Manufacturing and Mechanical Behavior of (Al/SiC) Functionally Graded Material using Powder Metallurgy Technique

Mulugundam Siva Surya, G. Prasanthi

Abstract*: This research focuses on manufacturing and mechanical characterization of functionally graded materials using powder metallurgy techniques. Owing to its low density and high strength to weight ratio, pure aluminum with mesh size No. 200 is chosen as the matrix. Silicon carbide with mesh size No. 220, which has a wide range of applications due to its high hardness, is selected as reinforcement. Specimens of two functionally graded materials(FGM) with 4 layers (0%, 3%, 7%, 10%)(FGM-1) and 5 layers (10%, 20%, 30%, 40%, 50%) (FGM-2) are sintered by varying the SiC composition from layer to layer. From the microstructure, it is clearly evident that four layered specimens achieved more homogeneous mixture than five layered. Also, mechanical properties of four layered specimens attained better results than five layered specimens.

***Index Terms*: Functionally graded material, Powder metallurgy, Silicon Carbide, Aluminum.**

I. INTRODUCTION

Gradual change in composition and structure over volume is an important characteristic feature of functionally graded material(FGM). Engineering components like brakes and piston cylinders are subjected to two different service conditions on either side in the thickness direction, which results in different property changes in either sides. In the case of gears, two desirable properties are high toughness and better surface hardness. High toughness helps in withstanding dynamic loads, while better surface hardness helps in avoiding wear. Keeping such devices in view a new category of advanced and innovative metals are being developed and studied with the goal of achieving superior and reliable performance based on the function and application the materials can be designed [1-3]. Al, Cu, Zn and Mg alloys are most widely used as matrix in metal matrix composites(MMCs), of these, Al alloy used in aircraft structures, especially for wing and fuselage structures has good machining characteristics, high strength and fatigue resistance, based on its features like low weight to strength ratio and high heat conductivity it is used widely for rotating and reciprocating parts like piston, brake rotors, drive shafts and automobile engines. Based on the chemical. composition, Al alloys exhibit a varied range of mechanical properties when reinforced with ceramic metals like Al2O3, B4C, TiC and SiC. Many scientists are working on Al/SiC composites due to the attractive properties of SiC [4-7]. Choice of fabrication method plays a pivotal role in FGM research. A wide range of production processes are put in place for processing FGMs. Examples powder metallurgy, thermal spray, slip casting, centrifugal casting, laser cladding and chemical vapor deposition [8]. Because of its advantages like low processing temperature vis-a-vis melting techniques, good distribution of reinforced particles and ability to manufacture near net shape products at low cost, powder metallurgy is a good technique for producing MMC's [9-10]. To find the constituents, present in the blended powder and to identify any reactions between the alloy and ceramic components XRD analysis is carried out [11-12]. To observe the distribution of ceramic reinforcements in each FGM layers, and to study the interfacial bonding between two adjacent layers the microstructural characterization is carried out. For visualizing distribution of reinforcing phases at higher magnification SEM analysis is performed [13]. Earlier work on Al-SiC metal matrix composite was carried out by the same authors where fabrication of Al-SiC functionally graded composite and its tribological properties were discussed [14]. It is shown that functional graded material possesses gradient in wear resistant from one edge to other edge of the sample with improvement in wear properties than Cast iron which is generally used for breaks discs. Thus, the authors show that the CI can be replaced with Al-SiC metal matrix functionally graded material. However other mechanical properties like hardness, toughness and tensile strength are also critical in comparing the behavior of the MMCs and FGMs [15-17] with the present comparative material that is Cast Iron. This work focus on the mechanical properties such as hardness, toughness and tensile of the composite with sic reinforcement within Al matrix for brakes application. It is expected that as this material are functionally graded, the mechanical behavior may have significant influence and it is worth to focus on such change in mechanical behavior of overall product due to such functionally gradient properties.

II. MATERIALS AND METHODOLGY

In the current work, Aluminum-silicon carbide FGMs are produced using powder metallurgy method and the performance of these FGMs are investigated experimentally. Preparation of the FGM samples is done using the raw materials purchased from NICE chemicals private limited Hyderabad. For both aluminium and silicon carbide mesh sizes of No. 200 and No.220 are used. Silicon carbide, a ceramic material known for its hardness is used in the FGMs for reinforcement. This improves the hardness and abrasive efficiency of the corresponding FGM samples. It is applied to each and very layer of the FGM

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samples but in different proportions (Table 1). Pure aluminum is used as matrix material owing to its higher hardness and strength as the age progresses.

