International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 4, October 2014

Research Paper

CASE HARDENING EFFECTS ON MECHANICAL PROPERTIES IN GRAPHITE REINFORCED Al6061 MMCS

K Kiran Kumar Rao[1]*, Pradeep G R C[1] and K Prabhakar[1]

*Corresponding Author: K Kiran Kumar Rao, ✉ kirankumarraokaranam@gmail.com

In recent times the application of Aluminum based composites are increasing in various industries, owing to their improved mechanical properties. These materials are of much interest to the researchers from past four decades. In this paper it is aimed to present the experimental results of the studies conducted regarding effect of a case hardening process like Nitriding on mechanical properties of Al6061-Graphite composites. The composites are prepared using the liquid metallurgy technique, in which graphite particulates were dispersed in the base matrix in steps of 0, 3 and 5 wt.%. The experimental results showed that, after Nitriding of the Graphite reinforced Al6061 metal matrix composite material, the values of the mechanical properties like Brinell's hardness, Tensile strength, Young's modulus and % elongation compared to those values without Nitriding were found to be improved.

Keywords: Al6061, Graphite, Case hardening, Nitriding, Composites, Mechanical properties

INTRODUCTION

Metal Matrix Composites (MMC) are of wide interest owing to their high strength, fracture toughness and stiffness. The light metals such as Al and its alloys form superior composites suitable for elevated temperature applications when reinforced with ceramic particulates (ASM, 2001). It was found that the matrix hardness has a strong influence on the dry sliding wear behaviour of Al_2O_3 particulate Al6061 MMC (Martin *et al.*, 1999). In the investigation on the tribological behavior on Al6061 reinforced with Al_2O_3 particles it was concluded that a characteristic physical mechanism exists during the wear process (Szu Ying Yu *et al.*, 1997). When a sufficiently high load is applied on the contact, the matrix phase is plastically deformed, and the strain is partially transferred to the particulates, which are brittle with small failure strains. It was clearly demonstrated that the effects of applied load and temperature on the dry sliding wear

[1] Department of Mechanical Engineering, Gates Institute of Technology, Gooty, Anantapur (Dist.), India.

behavior of Al6061 alloy matrix composites reinforced with SiC whiskers or SiC particulates and concluded that, the wear rate decreased as the applied load is increased (Basavarajappa *et al.*, 2006). At higher normal loads (60 N), severe wear and silicon carbide particles (SiC) cracking and seizure of the composite was observed in pin-on-disc test during dry sliding wear of Al2219 alloy MMCs (Liang *et al.*, 1995). MMCs having SiC of 3.5, 10 and 20 μm size with 15 vol.%, produced by P/M route displayed good wear resistance with increasing particle size in sliding wear (Basavarajappa and Chandramohan, 2005). Sliding distance has the highest effect on the dry sliding wear of MMCs compared to load and sliding speed (Lee *et al.*, 1992). Addition of 20% reinforcements increases the wear resistance of the composites, but beyond that no improvement was observed (How and Baker, 1997). In the investigation of wear behaviour of Al6061 alloy filled with short fiber (Saffil) it was concluded that Saffil reinforcement are significant in improving wear resistance of the composites (Jen Fin Lin *et al.*, 1996). Self-lubricating graphite was incorporated in Al6061 alloy to prepare composites (Seah *et al.*, 1995).

The above literature reveals that the nitriding effects on mechanical behavior of the composites are not discussed, further very little information is available with MMCs of Al6061 reinforced with graphite particulates. Hence the present paper describes the mechanical behavior of nitrided and graphite filled Al6061 metal matrix composites.

EXPERIMENTAL DETAILS AND MATERIALS USED

The following section highlights the material, its properties and methods of composite preparation and testing.

The matrix material for the present study is Al6061. The reinforcing material selected was graphite. Table 1 gives the chemical composition Al6061 and Table 2 gives the physical and mechanical properties of Al6061 and graphite.

Table 1: Chemical Composition of Al6061 by wt%

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.62	0.23	0.22	0.03	0.84	0.22	0.10	0.01	Bal

Table 2: Physical and Mechanical Properties of Al6061 and Graphite

Material	Elastic Modulus (GPa)	Density (g/cc)	Hardness (HB500)	Tensile Strength (MPa)
Al6061	70-80	2.7	30	115
Graphite	8-15	2.09	1.7*	20-200**

Note: * Mohs scale; ** Compressive Strength (MPa).

