Tribological and Mechanical Characterization of Al-Ni-Sic Metal Matrix Composites

Ravi Kumar V[a*], Dileep B P[b] and Vital H R [c]

[a,b] *Department of Mechanical Engineering, Amrita School of Engineering, Bengaluru, Amrita Vishwa Vidyapeetham, Amrita University, India*
[c] *Department of Mechanical Engineering, SJBIT, Bengaluru, India*

Abstract. Aluminium being light weight metal used widely in many engineering applications. It's being a highly ductile material in its purest form also limits its applications in load carrying members. Addition of alloying elements like nickel and silicon carbide can make aluminium a better material for many applications. In this work aluminium metal matrix composite is prepared by adding nickel powder of 30 microns4% and silicon carbide of 45 microns in 2,4,6and 8% by weight of matrix material. Composite was prepared by using a powder metallurgy (PM) at room temperature compaction. The compaction load was optimized to 15tonns for successful fabrication of green specimen; these green specimens were sintered in a furnace to 540^0 temperatures and furnace cooled. It was found that reinforcement of nickel and silicon carbide significantly improved the mechanical properties of the composite; hardness is improved by 35% in that compaction load. Wear rate of the composite is reduced from 200 micrometers to 50 micrometers for 5000 meters of track length at a load of 5N.The prepared composite also shown a uniform distribution of reinforcement particle in the matrix material under micro structural studies .

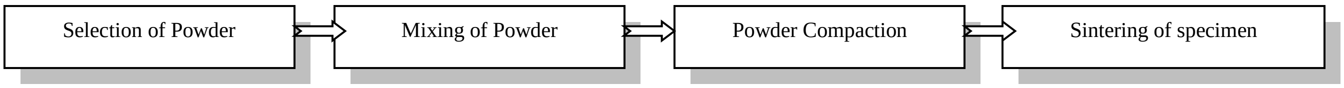
Keywords: Powder metallurgy, Metal matrix composites, Wear resistance, Hardness.
PACS: 81.20.Ev, 81.40.Pq

INTRODUCTION

Aluminium being the base matrix [1], it was imperative that the composite possessed higher hardness [2] and wear resistance that would enable its usage in more demanding applications. Thus silicon carbide was chosen to improve the tribological properties. To further improve the corrosion resistance of aluminium, Nickel, which possesses excellent resistance to chemical attacks, was chosen as the second reinforcement material. Silicon carbide (SiC) is a thoroughly wear resistant [9] material with superior mechanical properties, plus thermal shock resistance. It is in widespread use in industry and is fairly easy to manufacture. SiC is available in different forms, as powder or in grinding wheels, cutters, etc. The vital use of nickel is, they are are characterized by better strength, ductility, and resistance to corrosion environment. It is a silvery-white, hard, malleable, and ductile metal. The choice of matrix material depends on the application. Light matrix materials [14] are easy to process. Hence alloy systems [6] such as aluminium, copper, iron and steels, and titanium have been utilized as matrixes. The choice for this project was Pure Aluminium. Aluminium is a metal that has found uses in almost all fields of engineering and common life, thanks to its good overall properties like low weight/density [7], high strength, high thermal and electrical conductivity, high corrosion resistance, and easy availability. Aluminium and its alloys [10] and composites [5] are being used to power today's automobiles, aircraft, space technology, marine applications, MEMs, and nanotechnology. Aluminium is also very easy to recycle. Aluminium is the most popular choice of matrix for MMCs [4]. In order to produce more environment friendly automobiles, the fuel economy plays a vital role. To achieve this, lightweight composites [13] are being used to induce weight saving. The most of automotive industries uses glass-reinforced plastics to keep costs low, some components [11] like wheel rims and inlet manifolds could be produced using these. Sports applications have seen the widest use of composites since their discovery. Composites like carbon fiber, FRPs, boron fiber show quite a lot of promise for making stronger, lighter, and stiffer equipment.

