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INVESTIGATION OF EFFECT OF FORGING STAGES ON AL/SIC METAL MATRIX COMPOSITES FATIGUE BEHAVIOUR

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ABSTRACT

The objective of the present research work was to investigate to determine the effect of forging stages on Al alloy reinforced with different percentage of SiC particulate fabricated by using stir casting techniques. The casted specimens were machined into blanks and were subjected to single stage and double stage forging using Mega Newton press with graphite as a lubricant. The forged and ascast specimens were investigated for microstructures analysis and fatigue behaviour for comparison. The microstructure analysis reviled that the forged sample had higher finer grains with uniform dispersion of reinforcement. Fatigue properties of forged sample showed higher fatigue-life than that of ascast samples. The reinforcement addition of 2.5 and 5 % of SiC showed higher fatigue strength enhancement over 7.5 and 10 % of SiC additions. The fractography of fractured samples showed debonding between the metal and particle interface.

KEYWORDS: Metal Matrix Composite (MMC), Basalt Short Fiber, Fatigue Behaviour, Fracture Studies

1. INTRODUCTION

Metal Matrix Composites (MMCs) with better mechanical strength, are under development in order to introduce in structural components for automotive and aerospace applications, by reducing drastically the weight and increasing the specific strength [1]. But, the particular microstructural changes in MMCs induce stiffness in the direction of fiber but to poor transverse direction due to the weak at interface region. The severity of this problem is more in the case of particulate MMCs. On the other hand, the specific modulus of MMCs are increased, but reduced in ductility. To overcome these problems, researchers explored mechanical hardening like forging, rolling and extrusion on MMCs and they enhances both strength and ductility of Al MMCs. Moreover, the parameters of forging adequately controlled to obtain higher strength. [3–8].

The MMCs depends on the forging process parameters and MMCs composition such as reinforcement content, particulate aspect, particulate and matrix interfacial bonding, impurity / porous and even testing condition [9–10]. The addition of reinforcement results to low ductility and toughness [11] which are unsuitable for fatigue applications especially low cycle fatigue machine parts [12,13]. The objective of the research work was to determine the effect of forging parameters on grain boundaries and and fatigue behaviour SiC-Al MMCs at room temperature. The SiC reinforcement was varied from 2.5 to 10 weight percentage in interval of 2.5 to study the fracture surface fracture related to interfacial bonding strength.

2. EXPERIMENTAL STUDIES

2.1 Materials

Al 6061 alloy was considered as a matrix alloy and SiC of 50 μm size particles was considered as reinforcement. The chemical composition of Al 6061 is given in Table 1. The SiC particulates were washed and dried under force convection to remove dirt.

Table 1: Al 6061 Chemical Compositions

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
%	0.4	0.5	1.6	0.3	2.5	0.15	5.5	0.2	Bal

2.2 Composite Preparation

The Al/SiC MMCs with varying weight percentage ranging from 2.5 to 10% insteps of 2.5 of was prepared by gravity feed liquid metallurgy route. Preheated SiC particulates was introduced into Al melts under nitrogen environment followed by uniform stirring by mechanical stirrer at 400 rpm for 2 to 3 min then poured into the metal (MS) dies of dimensions .

2.3 Forging and Heat Treatment Operation

Both single and two stage forging were carried-out in closed die with graphite lubricant using 30 MN hydraulic press in the temperature range of 425 to 500 °C. The initial billet diameter of 75 mm was forged into the final billet diameter of 25 mm (ratio 3:1 with 0.1/s strain rate [13]). The specimens were prepared by using electron-erosion technique followed by heat treatment process which consists of heating the specimen's upto 532 °C and soaked at this constant temperature for 3 hours. The microstructural analysis was carried out on the samples before forging and after forging using optical microscopy following standard metallographic procedures.

