STRESS CORROSION CRACKING BEHAVIOUR OF Al-Li ALLOY 8090-T8171

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Abstract

The stress corrosion cracking (SCC) behaviour of 8090-T8171 plate was investigated performing accelerated tests under constant deformation, constant load and slow strain rate conditions. Synthetic environments used were an aqueous 3.5% NaCl solution, an aqueous solution of 0.5 M NaCl + 0.1 M LiCl + 0.05 M $NaHCO_3$ + 0.05 M Na_2CO_3, and substitute ocean water according to ASTM D1141. In longitudinal and long transverse directions, very high SCC resistance of alloy 8090-T8171 was determined. Environmentally assisted cracking occurred when stress was applied in the short transverse direction. A SCC threshold stress below 100 MPa was found. Under permanent immersion conditions in the chloride-carbonate-bicarbonate solution, the surface condition of the smooth specimens had a significant influence on the time-to-failure lives. Scatter in data was reduced by chemical cleaning. Substitute ocean water also promoted environmentally assisted cracking. Poor correlation was found between the results of the alternate immersion tests and those of the slow strain rate testing technique using substitute ocean water and the chloride-carbonate-bicarbonate solution.

Introduction

Aluminium-lithium alloys were initially developed for a direct substitution of established 2XXX and 7XXX series aluminium alloys used in aircraft structures [1]. Although this goal has not been achieved with great satisfaction, many semi-fabricated product forms match requirements and specifications making them attractive for aerospace applications. Alcan International has concentrated its effort on products of the alloy 8090 [1]. A damage tolerant temper T8171 and a medium strength temper T8771 were developed for plate materials to replace 2024-T351 and 7010-T7651, respectively. For thick wrought products of aluminium-lithium based alloys, high toughness is associated with a coarse unrecrystallized structure [2]. Stretching of 6-8% after solution heat treatment provides a good combination of strength and fracture toughness. For underaged tempers required for damage tolerant applications, this high level of stretch allows to reduce aging temperatures, associated with a decrease in grain boundary precipitation [2]. Precipitates at grain boundaries and within the matrix have a marked influence on the sensitivity to stress corrosion cracking of Al-Li-Cu-Mg-Zr alloys [3]. In the present work, the SCC behaviour of damage tolerant 8090-T8171 plate has been studied performing different accelerated tests. Results of comparison tests with damage tolerant plate material of the Al-Li alloy 2091-T8X51 and the conventional alloy 2024-T351 are also reported.

Table I. Tensile properties of the 8090-T8171 plate studied

Orientation	0.2% proof stress [MPa]	Ultimate tensile strength [MPa]	Fracture elongation %
Longitudinal	394 ± 5	477 ± 7	6.1 ± 0.5
Long transverse	346 ± 3	467 ± 1	7.8 ± 0.7
Short transverse	285 ± 3	449 ± 4	7.0 ± 0.7

Experimental

A 52 mm thick 8090-T8171 plate supplied by Alcan Plate Ltd. was studied. Cylindrical threaded tensile specimens with 23 mm gauge length and a cross section of 10 mm^2 were machined with loading axis in longitudinal (L), long transverse (LT), and short transverse (ST) direction. Tensile properties of this alloy are given in Table I. Quintuplicate specimens were tensile tested in the three orientations at a strain rate of $3.5 \cdot 10^{-5}$ s^{-1}.

Static loading tests were performed under conditions of constant deformation and constant load using very stiff stressing frames and dead weight loaded tensile test machines, respectively. In the constant deformation tests, the specimens were alternately immersed in 3.5% NaCl solution according to ASTM G44, whereas they were permanently immersed in an aqueous solution of 0.5 M NaCl + 0.1 M LiCl + 0.05 M $NaHCO_3$ + 0.05 M Na_2CO_3 (pH 9.7) and in substitute ocean water according to ASTM D1141 without heavy metals, if constant load was applied. Failure criterion was fracture. Alternate immersion tests were terminated after 30 days when short transverse specimens were tested, and after 40 days when stressing was in L or LT direction. Under permanent immersion conditions, maximum exposure length was 1000 h.

