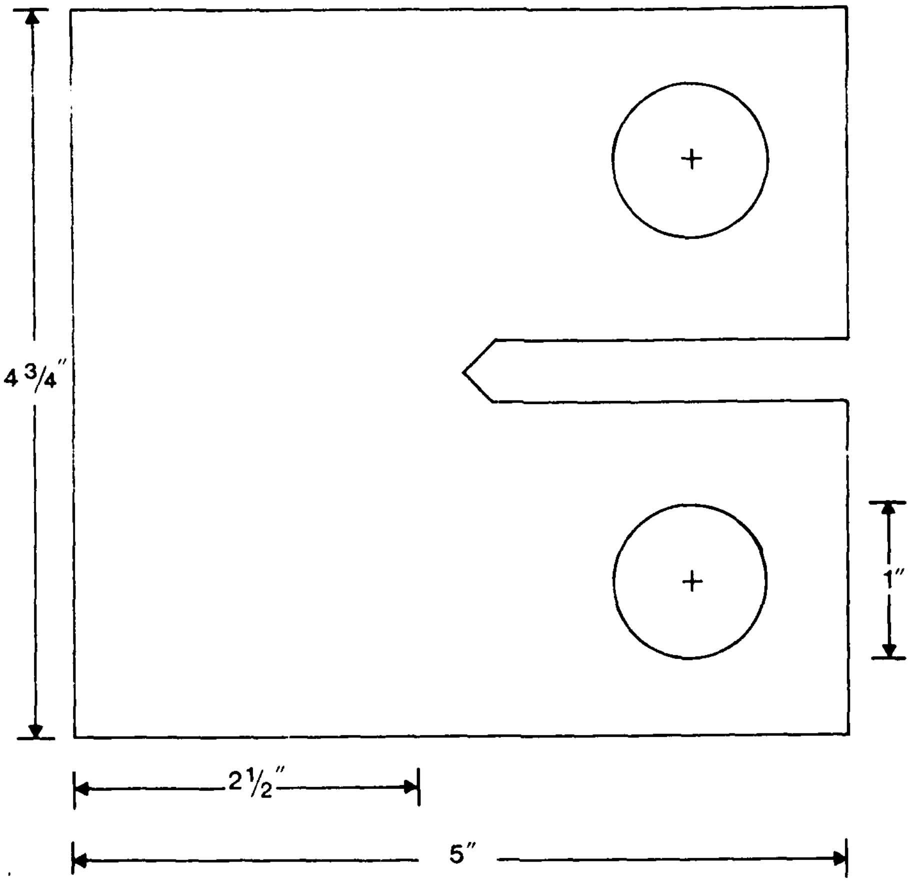
Another parameter significant to the application of the RRA heat treated 7075-T6 alloy to critical structural components is the plane strain fracture toughness, K_{1C}. Also significant is the relative change, if any, in the fatigue crack growth resistance of the RRA treated material in comparison to the T6 temper. These parameters are measured and compared to determine the variation resulting from the retrogression and reaging procedure.

The application of acoustic emission (AE) monitoring of fatigue crack growth is also of immediate interest to DREP because this technique has been proposed and is being actively pursued (Matthews, Schattschneider and Williams, Unpublished Manuscript, 1980) as a potential method for in-flight monitoring of aircraft structure[3]. Data were obtained and presented which evaluates the AE response of this material with respect to fatigue crack growth. Alteration of this response by application of the RRA heat treatment is also examined.

