FATIGUE BEHAVIOUR OF AL/SiC FIBERS COMPOSITES PRODUCED BY SQUEEZE CASTING TECHNIQUE

A.M.ABO EL-AINENE

Prod. Eng. & Mach. Design Dept., Faculty Of Engineering ,
Menoufia University Shebin El-Kom, Egypt.

ABSTRACT

In the present work, the fatigue behaviour of pure aluminium reinforced with SiC fibers composite has been investigated. The composite was fabricated by squeeze casting technique with different values of fibers volume fraction V_f. Rotating bending fatigue test was used to compare the fatigue strength of the composite with matrix material. Fatigue fracture furfaces of specimens were investigated by macroscopic and SEM observations.

The influence of volume fraction of fibers on the fatigue life was discussed. The obtained results showed that, in comparison with pure aluminium, the fatigue strength at 10^7 cycles of the composites is superior by 91.3% and 90.2% for $V_f = 45\%$ and $V_f = 35\%$, respectively. Fatigue crack does not propagate along the fibers-matrix interface, but propagates in the matrix. The fatigue strength ratio of SiC/Al composites indicated about 0.71.

1. INTRODUCTION

Fiber reinforced metal matrix composites are expected to achieve the weight saving and energy saving in the aerospace and automobile industries. Aluminium alloys are most useful candidate matrix materials for weight reduction . Carbon, boron, alumina, silicon carbide particles and

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fibers are universally admitted to be attractive reinforcement materials because of the high strength to weight and modules to weight ratios. Particularly, silicon carbide fibers have a prominent heat resistance, good compatibility with aluminium and high chemical stability [1-5]. However, SiC fiber reinforced aluminium matrix composites have not been extensively used in the commercial base yet, because of the lack of experimental data on its mechanical strength properties especially, no data is available today on the fatigue properties of these composites. So, the present work is concerned with the study of fatigue behaviour of squeeze casting of SiC fiber reinforced aluminium composite.

2- MATERIALS AND EXPERIMENTAL PROCEDURE

2-1 Fabrication of the Composites

A pure aluminium (99.7% commercial purity) was used as matrix material. Continuous SiC fiber having average diameter of 15 μm was used as a reinforcing fiber. SiC/Al composites were fabricated by the squeeze casting technique [6-8]. The process is that molten aluminium is forced to flow into a bundle of SiC fibers stacked (pre-heating of the fiber reinforced was carried out at 550°C) in a pre-heating die with a final pressure of 50 MP_a. The pressure is held for a duration of 90sec, on the metal until solidification is completed. The composite specimens, 20 mm diameter and 50 mm long, were obtained.

In the fabrication process, a trial was made to control a fiber volume fraction, V_f, of composites by means of varying total weight of fiber in the die, but, it was hard to control it, so that the composites with the fiber volume fraction scattered from 30 to 50 Vol. % were obtained. The reason of the scatter is that the fibers are arranged unidirectional without fixing each other so that each fiber bundle is squeezed to a different extent during composting process. So, SiC/Al composites obtained were classified into two groups of $30\% < V_f < 40\%$ and $40\% \leq Vf < 50\%$, and hereinafter referred to as $V_f = 35\%$ and $V_f = 45\%$, respectively. The fiber volume fraction of the composite was determined by photographic method, measuring both the fiber area and the matrix area in the cross section of the composites perpendicular to the fiber direction. A samples of pure Al (matrix) were processed by the same procedures route for comparison studies.

2-2 Mechanical Tests

2-2-1 Tensile Tests

In order to obtain the data of fatigue strength ratios of the composites to the matrix material (pure Al), the tensile tests were conducted on composites and pure Al specimens. Tensile specimens were machined mechanically from the final squeezed composites and pure Al. The specimens had a gauge diameter of 5 mm and a gauge length of 13 mm (according to BS 1987 and ASTM E8-896). The gauge length of specimens was parallel to the longitudinal axis of the casting. Tensile testing at room temperature was performed on an Instron testing M/C. A constant cross-head speed of 1 mm/min. was used.

2-2-2 Fatigue Tests

Fatigue tests were carried out at room temperature using hourglass-shaped specimens with a waist diameter of 4 mm. High-cycle fatigue tests were carried out at room temperature by using a cantilever type rotating bending fatigue testing machine at a frequency of 2800 R.P.M.