These aluminum and silicon carbide powders were ball-milled at 270C temperature for 1 hour in a ball mill at a speed of 100 rpm using tungsten balls. The ball- to powder mass ratio is 10:1[18]. For compacting a powder mixture of about 30gms, a cold uniaxial press with a die punch arrangement is employed. The powders are poured into the die and pressed in the cold pressing machine at a load of 150 kN. Zinc stearate is used as a lubricant to avoid the sticking of specimens on the wall of the die. It is also used for the powder to flow freely. Four test specimens are shown in Fig 1. The FGM specimens are sintered for 1 hour at a temperature of 580^0C in a protected atmosphere furnace.

Table I. composition of specimens.

Specimens/Layers	1	2	3	4	5
FGM-1(wt.%)	0	3	7	10	-
FGM-2(wt.%)	10	20	30	40	50

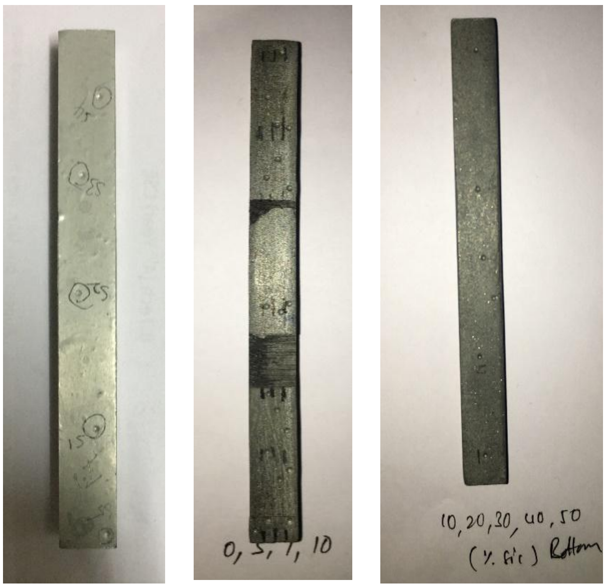

Fig .1. Pure aluminum, FGM-1, FGM-2 specimens

III. RESULTS AND DISCUSSION

A. XRD Analysis

To find the presence of intermediate phases in the FGM XRD analysis is carried. The XRD technique is one of the important phase analysis methods performed on the MMCs to determine the reaction between the alloy and ceramic components. The results of XRD analysis confirmed the presence of Al and SiC in both the FGMs as shown in Fig 2. It is clear from the XRD analysis that no other unwanted materials are present instead of Al and SiC. From the XRD graphs in Fig 2 it can be inferred that the percentage increase in SiC as reinforcement in the base metal has resulted in the increase of SiC intensity. Al and SiC peaks are indexed using ICSD codes.