Slow strain rate (SSR) tests were carried out in dry laboratory air (inert environment), substitute ocean water, and in an aqueous solution of 0.5M NaCl + 0.1 M LiCl + 0.05 M $NaHCO_3$ + 0.05 M Na_2CO_3. Nominal strain rates were in the range from $5 \cdot 10^{-8}$ to $5 \cdot 10^{-5}$ s^{-1}. During dynamic straining, the specimens were permanently immersed in the aerated corrosive media. The fracture energy, e.g. the area beneath the stress-elongation curve, was used to assess sensitivity to environmentally assisted cracking. Occurrence of stress corrosion cracking is indicated by reduced fracture energy values measured in the corrosive environment compared with those obtained from SSR tests in dry air, e.g. embedding the specimens in $Mg(ClO_4)_2$-powder, at the same applied strain rates. Because a reduction of fracture energy can also be associated with pitting, intergranular corrosion or hydrogen absorption occurring during immersion, pre-exposure tests were carried out to evaluate the degradation of specimens resulting from corrosion processes independent of stress. Details of the SSR testing technique are described elsewhere [4].

Prior to testing, the specimens were ultrasonically cleaned in ethanol, degreased in acetone vapour, and cleaned in an aqueous alkaline solution of 10 g/l Turco 4215 NC (Turco Chemie, Hamburg).

Results and discussion

Alternate immersion tests in 3.5% NaCl solution indicate very high SCC resistance for the 8090-T8171 plate in both L and LT directions. Within 40 days exposure, quintuplicate specimens did not fail at stress levels of 75 and 90% of the respective 0.2% proof stress. In ST direction, the material is sensitive to environmentally assisted cracking. Time-to-failure data are plotted in Figure 1. Results of constant deformation tests with alloy 8090-T8771 are also shown (cylindrical bars were machined from an 8090 plate received in the solution heat treated and 6% stretched condition T3771. Prior to final machining the short transverse tensile specimens were artificially aged 32 h at 170°C to the peak-aged temper T8771, using a heating-up rate of 10°C/h). Short transverse threshold stresses below 100 MPa are determined for 8090 plate in both underaged T8171 and peak-aged T8771 tempers. Time-to-failure data of damage tolerant plate material of the Al-Li alloy 2091-T8X51 and the conventional alloy 2024-T351 are presented in Figure 2. Short transverse threshold stresses below 100 MPa are measured with the latter alloys, too. Compared with 8090, however, failure occurred at shorter exposure times. As demonstrated by alternate immersion tests, the SCC behaviour of damage tolerant Al-Li alloy plate is similar to that of the conventional alloy 2024-T351. For lithium bearing aluminium alloys, alternate immersion testing in 3.5% NaCl solution correlates well with SCC tests in natural environments. Threshold stresses below 100 MPa have been also found with the alloys 2091-T8X51 and 8090-T8171 exposed to an urban industrial and a marine environment, respectively [5,6]. As reported by Gray, the SCC behaviour of 8090 plate improves with isothermal aging [7]. A threshold stress of about 100 MPa was measured in the peak-aged temper. In the present work, variations in low SCC resistance have not been studied because stresses below 100 MPa were not applied in constant deformation tests as recommended in ASTM G47.

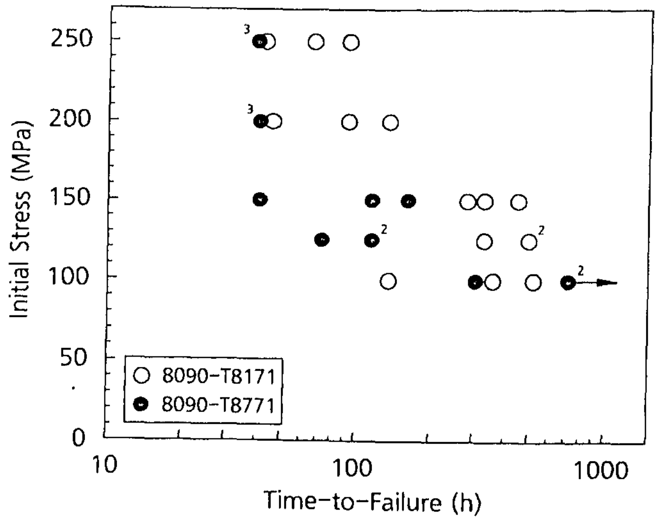

Figure 1. Time-to-failure data for 8090 plate material in the tempers T8171 and T8771. Short transverse tensile specimens were alternately immersed in 3.5% NaCl solution according to ASTM G44. Numbers indicate the numbers of specimens tested.

