Synthesis and Comparative Study of Microwave and Conventionally Sintered Al-SiC MMC through Powder Metallurgy

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***Abstract*- Metal matrix composites with Aluminum as the base metal and with varying weight percentage of Silicon Carbide (SiC) as the reinforcement are being synthesized through powder metallurgy route. Sintering of the green compacts is carried out by using conventional and microwave heating. The variation in mechanical properties due to the different sintering processes both conventional and microwave processes are studied. The consolidation of the powder is done under different pressures. It has been observed that green compact density increases with increasing pressure and decreases with increase in weight percentage of SiC. The metal matrix composites (MMC) produced is tested for their hardness and their microstructure variation. Hardness of microwave sintered compacts is more than that of conventional sintered samples. Micro structural investigation shows softening of Al in conventional sintering, but not so in microwave sintering.**

Keywords: Powder Metallurgy, Metal Matrix Composites, Conventional Sintering, Microwave Sintering, Microstructure.

I. INTRODUCTION

Microwave sintering has emerged in recent years as a new method for sintering a variety of materials that has shown significant advantages against conventional sintering procedures [1][2][3]. In the present paper metal matrix composite part is made through powder metallurgy route and sintered by conventional process and microwave process and the comparative study of variation in its mechanical properties are analyzed.

Aluminum Silicon Carbide (Al-SiC) is a metal matrix composite material that combines silicon carbide particles in aluminum matrix. Al-SiC materials provide superior thermal characteristics for high technology electronic components applications and are cost effective. It is also ideal for use in applications such as chip mounting, electronic packages, electronic boards and thermal spreaders.

Sintering is the process of consolidating the loose aggregate of powder of the desired composition under controlled conditions of temperature and time. SiC is most commonly used dispersion in aluminum. However, ceramic dispersions reduce the compressibility of aluminum powders and affect the sintering process at Al-Al contacts and hence results in poor bonding between matrix and reinforcement.

The densification response of unreinforced aluminum alloys was found to be improved when sintered with liquid phase. Required liquid phase is introduced through eutectic melting. Researchers have reported that successful sintering of aluminum requires the removal of the oxide layer in the process of liquid phase formation [4][5][6].

In conventional sintering, process samples are kept in the electric resistance furnace for 1 hour at the temperature of 450-500^{0}C. At that temperature the individual particle of the powder disappears and forms a porous mass. In microwave sintering microwave energy is transferred to the material by interaction of electromagnetic field at the molecular level. Because microwave radiation penetrates most ceramics, uniform volumetric heating is possible. In conventional sintering thermal gradients, which are produced because of conductive and radiative heat transfer can be minimized to a greater extent. By eliminating temperature gradient it is possible to reduce internal stresses, which further initiates the cracking of parts during sintering. It also creates a more uniform microstructure, which may lead to improved mechanical properties and reliability.

Recent investigations have identified the use of 2.45 GHz radiation for microwave sintering [7][8]. It is observed that the effect beyond the skin depth is very low. Hence very little penetration of microwaves takes place. However, in the case of fine metal powders rapid heating can occur. It was demonstrated that at higher frequency radiation, densification of alumina, fine grained microstructure could be obtained. In the present work, the radiation used was 28GHz and the temperature was 300-400^{0}C [9].

In this present study Al-SiC composite are synthesized through powder metallurgy route. Al-SiC powder mixtures with varying wt% of SiC are prepared and mixed in a ball mill. These powders are consolidated under different compaction pressures using cold die compaction technique. Green compact density of the compacts is calculated. The compacts are then heat treated using conventional electric furnace and microwave oven to improve inter particulate bonding and to induce strength. The sintered compacts are then tested for their hardness and microstructures.

