The Effect of Shot-Peening on the Fatigue and Fretting Fatigue Behaviour of 8090 and 7010 Aluminium Alloys

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Introduction

Aluminium alloys are widely used in the aircraft industry for their favourable strength-weight ratios. Al-Zn-Mg alloys have been in use for many years, but recently alloys based on Al-Li have been developed with improved strength-weight ratios and it is thought that they may become widely used aircraft alloys in the 1990s (1). Generally, the fatigue strength of an alloy is simply related to the yield stress or tensile strength, although this relationship can be greatly influenced by the nature of the environment. The effects of fretting on fatigue are not so predictable and as fretting is a likely occurrence in an aircraft structure, it was thought relevant to investigate its effect on the recently developed Al-Li alloys. To date, little or no information is available on the fretting characteristics of Al-Li alloys. Furthermore, data is not available of the effect of shot peening these alloys, a process which is known to improve the fatigue properties (2) and fretting fatigue properties (3) of many alloy systems.

The present work has therefore been concerned with the investigation of the fatigue and fretting fatigue characteristics of an Al-Li based alloy (8090) and, for comparison purposes, the investigation has included the more established Al-Zn-Mg-Cu alloy 7010.

Experimental

The materials used were in the form of 9.5mm dia. extruded rod. The compositions (wt.%) are shown in the following table:

Code	Li	Cu	Mg	Zn	Zr	Fe	Si
7010	-	1.59	2.26	5.96	0.12	0.08	0.04
8090	2.48	1.12	0.76	-	0.14	0.07	0.05

The heat treatment conditions are as follows:

Code	Solution Treatment		Ageing Conditions
7010	475°C 30 min.	cold stretch 2.5%	170°C 6 h
8090	530°C 30 min.		190°C 16 h

The mechanical properties after heat treatment were:

Code	0.2% PS (MPa)	UTS (MPa)	Elongation (%)	Hardness (HV)
7010	460	530	15	156
8090	552	580	5	157

The fretting-fatigue and fatigue specimens were 36mm in length with a pair of flats machined on them at the mid point reducing the thickness to 6.35mm. To produce the fretting action a pair of bridges of the same material as the specimen was clamped on to the flats by means of a proving ring. The clamping pressure was 32 MPa. The specimen was mounted in a four-point-loading rotating-bending fatigue machine running at 25 Hz (4). Samples were tested in both the as-heat-treated condition and after shot-peening to Almen intensities of 12-16A and 8-10C with steel shot of 1.04mm dia. Specimens were carefully degreased in acetone prior to testing.

Results

The experimental results are shown in the form of alternating stress versus number of cycles to failure (S-N) curves. Fig. 1 shows that the fatigue strength of 7010 is drastically reduced by fretting, the reduction being greater in the high cycle fatigue region. Shot peening to an intensity 12-16A significantly improves the fatigue strength with little distinction between fretting and plain fatigue. Fig. 2 shows the effect of heavier peening, 8-10C, with a similar result to the lighter peening except that the fatigue lives in low cycle fatigue are somewhat longer. This effect has been previously observed on another aluminium alloy (5).

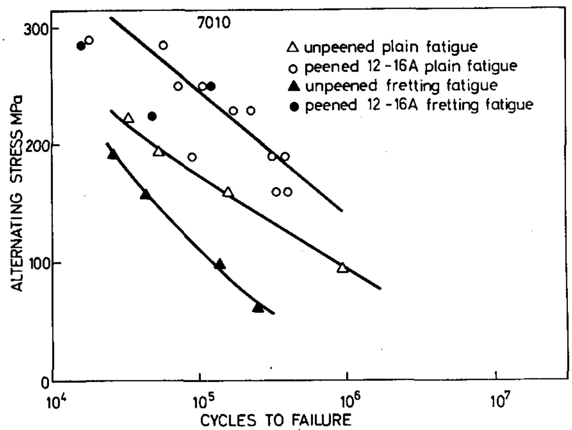

Fig. 1. S-N curves for 7010 alloy shot-peened to 12-16A and tested under conditions of plain fatigue and fretting-fatigue.

The 8090 alloy has a considerably higher fatigue strength, Fig. 3, than the 7010 but again it suffers a 50% reduction due to fretting. Shot-peening at intensity 8-10C produces an improved common curve for both plain and fretting-fatigue, but the effect is less marked in both low-cycle and high-cycle fatigue than is the case with the alloy 7010.