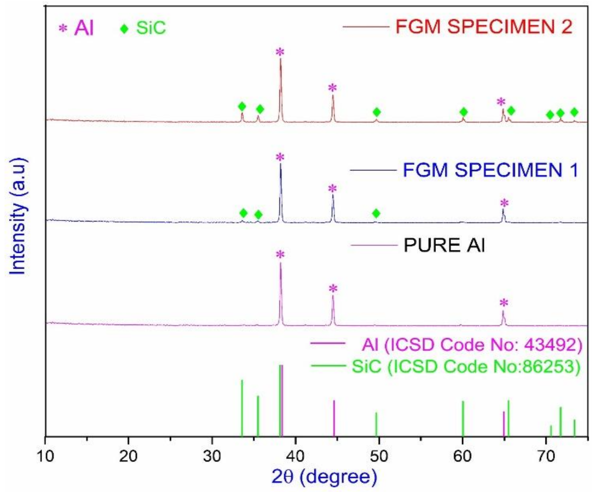

Fig.2. XRD Graph

B. Microstructure Of FGM-1 and FGM-2

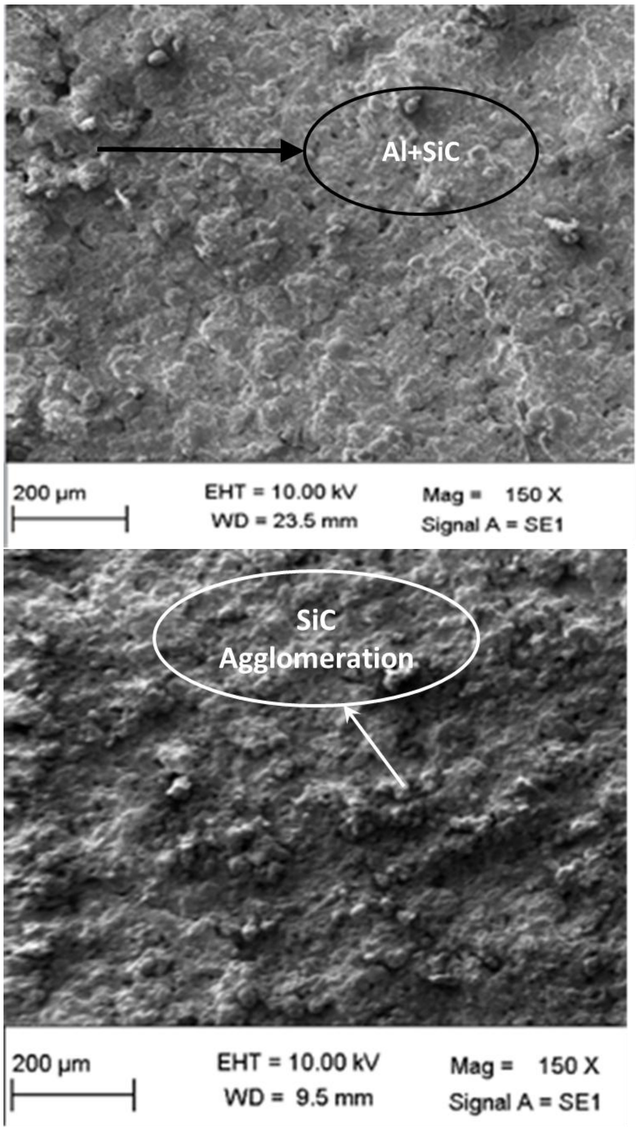

Fig. 3(a) and (b) SEM images of FGM-1&2

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Fig “3(a)” and Fig “3(b)” contains silicon carbide (as shown by arrows) distributed homogeneously throughout the matrix. However due to the higher fraction of SiC in Fig 3(b), it gets agglomerated whereas no agglomeration is observed in Fig 3(a).

C. Hardness of FGM-1 and FGM-2:

In order to measure the hardness of specimens, Rockwell hardness test has been carried out. According to the specifications of Rockwell hardness test for aluminium alloys, 1/16-inch stainless steel indenter was used and a constant load of 100 Kgf is applied for a duration of 20 seconds. The values obtained from Rockwell hardness test refer to B scale readings specified on the machine.

Table II. Pure Al Hardness

Composition	hardness			Avg. hardness
	Trail 1	Trail 2	Trail 3	
Pure AL	53	50	52	51.67

Table III. FGM-1 Hardness values

Layers	SiC % comp	Hardness			Avg. hardness
		Trail 1	Trail 2	Trail 3	
Layer 1	0	53	55	51	53
Layer 2	3	56	54	55	55
Layer 3	7	60	61	63	61.3
Layer 4	10	71	82	72	75

Table IV. FGM-2 Hardness values

Layers	SiC % comp	Hardness			Avg. hardness
		Trail 1	Trail 2	Trail 3	
Layer 1	10	65	60	66	63.67
Layer 2	20	62	70	74	68.67
Layer 3	30	71	71	70	70.67
Layer 4	40	72	78	74	74.67
Layer 5	50	83	93	84	86.67

Table 2,3 and 4 show the hardness values of pure aluminum, FGM-1(4 layers) and FGM-2(5 layers) specimens with varying SiC %wt. It is clear from the tables the hardness value of pure aluminum is less because of the absence of SiC and with the increase in SiC content hardness increases for FGM-1and FGM-2.

D. Toughness

Charpy impact test is used to determine the behavior of material when subjected to high rates of loading usually in bending, torsion and tension. The amount of energy absorbed by the specimen during charpy test indicates its physical nature. In case of specimens made out of brittle materials, little energy is absorbed and in case of ductile materials high energy is absorbed for fracture. The charpy specimen is placed in the vice so that it behaves like a simply supported beam.

