Effect of Sintering Temperature on Microstructure and Mechanical Properties of Aluminium Composites

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Abstract. Sintering temperature might have varied effects on the properties of composites in general. Through this paper, an attempt has been made to investigate the effect of sintering temperature on the properties of Aluminium composites fabricated by powder metallurgy process. Alumina and Silicon Carbide were different types of reinforcements in this work. Green compacts of Aluminium composites were made at a compressing load of 1 tonne and 2 tonne separately. These compacts were sintered at 2 different sintering temperatures of 400°C and 450°C in oxygen free environment using muffle furnace for 1 hour, followed by annealing process which took 12 hours. Sintered compacts were than subjected to micro-structural examination and mechanical properties evaluation. Higher hardness has been attained for the composites containing 2.5% Silicon Carbide. Optical microstructure images show the uniform distribution of particles into aluminium matrix.

1. Introduction

Particle reinforced metal matrix composites are in high demand today because of their varied applications. In such MMCs, a hard and strong ceramic material with high modulus is used as reinforcement for a ductile and tough metal. Such MMCs can be used for various applications in multiple fields. Aluminium based metal matrix composites have good corrosion and wear resistance properties. They have high stiffness, high modulus and excellent specific strength. As a result, they have tremendous scope for structural applications. They are also being used in automotive and aerospace industries [1-5]. The aluminium alloy-alumina silicate particulate composites were observed for their fatigue lives and it was established that at lower stress state such composites displayed longer fatigue lives than unreinforced aluminium alloy. On the other hand, at higher stress state they showed lesser fatigue lives [6]. The mechanical properties of silicon carbide reinforced composites were studied and it was concluded that the presence of silicon carbide particulates improved its hardness [7]. The effect of aluminium based zinc oxide reinforced composites was studied and the results clearly proved that the presence of the zinc oxide reinforcement tremendously influenced the micro structural and mechanical properties [8]. Different weight fractions of silicon carbide reinforcements on aluminium based MMCs were added and their properties were improved [9]. The impact strength and the hardness of the composites were greatly affected by the weight fractions. Aluminium composites with aluminium oxide reinforcement were studied for their microstructure and thermal conductivity and there is evidence that the volume fraction of the reinforcement influenced the thermal conductivity of the composites [10]. The addition of hard reinforcement such as silicon carbide, alumina, tungsten carbide, titanium carbide,
aluminium nitride, boron carbide were improved the mechanical properties compared to their matrix material[10-13]. In this paper, aluminium was used as the matrix material and alumina and silicon carbide was used as the reinforcement material.

2. Experimental Procedure

Samples prepared were prepared by powder metallurgy process and Table 2 shows the weight percentage of sample. Table 1 show the each sample was subjected to compressing loads of one tonne and two tonnes. They were then sintered at temperatures of 400 °C and 450 °C. Thus, four sets of six samples were prepared in total. The hardness and microstructure of all twenty four samples were analyzed carefully. Fig. 1 shows the methodology of our work.

Table 1. Load and Temperature variations given to the final product

| SI. No. | Load (Tonnes) | Temperature(°C) |
|---------|---------------|-----------------|
| 1       | 1             | 400             |
| 2       | 2             | 450             |

2.1. Weighing

The powders were accurately measured with the help of a weighing balance with accuracy of 0.1mg. It is an extremely sensitive and advanced measuring system. It is carefully guarded by glass walls that shelter the weighing balance from negative influence of air.

Density of Aluminium = 2.7 g/cm³ Density of Alumina = 3.95 g/cm³ Density of Silicon Carbide = 3.21 g/cm³ Height of the sample = 10 mm Diameter of the sample= 18 mm
Table 2. Composition of the samples

| Sample No. | Aluminium (%) | Alumina (%) | Silicon Carbide (%) |
|------------|---------------|-------------|---------------------|
| 1          | 100           | -           | -                   |
| 2          | 97.5          | 2.5         | -                   |
| 3          | 95            | 5           | -                   |
| 4          | 92.5          | 7.5         | -                   |
| 5          | 95            | 2.5         | 2.5                 |
| 6          | 92.5          | 5           | 2.5                 |

2.2. Blending
A unique approach was done to blend the powders together. They were poured in a bottle along with some solid stainless steel balls and rotated at a low speed for five minutes in a lathe machine. This is a very unique and creative approach as lathe machines are generally used for machining operations. However, here blending has successfully been done on a lathe machine. Blending is of utmost importance otherwise uniformity of the powder particles would be compromised. Ball mill mechanism has been used for blending which works on the principle of impact and attrition. The balls help in size reduction and uniform blending. Fig. 2 shows the Blending process carried out in the lathe machine.