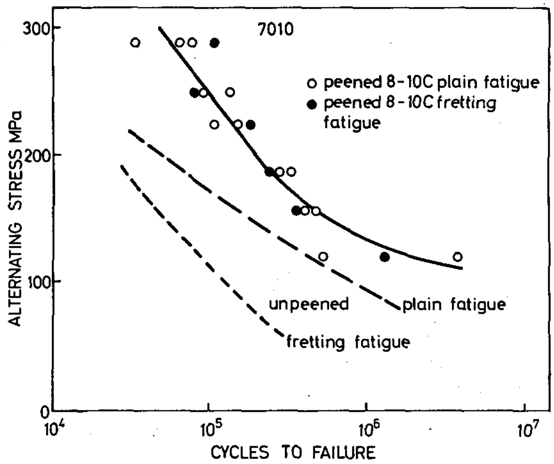

Fig. 2. S-N curves for 7010 alloy shot peened to 8-10C and tested under conditions of plain fatigue and fretting-fatigue.

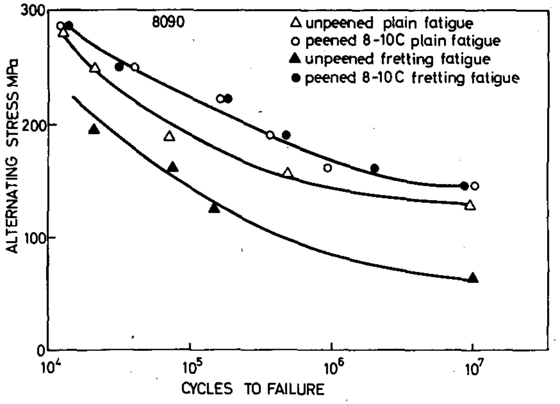

Fig. 3. S-N curves for 8090 alloy shot peened to 8-10C and tested under conditions of plain fatigue and fretting-fatigue.

Discussion

The reason that the 8090 alloy has a higher fatigue strength than the 7010, is the slower propagation rate of fatigue cracks due to the tortuous path they take because slip in this alloy is very planar and fatigue cracking follows the intense shear bands (6). This is illustrated in Fig. 4 which shows the fatigue crack following a characteristic zig-zag path. This should be compared with the form of the fatigue crack in 7010, Fig. 5, which is much less faceted.

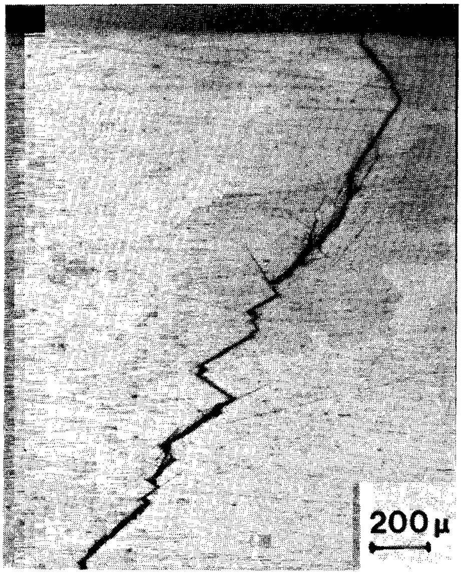

Fig. 4. Crack path in 8090 tested in plain fatigue.

Fretting has a very considerable effect on the initiation of a fatigue crack due to the local high strain fatigue in the contact region arising from the alternating friction force. The region of the S-N curve which is most influenced by crack initiation is the high-cycle region and, as a consequence, the S-N curves show a greater divergence between the plain fatigue and fretting-fatigue situation at large numbers of cycles. This is the case in both the 8090 and the 7010 alloys, although the fretting-fatigue properties are considerably lower in 7010 especially in the high-cycle region (compare figs. 2 and 3).

Shot peening has improved the fatigue and fretting fatigue properties of both alloys and this is the result of compressive stresses generated in the surface of the sample and the production of a heavily deformed surface layer. Fig. 6 shows the subsurface stress pattern produced by the heavy 8-10C shot peening. The peak compressive stress in both alloys occurs at a depth of 0.2mm, and the compressive layer extends approximately 0.7mm below the surface. The residual stress level appears to be somewhat lower in the case of 8090 alloy.

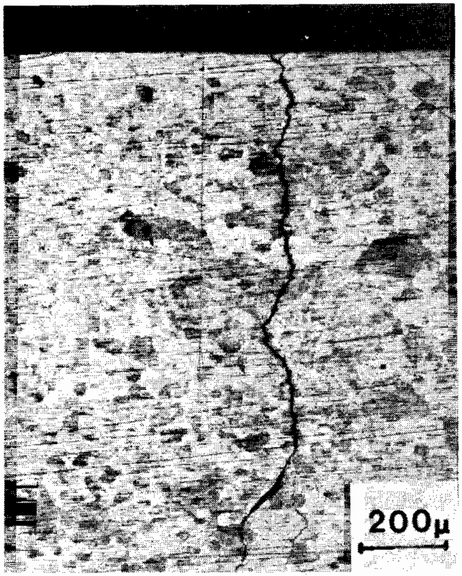

Fig. 5. Crack path in 7010 tested in plain fatigue.