Table V. FGM-2 Impact test Results

Sample	Toughness (J)		Avg. Toughness (J)
	On face	On side	
Pure AL	4	6	5
FGM-1	3	14	8.5
FGM-2	5	7	6

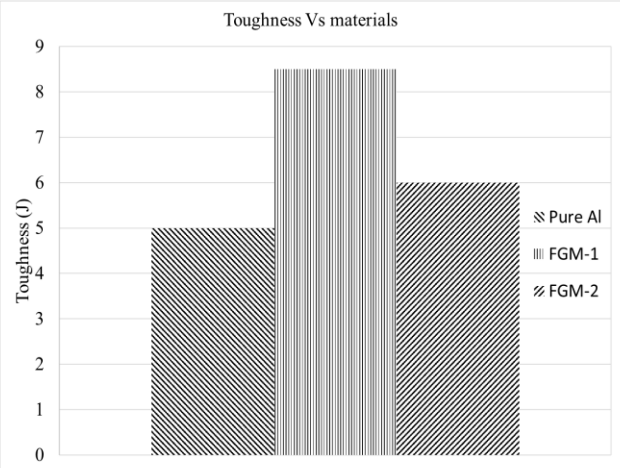

Fig. 4. Toughness values between different specimens

Table 5, shows the results of charpy impact test. Fig 4 shows the comparison between the multi-layered FGMs. FGM-1 can absorb high energy than FGM-2. In FGM-1 the total composition of SiC used was about 5.33% while it is 30% in FGM-2. Silicon Carbide, a brittle material which when added to a ductile material viz., aluminium may change the ductile properties of aluminium and can convert it into a brittle material, which is easily broken by sudden loads. This is one of the reasons for the failure of the specimen or for obtaining lows. So, the SiC content should be optimum in every specimen so that it gives good toughness values.

E. Tensile Test

The tension test is conducted as per ASTM E8 standard on a universal testing machine at room temperature. Table 6. tabulates the results for the tensile test.

Table VI. Tensile Test Results

Specimen	Load at yield point(N)	Yield Stress (N/mm^2)	Load at peak (N)	Tensile Strength (N/mm^2)	% Elongation
Pure Al	1120	16.776	1410	22	6.16
FGM-1	2530	38.142	3290	49.6	3.4
FGM-2	980	15.473	1280	21	1.84

The %wt. of SiC is directly proportional to its brittle nature. Even though aluminum is ductile in nature, it is unable to overcome the brittle nature induced by SiC. FGM-1 yielded better results than FGM-2. The same may also be inferred from the impact test results shown in Fig 5. The optimum value of SiC can be used is15%.

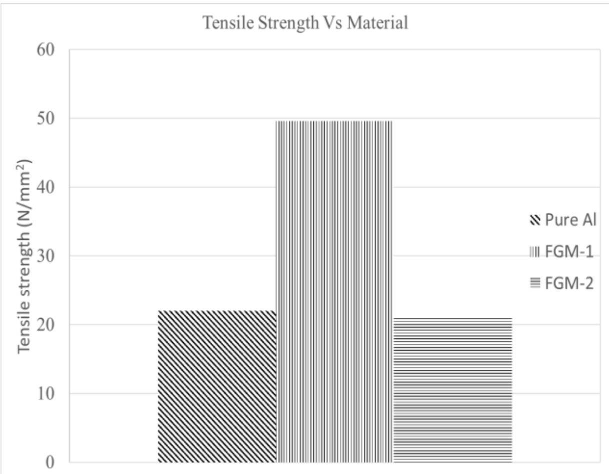

Fig.5. Tensile strength of different specimens

IV. CONCLUSION

FGM-1 has better impact strength and better resistance against deformation. Through microstructure study on manufactured specimens, it is clearly evident that FGM-1 (4 layered i.e., 0%, 3%, 7%, 10% composition of Silicon carbide) has attained homogeneous mixture than FGM-2(5 layered i.e., 10%, 20%, 30%, 40%, 50% composition of Silicon Carbide). This indicates that after certain %wt. of SiC, homogeneity is not achieved. Hardness and Charpy test values of FGMs are high when compared to pure aluminium specimens. When the two FGMs are compared with each other, FGM-1 has better Charpy test and tensile test results. This clearly shows that the composition of reinforcement has an adverse effect on the physical and mechanical properties of the specimens beyond a threshold point.