2-3 Metallographic Examination and SEM Fractography

The initial microstructure of the composites material was characterized by optical microscopy after standard metallographic preparation techniques, in order to investigate whether or not shrinkage holes or voids exists. The fracture surfaces of the tensile specimens (composites) were examined using JEOL scanning electron microscope, SEM, in order to check whether or not internal defects had existed at the time of fabrication. Also, fracture surfaces of the deformed fatigue specimens were examined using SEM and optical microscope, to determine the predominant fracture mode and to characterize the fine scale topography of the fatigue fracture surface.

3- RESULTS AND DISCUSSION

3-1 Microstructures of Composites

Figure (1) shows the microstructures of the composites. It appears that diameters of silicon carbide fibers scatter in the wide range of 10-20μm. It can be seen that neither voids or shrinkage holes were shown. The distribution of fibers was fairly uniform in the composites, and many contacts between fibers were observed.

3-2 Observations of Tensile Fractured Surfaces of the Composites

Figure (2) shows SEM Fractography of the tensile fracture surface of composite in which $V_f = 35\%$. In the low magnification micrograph (Fig. 2-a), it can be seen that the fracture surface is jagged. High magnification (Fig. 2-b) exhibts few fibers pull - out in the composite. Therefore, it is indicated that good fiber-matrix bond is achieved. Many of fiber failures are indicated at the contact points of fibers. It should be noted that the composite with $V_f = 45\%$ exhibited similar behaviour.

3-3 S-N Curves and Fatigue Strength Ratio

Figure (3) shows all the fatigue test results as the relation between the stress amplitude ,σ, and the number of cycles to failure, N, (S-N curves). From this figure, it is clear that the S-N curves of the composites decrease in the slope gradually beyond the cycles of about 10^6 numbers as well as of many metals, and the curves become almost horizontal at near 10^7 cycles. Additionally, the fatigue strength of composite with V_f=45% is higher than that of composite with V_f = 35%, and the fatigue strength of the investigated composites is superior to the matrix material.

Table (1) shows the fatigue strength at 10^7 cycles as the endurance limit of each material is taken, and the ratio of the fatigue strength to the ultimate tensile strength of the same tested material. According to this table, it is characterized that the SiC fiber reinforced aluminium composites has a high fatigue strength ratio cmpared with many metallic materials.

3-4 Influence of Volume Fraction of Fibers on the Fatigue Life

As mentioned before, the SiC/Al composites fabricated by the squeeze casting technique has some scatter of the fiber volume fraction. So, the relation between the volume fraction, V_f, and the fatigue life, N, might be obtained. In Fig.(4), the fatigue lives are plotted against the volume fraction of fiber under a given repeated stress of 310 MP_a. The figure includes the several plots which are reduced the plots within the stress level of 300 to 320 MP_a, to the plots under the given level of 310 MP_a by using the slope of the S-N curve as shown in Fig.(3). From Fig.(4), it seems that the fatigue life of the composite is remarkably affected by the volume fraction of fiber, namely, the fatigue life is increased nearly tenfold every a 10% V_f, while the fatigue life has some degree of scatter at a certain volume fraction. This may be due to the decreased in the repeated plastic strain in the matrix with the increase in the fiber volume fraction, based on the rule of mixture under a given stress.

3-5 Observations of Fatigue Fractured Surfaces

Figure (5) shows macroscopic photographs of SiC/Al composites specimen fractured by rotating bending fatigue test. It was observed that the composite specimen has a cylindrical fracture surface extruding toward the fixed end side (Fig. 5-a), while the matrix specimen (pure Al) has an almost flat fractre surface (Fig. 5-b). Therefore, the fracture configuration is one of the characteristic features which is met when a rotating bending stress is applied to the hourglass type of specimen reinforced by the continuous fiber.

Figure (6) shows the SEM micrographs of the fatigue fractured surfaces for SiC/Al composites. Figs. (6-a) and (6-b) show the fracture surface formed by the propagation of fatigue crack, and formed by the static fracture through the final fractured area, respectively. As declared, the fatigue crack propagated surface is almost plane, and has no pull out of fibers encountered. The matrix surrounding the fibers seems to be torn to a small pieces and no striation has been observed on it (Fig. 6-a). On the contrary, there are plenty of ups and down on the static fracture surface (Fig. 6-b), and the fracture at the fiber and matrix interface is encountered.

