SMALL DEFECTS INTRODUCED BY FABRICATION OR SERVICE ENVIRONMENT AND THE FATIGUE OF ALUMINIUM ALLOYS

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The effect of small defects on the high cycle fatigue properties of the extruded aluminium alloy 2014A is described. Particular attention is paid to defects introduced by either fabrication orin- service operation and the results have been analysed in termsof both the S-N approach complimented by the use of fracture mechanics and fatigue threshold concepts.

INTRODUCTION

The microstructural features and associated mechanical properties of rolled sheet and plate of alumium alloys is well documented in view of their extensive use in the Aerospace Industry. Despite their use in the Power Generation Industry for the vital application of retaining the copper conductor windings in very large electrical generators, there have been relatively few studies of extruded alumium alloys. This is despite the fact that it is well known that extruded products can exhibit pronounced metallurgical and mechanical anisotropy. For certain properties, this anisotropy can be a consequence of the coarse grain structure developed in the near surface regions of the extrusion. Some aluminium alloys such as Al-Cu-Mg (2014A) are particularly prone to the formation of this coarse near surface structure. Although it is common practice in the Aerospace Industry to machine off the surface layers, other industries use as-extruded components in service in order to avoid the economic penalty associated with machining. The position can be complicated further by the presence of small defects introduced into the material during fabrication (intergranular corrosion cracks) or in service (corrosion pits and / or fretting cracks).

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The present paper is concerned with the effect of the intergranular corrosion cracks on fatigue behaviour of an aluminium alloy 2014A and the palliative action resulting from glass bead peening.

EXPERIMENTAL

Microstructure of the As-Extruded 2014A Alloy

The microstructure of the as-extruded 2014A bar which had been heat treated to the T6 peak hardness condition (solution treat at 505C, quench, age at 170C for 10 hours) consisted of a three layer grain structure:

(1) At the extrusion surface, a very narrow band of equiaxed grains was found, typically 40μm in diameter and one or two grains deep.

(2) Below this surface layer, very coarse grains were found in a band typically 0.5 to 3mm thick.

(3) The third layer at the core of the bar consisted of fine equiaxe grains typically of 10μm diameter.

Intergranular cracking was found in the surface and medium grain layers in the as-extruded bar, penetrating to the boundary with the coarse layer, a maximum depth of about 80μm. The intergranular defect density was measured both directly on the surface and on a number of polished, transverse sections taken through the extruded bar. An average density of $9/cm^2$ was found but it is known from sampling other 2014A extrusions that there is a large amount of scatter in defect density. The mechanism of formation of the intergranular cracks is unclear. They may form either during the extrusion process and / or by subsequent corrosion during service or storage.

Mechanical Properties

Tensile specimens were prepared from the extruded bar in both the longitudinal (L) and transverse (T) directions and the 0.2% proof stress was measured at 458MPa (L)and 437MPa (T) while the ultimate tensile stress was 504MPa (L) and 480 (T).

Fatigue Tests

Fatigue specimens were machined from the extruded bar in either the transverse (T) or longitudinal (L) orientation and subsequently tested in three or four point bend at a frequency of about 100Hz in an Amsler Vibrophore machine.

Tests were made on specimens in which the tensile surface was:

(a) retained in the as-extruded condition, T and L orientations

(b) 1mm was machined off the extruded surface, T and L orientations

(c) 0.1mm was removed from the as-extruded surface by grinding to a 600 SiC grit finish, T orientation only.

The majority of fatigue tests were carried out in laboratory air at ambient temperature and at two mean stresses of 210 and 390 MPa.

A few further tests were carried out:

* in air at 80°C (T orientation only)
* L orientation in dry hydrogen
* L orientation in wet hydrogen
*

A series of fatigue specimens of longitudinal orientation were subsequently peened with glass beads (400-800 μm diameter) with an Almen Intensity of 0.015-0.020N, prior to fatigue testing. The residual stress three dimensional profile was established using an X-ray technique and sequential polishing -see Figure 1.

RESULTS

Fatigue and Intergranular Defects

The main results from the present investigation are as follows:

(1) The as-extruded 2014A aluminium alloy exhibited a marked anisotropy in fatigue properties. At a mean stress of 210MPa in air at 20°C, fatigue strengths were +/- 40MPa for the T and +/- 90MPa for the L orientation respectively (see Figure 2). At the higher mean stress of 310MPa, the fatigue strengths in air and 20°C were measured at +/- 45MPa (T orientation) and +/- 65 MPa (L orientation).