REFERENCES

1. R Kumar and Dr C N Chandrappa, Synthesis and Characterization of Al-SiC Functionally Graded Material Composites Using Powder Metallurgy Techniques, International Journal of Innovative Research in Science, Engineering and Technology, vol.3, pp.15464-15471, 2014.
2. S.M.L. Nai, M. Gupta, Influence of stirring speed on the synthesis of Al/SiC based functionally gradient materials, Composite Structures, vol. 57, pp.227-233, 2002, doi: 10.1016/S0263-8223(02)00089-2
3. F. Erdemir, A. Canakci and T. Varol, Microstructural characterization and mechanical properties of functionally graded Al2024/SiC composites prepared by powder metallurgy techniques, Transactions of Nonferrous Metals Society of China, vol.25, pp.3569-3577,2015, doi: 10.1016/S1003-6326 (15)63996-6
4. Pulkit Garg, Pallav Gupta, Devendra Kumar and Om Parkash, Structural and Mechanical Properties of Graphene Reinforced Aluminum Matrix Composites, J. Mater. Environ. Sci, pp. 1461-1473, 2016.
5. Radhika N, Kamireddy Teja, Kanithi Rahul and Shiva Shankar A, Fabrication of Cu-Sn-Ni /SiC FGM for Automotive Applications: Investigation of its Mechanical and Tribological Properties, Silicon, 2018. doi: 10.1007/s12633-017-9657-3.
6. B. Venkatesh, B. Harish, Mechanical Properties of Metal Matrix Composites(Al/SiCp) Particles Produced by Powder Metallurgy, International Journal of Engineering Research and General Science, Vol. 3, pp.1277-1284. 2015.
7. Mahendra Boopathi, K.P. Arulshri and N. Iyandurai, Evaluation of Mechanical Properties of Aluminium Alloy 2024 Reinforced with Silicon Carbide and Fly Ash Hybrid Metal Matrix Composites, American Journal of Applied Sciences, vol.10, pp.219-229, 2013. doi:10.3844/ajassp.2013.219.229.
8. Manchang Gui, Suk Bong Kang, 6061Al/Al–SiCp bi-layer composites produced by plasma-spraying process, Materials Letters, vol. 46, pp.296-302, 2000, doi: 10.1016/S0167-577X (00)00191-9.
9. I.M. El-Galy, M.H. Ahmed, B.I. Bassiouny, Characterization of functionally graded Al-SiCp metal matrix composites manufactured by centrifugal casting, Alexandria Engineering Journal, vol.56, pp. 371-381, 2017, doi.org/10.1016/j.aej.2017.03.009.
10. Aravind Tripathy, Saroj Kumar Sarangi & Rashmikant Panda, Fabrication of Functionally Graded Composite Material Using Powder Metallurgy Route: An Overview, International Journal of Mechanical and Production Engineering Research and Development, vol. 7, pp. 135-146, 2017.
11. Gurpreet Singh & Sanjeev Goyal, Microstructure and mechanical behavior of AA6082-T6/SiC/B4C-based aluminum hybrid composites, Particulate Science and Technology, vol.36:2, pp.154-161, 2016, doi: 10.1080/02726351.2016.1227410
12. M. Sambath Kumar, P. Navaneethan Krishnan and K. Ponappa, Mechanical and Corrosion Behavior of Al7075 (Hybrid) Metal Matrix Composites by Two Step Stir Casting Process, Latin American Journal of Solids and Structures. 2017;243-255.
13. Mandira Bhattacharyya, Amar Nath Kumar and Santosh Kapuria, Synthesis and characterization of Al/SiC and Ni/Al2O3 functionally graded materials, Materials Science and Engineering: A, Volume 487, pp. 524-535, 2008. doi.org/10.1016/j.msea.2007.10.040.
14. M.S. Surya and G. Prasanthi, Tribological Behaviour of Aluminum Silicon Carbide Functionally Graded Material, Tribology in Industry, 2018, doi: 10.24874/ti.2018.40.02.08
15. J P Pathak, Singh, J K and Mohan S, Synthesis and characterization of aluminium-silicon-silicon carbide composite, Indian Journal of Engineering and Materials Sciences (IJEMS), Volume 13(3), pp. 238-246, 2006.
16. K.R. Padmavathi and R. Ramakrishnan, Tribological Behaviour of Aluminium Hybrid Metal Matrix Composite, Procedia Engineering, Volume 97, pp. 660-667, 2014. doi.org/10.1016/j.proeng.2014.12.295.
17. Chinta Neelima Devi, V. Mahesh and N. Selvaraj, Tensile and Impact behavior of Al-Sic-Zn-Cu Metal Matrix Composite, Research Journal of Engineering Sciences, Vol. 3(2), pp.17-22, 2014.

18. Linlin Yuan, Jingtao Han, Jing Liu, Zhengyi Jiang, Mechanical properties and tribological behavior of aluminum matrix composites reinforced with in-situ AlB2 particles, Tribology International, vol.98, pp.41-47,2016, doi: 10.1016/j.triboint.2016.01.046.

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