Apparatus and Procedure

Fatigue crack growth studies and plane strain fracture toughness measurements were conducted using standard compact tension specimens (1TCT, H/W = 0.6) manufactured from one inch thick plate of 7075-T6 aluminum alloy. Specimen design and loading was in accordance with ASTM specification E399-78. The dimensions and specimen design are shown in Figure 1, which also contains the applicable stress intensity equation[4]. The starter notch and crack orientation of all specimens is in the T-L direction. Three specimens were further heat treated from the T6 temper according to the retrogression and reaging procedure. An intermediate retrogression time of fifty minutes duration at 180°C was chosen to allow complete heating of the relatively thick section. This retrogression time, in combination with reaging, has been shown previously[2] to restore the initial yield strength of the T6 condition and to improve the stress corrosion crack growth resistance of this alloy. It has also been noted previously that the conductivity of the 7075 alloy may be used as a relative measure of resistance to SCC, the conductivity increasing with corresponding increases in stress corrosion crack resistance. The minimum conductivity of the 7075 alloy in the T6 temper is 32% IACS, while in the T73 condition it is 38% IACS. The measured conductivity value of the 7075-T6 plate in the "as-received" condition was 32.8% IACS, which was subsequently increased to a value of 37% IACS following the RRA heat treatment. It is deduced, therefore, that this heat treatment should consequently impart a resistance to stress corrosion crack propagation similar to that of the T73 temper.

All fatigue growth and fracture toughness measurements were conducted using a 50 Klb. capacity MTS servo-hydraulic testing facility operated at a maximum of 3 Hz. Plane strain fracture toughness measurements were conducted in accordance with ASTM specification E399-78. Fatigue crack lengths were measured at the specimen surface using the



$$K_Q = \left[P_Q / BW^{1/2}\right] \cdot f\left[a/w\right]$$

$$f\left[a/w\right] = \frac{\left[2 + a/w\right]\left[0.886 + 4.64\,a/w - 13.32\left[a/w\right]^2 + 14.72\left[a/w\right]^3 - 5.6\left[a/w\right]^4\right]}{\left[1 - a/w\right]^{3/4}}$$

a = CRACK LENGTH [in]

W = SPECIMEN WIDTH [5.0"]

B = SPECIMEN THICKNESS [0.97"]

P_Q = LOAD [lbf.]

Figure 1. Schematic Diagram of Specimen and Stress Intensity Equation.

Fractomat device with a foil gauge length of 0.79 in. The operation and accuracy of this technique have been reported elsewhere[5]. Acoustic emission monitoring is accomplished via 375 KHz resonant transducers, amplified to a final gain of 60 dB and subsequently bandpass filtered in the range 250-500 KHz. Initially, this signal was analyzed directly by an AETC Model 203 Amplitude Distribution Analyzer which was set to detect all AE events greater than a threshold value of 100 mV. It was noticed during these initial tests that several spurious sources of acoustic emision were present, caused mainly by fretting at the loading pins. To eliminate these "noise" emissions, a voltage controlled gate was introduced to only allow analysis of signals occurring at 80% or greater of the load peak. Therefore, only those AE signals resulting from fatigue crack growth were measured, at the expense of eliminating acoustic emission resulting from plastic zone growth[6]. A schematic diagram of the final experimental arrangement is presented in Figure 2.

