Analysis of properties of Aluminium-Graphite Metal Matrix Composites

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Abstract

Major use of an automobile alloy in aerospace and automotive application led to the modernisation of a material so far as the alloying properties is concerned. A study has been made to understand the density, electrical conductivity, hardness and microstructural behaviour of an Aluminium alloy 2014 T6 discontinuously reinforced with varying amounts of natural graphite particles. The Metal Matrix Composites (MMC) has been developed with powder metallurgy. L9 orthogonal array has been used to make various specimens of the composite with varying weight percentages of reinforced material, compacting pressure, sintering temperature and time. Quantitative evaluation of the properties of the composite and their significant changes were found. Microstructural observation has been carried out to know the distribution of the reinforced material.

Keywords—*Al2014 T6, Natural Graphite, powder metallurgy, MMC, microstructure.*

1. Introduction

The term 'composite' broadly refers to a material system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix). When the matrix is a metal, the composite is termed as Metal Matrix Composites. Particle Reinforced Metal Matrix Composite have drawn enormous attention in the wide production industries such as automobile, space vehicle, aircraft industries and sports requisite and many other disciplines because of significant changes in properties when compared with unreinforced metal and alloys. The majority of such material are Metallic Matrix reinforced with high modulus continuous fibre, short fibre, chopped fibre, whisker or particulates. The addition of reinforcement particle largely make changes in mechanical properties such as hardness, density, microstructure, etc. [1,2,3]. A study has been also conducted on Al based MMC with different reinforcement material to analyse various tribological and wear behaviour. [4,5] Also an extensive work has been carried out to know the mechanical, thermal and electrical properties of Al based Metal Matrix Composites. [6,7] A microstructural study also has been carried out to know about the plastic deformation of the Metal Matrix Composites. [8]

Various methods are available to make the Metal Matrix Composites like stir casting, rheo casting and powder metallurgy. [9,10] Among all the methods solid state process viz. powder metallurgy is a simple process which exhibits excellent finished performance due to its ability to obtain uniform distribution of reinforcement. [11,12,13]

The aim of the present study is to make Aluminium-Graphite composite by powder metallurgy route with graphite reinforcement percentages as 3, 5, 7, respectively by weight. The micro-hardness, density, electrical conductivity has been found out. Aluminium alloy particularly of 2XXX, 6XXX or 7XXX series are preferred to make Metal Matrix Composites because they offer number of advantages in terms of improving their properties. The present study uses Al 2014 T6 because of its low density and its capacity to be strengthened by precipitation, good corrosive resistance and good damping capacity with natural graphite particles which possess properties as low density, solid lubricator and small co-efficient of thermal expansion and high hardness.

The L9 orthogonal array (Taguchi method) has been used to get the composite specimen with different composition so far as compacting pressure, sintering temperature and time are concerned with different reinforcement percentages by weight. Results for hardness, density and electrical conductivity shows significant variation in specimen when investigated with MINITAB Software. Also the microstructural observation has been carried out to know about the distribution of reinforcement.

2. Experimental Details

2.1Specimen Preparation

The matrix material used in the present study was Aluminium Alloy of grade 2014 T6 whose chemical composition consist of 90.4-95 % Aluminium, 3.9-5 % Copper, 0.5-1.2 % Silicon, 0.4-0.2 % Manganese, 0.2-0.8 % Magnesium, 0.15 % Titanium, 0.25 % Zinc, 0.7 % Iron and 0.1 % Chromium (by percentage weight), while natural graphite powder was used as reinforcing phase with an average size of 400 mesh sieve size whose chemical composition consists of 95 % Carbon, 0.5 % Iron and 0.4 % Sulphur. The Aluminium powder of grain size 35 µm and that of Graphite powder of size 400 mesh was used. Using Equation.1 the masses of the metal matrix as well as reinforced material with their relative by weight percentages were calculated as shown in Table

1.

