Experimental Analysis of Hardness and Densification of Microwave Sintered AL/SIC/AL₂O₃/Flyash Composites

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Abstract

Objectives: Powder metallurgy is one of the best methods to achieve uniform distribution of reinforcement in matrix. In the present study, silicon carbide, alumina and fly ash are reinforced in Aluminium matrix at various proportions through powder metallurgical process using both conventional and microwave sintering and the mechanical properties were evaluated. Methods/Statistical Analysis: The compaction load has varied from 4000 kg to 8000 kg, and it was observed that the maximum densification of 84.04% at 8000 kg was obtained. All the samples were prepared at 8000 kg load and sintering was done using microwave furnace. For comparison purpose, all the samples were sintered conventionally using tubular furnace. Findings: Hardness and densification tests were conducted on both conventional and microwave sintered specimens. Composites, which are, processed through microwave sintering shows a better result than conventionally sintered specimens with saving the process timing and power consumption. It is being observed that the role of SiC in microwave sintering is very vital as it is an absorber of microwaves. Application/Improvements: The working area of a microwave furnace is very less and it restricts the size of the working sample. The role of other absorbers (semiconductors) of microwaves can be studied.

Keywords: Densification, Hardness, Microwaves, Powder Metallurgy, Sintering

1. Introduction

Powder metallurgy is the technique in which powder of materials such as metals, alloys, ceramics etc., are mixed, blended and compacted into the desired shape and then sintered in a controlled atmosphere to bond the particle and desired properties are obtained¹.². It is commonly designated as P/M. Metal Matrix Composites are composed of a metallic matrix Al, Mg, etc., or a dispersed ceramics like oxide, carbides or metallic phase like Pb, Mo, W, etc., Ceramic reinforcement may be silicon carbide, alumina, silicon nitride, etc. whereas Metallic Reinforcement may be tungsten, beryllium etc. MMCs are used for various applications such as space shuttle, commercial airliners, electronic substrates, etc., When compared to polymer matrix composites, the advantages of MMCs are strength and stiffness at elevated temperature, good abrasion and creep resistance properties. In conventional sintering, heating takes place due to conduction and hence the sintering time depends on thermal conductivity of a material. Though the thermal conductivity of aluminium-Silicon carbide composites is high, still it takes more time for sintering which leads to the higher power consumption. As an alternate, microwave heating can reduce power consumption and overall processing time with improved mechanical properties³.⁴. With response to
microwave, materials can be classified into three types, absorber (semiconductor), reflector (metals) and transparent (ceramics). Interestingly, combination of reflector (Aluminium), absorber (SiC) and transparent (Alumina) has been taken for the present study along with the filler material flyash. The volume fraction of reinforcement is limited to 30%.

2. Experimental Methodology

Powder metallurgy is a fabrication technique. First, the primary material is physically divided into many small individual particles. Next, the powder is passed through a die and pressures of 1-10 tons are commonly used to compact the metal powder. Then the powdered particles are sintered in the mould with temperature below melting point under non oxidizing atmosphere.

2.1 Die Preparation

The die material selected for this study was EN24 which is a medium carbon steel with Cr and Mo. To facilitate the easy removal of compacted specimen, tapered section has been used. Dimension of tapered section used is 16 to 15 mm for overall length of 50mm in punch and (40mm, 10mm) in die. The die has been designed in such a way to withstand 680 MPa. 3D view of the die shown in the Figure 1.

![Figure 1. 3D view of a die.](image)

2.2 Blending

Blending is a process of mixing the powders in a controlled atmosphere without any additives. Blending operation is carried out in a magnetic mixer. A magnetic stirrer is a laboratory device that employs a rotating magnetic field to cause a stir bar (also called “flea”) immersed in the powder to spin very quickly, thus stirring it. The rotating field may be created either by a rotating magnet or a set of stationary electromagnets, placed beneath the vessel.

2.3 Sample and its Composition

Interestingly, combination of reflector (Aluminium), absorber (SiC) and transparent (Alumina) has been taken for the present study along with the filler material fly ash and its composition in volume fraction has been listed in the Table 1.

| Sample | Al (%) | SiC (%) | Al₂O₃ (%) | Flyash (%) |
|--------|--------|---------|-----------|------------|
| 1      | 70     | 5       | 15        | 10         |
| 2      | 70     | 10      | 10        | 10         |
| 3      | 70     | 15      | 5         | 10         |
| 4      | 70     | 10      | 20        | -          |
| 5      | 70     | 20      | 10        | -          |

2.4 Compacting

The purpose of the compacting is to consolidate the powder into the desired shape and as closely as possible to final dimensions; it is designed to impart the desired level and type of porosity and to provide adequate strength for hardening. Compacting was done in UTM (Universal Testing Machine) as shown in the Figure 2. The various compacting load from 4000kg to 8000kg were used for compaction.

![Figure 2. Universal Testing Machine.](image)
2.5 Density Measurement and Calculation

Density of Aluminium = 2.7 g/cc; Density of Silicon Carbide = 3.21 g/cc; Density of Alumina = 3.88 g/cc

Theoretical Density, \( (2.71 \times 0.7) + (3.21 \times 0.1) + (3.88 \times 0.2) = 2.99 \text{g/cc} \)

Density = mass/volume; % Densification = \( \left( \frac{\text{Density of the sample}}{\text{Theoretical density}} \right) \times 100 \)

Al- 10%SiC- 20% Alumina at 4000kg load before sintering

Thickness of pellet = 1.006 cm; Mass of the pellet = 3.6 gram; Diameter of the pellet = 1.508 cm

Volume of the pellet = \( \frac{3.14 \times D^2 \times L}{4} = \frac{3.14 \times 1.508 \times 1.006}{4} = 1.79 \text{cc} \)

Green Density of the pellet = \( \frac{3.6 \text{g}}{1.79 \text{cc}} = 2.01 \text{g/cc} \)

2.6 Sintering

In the present study, microwave heating technology has been incorporated as it is faster than that of conventional\(^{11}\), the compacted specimens were sintered using microwave sintering technique to a temperature of 560°C for 30 mins in a 4 kW, 2.45 GHz\(^{4}\) microwave oven shown in Figure 3., under ambient atmospheric condition. The microwave sintered components are shown in Figure 4. For comparison purpose, conventional sintering has also been done using a tubular furnace at a temperature of 560 °C for 150 mins in argon gas environment to avoid oxidation.