PREPARATION OF COMPOSITES

The liquid metallurgy route (stir casting technique) has been adopted to prepare the cast composites as described below. Preheated graphite powder of laboratory grade purity was introduced into the vortex of the molten alloy after effective degassing. Mechanical stirring of the molten alloy for duration of 10 min was achieved by using ceramic-coated steel impeller. A speed of 400 rpm was maintained. A pouring temperature of 730 °C was adopted and the molten composite was poured into cast iron moulds. The extent of incorporation of graphite in the matrix alloy was varied from 0, 3 and 5 wt%. Thus composites containing particles 0, 3 and 5 wt% were obtained in the form of cylinders of diameter 22 mm and length 210 mm.

CASE HARDENING BY NITRIDING OF COMPOSITES

Among various case hardening processes, Nitriding is selected in the present research. The nitriding process is primarily used to increase the hardness, corrosion resistance and wear resistance, etc., of the components/ parts used in the various industrial applications. There are various methods for nitriding. For this experimentation Gas Nitriding was used. Because of the absence of a quenching requirement with attendant volume changes, and the comparatively low temperatures employed in this process, gas nitriding produces less distortion and deformation than either carburizing or conventional hardening. Some growth occurs as a result of nitriding but volumetric changes are relatively small. The cast composites were heated to a temperature of 500 °C in a gas tight furnace and then ammonia gas was introduced into the furnace chamber. This process of nitriding was carried out, in the presence of the nitrogen that is evolved from the decomposition of the ammonia gas, for a period of 24 hrs maintaining the temperature of 500 °C.

TESTING OF COMPOSITES

The cast composites were machined and the specimens for the measurement of hardness, as well as for mechanical behavior were prepared as per ASTM standards. Brinell's hardness tester was used to measure the Hardness of the composites before and after nitriding. The mechanical properties were evaluated before and after nitriding using Akash make computerized universal testing machine of 40-ton capacity.

RESULTS AND DISCUSSION

The test results of Al6061 and its composites containing graphite at various weight percentages, without and with nitriding, are presented in these sections.

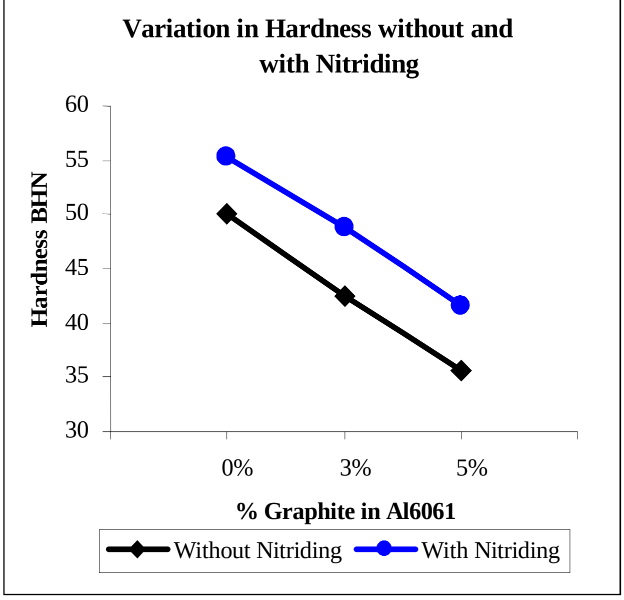
Effect of Nitriding on the Mechanical Properties

The effect of nitriding on mechanical properties such as hardness, tensile strength property, % elongation, Young's modulus, compressive strength property test results of Al6061 and Al6061 composites containing graphite at various weight percentages are presented in these sections.

Hardness

The change in the hardness of composites with varying content of graphite reinforcement, without and with nitriding is shown in Figure 1.

