FATIGUE CRACK GROWTH IN SiC-PARTICULATE-REINFORCED CAST ALUMINIUM ALLOY COMPOSITES

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ABSTRACT

Fatigue crack growth tests have been performed in squeeze cast, permanent mould cast or sand cast SiC particulate-reinforced A356 cast aluminium alloy composites. Effects of volume fraction and distribution of the SiC particles, morphology of eutectic Si particles and matrix ageing conditions on fatigue crack growth rates were investigated. Fatigue crack growth rates of the squeeze cast composite were comparable to those of the monolithic alloy. Slight improvement in the threshold levels was obtained in the composite. It was found that the eutectic Si particle played a dominant role in determining the fatigue crack growth behaviour of the composite as well as of the monolithic alloy.

1. Introduction

Metal matrix composites reinforced with ceramic particles have attracted a lot of metallurgists' and mechanical engineers' interests in recent years. Among those SiC particulate-reinforced aluminium alloys have been the most attractive composite because of their practical and economical benefits. Difficulty in machining of such composites to a final product, however, still remain as an obstacle to their industrial application, although conventional secondary mechanical and metallurgical fabrication routes, such as a rolling, extrusion and ageing have been applicable to the composites.

Cast aluminium alloys reinforced with SiC particles for net-shape forming have emerged as a solution to such a problem. Accordingly the cast composite will be the most promising candidate as a replacement of conventional ferrous and aluminium cast alloys for automobile usage.

Fatigue is of critical in such applications. Effects of microstructure and heat treatment on fatigue properties should be examined in order to get the optimized fatigue resistance. However, limited studies have been done on fatigue properties not only of the cast composite but also of the conventional cast aluminium alloys[1-3]. Therefore systematic researches are required on both the composite and the monolithic cast alloys.

The present paper has briefly summarized authors' recent experimental studies concerning fatigue crack growth in SiC particulate-reinforced cast aluminium alloys[4-6].

2. Materials, ageing and tensile properties

Microstructure

Cast A356 aluminium alloys reinforced with 10% or 20% SiC particles (DURALCAN) were used in the present study. The composite was supplied in the form of foundry ingot from the Alcan Asia Ltd.. Ingots were remelted under an Ar gas atmosphere and cast using various casting procedures : squeeze cast, permanent mould cast and sand cast, in order to obtain specimens with different SiC particle distribution.

Monolithic A356 aluminium alloys (comparable to the JIS AC4CH) were also produced in the same manner as a control alloy. Modification of eutectic Si particles was applied to some alloys with the 100ppm Sr addition.

Figure 1 shows microstructures of A356-10%SiC alloys cast at various conditions. For the squeeze cast composite (SQ), a large cooling rate and an applied pressure during solidification process (100MPa) provided fine dendritic cell structure and consequently homogeneous SiC particle distribution. While in the sand cast composite (S) SiC particles distributed delineating coarse dendritic cell structure and formed a characteristic net-work particle distribution. Coarse and irregular shaped eutectic Si particles were also observed in the sand cast composite due to their freezing process at small cooling rates. Permanent mould cast composite (P) exhibited an intermediate microstructural feature.

Ageing response

Both the composite and the monolithic alloys were homogenized at 520°C for 8h. After holding at room temperature for 24h the alloys were aged at 160°C for various times. Hardness measurements were made using two kinds of the applied load level. Global hardness measurement encompassing distributed SiC particles and the matrix was performed using a Vickers hardness tester with a 10kgf load. Micro-vickers hardness measurement of the matrix phase was made with a 5gf load in order to exclude the influence of SiC and eutectic Si particles. Comparable ageing responses were obtained for the three alloys exhibiting the peak hardness at about 20h as shown in Fig.2.

Tensile properties

Tensile tests were made using round bar specimens. Tensile properties of the three squeeze cast alloys at peak aged condition (20h) are summarized in Table 1. The 20 and 40% increase in elastic modulus were obtained in 10% and 20%SiC composite, respectively compared to the monolithic alloy. Yield stress values were also increased by 12% and 15% in 10%SiC and 20%SiC composite, respectively. A large decrease in elongation was obtained for 20%SiC composite, and this resulted in the lower UTS value in 20%SiC than that of 10%SiC composite.

TABLE I Tensile properties of the composites.

