A Study on Fatigue Characteristics of Al-SiC Metal Matrix Composites Processed Through Microwave Energy

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Abstract. Aluminium based Metal Matrix Composites are the very promising light materials with enhanced mechanical properties. Aluminium Metal Matrix composites (AMC) are identified as one of the very good materials for aerospace and automobile applications because of their lightweight, cost effectiveness and high stiffness. Metal Matrix Composites can be produced by various methods such as liquid infiltration, stir casting, spray deposition and powder metallurgy technique. Microwave processing of metals is a rapid developing technology which will offer significant time saving and can be cost effective. It is a volumetric process and very efficient to obtain high heating rates due to the interaction of microwave with the material in molecular level. The present work is an attempt made to study the fatigue characteristics of microwave processed Al-SiC metal matrix composite. Sintering of the compacted Aluminium powder with 4% SiC is carried out using microwave energy. The sintered metal matrix composite is subjected to secondary processing of Extrusion. The fatigue characteristics and micro hardness properties are investigated.

Key words: AMC, Microwave, Sintering, Extrusion, Fatigue strength.

1. Introduction

Aluminium Metal Matrix composites (AMC) are known as one of the very promising light materials with enhanced mechanical properties which are used in various industries for their lightweight, cost effective and high stiffness [1]. It can be used as a replacement in automotive and aerospace applications by reinforcing with Al2O3 and SiC which will reduce the weight and thereby increase the engine efficiency, reducing the fuel consumption [2]. Replacing cast iron engine components with lightweight aluminium alloys requires overcoming of the poor adhesion and seizure resistance of Al. This can be achieved by dispersing Al2O3, SiC or graphite particles in Al. Considerable reduction of wear and friction characteristics can be achieved by the using these particulates. Moreover, cylinder pressures can be increased because AMCs can withstand high thermal and mechanical loads and reduce the loss of heat by permitting closer fit that can be achieved because of the lower thermal expansion coefficient of AMCs [3]. Metal Matrix Composites can be produced by different methods such as liquid infiltration, stir casting, spray deposition and powder metallurgy technique. Among
these techniques, Powder metallurgy is the most effective method of manufacturing MMCs with high volume of reinforcement and uniform distribution. MMC’s which are processed by some traditional techniques results in some defects like non uniform distribution of reinforcement, porosity, irregular grain shapes etc. Also the time required for these processes is very high. In order to minimize all these drawbacks microwave processing technique is used. Microwave processing of metals is a fast developing technology in which heat will directly affect the grains of the materials and a temperature gradient will exist across the material which changes the microstructure and mechanical properties. Microwave heating has received considerable attention because of its major advantages such as, reduced processing time, high heating rates, less environmental hazards and low power consumption [4]. Microwaves are electromagnetic waves which consist of an electric and a magnetic field which are orthogonal to each other with wavelengths in the range of 1–1000 micrometer. Microwaves are wave energy which is converted into heat energy depending on the type of interaction with the target materials. The processing of a material by using microwave energy depends on its magnetic and dielectric properties. Microwave heating and melting of aluminium, tin, copper and lead with the aid of susceptors are found to have very good micro structural characteristics. Compared to the conventional melting, microwave melting was twice faster, more energy efficient and also safer to handle [5]. Processing of 5083 Aluminium alloy reinforced with Alumina by using microwave Sintering results in uniform powder morphology and good density. The hardness value will increase with increase in the reinforcement content [6].The main objective of this present work is to develop aluminium metal matrix composites reinforced with 4% of SiC through microwave energy and study their fatigue characteristics.

2. Methodology

In the present work Aluminium powder (Al 1100) with an average particle size of 40µm is used as a matrix material and Silicon Carbide powder with an average particle size of 23 µm is used as reinforcement. The properties of the Al and SiC powder used are listed in the table 1 and 2 respectively.

| Table 1. Properties of Al 1100 powder | Table 2. Properties of SiC powder |
|--------------------------------------|----------------------------------|
| **Property**                        | **Value**                        | **Property**                        | **Value**                        |
| Density (gm/cm³)                    | 2.8                              | Density (gm/cm³)                    | 3.1                              |
| Elastic modulus (MPa)               | 70*10³                           | Elastic modulus (MPa)               | 400*10³                          |
| Tensile strength (MPa)              | 110                              | Compressive strength (MPa)          | 3900                             |
| Hardness                            | 28                               | Hardness                            | 2800                             |
| Melting Temperature (°C)            | 640                              | Melting Temperature (°C)            | 3100                             |

2.1 Development of Al-1100-SiC Composite

The Aluminium powder is mixed with 4% of Silicon Carbide powder by using the bi-axial powder blender. The blending of the powders is carried at a speed of 150rpm for 30 minutes and 20% of ethanol is added to the powder sample. A compaction die of 35mm diameter is used for the compaction of the blended powders by using UTM. Sintering of the compacted powder is carried out by using microwave furnace of 900W power and 2.45GHz frequency. A microwave furnace utilizes one or two magnetrons lying on either side of the heating chamber for the generation of microwaves. Special magnetron (1100 watts) is used to heat the furnace electrically. A suitable susceptor will be provided, and it reacts with the electromagnetic waves and creates the instant heat in the system. Figure 1 shows the Microwave processing equipment. The compacted Aluminium-SiC billet is placed over the Silicon carbide susceptor so that initial coupling of the susceptor with the microwaves is formed which allows heating of MMC billet. The compacted billet along with the susceptor is placed inside the alumina
casket which will not allow microwaves to escape out of the chamber. Initial experiments were conducted to study the optimal time required for sintering of Al+4%SiC solid specimen which is already compacted. It has been observed that sintering occurred in 10 min at 550°C. The Al-SiC MMC is heated at 550 °C for 10 min at 900W. The Microwave processed MMC is subjected to secondary processing of extrusion, with an extrusion ratio of 12.25 at 320°C temperature.