FABRICATION OF COMPOSITE

Powder metallurgy technique [3] was used to prepare the specimens; this method involves blending of finely powdered materials, consecutively pressing the mixture into predefined form, then heating the compressed green [12]specimen in a controlled atmospheric condition to get the solid material. The final component is always near net shape and requires minimal machining. Powder metallurgy can also be used to produce fully finished components.



Powder Mixing

Powder mixing is a process where in powders of the different base material is of pre calculated amount is placed into the double cone mixer, the powder mixer is operated for a fixed period of time of 20 minutes for all combinations separately. It’s being one of the major processes in powder metallurgy process which decides the homogeneity of the final solid specimen. Double cone powder mixer is one of the most used instrument for this purpose.

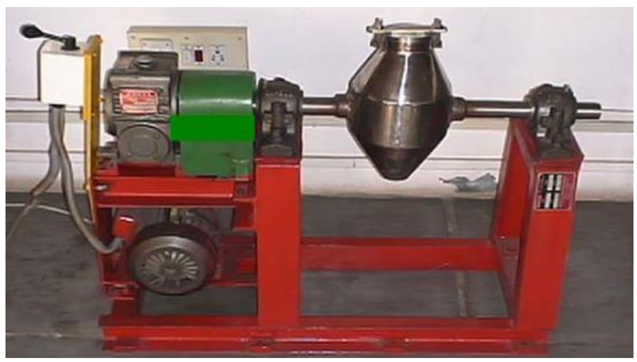


FIGURE 1.double cone powder mixer

Powder Compaction

Powder compaction is followed by compacting pre mixed metal powder is weighed for calculated amount and placed into the compaction die. The compaction process is achieved by using hydraulic operated universal testing machine. The compaction load is optimised to 160 KN after a number of trials starting from 100KN.This optimised compaction load is maintained for 2 minutes on powder for better compaction at room temperature. The major challenge in this process is to eject the compacted specimen out of the die safely hence a lubricating agent of zinc stearate is used effectively to eject the green specimen. This also works as a binder between the powder and help better bonding in green condition. Figure below shows the die that was used in the current work.

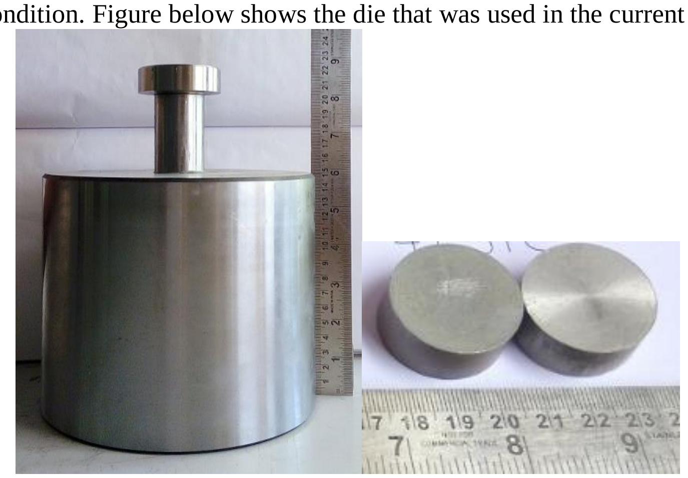


FIGURE 2. Die used for compaction **FIGURE 3.** Compacted green specimens

Sintering

Sintering is being one of the important process powder metallurgy techniques. The compacted green specimen in heated to 80% of matrix material melting temperature. In this aluminium metal matrix composites it is not necessary to maintain a sintering a`tmosphere vacuum or some inert gas condition aluminium is not prone to corrosion.
Once the green specimen are kept inside the furnace raise the temperature in the rate of 5^0C per minute till it reaches the 530 ± 5^0C it is the sintering temperature of aluminium which is a matrix material in this work. Once the furnace reaches the required temperature furnace is maintained for with same value for one hour then switch off the furnace and allow the specimens to reach room temperature. Now the specimens are ready for testing after a minimum cleaning and machining process.