Material	E (GPa)	$\sigma_{0.2}$ (MPa)	UTS (MPa)	δ (%)
A356	70.4	247	297	7.6
A356-10%SiC	85.3	279	315	2.4
A356-20%SiC	96.9	284	292	0.3

Change in 0.2% yield stress, UTS and elongation against ageing time in squeeze cast A356-10%SiC composite are shown in Fig.3. Elongation values decrease as increasing the ageing time. Specimens aged for 2, 20 and 96h are called UA (Under-Aged), PA (Peak-Aged) and OA (Over-Aged), respectively in the rest part of the present paper.

3. Fatigue crack growth behaviour

Fatigue crack growth tests

Fatigue crack growth tests were performed using CT specimens (W=30mm, B=8.5mm) under constant load condition at room temperature at a stress ratio of 0.1 and a testing frequency of 10Hz. Load shedding techniques was also used for crack growth rate measurements at low ΔK ranges.

Effects of SiC particle volume fraction

Fatigue crack growth rates(da/dN) for the two composites and the monolithic alloy fabricated by squeeze casting are shown as a function of stress intensity range(ΔK) in Fig. 4. All materials exhibit similar sigmoidal fatigue crack growth characteristics. At near threshold growth rates both composites exhibited lower growth rates compared to the monolithic alloy. In the linear growth regime (Paris regime), values of the exponent 'm' of the Paris equation ($da/dN=C(\Delta K)^m$, where C is a constant) increased with SiC particle volume fraction. Acceleration of the crack growth rate took place at lower ΔK values in the monolithic alloy than two composites. Many previous studies reported that, in the fast crack growth regime, composites normally fail at lower K_{max} (ΔK) compared to the monolithic alloy. However, this trend was not the case in the present study. This resulted from the effect of eutectic Si particles as subsequently discussed.

Effect of eutectic Si particle morphology

The eutectic Si particles in the homogenized monolithic alloy exhibited needle like morphology. This was in contrast to the spherical morphology of the eutectic Si particles in the composite. The coarse needle like eutectic Si particles act as areas of stress concentration resulting in both debonding at the particle-matrix interface, and even cracking of the particle itself. These particles are considered to promote void formation which accelerates the fatigue crack growth rates. While, in the composite, despite the large volume fraction of SiC particles both the SiC and eutectic Si particles have spherical morphology. Therefore it is considered that the enhanced void formation in the monolithic alloy due to the coarse and needle like eutectic Si particles provided the faster growth rates at the high ΔK range. It was also demonstrated that spherodizing or refining of the eutectic Si particles in the monolithic alloy by either (i) increased homogenization temperature or (ii) Sr addition to the alloy, resulted in improved fatigue crack growth resistance at high ΔK range, as shown in Fig.5.

Effect of ageing condition

Effect of ageing condition on the fatigue crack growth was examined using the squeeze cast A356-10%SiC composite. The da/dN-ΔK curves for three ageing conditions are shown in Fig.6. Comparable crack growth rates were exhibited at the threshold regime. The exponent m in the Paris regime increased with matrix strength levels (UA<OA<PA). While, at high ΔK regime acceleration of the crack growth rate took place as decreasing ductility(UA>PA>OA). SEM observations of fatigue surfaces found the evidence of little striation formation. Fatigue surface was covered with step-like morphology and damaged SiC and eutectic Si particles. Number of fractured SiC particles increased with applied ΔK in the three ageing conditions. The number of the fractured SiC particles, however, was less observed for the UA condition compared to the PA and OA conditions. Instead, decohered eutectic Si particles were evident in the UA condition.

Fatigue crack growth rates of the composites in the three ageing conditions are compared with those of the monolithic alloys in Fig.7. The fatigue crack growth resistance of the composite were generally comparable to the monolithic alloys. The composite showed improved fatigue crack growth resistance near threshold levels.

Effect of SiC particle distribution

Fatigue crack growth rates of the three composites fabricated by different casting procedures are compared in Fig.8. Similar crack growth rates were observed in the squeeze cast and the permanent mould cast composite due to their similar SiC particle distribution. While, the sand cast composite exhibited faster crack growth rates than the squeeze cast composite. The SiC particles formed a network structure of high density SiC particles. Such segregated SiC particle distribution might provide the preferential crack growth path and result in the accelerated fatigue crack growth rates.

