MECHANICAL PROPERTIES OF METAL MATRIX COMPOSITES (Al/SiC_p) PARTICLES PRODUCED BY POWDER METALLURGY

B.Venkatesh[1], B.Harish[2]

[1]Department of Mechanical Engineering, B.V.Raju Institute of Technology, Narsapur, TS, India

Email: bikkinavenkatesh8055@gmail.com

Abstract

Metal matrix composites (MMCs) have become attractive for engineering structural applications due to their excellent specific strength property and are increasingly seen as alternative to the conventional materials particularly in the automotive, aerospace and defence industries. Al/SiC MMC has aluminium matrix and the silicon carbide particles as reinforcements and exhibits many desirable mechanical properties. In the present study, an attempt has been made to fabricate Al/SiC composite by powder metallurgy route as it homogenously distributes the reinforcement in the matrix with no interfacial chemical reaction and high localized residual porosity. SiC particles containing different weight fractions (10 and 15 wt. %) and mesh size (300 and 400) is used as reinforcement. The paper presents the processing of Al/SiC by powder metallurgy method to achieve desired properties and also the results of an experimental investigation on the mechanical properties of Al/SiC are determined.

Keywords - MMC; Al/SiC_p; Powder metallurgy; Mechanical properties; Density; Hardness; XRD ; Microstructure.

1. INTRODUCTION

Aluminum has played and continuous to play a key role in the development of metal matrix composites (MMCs) reinforced with a variety of ceramic materials including Al_2O_3, TiC, B_4C, and SiC. From the wide range of MMCs systems studied thus far and on account of the attractive properties of SiC. Al/SiC composites have drawn the attention of a plethora of research scientists and technologists. Like with any other composite material, the materials behavior lies much in the matrix characteristics as in the reinforcement properties. Several aspects are to be considered with regard to the metallic matrix namely composition, response to heat treatments, mechanical and corrosion behavior. Since aluminum offers flexibility in terms of these aspects accordingly, a number of aluminum alloys have been used in studies intended for research and technological applications. The combination of light weight, environmental resistance and useful mechanical properties such as modulus, strength, toughness and impact resistance has made aluminium alloys well suited for use as matrix materials [1-4]. Moreover, the melting point of aluminium is high enough to satisfy many application requirements. Among various reinforcements, silicon carbide is widely used because of its high modulus and strengths, excellent thermal resistance, good corrosion resistance, good compatibility with the aluminium matrix, low cost and ready availability.

The main objective of using silicon carbide reinforced aluminum alloy composite system for advanced structural components to replace the existing super alloys The choice, however, for one or another alloy depends also on other factors as the composite processing route, which in turn can be dictated by the volume fraction of the reinforcement in the composite. Another important factor for selection of the aluminum alloy is the composites application and specific requirements in service. For instance, one composite may behave better under certain loads or in corrosive environments. In the present investigation aluminium (commercially pure having an assay of >99% of Aluminium) and SiC particulates have been used for the MMC fabrication. In the recent researches particle reinforced metal matrix composites have been extensively investigated. Usually, this kind of composites is produced by stir casting methods and also there are some investigations on generating them by powder metallurgy techniques. Powder metallurgy has got a great influence of producing net-shape components that minimizes the machining process particularly in case aluminium silicon carbide composite rapid tool wear rate takes place due to abrasiveness of the hard SiC particles and also machining process causes cracking of SiC particles [5].The main advantage of using powder metallurgy method to generate MMC (Al/SiC_p) is as it produces a uniform distribution of reinforcement in the matrix where as other manufacturing methods fail to satisfy, also the production methods such as spray co-deposition followed by rolling and In Situ process is very expensive which render its application [6].

2. EXPERIMENTAL METHOD

2.1 MATERIALS

It is indispensable to select pure metal powder and optimal processing parameters for the preparation of specimens. The specifications/ composition obtained is presented below. The aluminium alloy contains Al-99.0%, Fe-0.5%, Mn-0.01%, Zn- 0.0053%, Cu-0.05%, Pb-0.03% of other materials and Particle sizes 200 mesh (74µm).SiC_p containing assay 99% (metal basis) and particle sizes of 300 mesh (50µm), 400 mesh (36 µm) are applied.