FIGURE 4. Specimen placed in muffle furnace for sintering

FIGURE 5. Specimen after sintering

TESTING

The prepared specimens of different compositions were subjected to Hardness Test Using Brinell Hardness Tester (Model TKB 3000), Corrosion Test Using CH Instruments Electrochemical Analyzer, Wear Test Using Ducom Pin on Disc Tribometer (Model PR 20LE) and Microstructural Analysis Using Metallurgical Microscope

Hardness Test

The hardness test is conducted according to ASTM E10 standard. A hardened steel ball indenter of 10 mm diameter is used to create an indent on the specimen. The load applied is 500 kgf. The diameter of the indent is measured across perpendicular directions and the average diameter obtained from three indents is factored into the calculation

Wear Test

Wear is one of the important causes for the failure of a material in many applications, property to be tested for all the materials which are used in dynamic applications. A Pin-On-Disc Tester is mostly used device to test friction and wear characteristics of dry or wet sliding contact of a extensive varieties of materials like metals, polymers, composites, ceramics, heat-treated samples. The wear test is accomplished by rotating a test disc against a stationary prepared test pin specimen. Wear, frictional force, and contact temperature can be observed real time. The load, rotational speed of disc, and diameter of wear track can be altered according to the ASTM G99 standard.

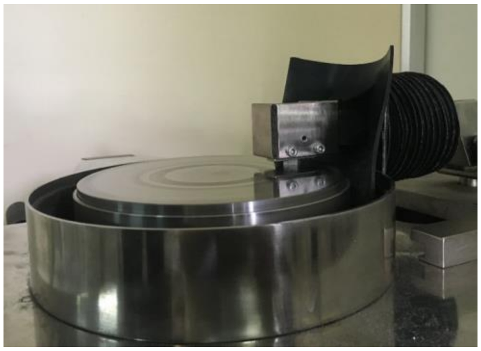


FIGURE 6. Pin-on-disc wear testing

Microstructure Analysis

The microstructure can be studied using a metallurgical microscope after the material has been polished to a mirror finish. The process was performed by following the standard procedure of polishing with abrasive emery papers of decreasing grit sizes (increasing fineness), followed by lapping with alumina paste and diamond paste on a velvet disc polishing machine. The polished surface of the metal matrix composite is then dipped in etchant solution, allowing the etchant to seep into the surface. The excess is then rinsed off and the component is placed under the microscope for observation. The etchant highlights the microstructure and also shows any deformations on the surface. The high-resolution microscope is binocular, with a computer interface and is equipped with high resolution camera which can save a digital image of the observed microstructure for future reference.

RESULTS AND DISCUSSION

Hardness

Indentations are made on specimens by applying load of 500kgf through a ball of diameter 10mm as specified by ASTM standards for Al alloy. In the four specimens of Al composites, base metal Al is reinforced with 4% of Ni (fixed) and varying percentages of SiC as 2, 4, 6 and 8%. One specimen is of pure Al, for comparison.

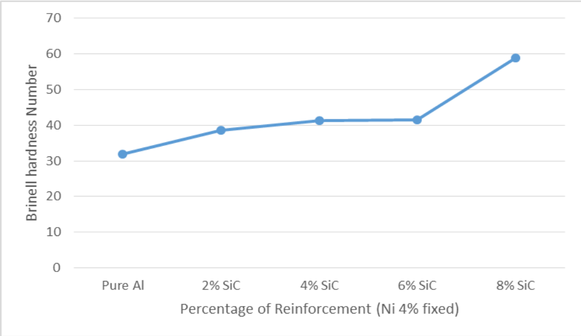


FIGURE 7. Hardness variation

Results show that there is an increase of hardness from pure Al, with increasing SiC percentage. Hardness for the mixture of 8% SiC is showed highest among all the combinations. This clearly indicates hardness of this aluminium composite is directly increased with increase of percentage of silicon carbide.

Wear Test

The wear resistance of the specimens was tested using a pin-on-disc tribometer. The operating parameters were set with load of 1kg and speed 500 rpm. The test was set to run such that the specimen slides for 5000 m. Readings were taken at 15 samples per minute. The output is then computed into a graph for analysis.