$$(Volume \times Density)\ (Metal\ Matrix) = Mass\ (Metal\ Matrix) \qquad (1)$$

Table 1. Mass of the Specimens

S.No	%Reinforcement	Al2014T6 (gm)	Graphite (gm)
1.	3	8.5272	0.26388
2.	5	8.3562	0.4398
3.	7	8.1803	0.61572

2.2 Preparation of Composites

The powder metallurgy rout for making composites involves the mixing, compacting and sintering processes. The powders of both the specimens were mixed for 10 minutes in a mixing machine at 50 rpm. A total of 9 specimens (3 each) were prepared by reinforcement percentages of 3, 5, 7, respectively. The mixture of powders were uni-axially cold compacted using the cylindrical die of 20 mm diameter and 10 mm height at a pressure of 350 MPa, 450 MPa and 550 MPa. The compacts were then sintered in the furnace under the control of Nitrogen. By adjusting the auto control power of the induction heat system, the mixed compacted powders were sintered at 350ºC, 400ºC and 500ºC for 1 hour, 2 hour and 3 hour, respectively. After sintering the specimens were taken out from the furnace and allowed to cool at atmospheric temperature for half an hour and then its new weight and height has been measured. TABLE 2. describes specimen Data before and after sintering.

Table 2. Specimen data before and after Sintering

S.No		Before Sintering	After Sintering
1.	Mass (gm)	8.96	8.72
	Height (cm)	1.200	1.213
	Diameter (cm)	2	2
2.	Mass (gm)	8.66	8.55
	Height (cm)	1.08	1.150
	Diameter (cm)	2	2
3.	Mass (gm)	8.51	8.45
	Height (cm)	1.1	1.101
	Diameter (cm)	2	2
4.	Mass (gm)	8.25	8.20
	Height (cm)	1.09	1.18
	Diameter (cm)	2	2
5.	Mass (gm)	8.33	8.05
	Height (cm)	1.09	1.085
	Diameter (cm)	2	2
6.	Mass (gm)	8.61	8.42
	Height (cm)	1.18	1.185
	Diameter (cm)	2	2
7.	Mass (gm)	8.30	8.14
	Height (cm)	1.08	1.09
	Diameter (cm)	2	2
8.	Mass (gm)	8.54	8.25
	Height (cm)	1.134	1.139
	Diameter (cm)	2	2
9.	Mass (gm)	8.26	8.119
	Height (cm)	1.13	1.154
	Diameter (cm)	2	2

The combination of compacting pressure, sintering temperature and sintering time has been followed with the help of Taguchi experimental plan of standard L9 3^^{4} orthogonal array which is a more effective method by practicing researchers to analyse the results. This experiment specifies 4 different process parameters including the reinforcement percentage (P1), compacting pressure (P2), sintering temperature (P3) and sintering time (P4). The process parameters and their levels are described in the TABLE 3.

Table 3. Process Parameters and their levels

S.No	Symbol	Process Parameters	Level 1	Level 2	Level 3
1.	P1	Reinforcement %	3	5	7
2.	P2	Pressure (MPa)	350	450	550
3.	P3	Temperature (^{0}C)	350	400	500
4.	P4	Time (hrs)	1	2	3

The below shown figure is the optical microscope on which microstructure was taken.

Fig 1. Optical Microscope

3. Results and Discussion

The 9 samples prepared are then polished to remove the coat formed due to sintering. Emery paper from grade 220 to 1000 grade are used to make the surface scratch free. Again to make mirror finish to the surface Disk Polishing Machine has been used with speed of 500 rpm. Finally to get fine microstructure Keller's Reagent as an etching material was used. Results were carried out for micro-hardness, density and electrical conductivity.

The changes in the properties of composites due to the influence of the process parameters was analysed by MINITAB 16 release by plotting the graphs.

3.1 Micro-hardness

Vickers Hardness Testing Machine manufactured by Matsuzaw Co. Ltd. , Japan was used to find out the micro-hardness of the samples.