3. Results and Discussion

The test sample of composition Aluminium - 10% Fly ash, 10% SiC, 10% alumina was taken for consideration and the compaction load has been varied from 4000kg to 8000kg using universal testing machine. The densification values obtained on green density are tabulated.

Figure 5, shows the densification of composite increases steadily with compaction load and the maximum densification of 84.04% at 8000 kg. The densification of composite increases with increase in magnitude of compaction load as shown in Table 2. This is because the powder metallurgical component has more porous due to the configuration of powder particles, which allows more voids inside it. From the Table 3, it is observed that the hardness of composites increases with increase in compaction load. This is due to the compacted surface has minimum voids as the particles were closely packed and transfer the load effectively to the matrix. So it can able to offer more resistance to the intender to penetrate. Figure 6, shows that the hardness of the specimen is uniformly increases with compaction load.

Table 4, shows that the density of microwave sintered composite is better than that of conventionally sintered composites for all the cases as shown in Figure 7. The maximum densification of 92.5% was achieved in Al-15%SiC - 5% alumina and 10% of fly ash. In microwave-sintered composites, the voids are very less due to the ability of powder particle surfaces to generate more heat when it reacts with microwave and it leads to better diffusion. It is also noted that the presence of SiC particle...
has a significant role in densification due to the fact that the semiconductors are good absorber of microwaves and can generate more heat. The role of fly ash is also very significant as the result shows the better values were obtained in the composite, which has 10% fly ash in it.

From the Table 5, it can be observed that the hardness of the microwave sintered composites are better than that of conventionally sintered composites and the maximum hardness of 171 HRB was obtained in Al-15%SiC - 5% alumina and 10% of fly ash composite. From the Figure 8, it can see that the hardness gradually increases with increasing the volume fraction of SiC. When compare with densification, the percentage increase in hardness of microwave-sintered specimen is quite higher than that of conventional one. It shows that the diffusion of powder particles is better in microwave heating. The role of SiC and fly ash is also very significant on hardness of composites.

**Figure 5.** Comparison of compaction load vs densification.

**Figure 6.** Comparison of compaction load vs hardness.

**Figure 7.** Comparison of densification of conventional sintered samples and microwave sintered samples.

**Figure 8.** Hardness of various test samples.

**Table 2.** Effect of compacting load on densification

| Load (kg) | Theoretical Density (g/cc) | Actual Density (g/cc) | Densification (%) |
|-----------|-----------------------------|-----------------------|------------------|
| 4000      | 2.82                        | 2.02                  | 71.6             |
| 5000      | 2.82                        | 2.21                  | 78.36            |
| 6000      | 2.82                        | 2.27                  | 80.49            |
| 7000      | 2.82                        | 2.19                  | 81.2             |
| 8000      | 2.82                        | 2.37                  | 84.04            |

**Table 4.** Comparison of densification of C.S and MWS hardness

| Sample | T.D (g/cc) | C.S Density (g/cc) | M.W.S Density (g/cc) | Densification (%) |
|--------|------------|--------------------|----------------------|-------------------|
|        |            |                    |                      | C.S               |
| 1      | 2.86       | 2.34               | 2.53                 | 81.81             |
| 2      | 2.82       | 2.42               | 2.61                 | 85.81             |
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Table 4. Effect of compacting load on hardness

| Sl.No | Load (kg) | Hardness (HRB) |
|-------|-----------|----------------|
| 1     | 4000      | 146            |
| 2     | 5000      | 149            |
| 3     | 6000      | 162            |
| 4     | 7000      | 163            |
| 5     | 8000      | 167            |

Table 5. List of various samples vs rockwell density vs. theoretical density

| Specimen | Hardness of Conventionally Sintered specimens (HRB) | Hardness of Microwave sintered specimens (HRB) |
|----------|---------------------------------------------------|---------------------------------------------|
| Sample 1 | 143                                               | 161                                         |
| Sample 2 | 149                                               | 168                                         |
| Sample 3 | 153                                               | 171                                         |
| Sample 4 | 138                                               | 158                                         |
| Sample 5 | 146                                               | 167                                         |

4. Conclusion

In this study, aluminium - silicon carbide-alumina and fly ash composites were prepared at various proportions using both microwave and conventional sintering. Hardness and densification tests were conducted on the samples. From the results, the following conclusions were made.

1. Densification and hardness increases with increasing the compaction load, this is due to, when the compaction load increases the porosity of the composite decreases and it leads to the higher load bearing capacity of the specimen.
2. Microwave sintered composites has got the densification of 92.5% and hardness of 171 HRB. On comparing these results with conventionally sintered specimens, microwave sintered specimens gives better results due to better diffusion of reinforced particles with matrix caused by the heat generated at the surface area of the particles.
3. The effect of silicon carbide on hardness is higher than that of alumina and the better properties were obtained in the composite which contains 20% volume fraction of SiC. This is due to the fact that the semiconductor (SiC) absorbs microwave and results better diffusion.
4. The presence of fly ash as a filler material has a significant role on hardness and densification of composite.
5. Time taken and power consumption for microwave sintering is quite low on comparing with conventional sintering process.

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