However, the particle distribution is not only the factor producing the difference between the sand cast composite and the others. The sand cast composite include coarse and irregular-shaped eutectic Si particles. Voids and cast shrinkages were also observed in the composite. These coarse eutectic Si particles and casting defects may also increase the fatigue crack growth rate. Therefore further studies are required using the microstructurally controlled specimens in order to separate the effects of those factors.

4. Concluding remarks

Effects of microstructure and matrix ageing condition on fatigue crack growth was examined in SiC particulate-reinforced cast aluminium alloy composites. In general, squeeze cast composites exhibit comparable fatigue crack growth rates to the monolithic alloy with a slight improvement in the threshold level. Significant influence of the eutectic Si morphology is demonstrated. Further systematic studies using more precisely microstructurally controlled materials are required in order to clarify fatigue crack growth behaviour of the cast composite.

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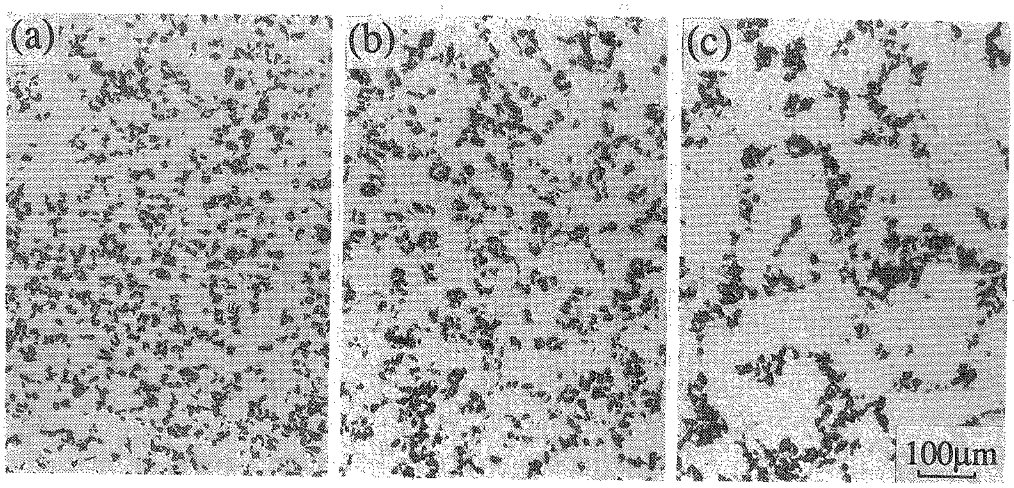

Fig.1 Optical micrographs of A356-10%SiC alloys cast at various conditions.
(a) Squeeze cast, (b) Permanent mould cast, (c) Sand cast

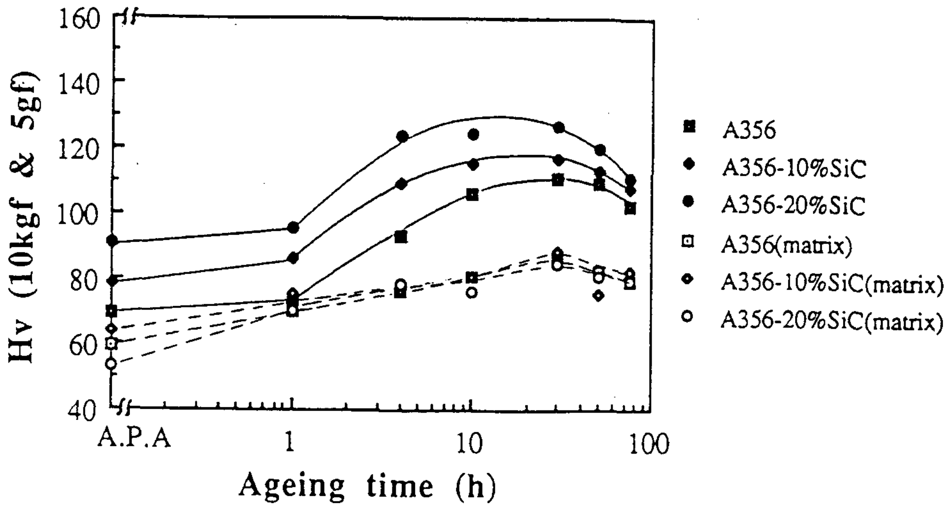

Fig.2 Age hardening curves for the monolithic and composite alloys. (Room temperature ageing for 24h followed by isothermal ageing at 160°C) [4]