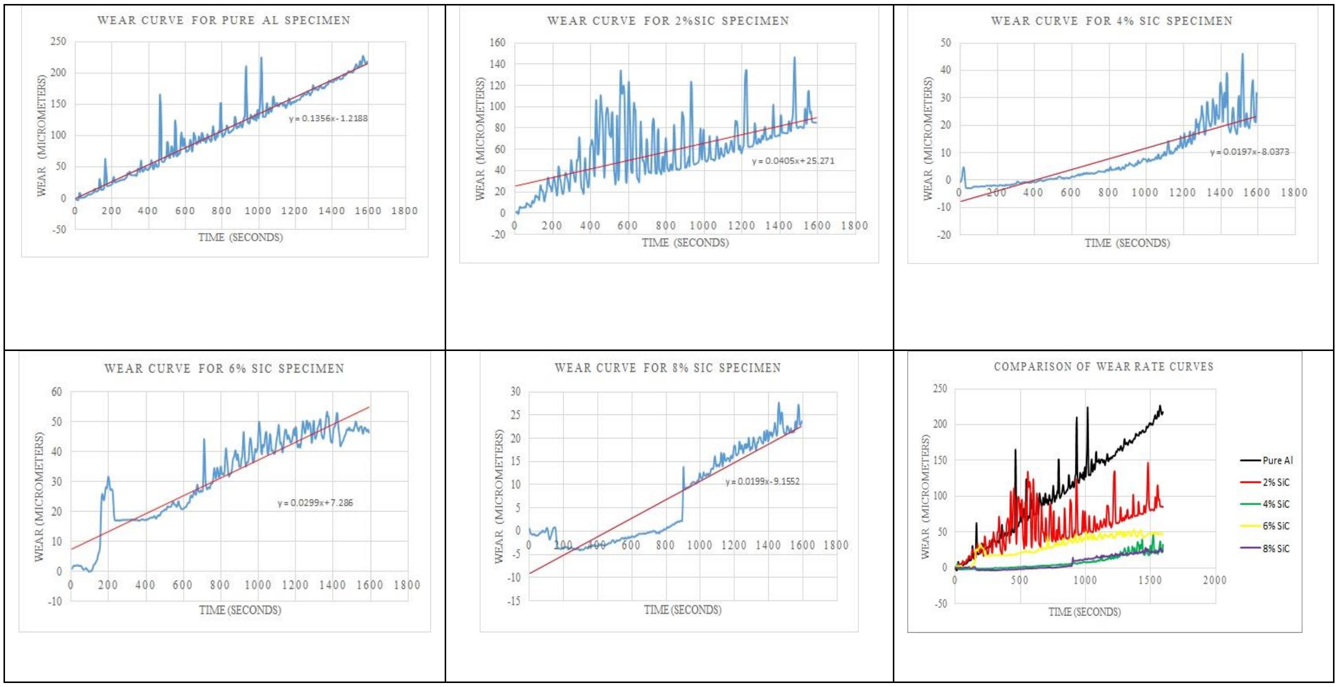


FIGURE 8. (a) Wear test for Pure Al (b) Wear test for 2% SiC + 4% Ni (c) Wear test for 4% SiC + 4% Ni (d) Wear test for 6% SiC + 4% Ni (e) Wear test for 8% SiC + 4% Ni (f) Comparison of wear rate curves after sliding 5000 m

The results depict that the amount of wear and the wear rate decrease considerably with increase in the content of SiC. There seems to be a huge gain in wear resistance even with slight addition of SiC into the matrix; this can be observed from the drastic reduction in the amount of wear between pure Al component and Al+2%SiC. The wear rate continues to decrease further as the SiC content increases, and is the least for the composite with 8% SiC. This result is in accordance with expectations, as the SiC imparts its properties to the composite.