On the other hand, Fig.(6-c) shows a SEM micrograph of the cylindrically fractured surface taken from the direction of perpendicular to specimen axis. As shown, a trace of the striation can be seen, which means that a fatigue crack propagates not along the fiber matrix interface, but in the matrix.

Figure (7-a) shows a scanning electron micrograph of the cracking surface of SiC/Al composite specimen which is not fractured at number of 10^7cycles and Fig.(7-b) presents a macroscopic micrograph of longitudinal section of the same specimen. From Fig.(7-a), it is observed that the matrix on the surface of specimen is failed and that the fibers covered with aluminium is exposed here and there. Fatigue crack seems to initiate in the matrix and to propagate along matrix phase, while it leaves the mechanism vague yet that the some of the uncovered fibers are seen. On the other hand, Fig. (7-b) indicates the fatigue crack to propagate parallel to fibers toward the fixed end . A calculation was made on the interlayer shear stress between fiber and matrix, finding that it is negligible small for this case. Therefore, such a type of the crack propagation may be attributed to the anisotropy of composites strength. It is possible explanation that the crack propagates along the matrix at the early stage of fatigue owing to a small tensile stress of mode I type, generating in the hourglass type of specimen subjected to rotating bending stress, because the one - directional fiber reinforced composites has a high strength to the fiber reinforced composites has a high strength to the fiber direction, but composites has a high strength to the fiber direction, but this is not true for the traverse direction. It is expected that, if the applied stress is low, the crack becomes non-propagating because the stress at the crack tip decreases gradually by the aids of the ligament, as the crack grows deep into the matrix. In the other case, the crack comes to change the direction and then to propagate perpendicular to the axis of specimen, where the maximum tensile stress along the axis reaches to an endurance limit. Consequently, one end of the fractured surface becomes to form an end of the cylindrical post. Finally, in order to prevent the crack from propagating cylindrically, it will be required for the specimen to provide a very large radius of curvature.

CONCLUSIONS

From this study, the following conclusion may be drawn :

1. The fatigue strength of SiC/Al composites increased with increasing volume fraction of SiC fibers.
2. The fatigue strength ratio of SiC/Al composites indicated about 0.71, and this value is high as compared with many metallic materials .

3. Fatigue crack does not propagate along the fiber-matrix interface, but propagates in the matrix.
4. The slope of the S-N curve of the composites was similar to that of matrix material.
5. In comparison with pure aluminium (matrix material) the fatigue strength at 10^7 cycles of the composites is superior by 91.3% and 90.2%, for $V_f = 45$ % and $V_f = 35$ %, respectively.

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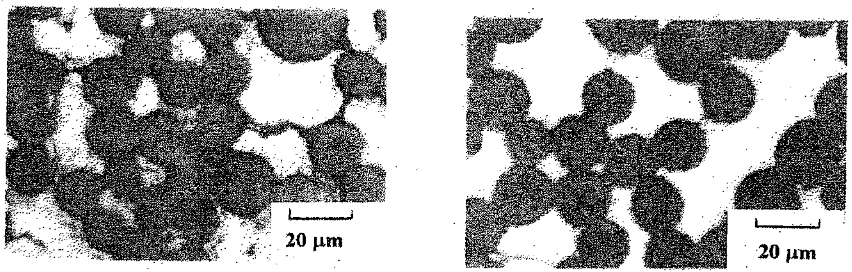
Table (1). Experimental results.

Samples	Fatigue limit σ_w, MP_a	Tensile strength σ_u, MP_a	Fatigue ratio σ_w / σ_u
Pure Al	27.2	66.3	0.41
Composite (V_f =35%)	276	280.2	0.73
Composite (V_f = 45%)	313	452.4	0.69



V_f = 45% V_f = 35%

Fig.(1) Microstructures of the investigated composites.

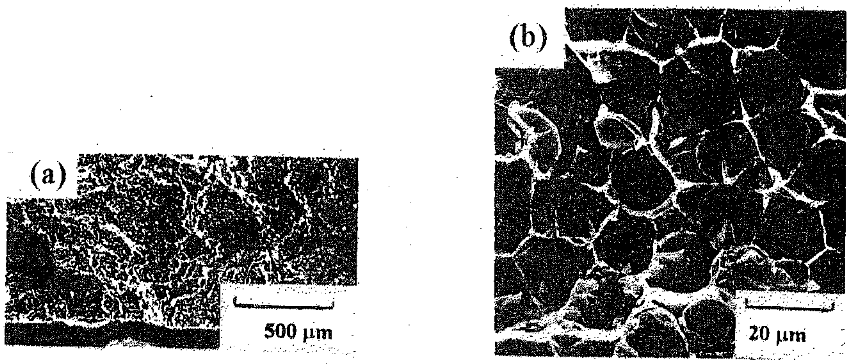


Fig.(2) SEM micrographs of tensile fracture surface of composite. V_f = 35%.