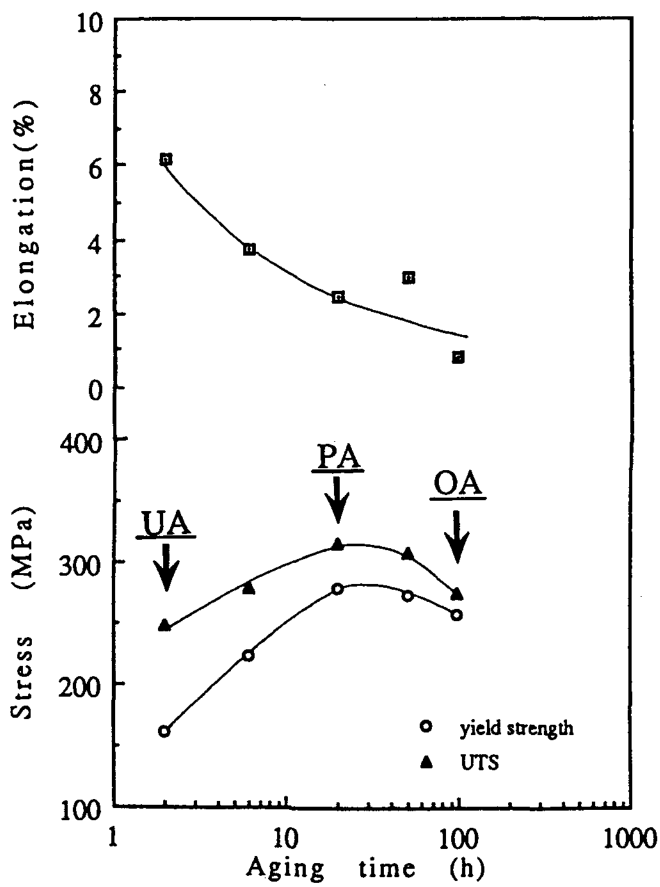

Fig.3 Effect of ageing time on tensile properties of A356-10%SiC alloys. [5]

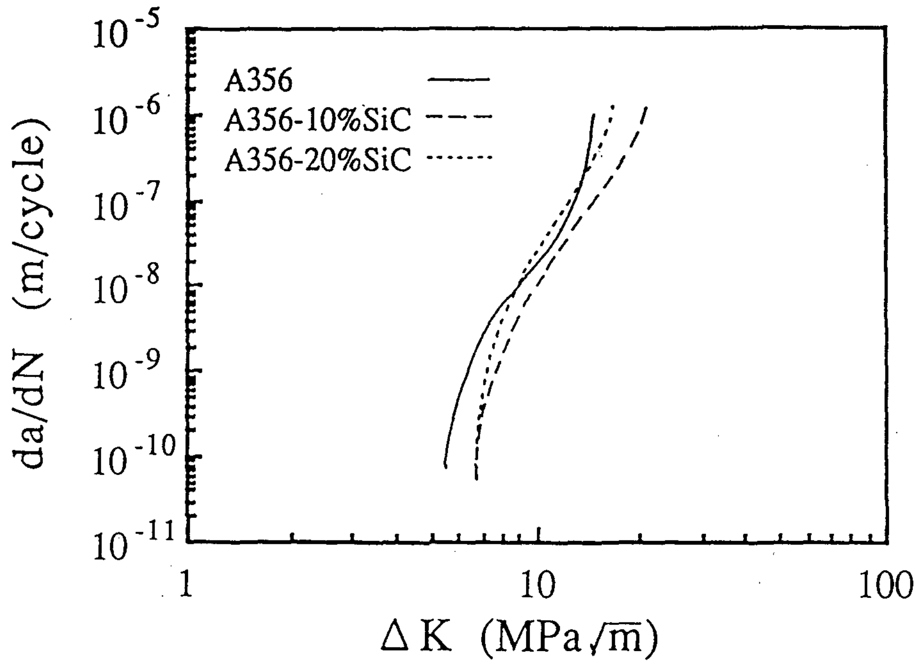

Fig.4 Fatigue crack growth rates for the two composites and the monolithic alloy fabricated by squeeze casting. [6]