(2) Increasing the test temperature to 80°C in air had a negligible effect on fatigue strength.

(3) Milling away 1mm from the as-extruded surface resulted in a large increase in fatigue strength as well as eliminating directional properties. For a mean stress of 210MPa in air at 20°C, fatigue strength for these machined specimens was +/- 150MPa for both T and L orientations.

(4) The as-extruded surface contained intergranular cracks up to a depth of

80μm. Removal by grinding of a 0.1mm deep surface layer containing these defects increased the fatigue strength to +/- 130MPa for T orientation at a mean stress of 210MPa in air at 20°C.

(5) Fractographic examination confirmed that fatigue cracks were initiating at the intergranular corrosion cracks in the as-extruded surface.

(6) For the L orientation, fatigue S-N behaviour in dry hydrogen was similar to that in air (mean stress 210MPa at 20°C). Tests in wet hydrogen at 22Hz caused a steadily decreasing fatigue strength with increasing imposed cycles i.e. in contrast to tests in air, a fatigue limit was not observed in wet hydrogen.

(7) Peening with glass beads gave a large increase (see Figure 3) in fatigue strength from +/-60MPa to +/-125MPa (mean stress 210MPa in air at 20°C).

(8) Crack initiation sites changed from being the intergranular corrosion cracks found for the as-extruded condition to either inclusions (mainly $CuAl_2$ particles) or glass particles in the peened specimens.

(9) After crack initiation in the peened samples, crack growth rate deceased until a minimum rate was found at a depth of about 200μm, beyond which growth rate increased. From a knowledge of the residual stress variation with crack depth (before and after fatigue testing), measured by the X-ray technique, short crack growth behaviour in peened specimens is probably related to the compressive residual stress fields, rather than the underlying microstructure.

Modelling

Fracture mechanics and fatigue threshold concepts can be used in order to model the growth of defects from either as-extruded (near zero residual stresses) or peened surfaces (compressive residual stresses given in Figure 1). A knowledge of the experimentally determined threshold parameter ΔKth is also needed for 2014A type alloys as a function of stress ratio R (Figure 4). From the intersection of the plots against crack depth for applied ΔK and threshold ΔKth (Figure 5), it is apparent that the critical defect size for sustained fatigue crack growth is increased from about 40μm (as-extruded- refer to ΔKthsra) to about 220μm (peened-refer to ΔKthpeen) which is in broad agreement with the experimental observations.

The large effects on fatigue behaviour of pre-existing intergranular corrosion defects and the benefits found from peening have been successfully presented in terms of fracture mechanics methodologies.

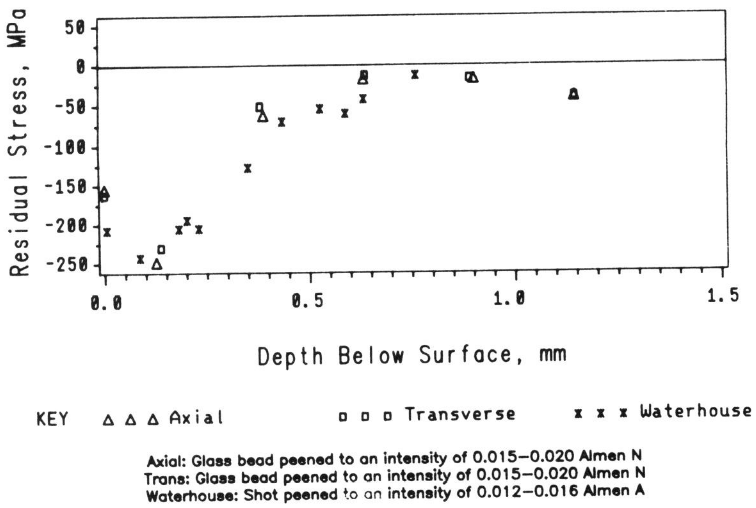

Figure 1 Measured near surface residual stresses in a peened specimen of 2014A aluminium