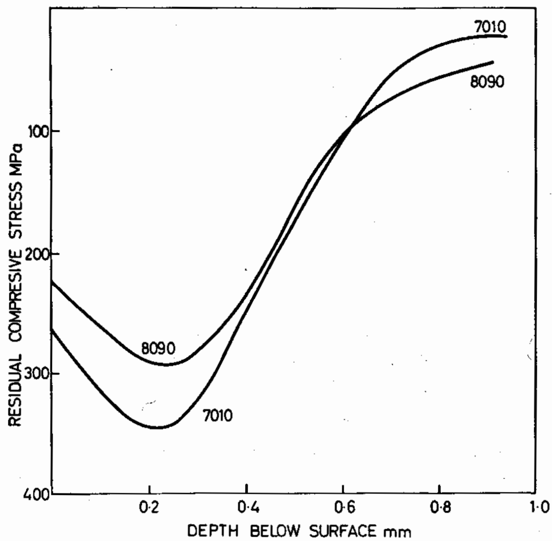

Fig. 6. Distribution of the residual compressive stress below the surfaces of 8090 and 7010 alloys.

Fig. 7 shows the extent of the heavily deformed surface layers in a shot peened 8090 alloy. Here the alloy has been heated for a short period at 250°C in order to decorate the slip bands with $S(Al_2CuMg)$ precipitates. This then enables measurement of the depth to which heavy plastic deformation has occurred during peening; in 8090 alloy shot peened to 8-10C the depth of deformation is 0.23mm.

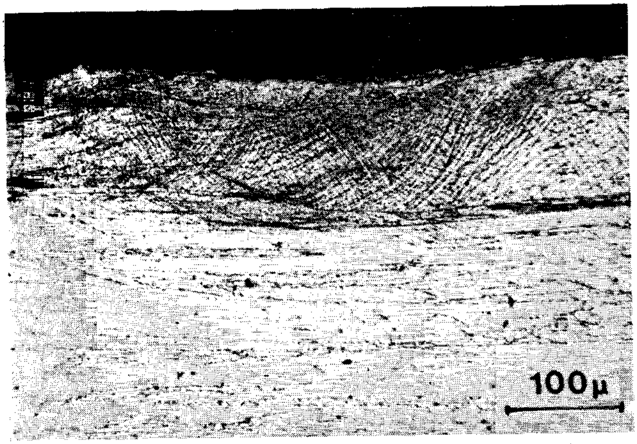

Fig. 7. Heavily deformed surface layers of shot-peened (8-10C) 8090 alloy.

The effect of shot peening on the fatigue behaviour has been to raise the plain fatigue and fretting fatigue curves to the same level. A similar effect has previously been observed on 7075 alloy (7). This means that, in the shot peened condition, the alloys are relatively insensitive to a fretting action at their surfaces. However, shot-peening has produced less improvement in the fatigue strength of the 8090 alloy. This may in part be due to the lower compressive stress induced in this alloy. The effectiveness of shot-peening on aluminium alloys has been related to the depth of the plastified layer (8). This is likely to be somewhat less in 8090 compared with 7010 because of the higher proof stress and lower elongation.

In the case of the 8090 alloy the effect of shot peening on fatigue and fretting fatigue is most pronounced under conditions of high-cycle fatigue, but has very little effect at low-cycle fatigue. The reason for this is probably because the surface layers of 8090 are heavily deformed during shot peening (as in fig. 7) and this will stop fatigue cracks following the slip planes and hence prevent the faceted fracture surface. This then eliminates early closure during the unloading part of the fatigue cycle and hence speeds up fatigue crack growth, nullifying the effect of the compressive stress at the surface. A similar effect in 8090 has been noted (9) during a study of the crack initiation and propagation rate in notched samples subjected to plain bending.

Conclusions

1. Fretting produces reductions in fatigue strength of 50% in both 8090 and 7010 alloys.

2. Shot peening improves the fatigue strength of both alloys bringing it to a common level in both plain and fretting-fatigue.

3. Shot peening has less effect on the low cycle fatigue and fretting-fatigue strength of 8090 because of the disruption of the microstructure by the heavy surface deformation.

Acknowledgement

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