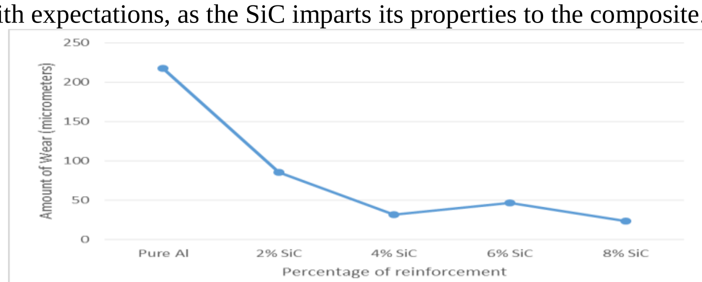


FIGURE 9. Comparison of amount of wear after sliding 5000 m

Microstructure Analysis

The specimens are polished by using emery papers followed by double disc polishing machine, brought to a mirror finish and dipped in suitable etchant. Surface of the composite specimens which were fabricated, were studied using a metallurgical microscope at 40x. From this we could find out the coarseness of the refinement particles in the base matrix. The following figures are microscopic images of the composites containing different percentages of reinforcements. The microstructures show the increasing content of reinforcements in the matrix, and suggest the distribution is uniform. The grain structure appears to be of equiaxed. Equiaxed crystals are crystals that have axes of approximately the same length.

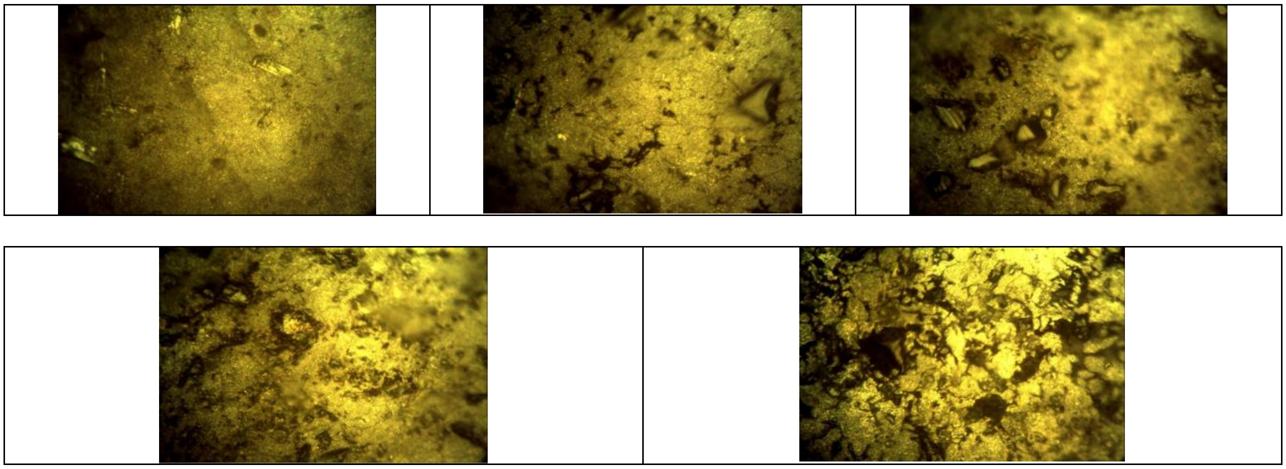


FIGURE 10. (a) Microstructure of Pure Al (b) Fig 4.17 Microstructure of 4% Ni and 2% SiC (c) Microstructure of 4% Ni and 4% SiC (d) Microstructure of 4% Ni and 6% SiC (e) Microstructure of 4% Ni and 8% SiC

CONCLUSION

Fabricated composites containing 4% Ni and 2, 4, 6, & 8% of SiC as reinforcements in base matrix of pure Al is successfully achieved with load of 160 kN and sintering temperature was optimized to 530±5 °C. The hardness of the composites increased with increasing percentage of SiC, maximum increase was obtained for 8% SiC composite, with an increase of 87%. The wear resistance of the composites improved significantly with the increase of SiC percentage. Max wear resistance was obtained for 8% SiC composite, with an increase of 90%. The addition of SiC to the matrix was thus effective in improving the mechanical and tribological properties of pure Al.

