FATIGUE, FRACTURE AND MICROSTRUCTURE RELATIONSHIPS OF AN ALUMINIUM AUTOMOBILE COMPONENT

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The aim of this work is to investigate relationships between mechanical properties and microstructure, i.e. the grain size and morphology in a cold forged AlMgSi automobile component. Different thermal treatments and deformation procedures are employed to vary the grain structure. The non-recrystallized fiber structure has better properties than recrystallized coarse grained microstructures. It is concluded that the processing of forged aluminium automobile components demands extensive knowledge of the interdependence between alloy composition, thermal treatments, particle and precipitate structures and deformation procedures.

INTRODUCTION

Aluminium alloys are progressively used in the automobile industry due to several advantages such as low specific weight, good formability, good corrosion resistance and a nice surface appearance. The standard production forming processes such as extrusion and forging, can give rise to large variations in the tensile, fatigue and fracture properties. In AlMgSi alloys yield stress have been shown to have only a weak dependence on grain size, i.e. Lohne and Næss (1). However, a large part of the variations in other properties can be traced back to differences in grain size. The aim of this work is to investigate the influence of the grain structure morphology on mechanical properties of a commercially produced AlMgSi automobile component and further, to compare these results with the properties of different grain structures produced in the laboratory.

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EXPERIMENTAL PROCEDURE

Production of Universal Joints

Cold forged products are strong, tolerances are tight and strength/ductility can be optimized by tempering. In the present work, joints having different grain morphologies are made from two conditions of alloy AA 6082: Alloy A which is rich in Mg and the low Mg containing alloy B also specified with Cr. Three different forging and heat treatments are employed to obtain different grain structures in the alloy A (Series 1-3). The alloy B series is similarly produced as Series 1 of the alloy A. All series are artificially aged to the T6 condition. After forging the joints are machined to the shown geometry (Figure 1-a). A parallel set of joints is machined with a serrated attachment hole, Figure 1-b.

Characterization of joints

A thorough metallographic characterization is carried out in scanning (SEM) and transmission electron microscopes (TEM). Tensile specimens are taken from the joint arm, two specimens from each joint. Fatigue life tests are conducted at a fully reversed torsion moment of ± 70 Nm at 10 Hz in moist air environment.

Characterization of laboratory material

Additional laboratory investigations involve five different grain morphologies in the alloy A (T6 temper). Fatigue life is determined from 3-5 electropolished specimens of each condition at R=-1 and 20 Hz. Further, fracture toughness in terms of $K_{max'sr}$ is characterized by loading 9.5 mm diameter short rod specimens (W=14.5 mm, t = 0.2 mm) in a servohydraulic MTS machine. The specimen geometry and test performance is in accordance with the proposed ASTM standard (2).

RESULTS AND DISCUSSION

Fatigue and mechanical properties of universal joints

The alloy B series and Series 1 of the alloy A have a larger elongation at fracture (e_f) than the two other series (Table 1). The average fatigue life tends to be longer in Series 2 and 3 than in the other series. Joints having serrated attachment holes have the fatigue life lowered by a factor ranging between 2 and 14 when compared to the smooth hole geometry, and all fatigue cracks are initiated in serrations. An important observation is that the Series 2 and 3 and the alloy B microstructures all seem to be more notch sensitive with respect to fatigue than the Series 1. Furthermore, enhanced fatigue life of the relatively coarse grained joints with serrated holes (alloy B and Series 1), may be due to roughness induced crack closure reducing the crack driving

TABLE 1 - Mechanical Properties and Fatigue Life at 70Nm, R=-1, Aluminium Universal Joints. E-modulus 73 GPa.