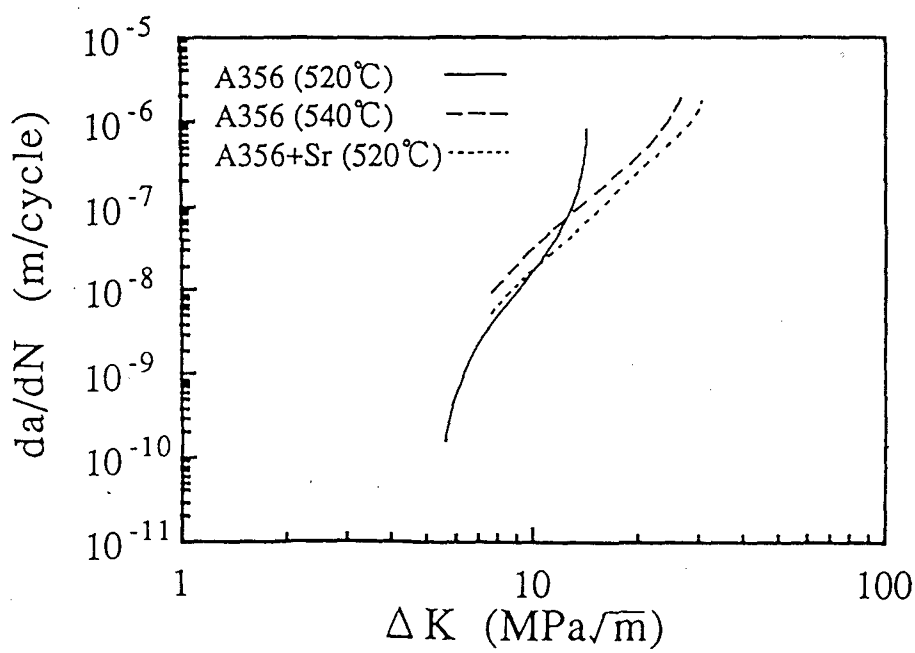

Fig.5 Effect of eutectic Si particle morphology on the fatigue crack growth rates. [6]

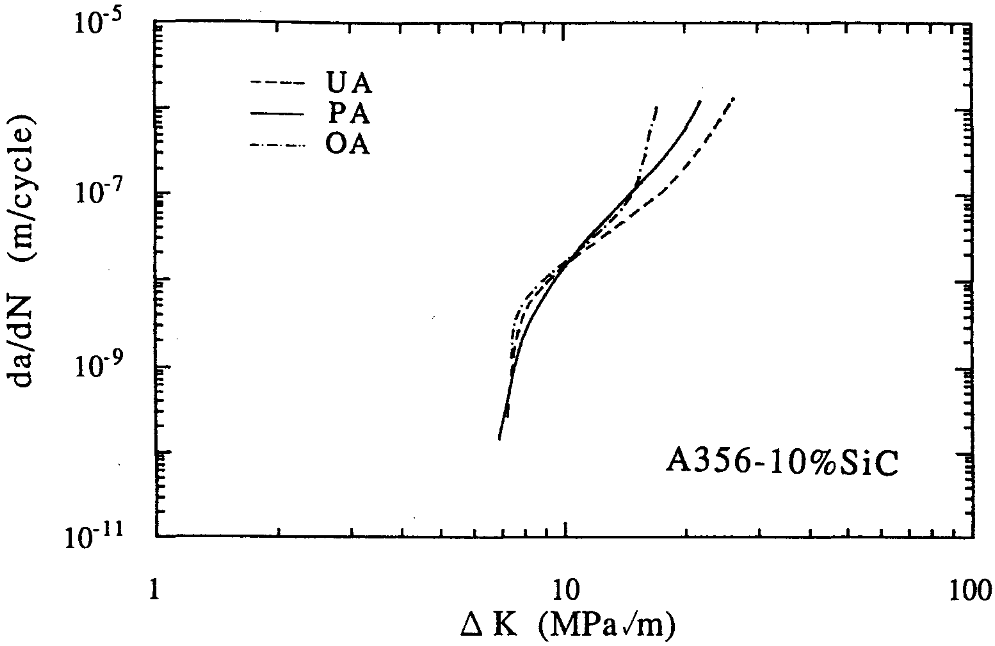

Fig.6 Effect of ageing condition on the fatigue crack growth rates in the squeeze cast A356-10%SiC alloys.