2.2 PRE-TREATMENT OF SIC PARTICULATES

The pre-treatment of SiC particulates is heated in presence of air at a temperature of 700°C in a muffle furnace (TEXCARETM, max.temp. 1000° C) as shown in Fig. 1 & Fig 2 and kept at the temperature for 1hour preceding to using it for fabrication of MMC samples As it is done to shape a thin layer of SiO_2 on the surface of SiC particulate to aluminium so that immediate reaction between aluminium and SiC particulates is prevented. [3-7].

Fig.1. Muffle furnace

Fig.2. Heating of SiC_p at 700° C

2.3 POWDER METALLURGY METHOD

The investigation specimens (Al/SiC_p) are made-up by using powder metallurgy technique by following steps.

2.3.1 Mixing of Powders

Total four categories of mixture were prepared.

- 90% Al + 10% SiC - 300 mesh
- 90% Al + 10% SiC - 400 mesh
- 85% Al + 15% SiC - 300 mesh
- 85% Al + 15% SiC - 400 mesh

Blending is performed in ball planetary mill which consists of two cylindrical containers made of chrome steel rotating about its axis and inside which 10 balls made up of chrome steel of sizes 10 mm. To get a uniform degree of fineness in the mixture the blending machine is allowed to rotate about 2-3 lakh of revolutions.

2.3.2 Compaction of the powder mix

The compaction is done with a powder mixture of about 50 gm in a cold uniaxial press in a die-punch arrangement.

2.3.3 Cold uniaxial pressing

A die composed of stainless steel of 30 mm internal diameter was utilized for this purpose. In this the powder sample is pressed in the cold isostatic pressing machine (Shenzhen of hydraulic type) is used to provide the green circular test by applying a load of 18 ton, with 3600 bar pressure. In order to prevent the specimen from sticking on to the walls of die and also to allow the powder flow freely stearic acid was used as a lubricant. The operation of pressing machine and compacted green samples with average diameter and thickness of pallets are 30 mm and 15 mm.are shown in the Fig .3 & 4.

2.3.4 Sintering of the green samples

It is carried out in a horizontal tubular furnace (Make: HIGHMECHTHERM) in which the green compacts are parched at an elevated temperature but kept below the melting point of the base metal for sufficient time. A total of four samples from each of the two mixtures containing 10, 15% SiC were sintered for 1 hour at a temperature of 650° C respectively. Due to high temperature in the sintering process proper bonding between metallic matrix and ceramic particles at interface and the morphology and distribution of pores and carbides in the matrix are achieved. The existence of SiC_p also holdup the aluminium melts from one particle to join melts from another. So increasing silicon carbide content increase the sintering temperature needed to achieve high strength composite.

Then furnace is allowed to cool to room temperature for a span of 24 hours. Then the specimens are removed from the furnace and dipped in concentrated H_2SO_4

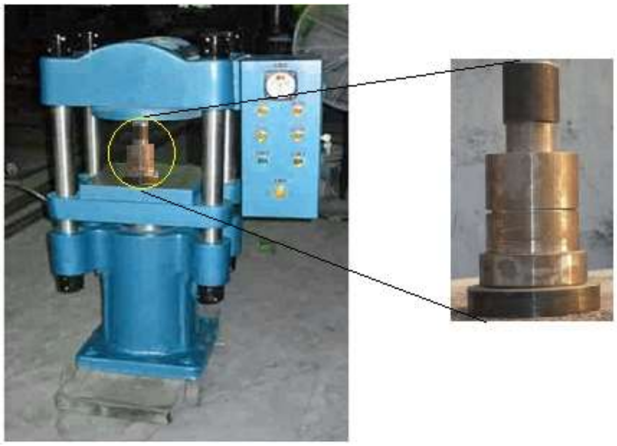


Fig.3.Cold Isostatic pressing machine

Fig.4. Green samples

2.3.5 Heat treatment

The heat treatment is given to the specimens to refine the grain structure inside a material part and increase its mechanical properties. Quenching was carried in a heat treatment furnace at 500°C for one hour and then quenched in iced water**.** After quenching in order to avoid natural ageing, all the specimens were artificially aged at 200°C holding a time of 8 hour in a closed muffle furnace and left cooled in it. The sintered samples prepared by the above discussed process are shown in Fig.5. These green samples are ready for further use. The properties of the samples were then measured by different equipments.