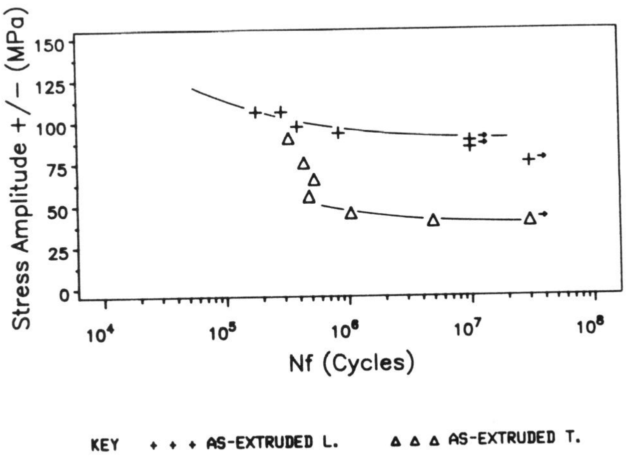

Figure 2 S-N curves for longitudinal (L) and transverse (T) orientations in as-extruded 2014A aluminium (mean stress 210MPa)

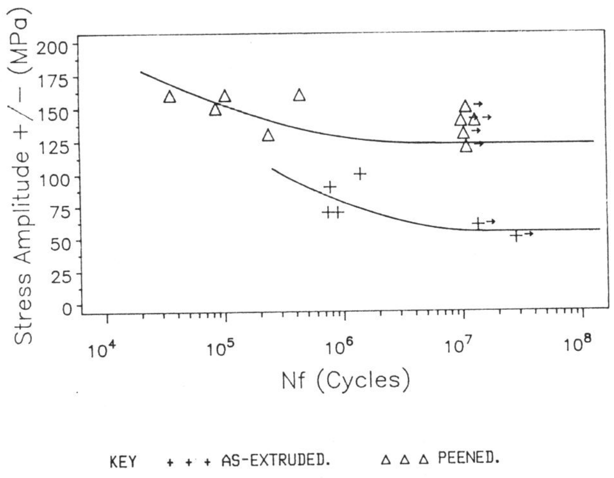

Figure 3 S-N curves for as-extruded and peened specimens of L orientation 2014A (mean stress of 210MPa).

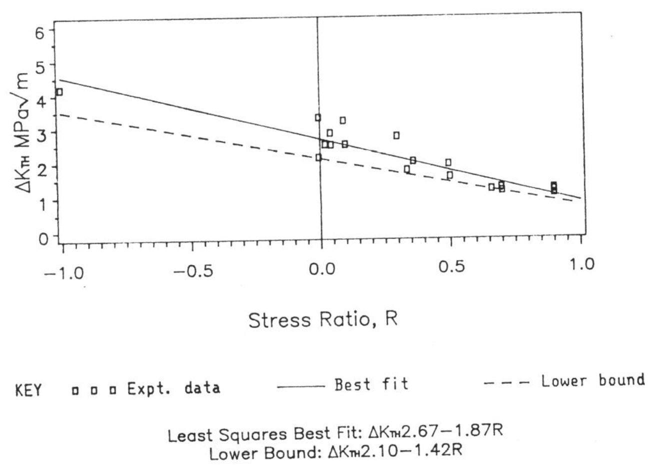

Figure 4 Fatigue crack growth threshold data for aluminium copper alloys

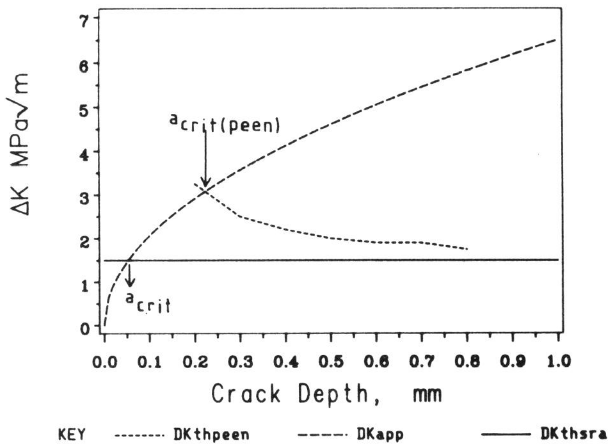

Figure 5 Applied ΔK and fatigue threshold ΔKth as a function of crack depth.