2.4 Low Cycle Fatigue Test

After heat treatment, total-strain controlled fatigue tests were carried out with total-strain amplitudes ranging from 0.001 to 0.01 in servo-hydraulic universal testing machines. Strain was measured with a clip-on extensometer attached directly to the gauge length at low and at room temperature (extensometer equipped). The stress level corresponding to the LCF (compression and tension) was fixed; nominal stress amplitude of 180 MPa with a constant load rate equal to 125 N/s was applied. The fatigue tests have been carried out in load control (in a fully reversed push-pull mode) with hydraulic test machine and a comparison of the stress versus cycles to failure behaviour of the un-forged, single and double forged specimens belong to both Al matrix alloy and Al/basalt composites as shown in Figure 2 and Figure 3 respectively.

3. RESULTS AND DISCUSSIONS

3.1 Microstructure Studies

Figure 1 shows the Al/10% SiC MMCs microstructure in both as-cast and forged conditions. The forged MMCs show that alignment of SiC in forging direction. The SiC particles rearranged themselves parallel to the forging direction.

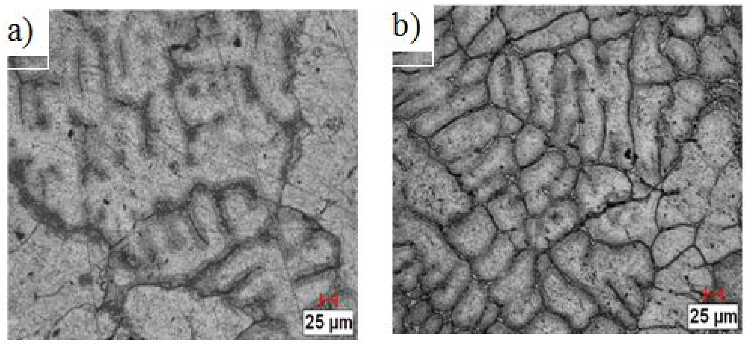

Figure 1: The Optical Micrograph of the Al/10 % Sic MMCs A) As Cast B) Forged Conditions

