INFLUENCE OF PRE-STRAIN ON FATIGUE STRENGTH OF SQUEEZE CAST AL-ALLOY

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ABSTRACT: *The influence of tensile pre-strain on the fatigue strength of a squeeze cast aluminum alloy cut out from a car wheel was investigated under rotating bending through the successive observations of the specimen surface by the plastic replication method. A crack was initiated from either surface slip bands or at an interface between eutectic Si particles and the matrix but was suppressed by eutectic Si particles in the materials without pre-strain.With tensile pre-strain, cracking or weakening occurred at an interface between eutectic Si particles and the matrix, and consequently the initiation of a fatigue crack was accelerated. However, the propagation process of a longer crack was suppressed by pre-strain.*

INTRODUCTION

Recently, aluminum cast products have been widely used in engineering structures and mechanical components, including industrial machines, airplanes and automobiles, because of their excellent qualities such as high productivity, cost efficiency, recyclability and being light in weight [1]. Moreover, aluminum diecasting technology has been dramatically improved to produce high quality castings, among which squeeze casting can achieve excellent mechanical properties, derived from its capability to suppress porosity and refine the microstructure [2-6]. Applications of squeeze cast aluminum have been increasing to a wide variety of products, which include large automobile parts such as cross members and heavy-duty large wheels. To apply aluminum cast products to these fields, the evaluation of fatigue properties is essential in designing reliable parts. For example, it is very important to clarify the influence of unexpected loads on the fatigue strength, because wheels often experience overload, mean stress or impact loads.

In this study, rotating bending fatigue tests were carried out for a squeeze cast aluminum alloy to investigate the influence of tensile pre-strain on fatigue strength of the alloy. Specimens were cut out from large wheels of a truck.

MATERIAL AND EXPERIMENTAL PROCEDURES

The material used was an aluminum cast alloy JIS AC4CH whose chemical composition was 7.02 Si, 0.08 Fe, 0.37 Mg, 0.12 Ti and remainder Al. The material was squeeze cast to large wheels for a truck as shown in Figure 1 by a vertical squeeze casting machine under the molten metal temperature of 1050 K and injection speed between 50 mm/sec and 80 mm/sec. Then the castings were heat treated under T6 conditions (solution and aging treatment). Mean dendrite arm spacing was about 30μm.

The mechanical properties are shown in Table 1. The tensile specimens for pre-strain tests were cut out from the wheel disc as shown in Figure 1 and machined to 10mm diameter. Then specimens for fatigue tests were machined after giving a tensile pre-strain of 0, 5, 10 % to the tensile specimens. Figure 2 shows the shape and dimensions of fatigue specimens. Prior to fatigue tests, all the specimens were electro-polished with about 20 μm taken from the surface to remove the work-hardened layer and make the observation of surface state of specimen easier. The observations of the surface state were carried out using a plastic replication method. The crack length was observed on the replica and measured in the circumferential direction of the specimen. The fatigue tests were carried out using the Ono type rotating bending machine with 15 N•m capacity at 50 Hz.

Table 1: Mechanical properties

Material	Pre-strain %	$\sigma_{0.2}$ MPa	σ_B MPa	σ_T MPa	ψ %
AC4CH	0	223	275	388	32.5
	5	301	308	375	19.7
	10	266	302	383	15.4

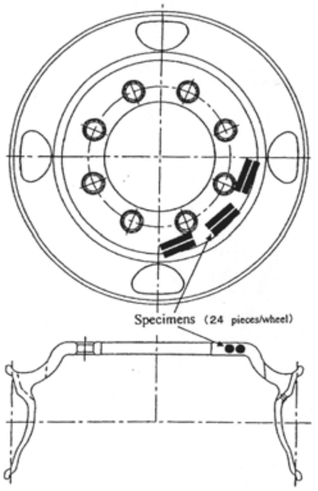


Figure 1: Wheel shape and specimens location

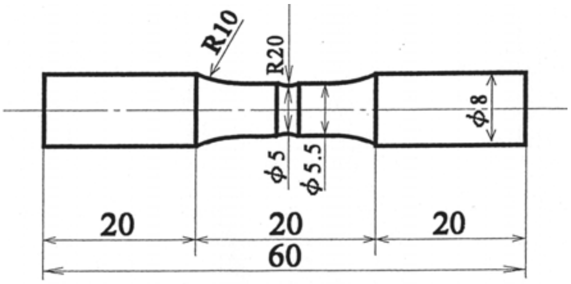


Figure 2: Shape and dimensions of specimen

EXPERIMENTAL RESULTS AND DISCUSSION

Figure 3 presents SEM photographs showing cracks initiated in specimens without pre-strain. Cracks initiate from surface slip bands or at an interface between eutectic Si particles and the matrix. Figure 4 shows the influence of microstructure on crack growth in a non-pre-strained specimen. The crack is delayed in propagation at the eutectic Si particles. Thus, the presence of eutectic Si particles in a cast aluminum alloy has a significant effect in both the processes of initiation and propagation of a crack.