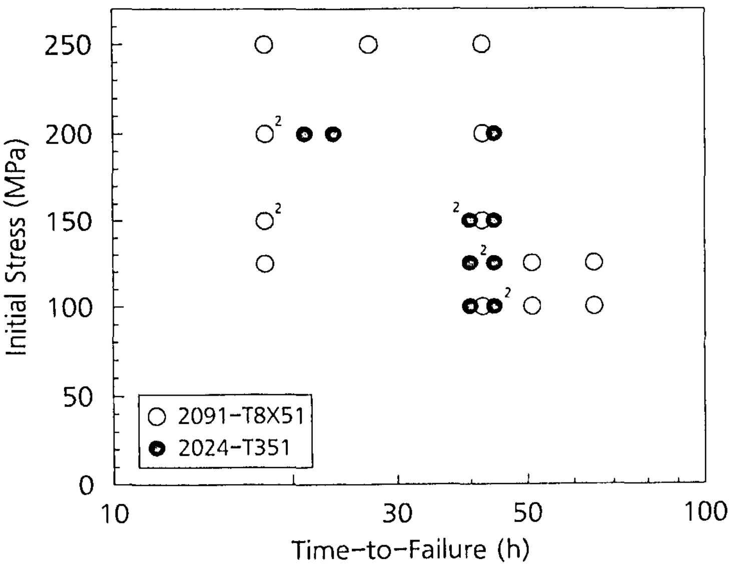

Figure 2. Time-to-failure data for plate material of the alloys 2091-T8X51 and 2024-T351. Short transverse tensile specimens were alternately immersed in 3.5% NaCl solution according to ASTM G44. Numbers indicate the numbers of specimens tested.

Figure 3 shows the results of constant load tests under permanent immersion conditions in an aqueous solution of 0.5 M NaCl + 0.1 M LiCl + 0.05 M $NaHCO_3$ + 0.05 M Na_2CO_3. Again, short transverse threshold stresses below 100 MPa are measured for the Al-Li alloys 8090-T8171 and 2091-T8X51. As illustrated in Figure 3, the surface condition of the smooth tensile specimens has a marked influence on time-to-failure. Specimens which were only degreased display a large scatter in data, which is considerably reduced by additional cleaning in the alkaline Turco detergent. To study effects of surface treatments, quintuplicate 8090-T8171 tensile specimens with different surface conditions were permanently immersed in the aqueous chloride-carbonate-bicarbonate solution at a constant load of 150 MPa initial stress. Average, standard deviation and variation coefficient of time-to-failure data measured are listed in Table II. The largest scatter, e.g. the highest value of the variation coefficient, is observed with specimens which were only degreased. Chemical cleaning in acid or alkaline baths reduces scatter, probably related to a more uniform wetting of the etched surfaces and, thus, to shorter incubation periods.

In L and LT directions, constant load tests in an aqueous solution of 0.5 M NaCl + 0.1 M LiCl + 0.05 M $NaHCO_3$ + 0.05 M Na_2CO_3 indicate high SCC resistance of the alloy 8090-T8171. At applied stresses of 75 and 90% of the respective 0.2% proof stress, no failure was observed with quintuplicate specimens during 1000 h immersion. These results are again in agreement with those of alternate immersion tests in 3.5% NaCl solution. For Al-Li alloys, chloride-carbonate-bicarbonate solutions seem to be effective synthetic environments to be used in accelerated static loading SCC tests under permanent immersion conditions.

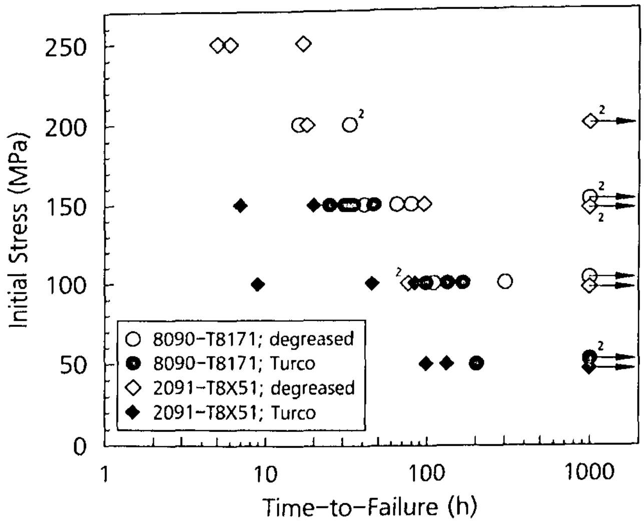

Figure 3. Time-to-failure data for plate material of the alloys 8090-T8171 and 2091-T8X51. Short transverse tensile specimens which were degreased or cleaned in an alkaline detergent were permanently immersed in an aqueous chloride-carbonate-bicarbonate solution under constant load conditions. Numbers indicate the numbers of specimens tested.