3.2 Fatigue Resistance

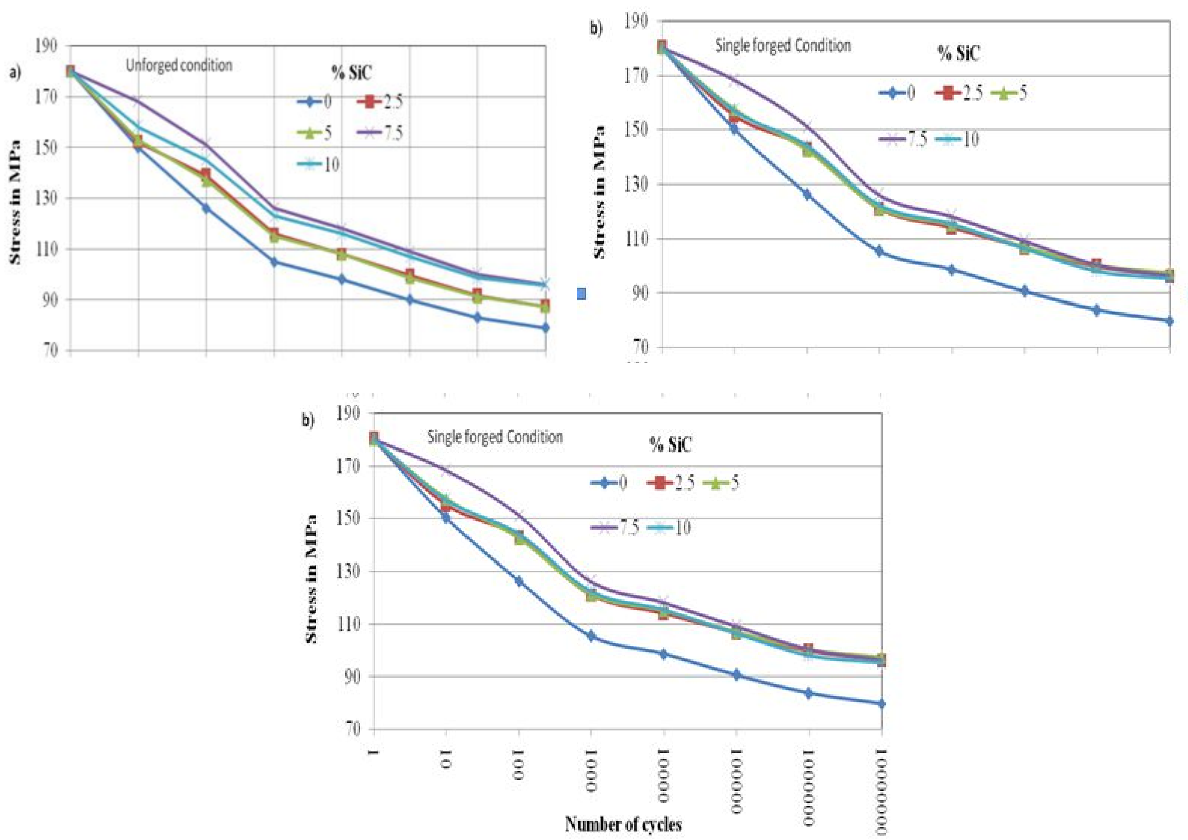

Figure 2: Wo¨hler curves for Al and Al/SiC MMCs for a) Unforged b) First Stage Forging and c) Second Stage Forging

Figure 2 Exhibits an increase in content of SiC resulted in enhanced fatigue resistance of the composites independent of orientation. The magnitude of enhancement fatigue resistance is higher at lower wt. % of SiC (0-5 wt.%) but, no significant change can be seen at higher percentage (7.5 and 10 wt.%). Several studies have shown that increasing wt. % of particles MMCs enhanced fatigue strength [14]. The maximum fatigue load could be borne by SiC particulate. The fatigue life of SiC-Al MMCs is usually longer than that of ascast condition materials. The enhancement is due to higher strength of SiC than matrix materials. The change in fatigue resistance vs. the forging condition is shown in

Figure 3 for the matrix alloy and MMCs specimens. The fatigue signature show that both forged and un-forged specimens showed a similar behaviour with number of cycles. The fatigue strength in forged condition specimen (single stage and double stage) shows that there is no significant change in matrix alloy but in 2.5 and 5% SiC reinforced MMCs shows significant changes in their behaviour as shown in Figure 3. On the other hand there is no significant effect of forging on fatigue resistance of hand 7.5 % and 10% reinforcement. The enhancement of fatigue strength is due to the addition of higher stiffness SiC particulate into the Al MMCs, they help to load transfer capacity of the interface. Some time the porosity and micro or macro cracks reduce reduce the elastic modulus [15]. Lee et. Al. [15] and Lloyd [17] onfirmed that the deformation can also reduce the elastic modulus with presence of porosity. The forging reduces the porosity with great extent and it enhances the mechanical strength as well as elastic modulus.