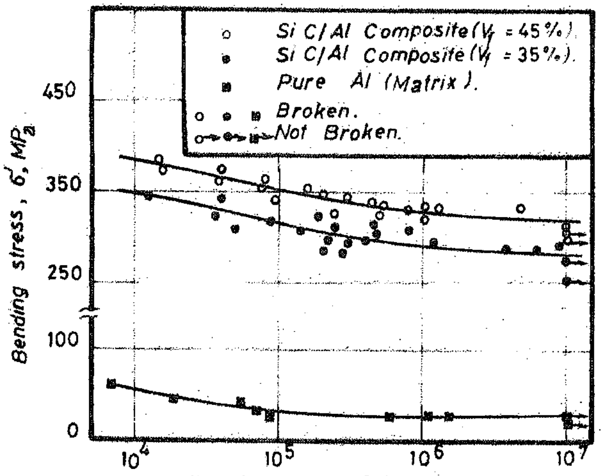


Fig.(3) S-N Curves of composites and matrix material (Pure Al).

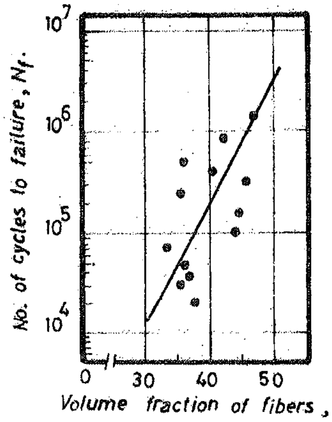


Fig.(4) Effect of the volume fraction of fibers on the fatigue life of composites under stress level of 310 MP_a.

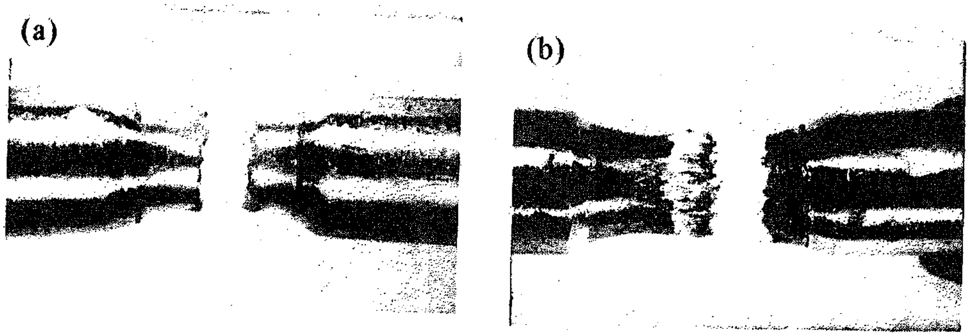


Fig.(5) Macroscopic views of the fatigue fractured specimens (the right side of photographs shows the fixed end).
(a) pure aluminium (matrix).
(b) SiC/Al composite.

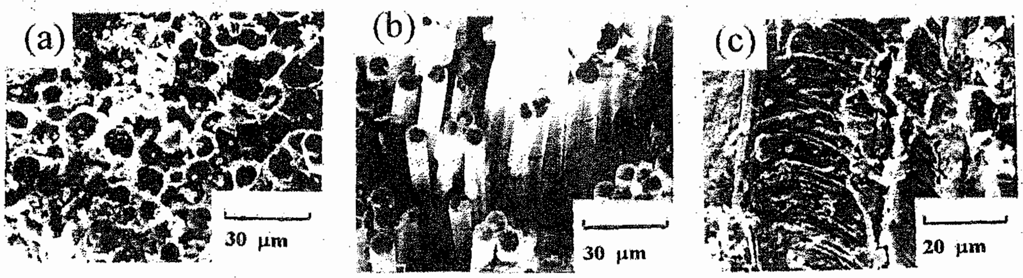


Fig.(6) SEM micrographs of the fatigue fractured surfaces for SiC/Al composites.

(a) Fatigue fractured surface.