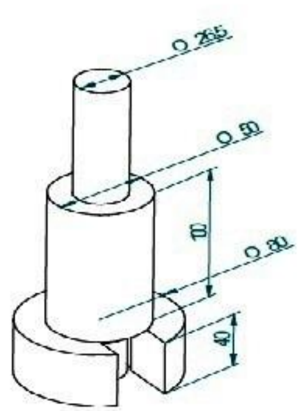
II. METHODOLOGY

Aluminium is selected as the base material. The particle size is about 70 microns(200mesh). Green silicon carbide is used as reinforcement. The particle size is about 10 microns(F800 grit). The compositions (wt%) of the powder mixtures are 100% Al + 0% SiC, 95% Al + 5% SiC, 90% Al + 10% SiC and 85% Al + 15% SiC. Blending of the aluminium and silicon carbide powders is done in a self made ball mill consisting of steel balls of different diameters placed in a container.The container is rotated using a 5 volt D.C motor mounted on a wooden pedestal. Blending is carried out for about 30 minutes.After blending, compaction is done to produce green compact of sufficient strength to withstand further handling operations. Cold die compaction technique is used. It involves application of high compaction pressures through punches from both ends of the toolset. The compaction pressures are applied using a Universal testing macine(UTM). The compaction tools used are die, upper punch, lower punch & ejection ring. Ejection of green compacts is also done by UTM. An ejection ring is placed under the die for this purpose. An ejection force of approximately 0.3 times of the compaction force is applied to eject the green compact.

The tools used for compaction are die, upper punch, lower punch and ejection ring. The material used for all these compaction tools is High Speed Steel(HSS). Fig 1 shows tooling arrangement during compaction.

Figure 1. *Die punch arrangement during compaction*.

Figure 2. *Com paction tool during ejection.*



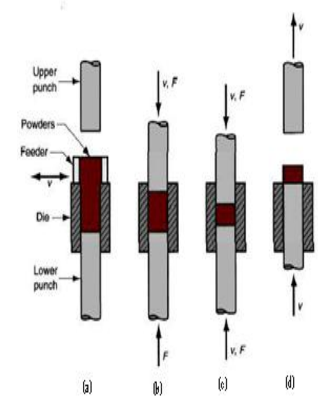


Figure 3. *Various steps during compaction & ejection.*

Fig 2 shows compaction tool assembly during ejection. Fig 3 shows various steps during compaction and ejection. Fig 3(a) shows filling of die cavity with powder by automatic feeder. Fig3(b) & 3(c) shows initial and final positions of upper and lower punches during pressing. Fig3(d) shows ejection of the part. Microwave sintering is done in domestic microwave oven. Sintering is done with reference to time rather than temperature. Quartz crucible is used for holding the sample and suceptor. Quartz is used as it is transperent to microwave and can withstand temperature up to 1080^{o}C. The quartz crucible is lined inside with kaowool that act as an insulating material. Silicon carbide chips are used as suceptors.These chips are placed in the crucible and sample is placed over it. Then the sample is uniformly covered with silicon carbide chips. The sintering operation is done in the oven at 800 watts for 2 minutes. It is allowed to cool in the oven for 10 minutes.

Convntional sintering process is carried out using electric resistance furnace. In this process samples are kept in the electric resistance furnace for 1 hour at the temperature of 450^{0}C. Samples are taken out from the furnace and kept in the air for cooling. The furnace has a temparature controller.

III. EXPERIMENTAL DETAILS

Various tests were conducted to study the hardness and microstructure of the samples.The aim was to observe the variation in the mechanical properties due to microwave or conventional sintering. The surface of the specimen is prepared by proper sanding using emery papers of different grades and the polishing is carried out by using the Keller's agent as an etching agent. Test was carried out on the sintered samples named as MS1(microwae sintered sample 1), CS1(conventional sintered sample 1), MS2, CS2, MS3, CS3. The samples MS1 MS2, MS3, are the three microwave sintered samples and CS1, CS2, CS3 are conventional sintered samples. The travelling speed of the cross head of the UTM was 0.01mm/min. Table 1 shows the details of above mentioned sintered samples.