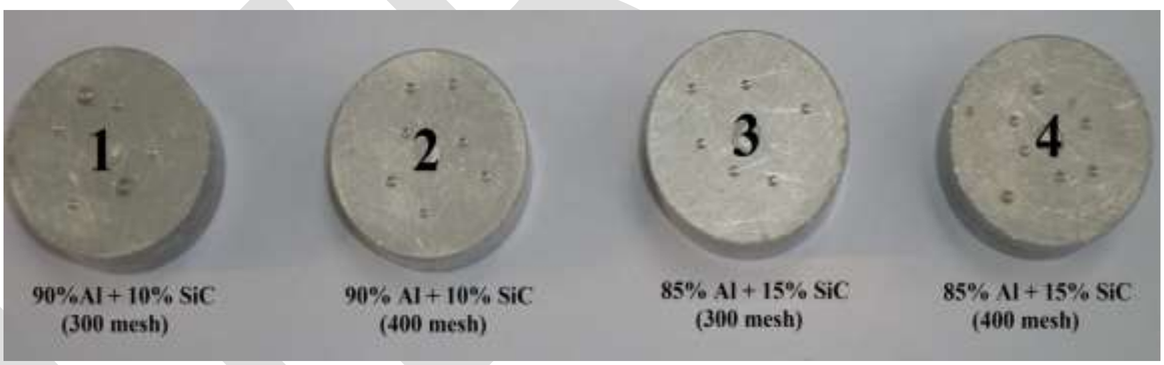


Fig.5. Sintered Samples

3. RESULTS AND DISCUSSIONS

3.1 XRD ANALYSIS

The XRD analysis is performed to confirm the constituents present in the blended powder. The peaks obtained after XRD analysis is shown in the Fig.6. which confirms that there is presence of only two phases i.e. Al and SiC crystals and also it shows aluminium is 99.7% pure and the left over contains aluminium alloys such as aluminium manganese, aluminium silicon and aluminium titanium. The XRD test is also performed on silicon carbide particulates of mesh size (300, 400) and it is observed that SiC mostly contains moissanite-6H i.e. SiC and extremely minute traces of Paladium Oxide and $Al_2Si_3O_{12}$.It was also found that the specimen is free from chrome steel crystals which is used during blending in a chrome steel crucible. These outcomes prove the appropriateness of the specimens in terms of uniform distribution of particles and prove that they are accurate for advance investigation.