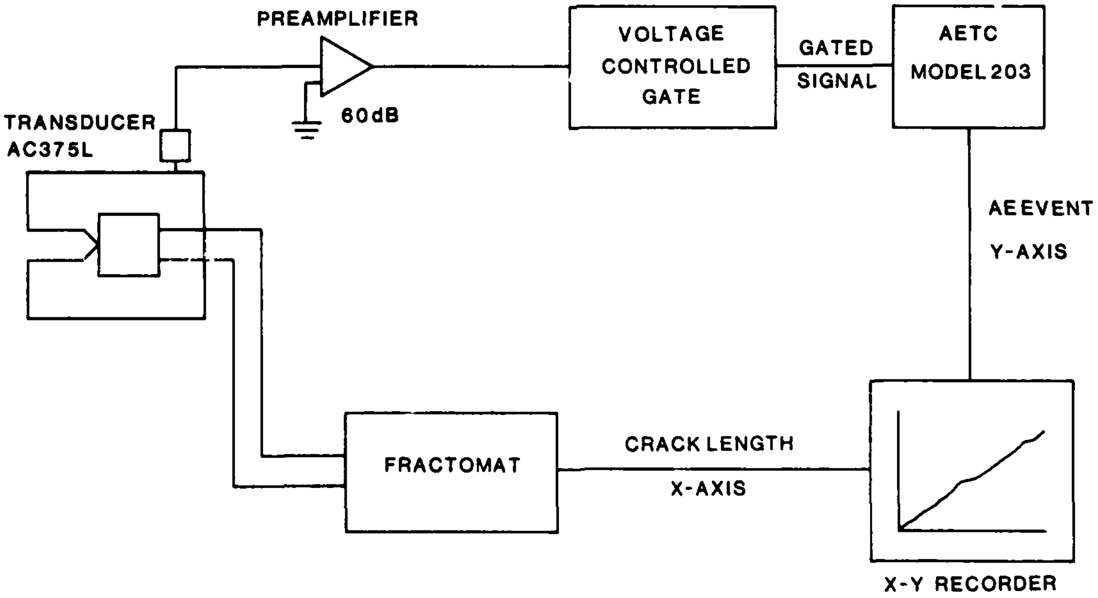


Figure 2. Schematic Diagram of Equipment for AE Data Acquisition.

Plane Strain Fracture Toughness and Fatigue Crack Growth Resistance

Typical plots of applied load, P, as a function of clip gauge displacement, δ, for the 7075-T6 and RRA heat treatments are shown in Figures 3 and 4, respectively. Values of P_Q were measured by 5% deviation from the linear elastic region of these plots, in accordance with ASTM E399-78. Plasticity is also seen to be within the acceptable limits determined by the specification. Crack length was measured directly from the fractured specimen using a seven point average. Critical plane strain stress intensity values were then calculated using the appropriate equations (Figure 1) and found to be 27.5 KSI $\sqrt{in}$ for the 7075-T6 aluminum alloy and 29.7 KSI $\sqrt{in}$ for the same alloy in the retrogression-reaged condition. The K_{Ic} value obtained for the 7075-T6 alloy is the average of three determinations, for which the largest deviation from mean was 0.55 KSI $\sqrt{in}$. The second value is the average of only two measurements varying by 0.2 KSI $\sqrt{in}$ from the mean. Since all specimens were manufactured from the same plate material and the cracks were oriented in the same direction relative to the rolling direction of the plate, it is very likely that the slight increase (2.2 KSI $\sqrt{in}$) in the K_{Ic} value after application of the RRA heat treatment is valid, although the number of measurements is not large enough for statistical evaluation. The observed increase is small and has little significance other than to indicate that the RRA heat treatment does not seriously alter the fracture toughness of 7075-T6.

The relative resistance of both materials to fatigue crack growth in the one inch thick section was also investigated. Crack length (a), measured at the specimen surface, is continuously recorded as a function of the number of cycles, N. The rate of crack growth per cycle (da/dN) and the corresponding value of the alternating stress intensity (ΔK) are calculated by the secant method in accordance with ASTM specification E647[7]. Crack growth rate was recorded for specimens fatigued to failure and during