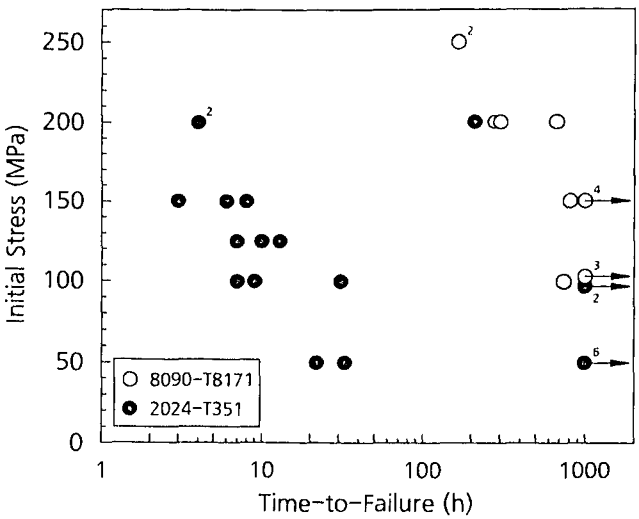

Figure 4. Time-to-failure data for plate material of the alloys 8090-T8171 and 2024-T351. Short transverse tensile specimens were permanently immersed in substitute ocean water under constant load conditions. Numbers indicate the numbers of specimens tested.

Table 2. Effect of different surface treatments on time-to-failure data for 8090-T8171 plate*

surface treatment	average	standard deviation	variation coefficient
degreased in acetone vapour	437 h	514 h	1.18
cleaned at 50°C for 5 min in an aqueous alkaline solution of 10 g/l Turco detergent	34.2 h	8.1 h	0.24
chempolished at 60°C for 45 s in a mixture of 800 ml H_3PO_4 + 150 ml H_2SO_4 + 50 ml HNO_3	19.0 h	3.8 h	0.20
chempolished at 80°C for 30 s in a mixture of 850 ml H_3PO_4 + 150 ml HNO_3	23.4 h	5.7 h	0.24
cleaned at 23°C for 5 min in a 5% NaOH solution and then dipped for 10 s in HNO_3	115 h	24.2 h	0.21

* Short transverse tensile specimens were permanently immersed in an aqueous chloride-carbonate-bicarbonate solution at an initial applied stress of 150 MPa.

Figure 4 shows the time-to-failure data obtained from constant load tests in substitute ocean water. For the conventional alloy 2024-T351, a short transverse threshold stress below 50 MPa is measured. Compared with alloy 2024-T351, time-to-failure lives of 8090-T8171 specimens are longer and the threshold stress seems to be higher. However, the specimens which passed the maximum exposure length of 1000 h were severely embrittled as found in subsequent tensile tests under inert environmental conditions. Fracture stresses below 200 MPa were measured, based on the original cross-sectional area. No deterioration in strength was observed with specimens which were 1000 h immersed in substitute ocean water without applied stress. Thus, the degradation of specimens exposed with applied stress results from environmentally assisted cracking, and failure would have occurred when the constant load tests were run longer.

Results of the SSR tests with alloy 8090-T8171 are plotted in Figures 5 and 6. Short transverse tensile specimens were dynamically strained in an inert environment, in substitute ocean water (Fig. 5), and in an aqueous solution of 0.5 M NaCl + 0.1 M LiCl + 0.05 M $NaHCO_3$ + 0.05 M Na_2CO_3 (Fig. 6). Data for pre-exposure tests in the respective corrosive environment are also shown. In substitute ocean water, the fracture energy of specimens tested at strain rates below $1 \cdot 10^{-6}$ s^{-1} decreases with decreasing strain rate. In the strain rate range between $3 \cdot 10^{-7}$ to $1 \cdot 10^{-6}$ s^{-1}, a large scatter in the fracture energy data is observed. As shown by pre-exposure tests, the degradation of specimens dynamically strained in this corrosive environment is primarily caused by corrosion processes independent of stress. However, specimens tested at strain rates below $5 \cdot 10^{-8}$ s^{-1} were entirely embrittled and exhibited fracture stresses significantly lower than the 0.2% proof stress, whereas the proof stress of the pre-exposed specimens did not deteriorate during immersion. Thus, stress corrosion cracking occurs at these low strain rates. In the chloride-carbonate-bicarbonate solution, fracture energy data reveal also a scatter at strain rates below $3 \cdot 10^{-7}$ s^{-1}. Although a significant loss of ductility was observed for the pre-exposed specimens, their degradation was not so severe than that of the specimens dynamically strained in the corrosive environment. Stress corrosion cracking seems to contribute to