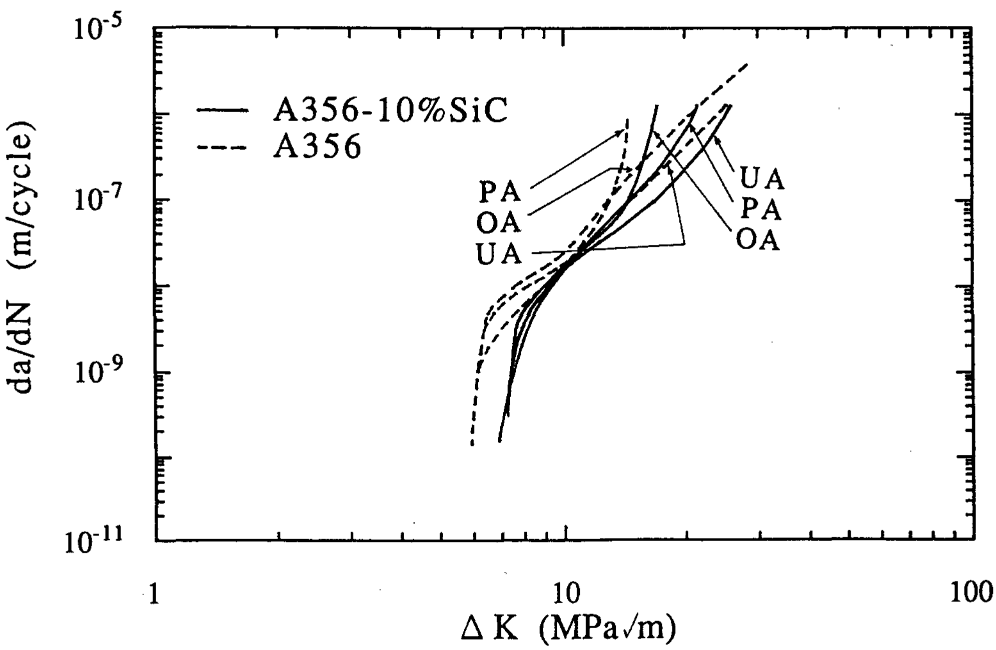

Fig.7 Comparison of the fatigue crack growth rates between A356-10%SiC and A356 monolithic alloy.

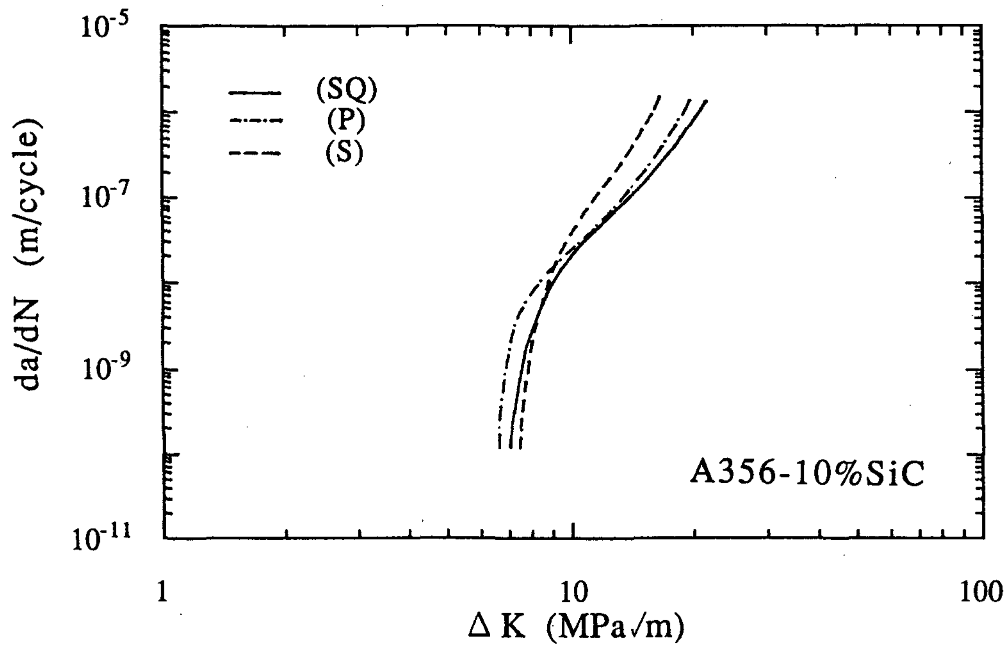

Fig.8 Fatigue crack growth rates of the three composites fabricated by different casting procedures.