Alloy	Series	Serration	$\sigma_{0.2}$ (MPa)	σ_{TS} (MPa)	e_f (%)	N_f (10^6 cycles)
A	1	No Yes	332	352	11	1.0 +/- 0.4** 0.4 +/- 0.3
A	2	No Yes	325	330	6	1.5 +/- 0.6* 0.1 +/- 0.02*
A	3	No Yes	328	334	8	1.6 +/- 0.7 0.2 +/- 0.09
B	-	No Yes	321	352	12	1.4 +/- 0.2** 0.2 +/- 0.08

* 2 samples
** 5 samples

force, i.e. Suresh and Ritchie (3). Alloys with precipitate free zones (PFZs), as with the alloy B and Series 1, have been shown to generate higher closure levels than alloys without PFZs, i.e. Roven and Starke (4).

Microstructure of universal joints

The most significant variation in the microstructure due to changes in the heat treatment/deformation procedure is in the grain structure morphology, Figure 2. Series 1 of the alloy A has a partly elongated recrystallized structure, i.e. 40 μm high vs. 60 μm long. Series 2 and 3 are both unrecrystallized having a short and a long fiber-shaped structure respectively. The alloy B series has a recrystallized almost equiaxed grain structure, ~ 140 μm in diameter.

SEM particle analyses show that the alloy B series has less of the small (~ 1 μm) and significantly more of the coarse (> 5 μm) particles than Series 1. This can contribute to the formation of a coarse grain structure in the alloy B, i.e. Humphreys (5).

TEM studies show that Series 2 and 3 have both a higher dislocation density and a coarser precipitate structure than Series 1, i.e. slightly overaged. These two facts may govern the lower tensile ductility and the increased fatigue notch sensibility in the Series 2 and 3.

Correlation to laboratory material data

The tensile and fracture properties of the five laboratory conditions are shown in Table 2. The morphologies (ii), (iii) and (iv) correspond respectively to the grain structures of the alloy B, Series 1 and Series 2/Series 3. In general, the laboratory materials show better tensile properties than the joints. Taking into account the observed coarse precipitate structures in the joints, i.e. Series 2 and 3, the lower strength and ductility of these joints are probably due to overaging effects.

TABLE 2 - Tensile Properties and Short Rod Fracture Toughness ($K_{max'sr}$) of the five Grain Morphologies of the Alloy A. (Here: rex. = recrystallized).

Grain structure	$\sigma_{0.2}$ (MPa)	σ_{TS} (MPa)	e_f (%)	$K_{max'sr}$ $MPam^{1/2}$
(i) Rex. columnar	273 +/- 3	342 +/- 3	12 +/- 1	34 +/- 1
(ii) Rex. 200 μm	332 +/- 3	365 +/- 3	12 +/- 1	35 +/- 1
(iii) Rex. 50 μm	330 +/- 3	360 +/- 3	19 +/- 1	29 +/- 1
(iv) Non-rex. fiber	341 +/- 3	366 +/- 3	16 +/- 1	40 +/- 1
(v) Deformed fiber	344 +/- 3	385 +/- 3	16 +/- 1	27 +/- 1

As seen from Table 2, the non-recrystallized fiber structure has the highest fracture toughness. Further, the recrystallized (50 μm) and the deformed fiber structure shows a significantly lower $K_{max'sr}$-value than the undeformed fiber structure.

From the smooth specimen S-N curves of the five laboratory conditions, Figure 3, it is easily seen that the non-recrystallized fiber structure has better fatigue resistance than the recrystallized structure. This is in agreement with the fatigue life data of the joints, Table 1.

CONCLUSIONS

- The non-recrystallized fiber structure has better fatigue resistance and fracture toughness than recrystallized coarse grained microstructures.
- Processing cold forged/extruded aluminium automobile components with a property optimized microstructure demands extensive knowledge of the interdependence between alloy composition, thermal treatments, particle and precipitate structures and the deformation procedure.