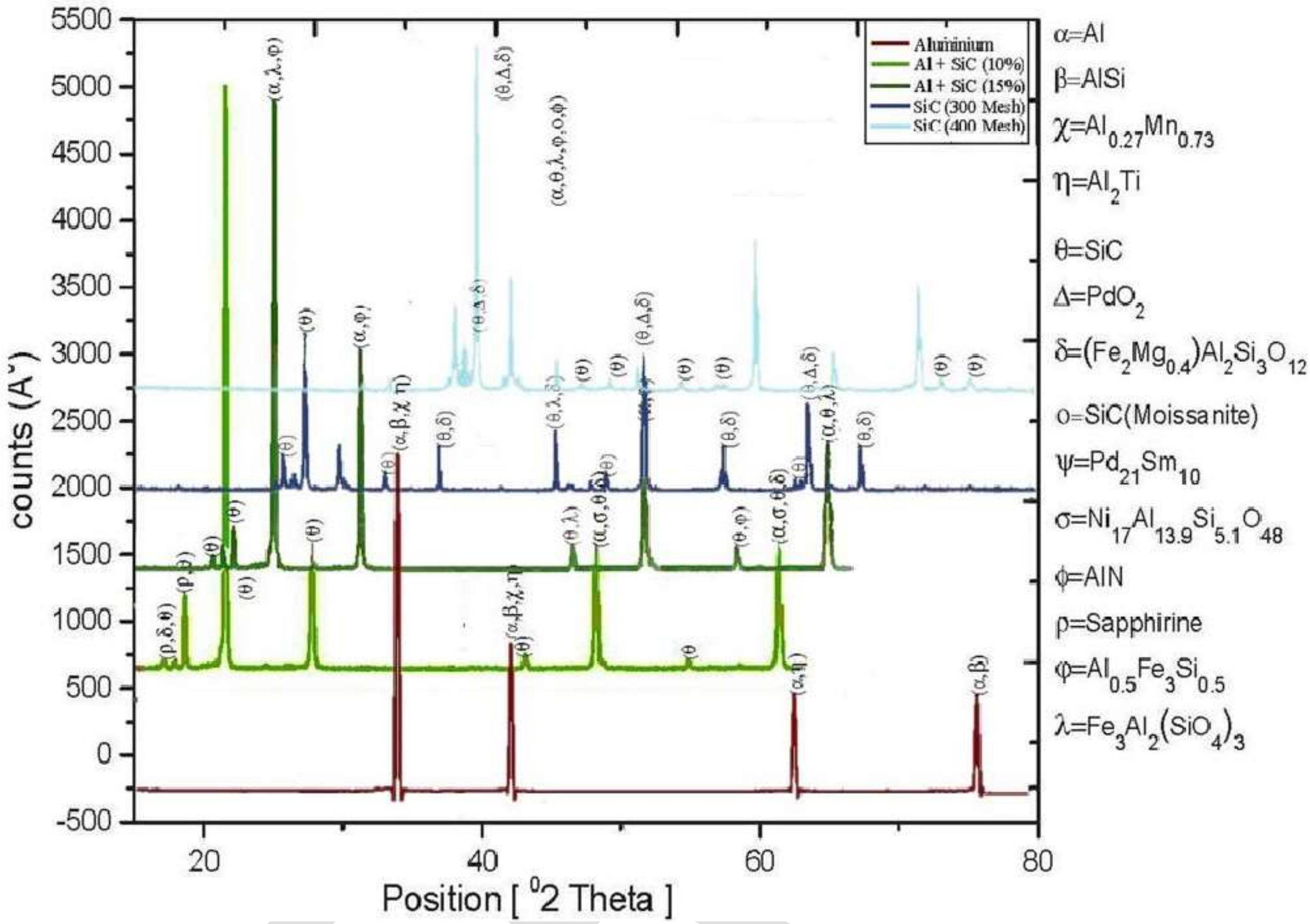


Fig.6. XRD Graphs

3.2 DENSITY

The actual densities of the samples are obtained through water immersion method shown in Table 1.Theoretically; the densities of the composites are measured using the following relation. Using the below equation, the theoretical density of the MMC is found to be 0.00268 g/mm^3. The average actual density is found to be 0.00230 g/mm^3. The difference in density is attributed to presence of voids in the samples.

$$\rho_c = \frac{1}{\left(\frac{W_{Al}}{\rho_{Al}}\right) + \left(\frac{W_{SiC}}{\rho_{SiC}}\right)}$$

Where

ρ_c = Composite density, g/mm^3
W_{Al} = Weight fraction of aluminium
ρ_{Al} = Density of aluminium (0.00262 g/mm^3)
W_{SiC} = Weight fraction of Silicon Carbide
ρ_{SiC} = Density of Silicon Carbide (0.0032 g/mm^3)

From Table 1, it is observed that maximum of 67.63% increase in density occurs after sintering the green samples due to filling up of the voids between particles with melted aluminium and also Fig.7 tell us about the result of density increases with wt% of SiC after sintering. Finally this graph confirms that MMC depend on both, the wt. % as well as mesh size of SiC_p.