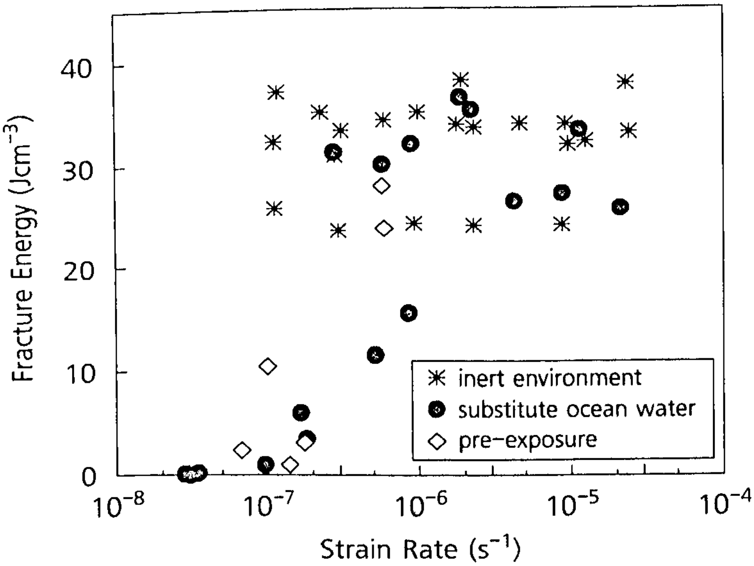

Figure 5. Results of slow strain rate tests for 8090-T8171 plate using substitute ocean water.

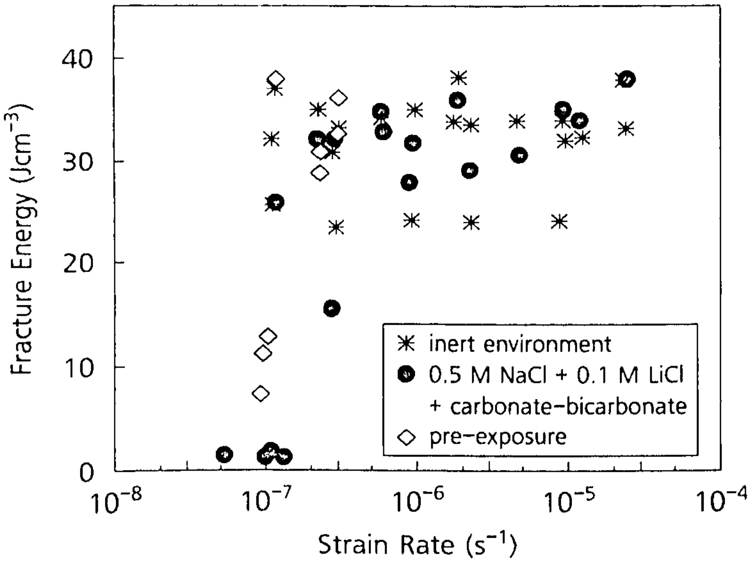

Figure 6. Results of slow strain rate tests for 8090-T8171 plate using an aqueous chloride-carbonate-bicarbonate solution.

the deterioration at strain rates of about $1 \cdot 10^{-7}$ s^{-1}. However, the sensitivity indicated for the alloy 8090-T8171 is rather slight in contrast to the alternate immersion tests. Good correlation between the results of static loading tests and the SSR testing technique was found for the Al-Li alloy 2091-T8X51 [8]. Therefore, further work is needed to determine whether or not substitute ocean water and chloride-carbonate-bicarbonate are useful synthetic environments to be used with the SSR testing technique for Al-Li alloys.

Conclusions

1. As found in accelerated static loading tests, 8090-T8171 alloy plate is virtually immune to environmentally assisted cracking when stress is applied in L and LT directions.
2. When loaded in ST direction, 8090-T8171 plate is sensitive to stress corrosion cracking. A threshold stress below 100 MPa is obtained from constant deformation tests under alternate immersion conditions according to ASTM G44.
3. Short transverse SCC initiation resistances of 8090 plate are similar in the underaged T8171 and in the peak-aged T8771 tempers.
4. Results of constant load tests under permanent immersion conditions in an aqueous solution of 0.5 M NaCl + 0.1 M LiCl + 0.05 M $NaHCO_3$ + 0.05 M Na_2CO_3 are in accordance with those of alternate immersion tests. Time-to-failure data are influenced by the surface conditions of the smooth specimens.
5. Substitute ocean water is also conducive to environmentally assisted cracking with 8090-T8171 plate. In permanent immersion tests, the maximum exposure length of 1000 h may be too short to detect SCC failure.
6. The correlation between the results of the static loading tests and those of the SSR testing technique is poor for the alloy 8090-T8171. The latter testing method indicates, if any, a slight SCC sensitivity. The degradation of dynamically strained specimens is primarily caused by corrosion processes independent of stress.

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