Fig. 2 Vicker Microhardness Tester

Figure 3 shows the variation in micro-hardness with respect change in reinforcement, pressure, temperature and time.

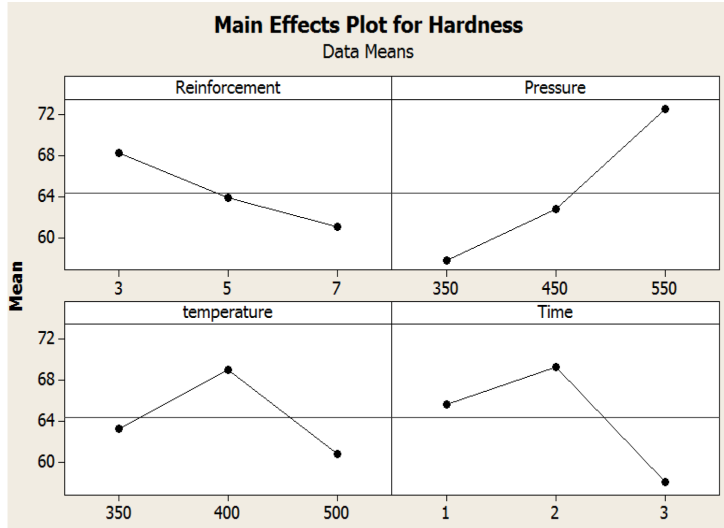

Fig. 3 Plot for Micro-hardness

The hardness values for those specimens has been given in TABLE 5.

3.2 Density

The composite specimens after sintering shows significant change in the weight and size. The weight significantly reduces with increase in height. Hence the density is measured by calculating the new weight and volume. The sample calculation for specimen carried out as follows by using equation 2.

$$Density = \frac{Mass\ after\ Sintering}{Volume\ after\ Sintering} \qquad (2)$$

Figure 4 shows the variation in density with respect to change in reinforcement, pressure, temperature and time.

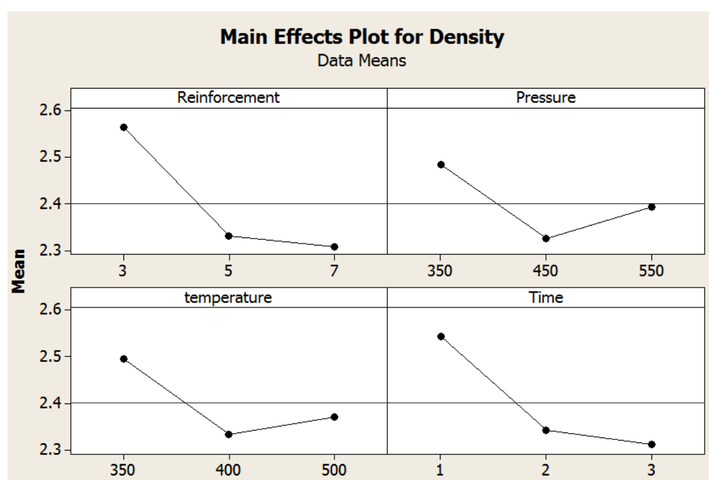

Fig.4 Plot for Density

The result for the subsequent specimens are being tabulated in TABLE 5.

3.3 Electrical Conductivity

Aluminium-Graphite Composite are generally used in the application where strong altering thermal load and high temperature appears. Also the use of this composite in power electronics, micro-electronics and optical-electronics is a major concern to know the electrical conductivity.

Electrical conductivity, reciprocal of Resistivity can be easily found out by knowing resistance, area and length.