Figure 1: Variation in the Hardness with Different wt% of Graphite (Without and with Nitriding)



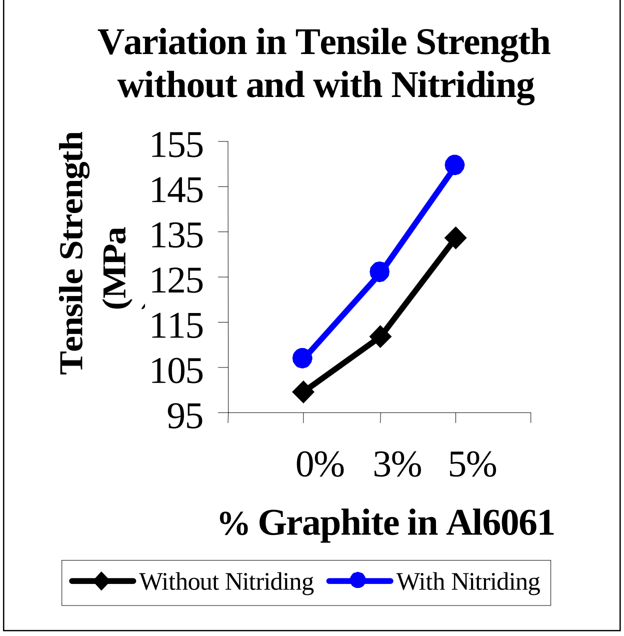
The figure represents the variation in hardness evaluated at a load of 500 kg with increasing percentage of graphite in Al6061 with and without nitriding. It is observed that the hardness of Al6061 composites decreases with increased content of the graphite reinforcement.

There is a good reason for this phenomenon, though, since graphite, being a soft dispersoid, does not contribute positively to the hardness of the composite. Seah *et al.* (1995) have reported a reduction in hardness from 107 BHN to 77 BHN (about 28% differences) on addition of similar weight percentages of graphite to ZA-27 (Zinc Aluminium) alloy. Such a monotonic decrease in the hardness of the composite as graphite content is increased poses a limit to how much graphite may be added to enhance its other mechanical properties, since hardness is directly related to wear resistance. Consequently, a compromise is necessary when deciding how much graphite should be added to enhance the ductility, UTS, compressive strength, and Young's modulus of the composite without sacrificing too much of its hardness, especially in components like engine bearings, pistons, piston rings and cylinder liners, in which wear resistance is of paramount importance. Further the hardness values of the composites were found to be increased after nitriding compared to those values before nitriding. This is clearly depicted in the Figure 1.

Tensile Properties

From the study of Figure 2 it can be seen that the tensile strength increases with increasing percentage of graphite. From the figure, it can be observed that the tensile strength of the composites is higher than that of the matrix alloy. Further, from the graph, the trends of the tensile strength can be found to be increased with increase in graphite content in the composites. This increase in tensile strength may be due to the graphite particulates acting as barriers to dislocations in the microstructure. One great advantage of this dispersion-strengthening effect is that it is retained even at elevated temperatures and for extended time periods because the particles are unreactive with the matrix phase. Also the tensile strength of the composites was found to be increased after nitriding compared to that before nitriding. This is clearly seen in the Figure 2.

Figure 2: Variation in Tensile Strength of Al6061 with Increasing wt% of Graphite (Without and with Nitriding)



% Elongation

From the study of Figure 3 it can be seen that the % elongation increases with increasing percentage of graphite. From the figure, it can be observed that the % elongation of the

Figure 3: Variation in % Elongation of Al6061 with Increasing wt% of Graphite (Without and with Nitriding)

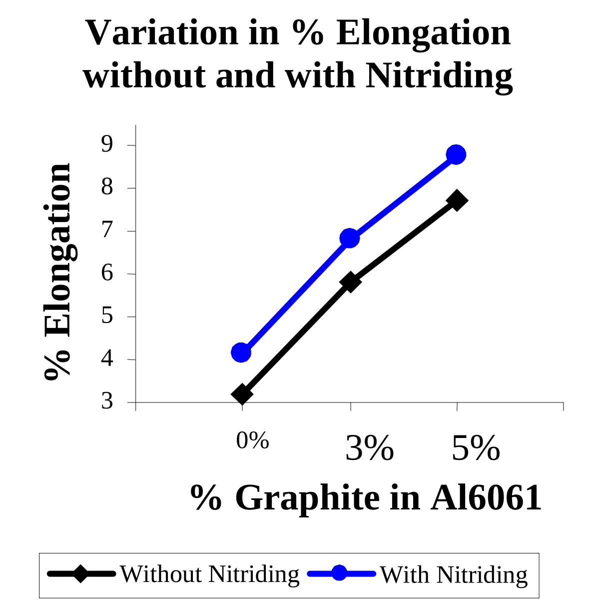
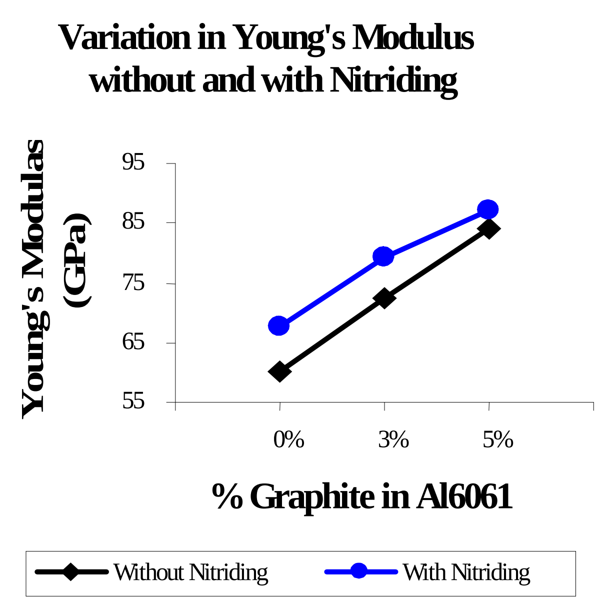