REFERENCES

[1] Gaurav Mahajan, Nikhil Karve, UdayPatil, P. Kuppan and K. Venkatesan, Analysis of Microstructure, Hardness and Wear of Al-SiC-TiB_2 Hybrid Metal Matrix Composite, in Indian Journal of Science and Technology, Vol. 8(S2), January 2015, pp. 101-105.

[2] A.B. Gurcan, T.N. Baker, Wear behaviour of AA6061 aluminium alloy and its composites, in: Wear, Vol. 188, 1995, pp. 185-191

[3] Pay Yih and Deborah D.L. Chung; Powder Metallurgy Fabrication of Metal Matrix Composites using Coated Fillers, in: The International Journal of Powder Metallurgy, Vol. 31, No 4, 1995.

[4] Dunia Abdul Saheb, Aluminium Silicon Carbide and Aluminium Graphite Particulate Composite, in: ARPN Journal of Engineering and Applied Sciences, Vol. 6, No. 10, October 2011.

[5] SedatOzden, RecepEkici and Fehmi Nair in: Composites: Part A 38, 2007, pp. 484.

[6] D. Sujan, Z. Oo, M.E. Rahman, M.A. Maleque and C.K. Tan, Engineering and Applied Sciences 6, 2012, pp. 288.

[7] E. Bayraktar, D. Katundi, Development of a new aluminium matrix composite reinforced with iron oxide (Fe_3O_4), in: Journal of Achievements in Materials and Manufacturing Engineering, Vol. 38, Issue 1, January 2010.

[8] Asif M, Chandra K and Misra P S, Development of Aluminium Based Hybrid Metal Matrix Composites for Heavy Duty Applications, in: Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No. 14 , 2011, pp. 1337- 1344.

[9] E. Bayraktar, J. Masounave, R. Caplain, C. Bathias, Manufacturing and damage mechanisms in metal matrix composites, in: Journal of Achievements in Materials and Manufacturing Engineering, Vol. 31, Issue 2, December 2008.

[10] Muna K. Abbass, Khairia S. Hassan, and Abbas S. Alwan, Study of Corrosion Resistance of Aluminium Alloy 6061/SiC Composites in 3.5% NaCl Solution, in: International Journal of Materials, Mechanics and Manufacturing, Vol. 3, No. 1, February 2015.

[11] A. Włodarczyk-Fligier, M. Adamiak, L.A. Dobrzański, Corrosion resistance of the sintered composite materials with the EN AW-$AlCu_4Mg_1$(a) alloy matrix reinforced with ceramic particles, in: Journal of Achievements in Materials and Manufacturing Engineering, Vol. 42, Issues 1-2, September-October 2010

[12] Arun Kumar M. B, R. P. Swamy; Experiments on Al6061, Fly ash and E Glass Fiber reinforced Hybrid Metal Matrix Composites, in: ARPN Journal of engineering and science, Vol. 6, 2011, pp. 135-156

[13] Dinesh Kumar Koli, GeetaAgnihotri, Rajesh Purohit, Properties and Characterization of Al-Al_2O_3 Composites Processed Powder Metallurgy Routes, in: International journal of latest trends in engineering and technology, Volume-2, Issue-4, July-2013.

[14] DileepB P, Ravi kumar V, Mrudula prashanth, Phanibhushana M V, Effect of Zinc coating on Mechanical Behavior of Al 7075, in: Applied Mechanics and Materials. 592-594, 2014, pp. 255-259.

[15] Mohan Kumar S , Pramod R , Shashi Kumar M E , Govindaraju H K, Evaluation of Fracture Toughness and Mechanical Properties of Aluminum Alloy 7075, T6 with Nickel Coating, in: Procedia Engineering 97, 2014, pp. 178 – 185.

[16] P. Krishnakumar, K. Prakash Marimuthu, K. Rameshkumar, K. I. Ramachandran, Finite element simulation of effect of residual stresses during orthogonal machining using ALE approach, in: Int. J. Machining and Machinability of Materials. 14, 2013, pp. 213-229.