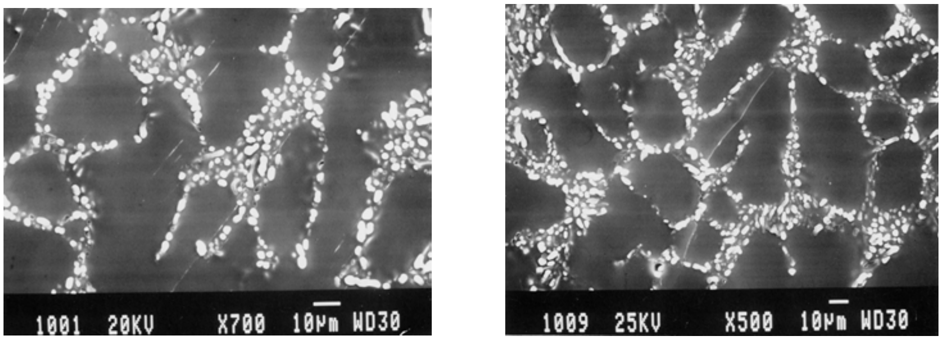


Figure 3: Crack initiation.

Figure 5 shows S-N curves. Fatigue strength is only a little or not at all influenced by tensile pre-strain.

Figure 6 shows crack growth curves. The crack initiation and early propagation processes are accelerated but the crack growth rate of a longer crack e.g. over 0.5 mm is suppressed by tensile pre-strain. These influences are most marked in large pre-strain specimens.

Figure 7 shows the change in surface state of a specimen due to the fatigue process. In general, pre-strained metals soften due to stress repetitions [7-9]. However, this aluminum alloy originally has a cyclic softening property irrespective of pre-strain [10,11], and a region, once slipped, can glide more easily. As stated before,

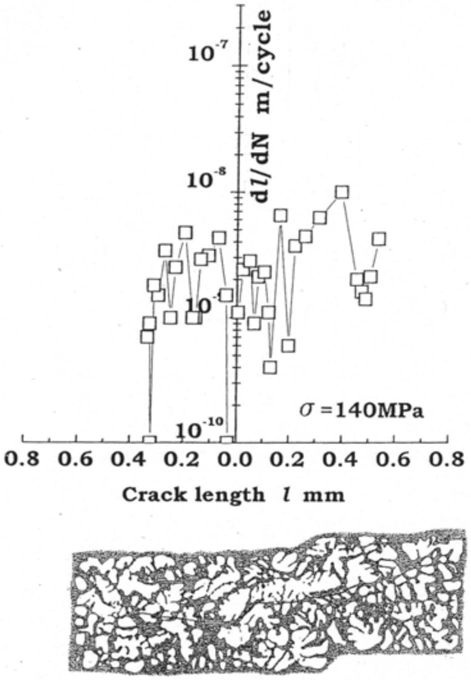


Figure 4: Influence of microstructure on crack growth.

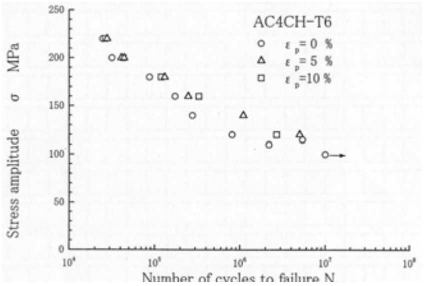


Figure 5: S-N curves

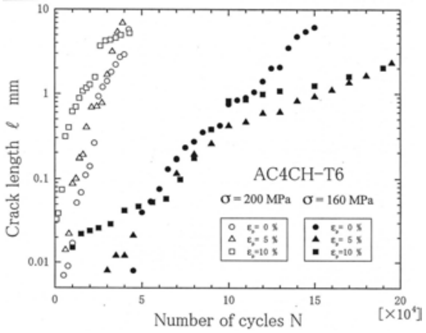
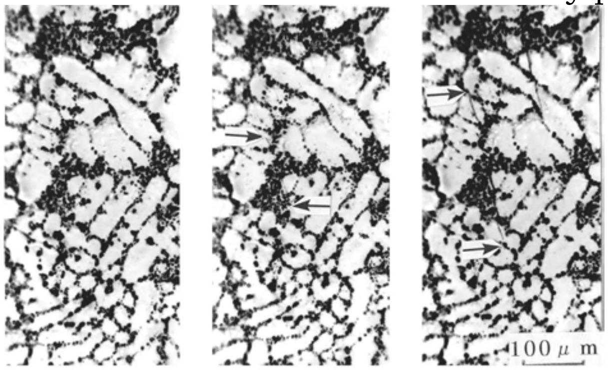