The length after polishing is measured which is less than the length after sintering due to removal of upper material layer (TABLE IV). Resistance of each specimen was measured by multi-meter by setting it to 200Volts. The calculation for electrical conductivity of the specimen was carried from Equation 3.

$$Electrical\ Conductivity = \frac{Length\ after\ Polishing\ (cm)}{Resistance\ (ohm)*Area\ (cm2)} \quad (3)$$

Table 5 Specimens data after Polishing

S.No	Height after polishing (cm)
1.	1.176
2.	1.117
3.	1.079
4.	1.16
5.	1.029
6.	1.145
7.	1.016
8.	1.076
9.	1.085

Figure 5 shows the variation in electrical conductivity with respect change in reinforcement, pressure, temperature and time.

Table 5. L9 Array Results

S No.	P1	P2	P3	P4	Micro-Hardness (Vickers)	Density (gm/cm^3)	Electrical Conductivity (siemens/cm)
1.	3	350	350	1	61.73	2.288	0.1134
2.	3	450	400	2	76.26	2.366	0.0592
3.	3	550	500	3	66.7	2.44	0.2862
4.	5	350	400	3	55.6	2.2617	0.3037
5.	5	450	500	1	60.066	2.372	0.4631
6.	5	550	350	2	75.9	2.381	0.2519
7.	7	350	500	2	55.83	2.3055	0.1902
8.	7	450	350	3	52.13	2.239	0.1726
9.	7	550	400	1	75.1	2.3771	0.0752

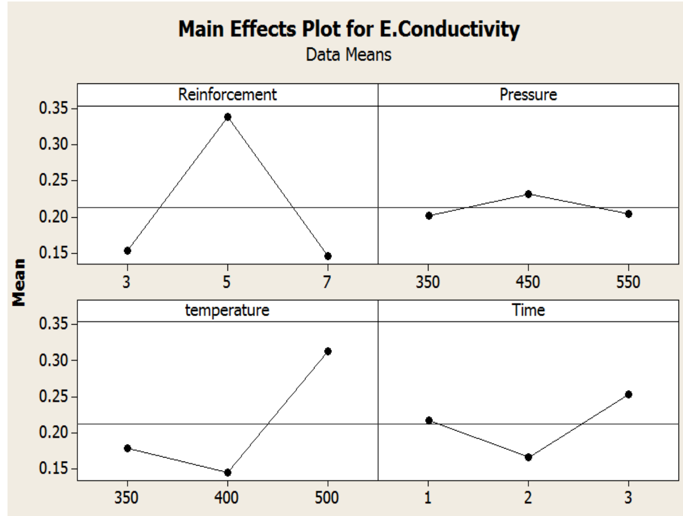

Fig.5 Plot for Electrical Conductivity

The result for other specimen has been tabulated in TABLE V.

3.4 Microstructure

The microstructure for all the 9 specimens has been taken by optical microscope (Carl Zeiss make) at 200x (50 µm magnification along with Clemex Vision Professional Edition image analysis software. The microstructure has been taken to know the distribution of graphite in the composite which is largely influenced by the process parameters. Figure 7a, 7b, 7c shows the microstructure of the specimens according to L9 array orthogonal chart.
The 9 specimens has been shown in Figure 6 according to L9 orthogonal array chart.