2.2 Fatigue characterization of the processed MMC

Fatigue test was conducted on the rotating beam testing machine as shown in the figure 2. The specimen used for the testing is prepared as per ASTM E466. The test is conducted by mounting a test specimen on the Rotating beam fatigue testing machine, which is operated at a constant speed of 2000 rpm with an applied load starting from 5Kg and the test is repeated for similar test specimen with same speed by applying lesser loads till it reaches the endurance limit. The number of cycles required for specimen to fail is noted down for each loading condition and the stress corresponding to that load is calculated. Results obtained from rotating beam bending test for are useful finite life design calculations. For this S-N curve can be modeled by Basquin equation. \( \sigma_f = (A)(N_f)^B \). This equation becomes linear when represented on log-log scale. This equation can be used for design calculations by determining constants A and B which are unique for a particular material.
2.3 Microhardness of the processed MMC

Hardness value has been determined by using Vickers micro Hardness tester according to ASTM E-384 standard. The micro hardness test procedure, ASTM E-384, specifies a range of light loads using a diamond indenter to make an indentation which is measured and converted to a hardness value.

3. Results and Discussion

3.1 Fatigue strength

The extruded specimen with 0% SiC and 4% SiC were subjected to rotating beam bending test to evaluate their fatigue strength parameters. S-N curve for the two materials were plotted using the test results, which are shown in figure 3.

**Table 3. Fatigue test results**

| Load (Kg) | Stress (MPa) | Number of cycles | Load (Kg) | Stress (MPa) | Number of cycles |
|-----------|--------------|------------------|-----------|--------------|------------------|
| 5         | 115.65       | 10123            | 5         | 115.65       | 13564            |
| 4.5       | 104.085      | 32461            | 4.5       | 104.085      | 54126            |
| 4         | 92.52        | 70953            | 4         | 92.52        | 102103           |
| 3.5       | 80.95        | 301048           | 3.5       | 80.95        | 425128           |
| 3         | 69.3         | 960253           | 3         | 69.3         | 990236           |

**Figure 3. S-N plot of MMC**

It can be observed from the test results that Fatigue life increases with the decrease in the stress amplitudes and the curves are almost asymptotic with x-axis at about 69 MPa stress amplitude. It can also be observed that for identical stress amplitudes, material with 4% SiC is having marginally longer...
life when compared to material with 0% SiC. Results obtained from rotating beam bending test are useful for finite life design calculations. S-N curve shown in figure 3 can be modeled by Basquin equation. \( \sigma_f = (A)(N_f)^B \). This equation becomes linear when represented on log-log scale. This equation can be used for design calculations by determining constants \( A \) and \( B \) which is tabulated in table 4.

| Material      | A    | B     | \( \sigma_{\text{end}} \) (MPa) |
|---------------|------|-------|-------------------------------|
| Al + 0% SiC   | 336.08 | -0.1224 | 28.95                         |
| Al + 4% SiC   | 379.39 | -0.1223 | 32.75                         |

Figure 4. SEM images of fatigue test specimen after failure

Figure 4 shows the SEM image of fracture surface of the specimen subjected to fatigue test. Striation marks are clearly visible on the fracture surface, indicating plastic deformation of the material under repeated load before failure. Cracks formed in the material due to coalescence of micro voids can also be seen from the SEM image.

3.2 Micro hardness

Figure 5 shows the bar chart representation of hardness values of different samples. It can be observed from the test results that there is an improvement of about 16% in hardness with the addition of 4% SiC when compared to matrix material alone. This can be attributed to the strengthening of the material structure, with uniform distribution of harder SiC phase in the relatively softer matrix phase. The test results also indicate an increase of about 20-22% in hardness of extruded samples compared to as processed samples. During extrusion process the material undergoes grain refinement, reduction in porosity as well as increased dislocation density which results in increased hardness of the material.
Figure 5. Comparison of the Hardness values of MMC before and after extrusion

4. Conclusions
The investigations of the present work have provided encouraging results and following conclusions are drawn based on the test results.

1. Aluminium-SiC Metal matrix composite is successfully fabricated by using Microwave processing technique.
2. The time required for the processing of Metal matrix composite by using Microwave processing technique is less compared to conventional processing technique.
3. Fatigue strength parameters have been determined for the microwave processed material. The fatigue strength was found to be increased by 13% with the addition of 4% SiC to the base alloy.
4. There is an increase of about 16% in hardness value of Al+4%SiC MMC compared to the base alloy. Also the hardness value was found to increase by about 20-22% after the extrusion.

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