![Blending process carried out in the lathe machine](image)

2.3. Compaction
In aluminium based composite materials, silicon carbide is generally used as the reinforcement material. In the powder compaction process, a solid powder material is formed by compaction in a container to a desired shape. To perform sintering of the green compacts, they are heated to a temperature below their melting points. The compact testing machine has been done to perform the compaction process. Load applied are 1 tonne and 2 tonnes respectively and dwell time for load is 10 seconds. Fig. 3 shows the Universal Testing Machine for the powder compaction. Fig. 4 shows the green sample after the compaction.
2.4. Sintering
Sintering is a process by which a solid mass of material is formed by the application of heat and pressure at a temperature below its melting point. Sintering has been done in the absence of oxygen by the passage of argon inert gas. The bonds formed as a result will be stronger. Surfaces which are sensitive to oxidation will also not be damaged. A muffle furnace has been used to heat the green compacts at temperatures of 400°C and 450°C in oxygen free environment by passing argon gas for 1 hour, followed by annealing process for 12 hours. Fig. 5 shows the image of muffle furnace which used for sintering the green compact sample at required temperature.

2.5. Rockwell Hardness Test
In the Rockwell hardness testing machine, B type scale is being chosen to measure hardness of structure. 1/16 inch diameter steel sphere was used and load of 100 kgf was applied. Fig. 6 shows the digital Rockwell hardness testing machine.
3. Results and Discussion

3.1. Hardness Study
Fig. 7 shows the graphical representation of hardness vs temperature for 1 tonne load. Among all the different samples, the sample number 5 containing 92.5% Al, 5% Al2O3, 2.5% SiC has the maximum hardness value at 450°C. It can be inferred from the above chart that the hardness increases with the increase in temperature. This is because greater the sintering temperature, lesser the porosity developed in the composite material and thus greater is the hardness.
Fig. 8 shows the graphical representation of hardness vs temperature for 2 tonne load. Among all the different samples, the sample number 5 containing 92.5% Al, 5% Al2O3, and 2.5% silicon carbide has the maximum hardness value at 450°C. It can also be inferred from the above chart that the hardness increases with the rise in temperature. This is because greater the sintering temperature, lesser the porosity developed in the composite material and thus greater is the hardness.

Fig. 9 shows the graphical representation of hardness vs load for different composition at 400°C. Among all the different samples the sample number 5 containing 95% Al, 2.5% aluminium oxide and 2.5% silicon carbide has the maximum hardness value at 2 tonnes load. It can be inferred from the graph that the hardness in general increases with the increase in load. The reason for this is that greater the compressive load, better the interfacial bonding between aluminium matrix and the reinforcements.
Fig. 10 shows the graphical representation of hardness vs load for different composition at 450°C. Among all the different samples the sample number 5 has the maximum hardness value at 2 tonnes load. It can also be inferred from the above chart that the hardness increases with the increase in load. The reason for this is that greater the compressive load, better the interfacial bonding between aluminium matrix and the reinforcements. The problem of porosity is also solved by the application of greater load.

3.2. Microstructure Study

Figure 11. microstructure of 92.5 % Al and 7.5 % Al$_2$O$_3$

Figure 12. microstructure of 95 % Al and 5%Al$_2$O$_3$
Fig. 11 to 15 shows the optical microstructure image of prepared sample. From the microstructures, we can find the uniform distribution of reinforcements into matrix material.

4. Conclusion
All samples were prepared successfully by powder metallurgy process. The Rockwell hardness of the materials increases with increasing of SiC contents and with increase in sintering temperature and compression load. Higher hardness value has been exhibited for the aluminium composites containing 95% of Aluminium, 2.5% of Alumina, and 2.5% Silicon carbide (sample 5). The approximate percentage increase in hardness for sample 5 when compared to pure aluminium (sample 1) for 1 tonne load and 400°C is 35%, for 1 tonne load and 450°C is 53%, for 2 tonnes load and 400°C is 29% and finally for 2 tonnes load and 450°C is 20%. The reason for this is that greater the compressive load, better the interfacial bonding between aluminium matrix and the reinforcements. Also greater the sintering temperature, lesser the porosity developed in the composite material and thus greater is the hardness. The porosity developed is mostly due to the formation of agglomerations of the reinforcement particles. The porosity is an indication of weak bonding, which can in turn be solved by the application of greater compressive load. From the optical microstructures, we studied the uniform distribution of reinforcements into matrix material.

5. References
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