%SiC	MESH	DENSITY (g/mm^3)		%INCREASE
		BEFORE SINTERING	AFTER SINTERING	
10	300	0.001716	0.00203	18.29
10	400	0.001736	0.00244	40.55
15	300	0.001726	0.00266	54.11
15	400	0.001730	0.00290	67.63

Table.1. Density values of AlSiC before and after sintering

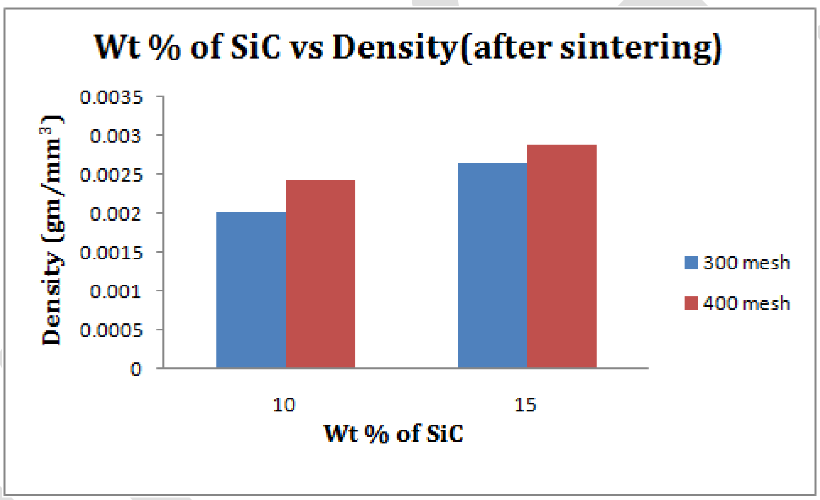


Fig.7. Variation of density with Wt% of SiC (after sintering)

3.3 HARDNESS

Hardness of the green and sintered samples is measured by the equipment Rockwell hardness measuring machine (Wilson Hardness Tester, USA Model: LM 2481T) From Table 2, it is observed that hardness increases by at least 20% after sintering.

%SiC	MESH	LOAD APPLIED (kgf)	HARDNESS(HRC)		%INCREASE
			BEFORE SINTERING	AFTER SINTERING	
10	300	150	62.3	75	20.38
10	400	150	57.4	72.6	26.47
15	300	150	63	76.5	21.35

15	400	150	56.6	73.1	28.26

Table.2. Hardness values of AlSiC before and after sintering

The average hardness for samples is found to be 73.82 and 74.80 HRC for SiC weight percentage of 10 and 15 respectively whereas hardness for aluminium is 22 HRC.Fig 8 shows the variation of hardness after sintering and it is observed that the percentage of hardness is increasing with increasing wt. % but decreasing with increasing in mesh size of SiC after sintering.