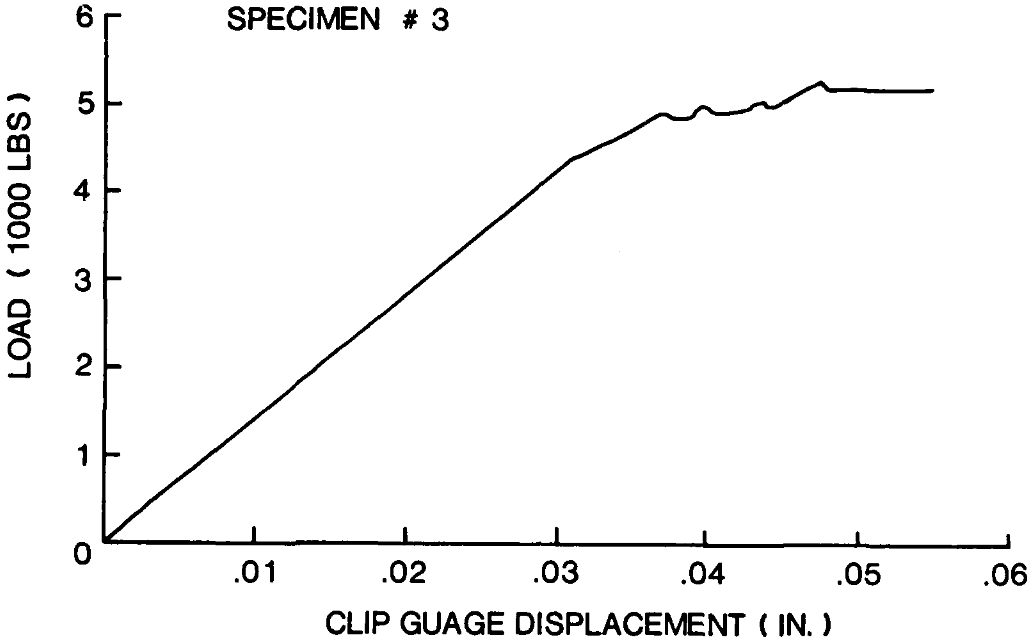


Figure 3. Load vs Clip Gauge Displacement 7075-T6.

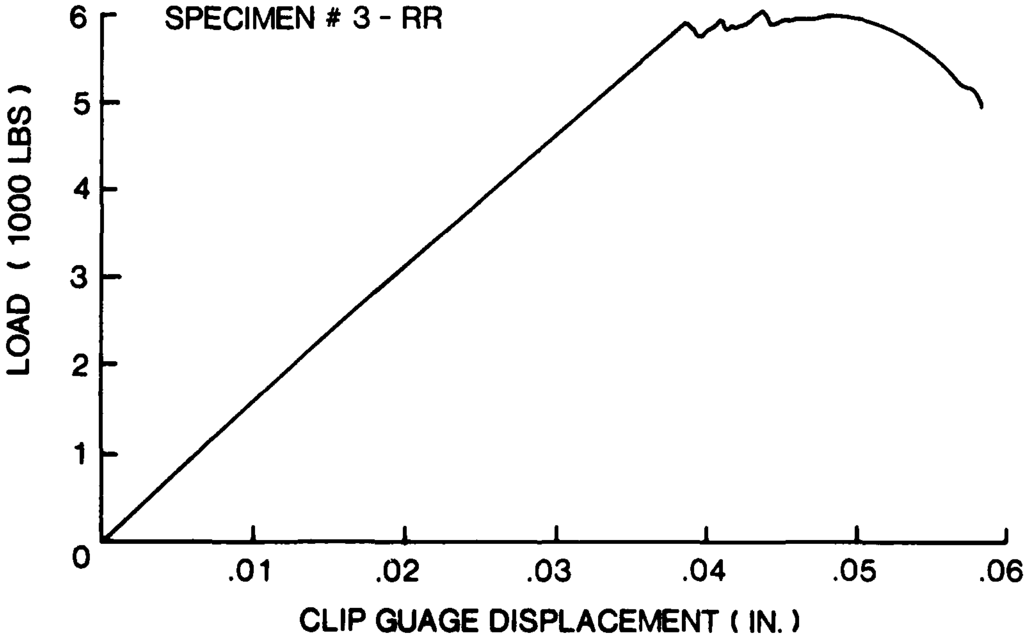


Figure 4. Load vs Clip Gauge Displacement 7075-T6 RRA.

fatigue pre-crack preparation of the fracture toughness specimens. An alternating load of 2500 pounds and a stress ratio of R = 0.167 was used for all specimens. Figures 5 and 6 show the conventional log-log plots of da/dN as a function of ΔK for 7075-T6 and the retrogression-reaged alloy, respectively. Both plots show the typical "dog-leg" feature at low crack growth rates near threshold stress intensity. Least squares fitting of those data points within the major linear portions of the plots to the Paris equation ($da/dN = c\Delta K^n$) produced values of $c = 2.645 \times 10^{-10}$ and $n = 3.711$ for the 7075-T6 alloy. Fitting the data obtained for crack growth in the RRA material indicated a somewhat smaller exponent, $n = 2.633$. The value of the exponent of the Paris equation may be considered to be a measure of the resistance to fatigue crack growth for any particular material. As is evident from the smaller exponent, fatigue crack growth rate is somewhat slower for the retrogression-reaged 7075-T6 alloy than for that of the normal T6 temper. As in the comparison of the fracture toughness of these heat treatments, the improvement in fatigue crack growth resistance by RRA treatment is quite minor. However, it is again significant that the retrogression-reaging procedure results in no degradation of fatigue crack growth resistance.