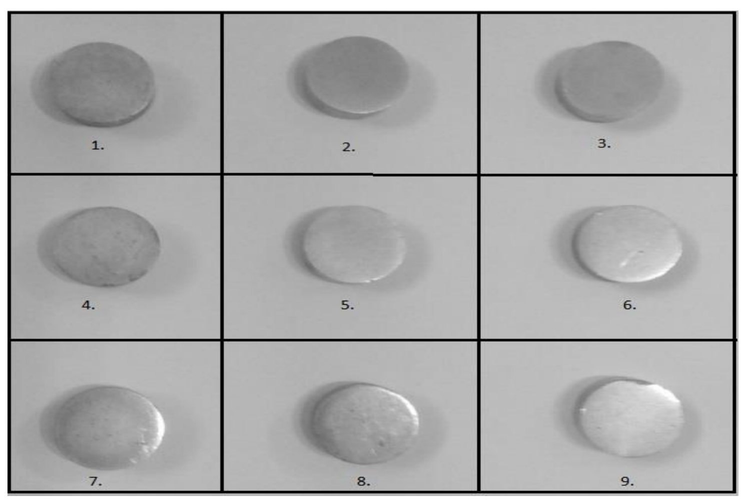

Fig 6. Specimen samples of Al2014 T6- Graphite composite according to L9 array

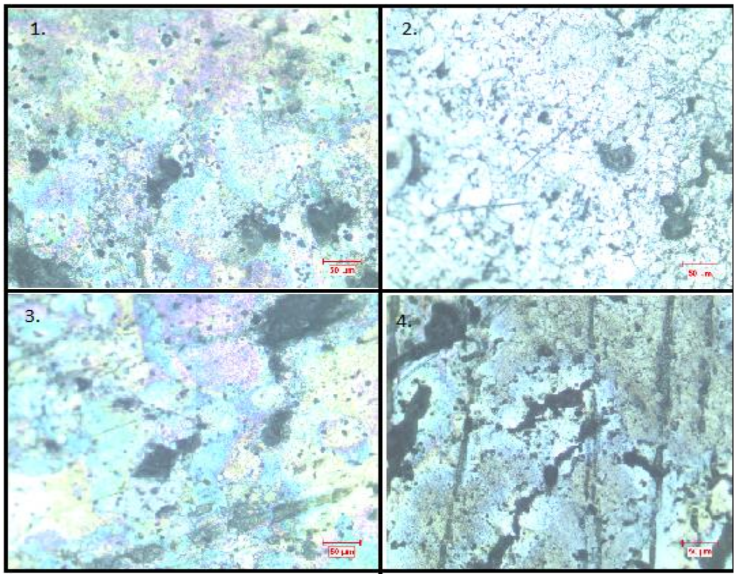

Fig.7a Microstructure of specimens 1,2,3,4 at 50 µm

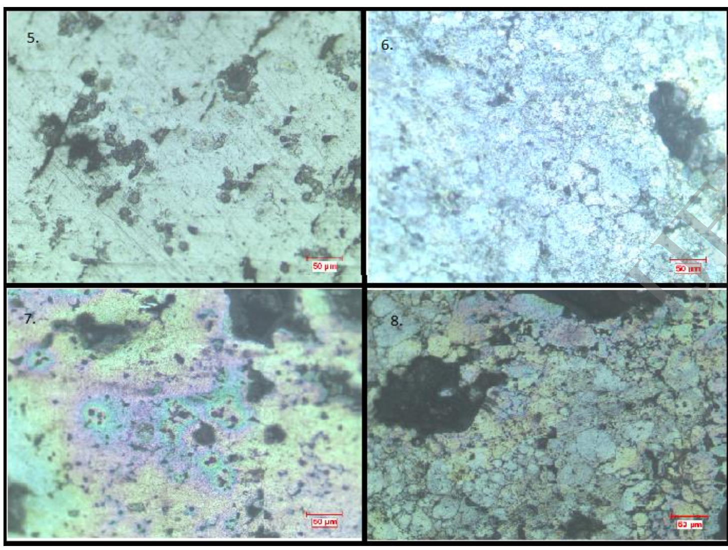

Fig 7b Microstructure of 5,6,7,8 specimens under 50µm.