Table 1. *Densities of green compact for varying composition of SiC and varying compaction pressures*

Sample	Composition	Wt. (gm)	Ht (mm)	Volume (cm^3)	Green density (gm/cm^3)
MS1	100% Al	7.638	6.74	3.72	2.04
CS1		8.100	6.90	3.82	2.12
MS2	95% Al 5%Si	9.383	8.06	4.47	2.09
CS2		9.426	8.13	4.50	2.09
MS3	90% Al 10%Si	9.957	8.80	4.86	2.04
CS3		9.235	8.08	4.46	2.06

"Clemex Intelligent Microscope" was used for microstructure analysis which has a magnification of upto 400X. For each sample two microstructure images, one at 100X zoom level and other at 400X were taken. Rockwell hardness test is used to measure the hardness. The load used in test was 1kN.

IV. RESULTS & DISCUSSION

A. Green Compact Density.

The green compact density of Al-SiC MMCs decreases with increase in percentage of SiC. This is due to the incompressible nature of silicon carbide. Whereas the green compact density of Al-SiC, MMC increases with increase in the compaction pressure. This is due to closer packing of powder in the compacts with increasing compaction pressure. Table 2 shows the variation of green compact density with respect to pressure and compaction. Fig 4shows the variation of the density with respect to compaction pressure. Fig 5 shows the variation of density with respect to the wt% of SiC.

Table 2. ***Variation of Green compact density*** in Kg/m^3 ***with compaction pressure*.**

Compaction Pressure(MPa)	Wt % of Si		
	0	5	10
50	1.82	2.12	2.24
100	1.81	2.09	2.21
150	1.80	2.04	2.21

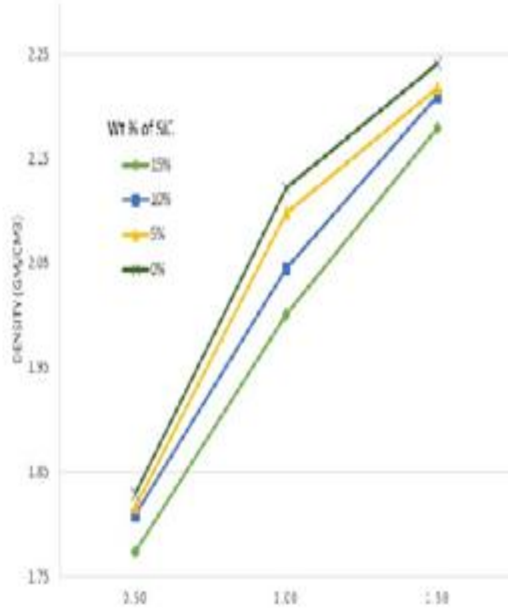


Figure 4. *Density vs. Compaction pressure.*

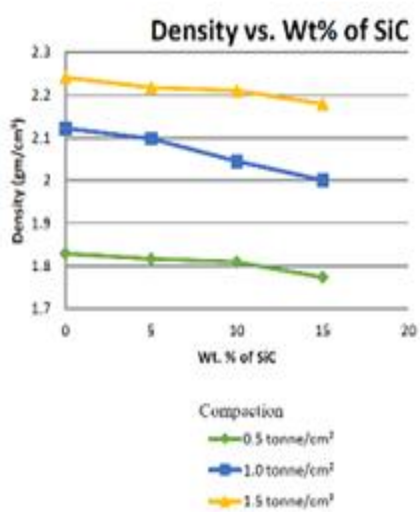


Figure 5.*Density vs. Wt% of SiC*

B. Hardness.

Rockwell hardness test was carried out on the conventional and microwave sintered samples. All the samples for testing purpose were compacted at the compression pressure of 1MPa. Table 3 shows hardness value for conventional and microwave sintered samples.