Acoustic Emission Response During Fatigue Crack Growth

Typical acoustic emission data obtained during fatigue crack growth in 7075-T6 and RRA-treated 7075-T6 alloys are presented in Figure 7, expressing the total number of acoustic emission events as a function of crack length. It may be seen that the total amount of acoustic emission from both alloys is similar up to approximately 0.6 inches of crack growth in the one inch thick CT specimens. It should also be noted that the AE response in this region is approximately a linear function of crack length or total crack area. This observation is consistent with the proposed

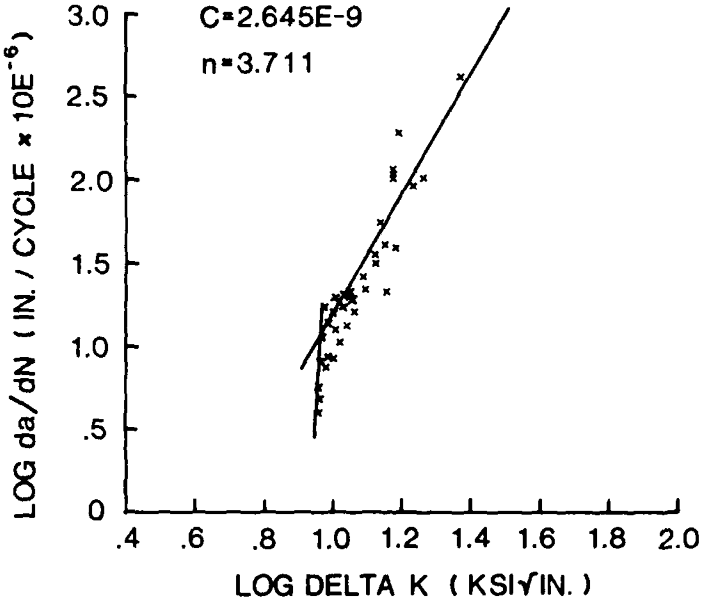


Figure 5. Fatigue Crack Growth - 7075-T6 Aluminum

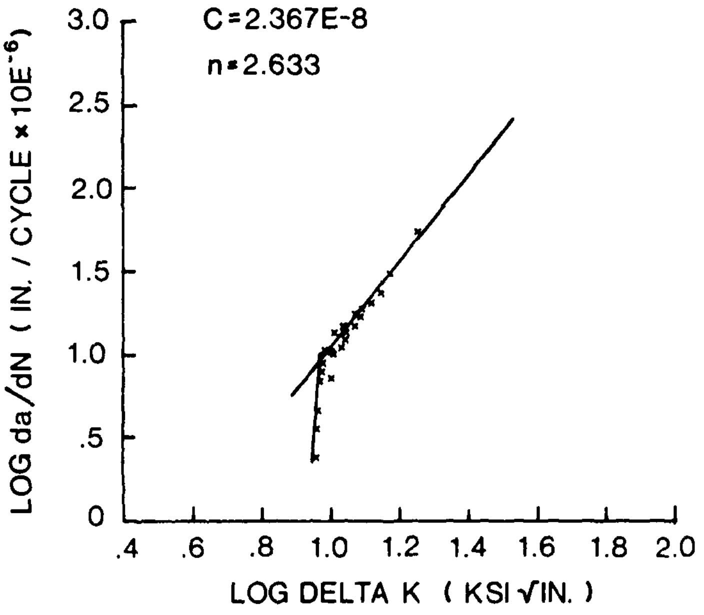


Figure 6. Fatigue Crack Growth - 7075-T6 RRA

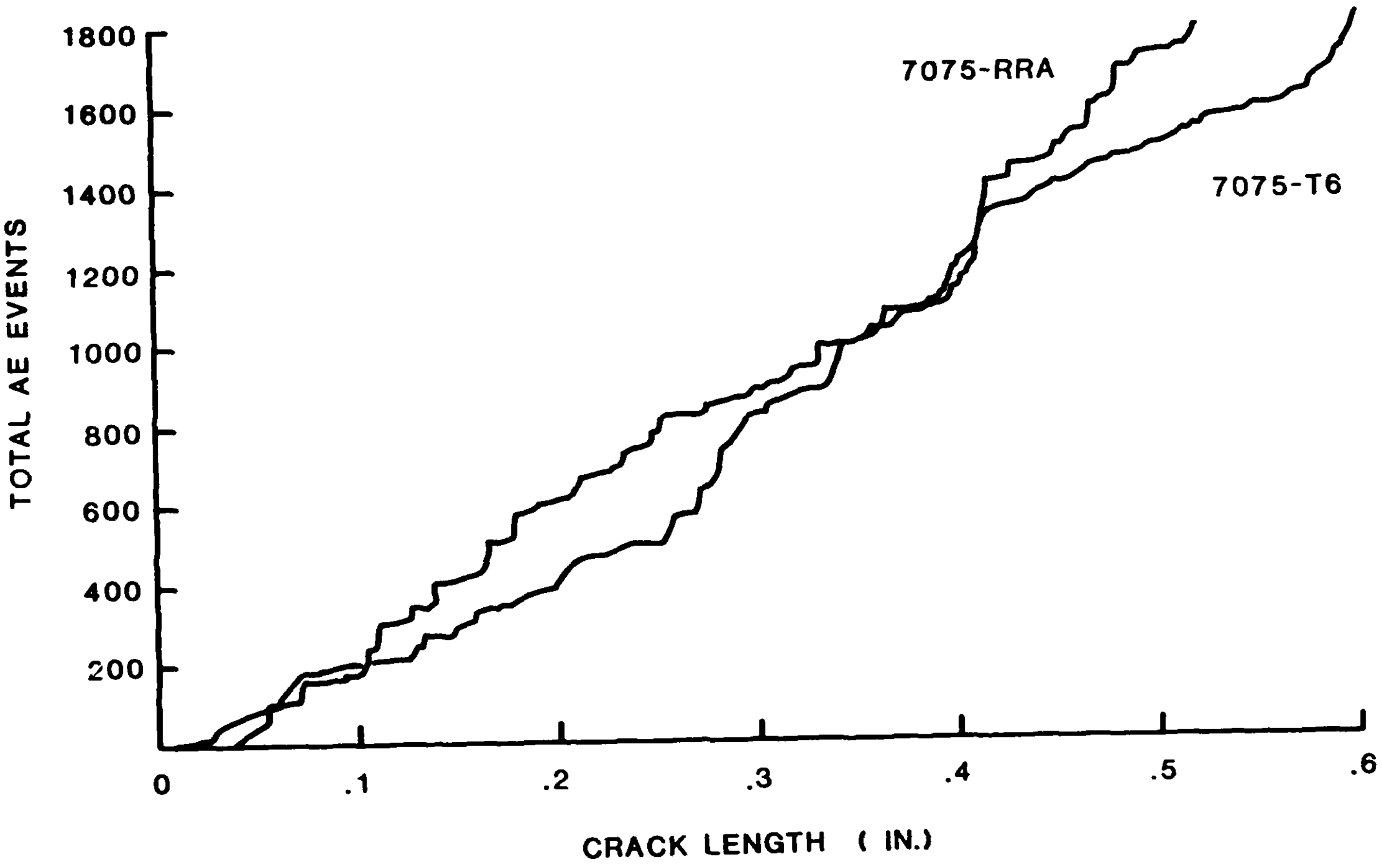


Figure 7. Acoustic Emission Event Count vs Crack Length.