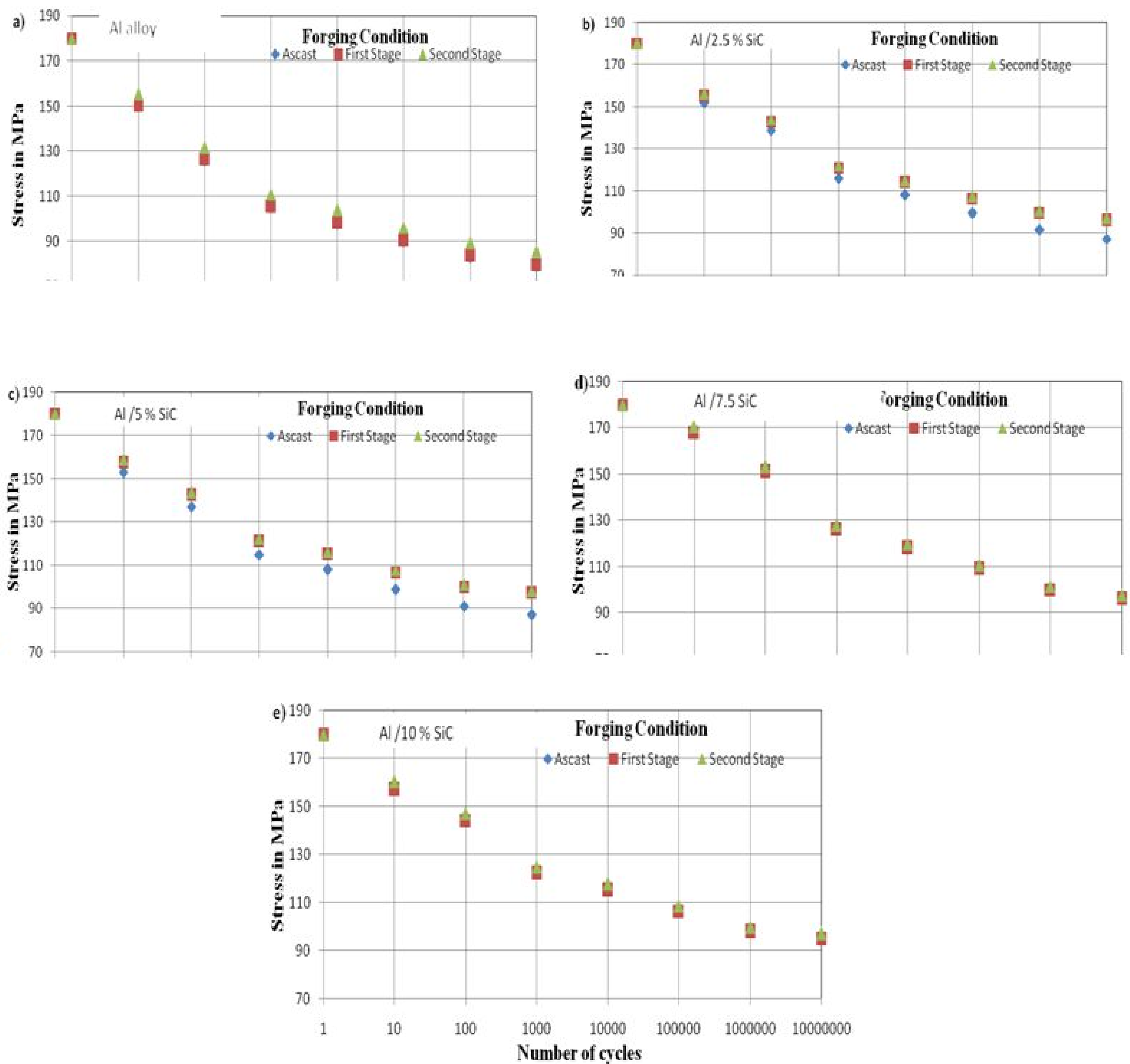

Figure 3: Wo¨hler Curves for Ascast, First Stage Forging and Second Stage Forging For Al, Al/ 2.5%, Al/5%, Al/7.5% And Al/10% Basalt Short

3.3 Fracture Studies

The typical fractured surface of Al alloy and Al/5 wt.% SiC composites (both ascast and two stage forged conditon) after fatigue fractured are shown in Figure 4 and Figure 5 respectively. Figure 4 (a) shows after crack initiation at pores, two distinct fracture morphologies were observed and marked the same 'A' (ductile fracture) and 'B'(brittle frature) and fatigue crack (FC) propagated between these two regions. The region 'A dominate more than the region 'B' and the fatigue crack is formed in the severe damage region. Figure 4(b) shows fracture surface of both the two stage forging.

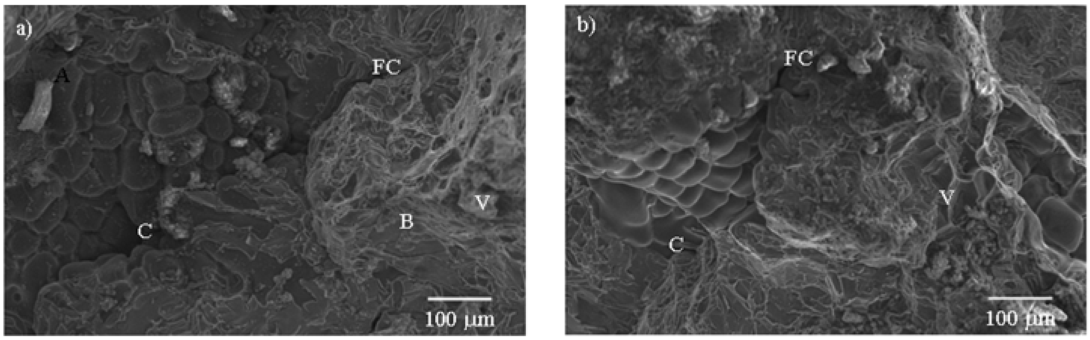

Figure 4: Fracture Surface of a) un-Forged and b) Forged Vondition Al7075 Allay Specimen After Fatigue C- Main Crask, Fc- Fatigue Crack, V-Void In Matrix Alloy