Table 3. *Hardness values in HRB for conventional and microwave sintered samples***.**

Wt% of SiC	Hardness value(HRB)	
	Conventionally Sintered	Microwave sintered
0	56	62
5	64	73
10	75	80
15	82	89

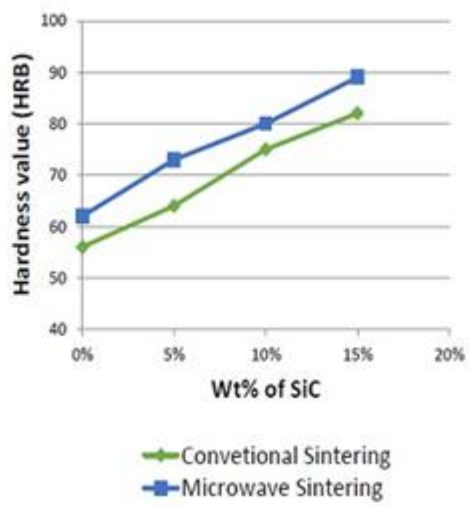


Figure 6.*Wt% of SiC vs. Hardness value*

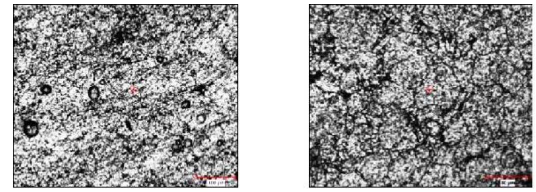
Hardness increased with increase in wt% of SiC. This is due to the distribution of fine SiC particles in the Al matrix which results in sharing of applied load between Al matrix and SiC particles.

Hardness of microwave sintered compact was more than that of conventional sintered samples due to the fast heating rate which prevents softening of aluminum.

C. Microstructure.

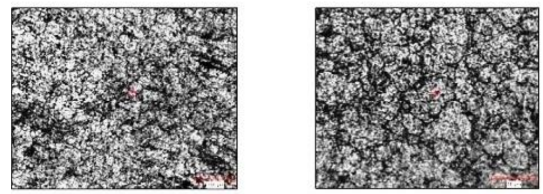
Microstructure with well defined grains and small amount of porosity mostly at inter particulate regions can be seen for unreinforced pure Al compacts. Porosity distribution is uniform in microwave sintered samples whereas porosities are concentrated more at the core in conventional sintered samples (indicating reduced the heat flux in thecore).

In conventional sintering the grains of Al are coarser indicating re-crystallization and grain growth. While in microwave sintering the contact points are welded without much heating of grains and hence the strength properties of microwave composites are much better. The microstructures of different samples are as shown in fig 7, fig 8, fig 9 and fig 10.



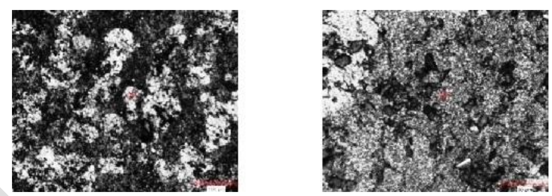
At 100x At 400x

Figure7. *Microstructure of sample MS1 (Microwave sintering)*



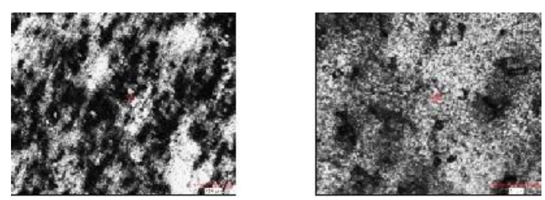
At100x At400x

Figure8.*Microstructure of sample CS1 (Conventional sintering)*



At 100x At400x

Figure9. *Microstructure of sample MS2(Microwave sintering)*



At 100x At400x

Figure10. *Microstructure of sample CS2(Conventional sintering)*

V. CONCLUSIONS

The mechanical properties of compacts through powder metallurgy are essentially determined by the cohesion of constituents due to proper mixing, pressing, compacting and sintering. In the present paper the comparative study of the MMC obtained through powder metalurgy route is examined for its density, hardness and microstructure variation. It has been observed that density increases with increasing compaction pressures and decreass with increase in weight% of SiC. Hardness increases with increase in weight % of SiC. Microwave sintered samples exhibited higher hardness than conventional sintered samples. Porosity distribution is uniform in microwave sintered samples whereas porosities are concentrated more at the core in conventional sintered samples. The microstructure of microwave sintered samples are hardly altered by the microwave sintering process. In conventional sintering process the grains are recrystallized and becomes soft.

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