mechanism of acoustic emission in 7075-T6[8,9]. It has been demonstrated previously that the major source of burst emission during crack growth in this alloy was the direct result of the fracture of larger, non-metallic inclusions. This inclusion fracture mechanism would be expected to yield the observed linear AE response with crack area because the inclusion distribution is relatively constant over the crack surface. Both heat treatments of this alloy yield similar quantities of acoustic emission, which further supports the proposed inclusion fracture mechanism. It is evident upon comparison of the microstructures, Figure 8, that the retrogression-reaging procedure has a very subtle effect on the T6 temper which is not visible by normal microstructural observation. The RRA procedure has no effect on the size or distribution of the large, non-metallic inclusions. If the inclusion fracture mechanism is accepted, there should be no significant change in the AE output of the RRA material, since the inclusion distribution remains unchanged.

The total number of acoustic emission events detected after amplification of the signal by 60 dB is quite low with respect to the total crack length required to generate these events. In terms of crack area, the gated AE response to fatigue crack growth is only approximately 3500 events per square inch. However, the total crack area at the critical crack length in many 7075 structural components, such as aircraft wing skin (typically 0.060" thick), may be only of the order of 0.01 square inch. The total accumulated acoustic emission event count in that case would be reduced to approximately 50 events. The probability of the detection and accurate length determination of a sub-critical flaw in such a structure would be extremely low because of the relatively low acoustic emission yield of this material during fatigue crack growth.

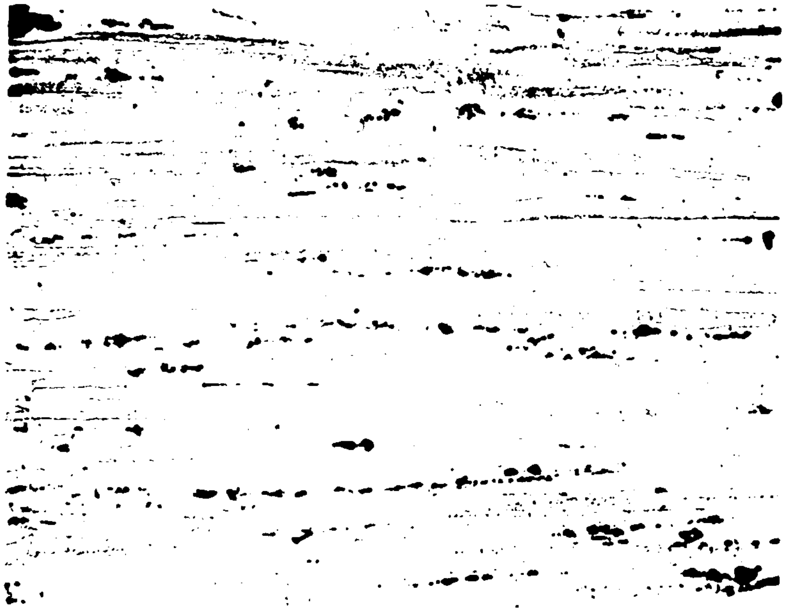


Figure 8a. Microstructure of 7075-T6. (X340)

Figure 8b. Microstructure of 7075-T6 RRA. (X340)

Conclusions

1. The fracture mechanics properties related to crack resistance of the material with an existing flaw, i.e. K_{Ic} and fatigue crack growth rate remain unaltered or are slightly increased by the retrogression-reaging treatment of the 7075-T6 aluminum alloy. Plane strain fracture toughness in the T- direction for 7075 aluminum in the T6 and RRA conditions were found to be 27.5 Ksi $\sqrt{in}$ and 29.7 Ksi $\sqrt{in}$, respectively.

2. The acoustic emission response to fatigue crack growth shows an approximately linear relation of AE events to the total crack area. This is consistent with the proposed inclusion fracture AE mechanism for 7075-T6. The acoustic emission event rate remains unchanged after heat treatment to the retrogression and reaged condition, since this heat treatment has no effect upon the inclusion distribution in the 7075-T6 aluminum alloy.

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