Al alloy after fatigue failure contains two regions 'A' (ductile failure) and 'B' (brittle failure). The region B is more dominate than the region 'A' which due to foringing reduces the porosity and refine the grain boundaries the matrix alloy. Similar to unforged specimen the crack (C) and FC continous and are formed in the severe damage reigon.

Figure 5(a) and 5(b) show the fracture surface of ascast and forged conditions of Al /5% basalt fiber reinforced composites specimens respectively. Unlike Al matrix alloy, these do not show any two clear distinct regions in both ascast condition and forged condition. Cavaliere [1] noted that as the interspacing decreased, the degree of constraint due to triaxiality of stress increased, so striation formation was hindered and the dominant damage mechanism changed to void formation. After stable crack propagation, a fast fracture region was typically observed. Because of the high-crack velocity associated with this portion of the fracture surface, large-scale fracture took place.

The fracture surfaces also displayed the presence of very few cracks (Figure 5(b)), probably originated from casting defects or during cooling from the fabrication. This is in accordance with the increased density of the composite after forging. Because of reduciton in porosity, the ductility of composites increases and it leads the large elongated dimples, tear ridges and shear bands which are shown in the fracture surface.

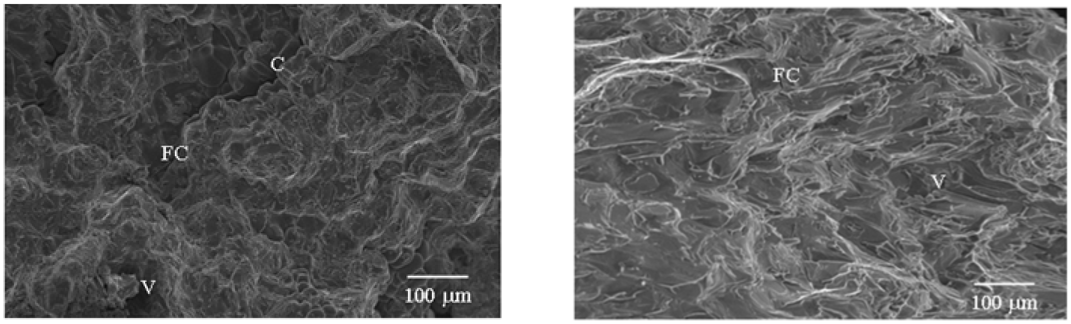

Figure 5: Fracture Suface of a) un- Forged and b) Forged Condition Al 7075/5 wt % of Basalt Short Fiber Mmc S after Fatigue Text. C-Main Crack, V-Void in Matrix Alloy Fracture Studies

CONCLUSIONS

In this researchwork, the effects of SiC content and the forging process on the faigue properteis of Al /SiC MMCs were studied and the following conclusions are drawn from the experimental observations:

- The microstructures of the as-cast and forged Al/SiCMMCs exhibit uniform distribution of SiC and porosity content in forged specimen is substanially reduced.
- The matrix alloy and MMCs behave more like a monolithic material, since the homogeneous spatial distribution of the SiC enables efficient load tranfer from the reinforcement fiber to matrix without producing sufficient stress concentration to initiate fatigue cracks.
- With increasing basalt fiber content, the fatigue value has been increased upto 7.5 % in the as-cas, single and double stage forged specimens and it has beed found that there is no significant change when more than 7.5 wt % of SiC added.
- SEM analyses of the fracture surfaces showed the broken particles, surrounded by ductile region and decohesion at the matrix and fiber interfaces. The tear ridges in the MMCs can be attributed to high local plastic constraints induced by fiber cluster.

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