Figure 4: Variation in Young's Modulus of Al6061 with Increasing wt% of Graphite (Without and with Nitriding)



composites is higher than that of the matrix alloy. Further, from the graph, the trends of the % elongation can be found to be increased with increase in graphite content in the composites. This considerable increase in ductility is due to the graphite additions, being an effective solid lubricant, eases the movement of grains along the slip planes. The effect of graphite is expected to be mechanical in nature since the particles are un-reactive with the matrix phase. It was also observed that the % elongation of the composites is increased after nitriding.

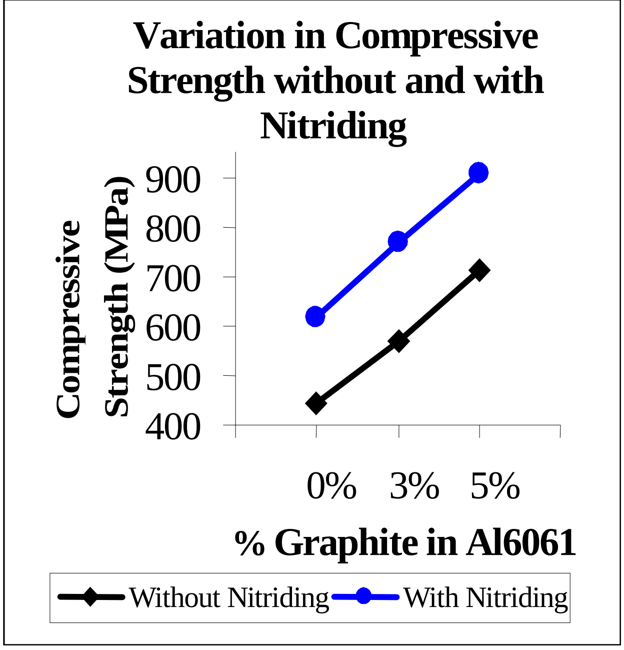
Young's Modulus

From the study of Figure 4 it can be seen that the Young's modulus increases with increasing percentage of graphite. From the figure, it can be observed that the Young's modulus of the composites is higher than that of the matrix alloy. Further, from the graph, the trends of the Young's modulus can be found to be increased with increase in graphite content in the composites. Similar results have been obtained in aluminium matrix composites where the Young's modulus has been reported to increase with increase in the content of the reinforcing material, regardless of the type of reinforcement used. The values of the Young's modulus of the composite were found to be enhanced after nitriding. This is clearly seen in the Figure 4.

Compressive Properties

From the study of Figure 5 it can be seen that the compressive strength increases with increasing percentage of graphite. From the figure, it can be observed that the compressive strength of the composites is higher than that of the matrix alloy. Further, from the graph, the trends of the compressive strength can be found to be increased with increase in graphite content in the composites. Also the compressive strength

Figure 5: Variation in Compressive Strength of Al6061 with Increasing wt% of Graphite (Without and with Nitriding)



values of the composites were found to be improved after nitriding compared to those values before nitriding. This is clearly depicted in the Figure 5.

CONCLUSION

The significant conclusions of the studies carried out on Al6061-Graphite composites are as follows.

Cast Al6061-Graphite composites were prepared successfully using liquid metallurgy techniques.

The properties of the cast Al6061-graphite composites are significantly changed by varying the amount of graphite therein. It was found that increasing the graphite content within the matrix material resulted in significant improvement in ductility, tensile strength, compressive strength and Young's modulus, but a decrease in the hardness.