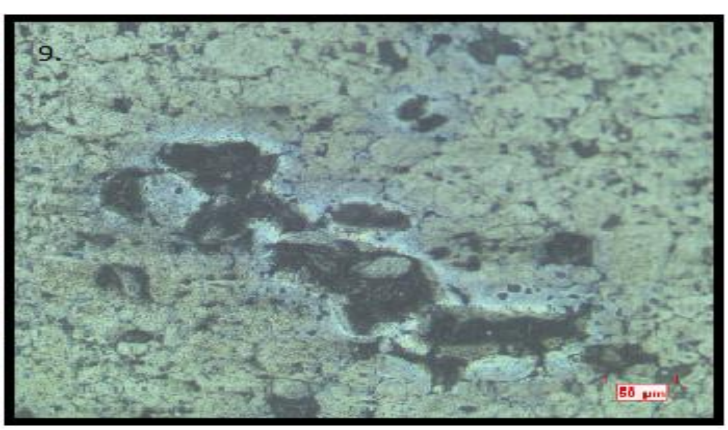

Fig. 7c Microstructure of specimen 9 under 50 µm

4. Conclusion

Following conclusions have been revealed after the experimental study on the composite in concern with the problem.

1) Figure shows significant changes in the hardness of the Metal Matrix Composite. Increase in the cold compacting pressure increases the hardness while other process parameter shows increase up to certain level then decrease in the hardness has been found.

2) Decrease in density almost by changing every process parameter as shown in the Figure points out that such composites can be used in such application wherein weight is an issue of major concern.

3) Significant changes has been found in the electrical conductivity by changing different process parameters. Figure reveals that 5% reinforcement along with 500^0C sintering temperature give high electrical conductivity. Compacting pressure is not causing much move while electrical conductivity is concerned.

4) Figure of the microstructure shows that increase in sintering temperature and time gives good distribution of reinforcement in the composite.

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6. References

[1] Das.S, Mondal.D.P, Dixit.G, "Correlation of abrasive wear with microstructure and mechanical properties of pressure die-cast aluminium hard-particle composite," Metallur Makr Transac, Vol. 324: pp. 633-637, 2001.

[2] Rabinowicz E.D, "Friction and wear of work hardening in the design of wear resistant material," Wiley, New York, pp. 168-7, 1965.

[3] M.K. Surappa, "Aluminium Matrix Composites: Challenges and Oppurtunities," Sadhana, India, Vol. 28, pp. 319-334, Feb-April 2003.

[4] Yusuf Sahin, "Abrasive wear behaviour of SiC/2014 aluminium composite," ELSEVIER, Tribology International, Vol. 43, p. 940, 2010.

[5] A. Venel, A. Rac, I.Bobic, "Tribology behaviour of Al based MMCs and their Application in Automobile Industry," Tribology in Industry, Vol. 26, Issue no. 3& 4, pp. 31-34, 2004.

[6] G.Q. Tong, K.C Chan, Matter Lett. Vol. 38, pp. 326-330, 1999.

[7] P.E. McHugh, R.J. Asaru, C.F.Shih, S.Suresh, A. Mortensen, A.Needlemann (Eds), "Fundamentals of Metal Matrix Composites," USA, p. 139, 1963.

[8] Zang Peng, Li Fuguo, "Microstructure based simulation of plastic deformation behaviour of SiC Particle reinforced Al Metal Matrix Composites", Chinese Journal of Aeronautics, pp. 664-665, 2009.

[9] T.W. Clyne, P.J. Withers, "An Introduction to Metal Matrix

Composites", Cambridge University Press, Cambridge, p. 71, 1993.

[10] D.J.Lloyd, "International Materials review", Vol. 39, pp. 1-23, 1994.

[11] Lim CYH, Lim SC, Gupta M, "Wear behaviour of Aluminium based Composites", Wear, Vol. 255, pp. 629-637, 2008.

[12] Min.K.H, Kang.S.P, Kin.D.G, Kim.Y.D, "Sintering Characteristics of Al_2O_3-reinforced 2XXX series Al Composite powder", J.Alloys Comp, Vol. 400, pp. 150-3, 2003.

[13] Angers.R, Krishnadev.M.R, Tremblay.R, Corriveau.J.F, Dube.D," Characterisation of SiC/2024 Aluminium Alloy Composite prepared by Mechanical processing in a low energy ball", Material Science Engineering, pp. 9-15, 1999.

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