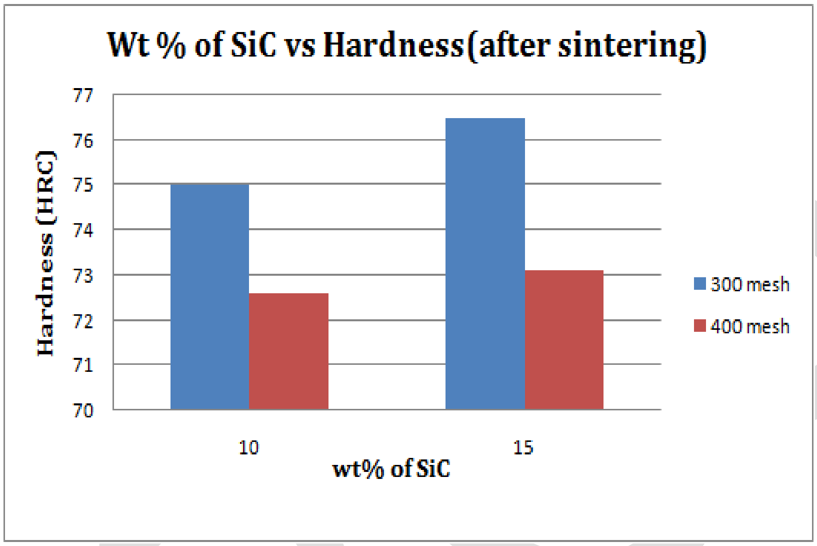
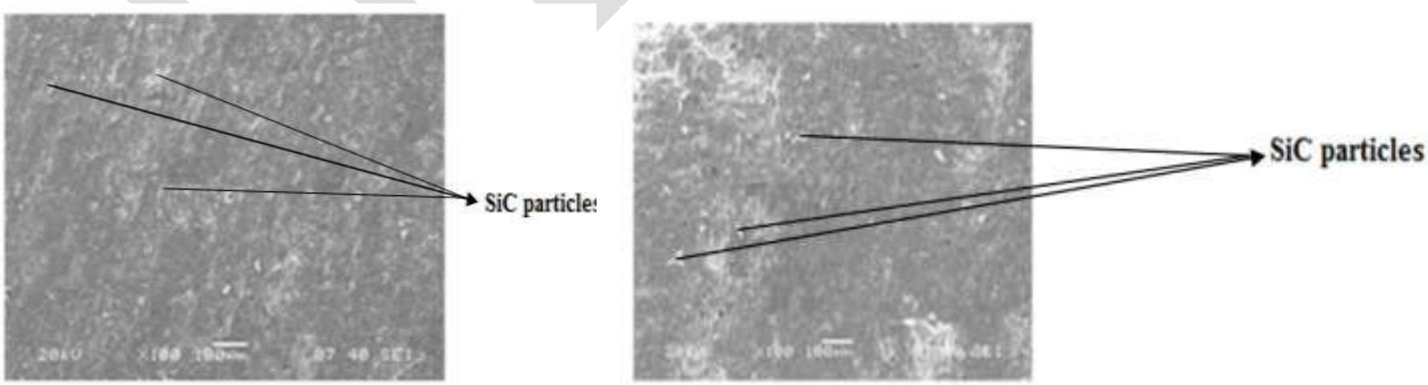


Fig.8. Variation of hardness with Wt% of SiC (after sintering)

3.4 MICROSTRUCTURE

The morphology of raw powders having 10 and 15 weight percentage of silicon carbide before sintering was made with Scanning Electron Microscopy (SEM), JSM-6480 Model (JOEL) shown in Fig.9 (a).Green samples it is observed that SiC particles are equivalently distributed in the matrix. A few clustering of the reinforcement is observed in both the micrographs and increases with the percentage of reinforcement and mesh size increases

.

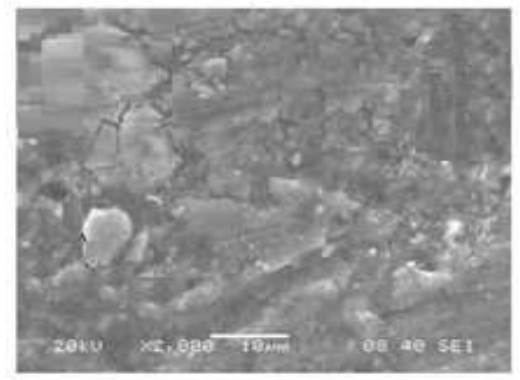


(a) **(b)**

10% SiC (300 Mesh size) **15% SiC (400 Mesh size)**

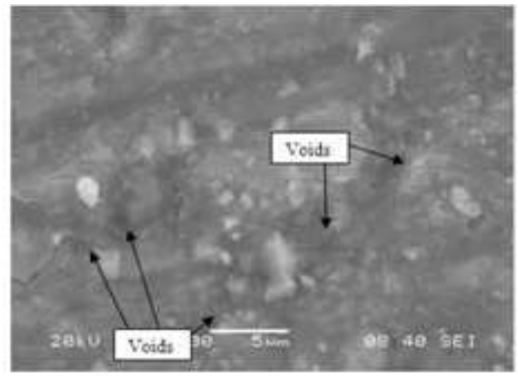
Fig. 9(a).Micrographs showing the distribution of the reinforcement in the green samples

From the Fig.9 (b) Sintered samples it is observed that silicon carbide particles enclosed by melted aluminium particles and also compared with 10% weight of silicon carbide more number of voids is observed in the samples of 15% weight of silicon carbide