(b) Statically fractured surface at the final stage of fatigue test.

(c) Cylindrically cracked surface.

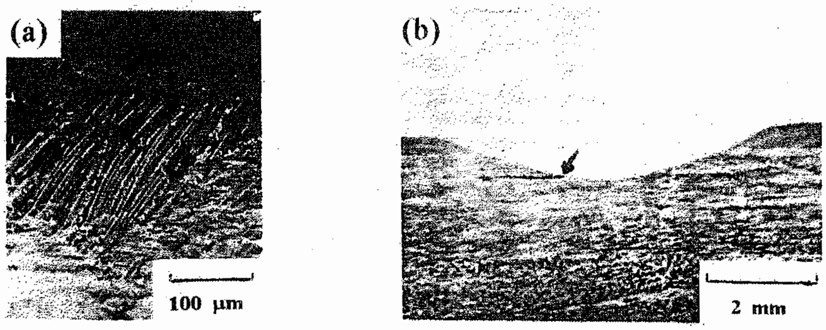


Fig.(7) Photographs of the specimen which is not fractured at the number of 10^7 cycles.

(a) SEM micrograph of hourglass surface, showing fatigue damage.

(b) Micrograph of longitudinal section, showing non-propagating crack.

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"سلوك الكلال لمؤتلفة الالومنيوم المعززة بألياف كربيدالسليكون والمنتجة بأسلوب السباكة تحت ضغط" .

د./ أحمد موسى أبو العينين
قسم هندسة الإنتاج والتصميم
كلية الهندسة والتكنولوجيا - جامعة المنوفية

الملخص العربي:-

يهدف هذا البحث إلىدراسة سلوك الكلال لمؤتلفات الألومنيوم النقية (درجة نقاوة ٩٩,٧٪) المعززة بألياف كربيد السليكون والمنتجة بأسلوب السباكة تحت ضغط (٥٠ ميجابا سكال) . ولقد اشتملت الدراسة في هذا البحث على استخدام ألياف كربيد السليكون بنسب حجوم مختلفة تتراوح فيما بين ٣٠ – ٥٠٪ .

كما تم استخدام الميكروسكوب الضوئي لفحص البنية البلورية لهذه المؤتلفات. كذلك أجريت اختبارات الشد الميكانيكية لتعيين الخواص الميكانيكية لهذه المؤتلفات.

أيضا اشتمل البحث على إجراء اختبارات الكلال علىماكينة اختبار الكلال الانحنائية الدوارة ذات الكابولى Cantilever Rotating Bending Fatigue Testing M/C وعند سرعة دوران 2800 R.P.M .

كما تم استخدام الميكروسكوب الماسح الالكتروني **SEM** لدراسة سطح الكسر للعينات المنهارة في كل من اختبارات الشد الميكانيكية واختبارات الكلال. أيضا تم استخدام الميكروسكوب الضوئي المجسم Stero Optical Microscope لفحص الوصف التفصيلي والدقيق(الطبوغرافية الدقيقة) لشكل سطح كسرالكلال Fatigue Fracture Surface .

ولقد خلصت الدراسة الى عدة نتائج نوجزها في النقاط التالية:

١. تتزايد مقاومة الكلال Fatigue Strength بتزايد نسبة الحجوم , Volume **Fraction** V_f, لألياف كربيد السليكون في المؤتلفة .

٢. أظهرت الدراسة ان النسبة فيما بين مقاومة الكلال ومقاومة الشد القصوى Max. Tensile Strength حوالي ٧١,٠وهذه القيمة تكون مرتفعة مقارنة بقيمتها لكثير من المواد المعدنية Metallic Materials .

٣. شرخ الكلال Fatigue Crack لهذه المؤتلفات لا ينمو على طول السطح البيني بين الألياف والبطانة Fiber-Matrix Interface ولكنه ينمو في البطانة Matrix .

٤. أظهرت النتائج أن ميل منحنيات الـ S-N (Stress Level - No. of Cycles to Failure) لهذه المؤتلفات ولمادة البطانة تكون متماثلة .

٥. تزايد مقاومة الكلال Fatigue Strength لهذه المؤتلفات مقارنة بمقاومة الكلال لمادة البطانة بنسبة ٩١,٣٪ ، ٩٠,٢٪ وذلك عند نسب حجوم Volume Fraction, V_f, لألياف كربيد السليكون ٤٥٪ ، ٣٥٪ على الترتيب .