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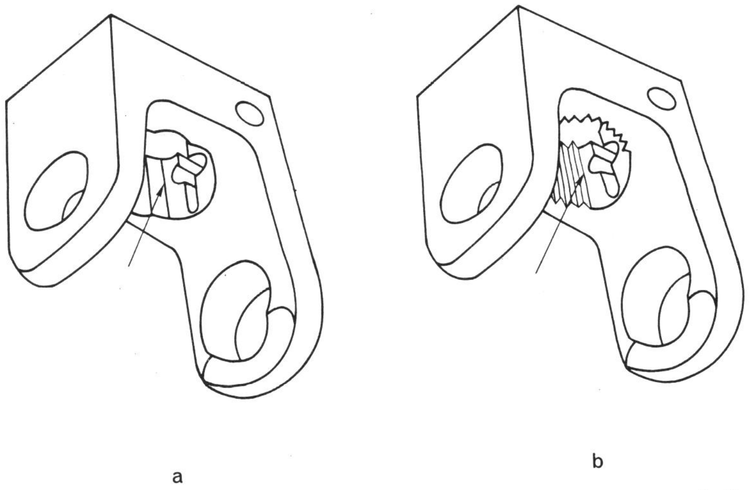

Figure 1. Sketch of cold forged AlMgSi universal joint; a) Smooth attachment hole and b) Serrated attachment hole.

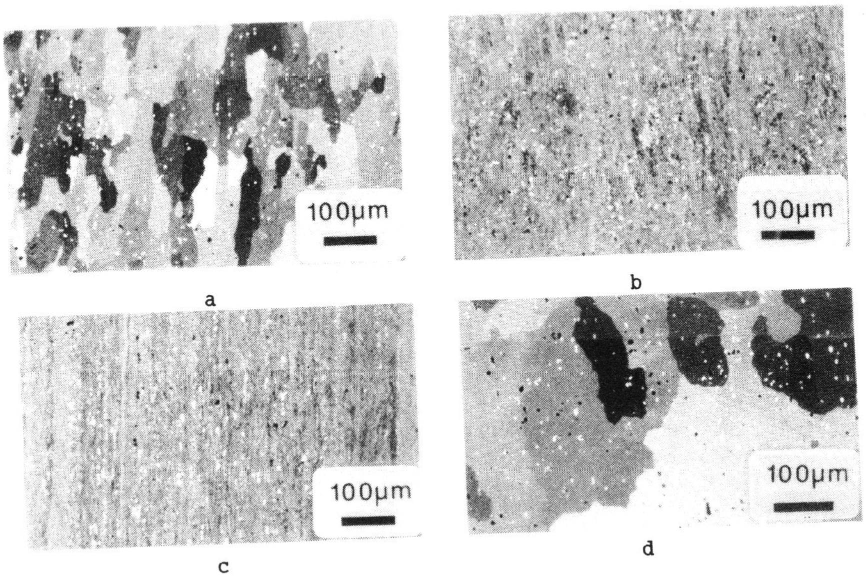

Figure 2. Grain structure in AlMgSi universal joints a) Series 1, b) Series 2, c) Series 3, all of the alloy A and d) alloy B.

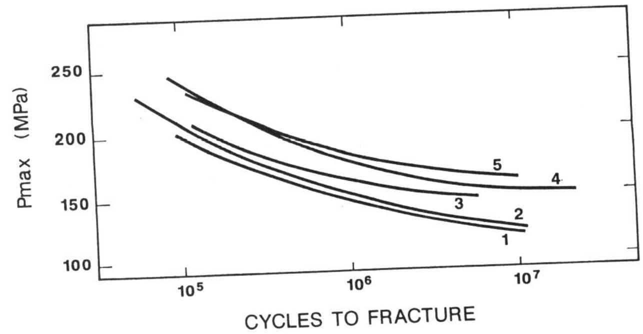

Figure 3. Smooth specimen fatigue life curves for the laboratory conditions of the alloy A showing the effect of grain morphology (AlMgSi alloy AA6082). 1: Recrystallized columnar, 2: Recrystallized 200 μm 3: Recrystallized 50 μm 4: Non-recrystallized, fiber and 5: Deformed fiber structure