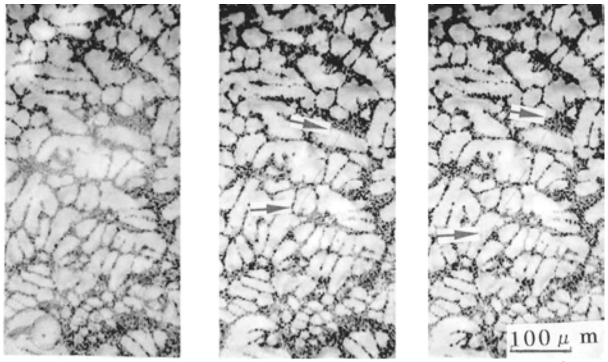
Figure 6: Crack growth curves

a crack often initiates at eutectic Si particles in the cast aluminum alloy. A smaller crack propagates along the slip bands until the crack develops to a certain length. During this stage, the crack often propagates in a shear direction and in a zigzag manner. There is only a little or no influence at all of tensile pre-strain on such feature as far as the specimen surface was observed. However, as stated before, cracks of the cast aluminum alloy initiate at a colony of eutectic Si particles in most cases. This was observed irrespective of pre-strain. This fact suggests that the assembled state of eutectic Si particles may be affected by tensile pre-strain and be the cause of the acceleration of crack initiation and its early propagation.



N=0 cycle 7×10^4 7.5×10^4

(a) Pre-strain 0 % (σ=160MPa, N_f=3.4x10^5)

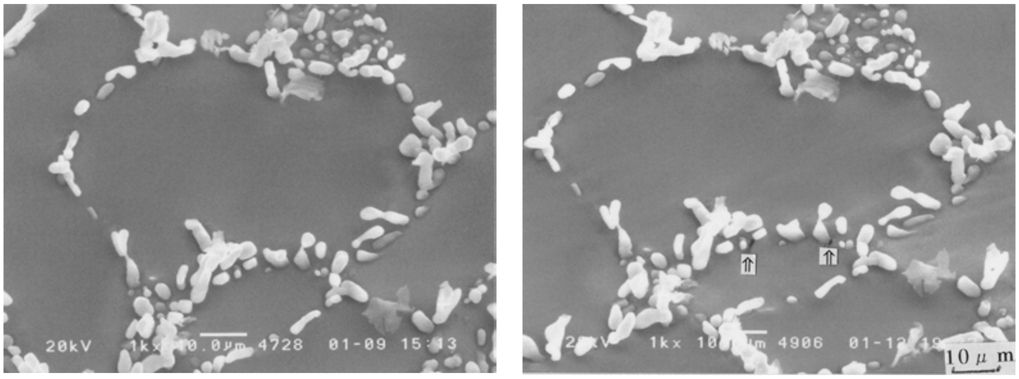


N=0 cycle 2.2×10^4 4.8×10^4

(b) Pre-strain 10 % (σ=160MPa, N_f=4.6x10^5)

Figure 7: Change in surface states due to stress repetitions.

Figure 8 shows the change in surface state of a tensile specimen following tensile pre-strain. This specimen was machined and electro-polished and then pre-strained by about 10% to make the observation of the influence of tensile pre-strain on the assembled state of eutectic Si particles easier. Cracking of the interface between eutectic Si particles and the matrix is observed (see ⇑). That is, the interface is cracked or weakened by tensile pre-strain. This may be the main reason for the acceleration of the initiation and early propagation phases of a fatigue crack due to tensile pre-strain. These results point out that great attention must be paid to unexpected large loads such as overload, impact load and so on in practical applications of cast aluminum alloys. The suppression of crack growth due to pre-strain may be caused by work hardening. The reason for a limited influence of weakening of the interface on the process of crack growth is that the crack mainly propagated through the matrix that was work-hardened as seen from Fig.6.



(a) Before pre-strain (b) After pre-strain

Figure 8: Cracking pre-strain effects.

CONCLUSIONS

1. A crack tended to initiate at the colony of eutectic Si particles but these obstructed to propagation.
2. Fatigue strength was only a little or not at all influenced by tensile pre-strain.
3. Crack initiation and early propagation were accelerated by tensile pre-strain.
4. The growth of a longer crack was suppressed by tensile pre-strain.
5. The interface between a colony of eutectic Si particles and the matrix was cracked or weakened by tensile pre-strain. This is the main reason for the Conclusion 3.

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