(a)

10% SiC (300 Mesh size)



(b)

15% SiC (400 Mesh size)

Fig 9(b) Micro-graphs showing aluminium and voids in the composite (sintering samples)

4. CONCLUSION

- In this experimental study it is found that both density and hardness properties of the MMC is increasing with increasing sintering temperature.
- The mechanical properties like density and hardness of MMCs under investigation depend on both, the weight percentage and mesh size of SiC_p.
- Heat treatment after sintering is increasing hardness as well as density. After heat treatment the percentage of density is increasing as the SiC_p reinforcement, weight % and mesh size increasing.
- The percentage of hardness is increasing with increasing wt. % but decreasing with increasing in mesh size of SiC_p after heat treatment.
- It is concluded that heat treatment after sintering is influencing the properties. The density is increasing when SiC_p is increasing.
- The hardness of MMC is increasing with increasing weight % of SiC_p in the composite and mesh size.

REFERENCES:

[1] N. Muthukrishnan, M. Murugan, K.P. Rao, Machinability issues in turning Al-SiC (10%) metal matrix composites, International Journal of Advanced Manufacturing Technology. 17(3-4) (2008) 1220-1228.
[2] A.R. Ahamed, P. Asokan, S. Aravindan, EDM of hybrid Al-SiCp-B4Cp and Al-SiCp-Glassp MMCs, International Journal of Advanced Manufacturing Technology.44(5-6) (2009) 520-528.
[3] W.M. Khairaldien, A.A. Khalil, M.R. Bayoumi, Production of aluminum-silicon carbide composites using powder metallurgy at sintering temperatures above the aluminum melting point, Journal of Testing and Evaluation. 35(6) (2007)111-125.
[4] Slipenyuk V. Kuprin Yu. Milman V. Goncharuk J. Eckert Properties of P/M processed particle reinforced metal matrix composites specified by reinforcement concentration and matrix-to-reinforcement particle size ratio, Acta Materialia. 54(1) (2006) 157–166.
[5] A.R. Ahamed, P. Asokan, S. Aravindan, EDM of hybrid Al-SiCp-B4Cp and Al-SiCp-Glassp MMCs, International Journal of Advanced Manufacturing Technology. 44(5-6) (2009) 520-528.
[6] W.M. Khairaldien, A.A. Khalil, M.R. Bayoumi, Production of aluminum-silicon carbide composites using powder metallurgy at sintering temperatures above the aluminum melting point, Journal of Testing and Evaluation. 35(6) (2007) 111-125
[7] T. Sritharan, L.S. Chan, L.K. Tan ,N.P. Hung, A feature of the reaction between Al and SiC particles in an MMC, Materials Characterization. 47(1) (2001) 75–77.
[8] C. Tatar, N. Özdemir, Investigation of thermal conductivity and microstructure of the α-Al2O3 particulate reinforced aluminum composites (Al/Al2O3-MMC) by powder metallurgy method, Physica B: Condensed Matter.405(3) (2010) 896-899.
[9] C. Sun, M. Song, Z. Wang, Y He, Effect of Particle Size on the Microstructures and Mechanical Properties of SiC-Reinforced Pure Aluminum Composites, Journal of Materials Engineering and Performance. 20(9) (2011) 1606-1612.
[10] F. Bedir, B. Ogel, Investigation of hardness, microstructure and wear properties of SiC_p reinforced Al composites. In: Proceeding of the 11th International Conference on Machine Design and Production, Turkey, 2004.

[11] T. Lemerise, C.S. Rao, G.S. Upadhyaya, 2014 and 6061 aluminium alloy-based powder metallurgy composites containing silicon carbide particles/fibres, Materials and Design.16(6) (1995) 21-33.
[12] H. Abdizadeh, M. Ashuri, P. T. Moghadam, A. Nouribahadory, H. R. Baharvandi, Improvement in physical and mechanical properties of aluminum/zircon composites fabricated by powder metallurgy method, Materials and Design. 32 (2011) 4417–4423