The mechanical properties like hardness, tensile strength, % elongation, Young's modulus and compressive strength of the composites were found enhanced with the nitriding heat treatment process.

REFERENCES

1. ASM (2001), *Handbook of Composites*, Vol. 21.
2. Basavarajappa S and Chandramohan G (2005), "Wear Studies on Metal Matrix Composites-Taguchi Approach", *Journal of Mat. Sci. and Tech.*, Vol. 21, No. 6, pp. 845-850.
3. Basavarajappa S, Chandramohan G, Subramanian R and Chandrasekar (2006), "Dry Sliding Wear Behaviour of Al2219/SiC MMC", *Materials Science-Poland*, Vol. 24, Nos. 2/1, pp. 357-366.
4. Biswas S, Santharam A, Rao N A P, Narayanaswamy K, Rohatgi P and Biswas S K (1980), *Tribology Internationa*, Vol. 8, p. 171.
5. Bragg W L (1928), *Introduction to Crystal Analysis*, p. 64, Bell and Son, London.
6. Callister W D Jr (1991), *Materials Science and Engineering: An Introduction*, 2nd Edition, p. 536, John Wiley, New York.
7. Dieter G E (1988), *Mechanical Metallurgy*, pp. 212-219, McGrawHill, New York.
8. How H C and Baker T N (1997), "Dry Sliding Wear Behaviour of Saffil-Reinforced AA6061 Composites", *Wear*, Vol. 210, pp. 263-272.

9. Jen Fin Lin, Ming Guu Shih and Yih Wei Chen (1996), "The Tribological Performance of 6061 Aluminum Alloy/ Graphite Composite Materials in Oil Lubricants with EP Additives", *Wear*, Vol. 198, pp. 58-70.

10. Krishnan B P, Raman N, Narayanaswamy K and Rohtagi P K (1980), *Wear*, Vol. 60, p. 1.

11. Lee C S, Kim Y H and Han K S (1992), "Wear Behaviour of Aluminium Matrix Composite Materials", *Journal of Materials Science*, Vol. 27, pp. 793-800.

12. Liang Y N, Ma Z Y, Li S Z, Li S and Bi J (1995), "Effect of Particle Size on Wear Behavior of SiC Particulate-Reinforced Aluminum Alloy Composites", *Journal of Materials Science Letters*, Vol. 14, pp. 114-116.

13. Martin A, Rodriguez J and Llorca J (1999), "Temperature Effects on the Wear Behavior of Particulate Reinforced Al-Based Composites", *Wear*, Vols. 225-229, pp. 615-620.

14. McDanels D L (1985), "Analysis of Stress-Strain, Fracture and Ductility Behaviour of Aluminium Matrix Composites Containing Discontinuous SiC Reinforcement", *Metall. Trans. A*, Vol. 16, pp. 1105-1115.

15. Pai B C, Pillai R M and Sathyanarayana K G (1994), "Prospects for Graphite Aluminium Composites in Engineering Industries", *Indian Journal of Engineering and Materials Science*, Vol. 1, October, p. 279.

16. Ramesha A, Prakash J N, Shiva Shankare Gowda A S and Sonnappa Appaiah (2009), *Journal of Minerals & Materials Characterization & Engg.*, Vol. 8, No. 2, pp. 93-106.

17. Rohatgi P K, Ray S and Lin Y (1992), "Tribological Properties of Metal Matrix Graphite Particle Composites", *International Materials Review*, Vol. 37, No. 3, p. 129.

18. Seah K H W, Sharma S C and Girish B M (1995), "Mechanical Properties of Cast ZA-27/Graphite Particulate Composites", *Materials and Design*, Vol. 16, pp. 271-275.

19. Straffelini G, Bonollo F and Tiziani A (1997), "Influence of Matrix Hardness on the Sliding Behavior of 20 vol% Al_2O_3-Particulate Reinforced 6061 Al MMC", *Wear*, Vol. 211, pp. 192-197.

20. Szu Ying Yu, Hitoshi Ishii, Keiichiro Tohgo, Young Tae Cho and Dongfeng Diao (1997), "Temperature Dependence of Sliding Wear Behavior in SiC Whisker or SiC Particulate Reinforced 6061 Aluminum Alloy Composite", *Wear*, Vol. 213, pp. 21-28.