Journal of Engineering Science and Technology
Vol. 8, No. 6 (2013) 754 - 763

MECHANICAL PROPERTY EVALUATION OF A356/SiCp/Gr METAL MATRIX COMPOSITES

B. M. VISWANATHA[1,*], M. PRASANNA KUMAR[2], S. BASAVARAJAPPA[3], T. S. KIRAN[4]

[1,4]Department of Mechanical Engineering Kalpataru Institute of Technology, Tiptur-572202, India
[2]Department of Mechanical Engineering Bapuji Institute of Engineering and Technology, Davanagere-577004, India
[3]Department of Mechanical Engineering University B.D.T. College of Engineering, Davanagere-577004, India
*Corresponding Author: vishwanathabm@gmail.com

Abstract

In the present investigation, studies on microstructure and mechanical properties of Aluminium Matrix Composites (AMCs) reinforced with silicon carbide (SiCp) and graphite (Gr) particles. A356 alloy is used as the matrix material with varying the reinforcement of SiCp from 0 to 9 wt% in steps of 3 wt% and fixed quantity of 3 wt% of graphite. The composites were fabricated by liquid metallurgy method. The prepared composites were examined for microstructure to know the particle distribution in the matrix material. Hardness and tensile properties were studied and compared with the alloy. There was a significant improvement in hardness and tensile properties by increasing the weight percentage of SiC particles.

Keywords: Metal matrix composites, Stir casting, Microstructure, Hardness, Tensile properties.

1. Introduction

Aluminium is used as a matrix material because of its attractive characteristics and second most available material. Aluminium alloy alone shows poor mechanical and tribological properties. This leads for the development of new material. Most of research work on MMCs was carried out on SiC, Al_2O_3, Gr particle reinforcements and few worked on combination of reinforcements (hybrid composites).

The composite is a fascinating material due to their attractive properties, such as high strength to weight ratio, modulus of elasticity, light weight, and low coefficient of thermal expansion, etc. The Metal Matrix Composites (MMCs) a class material consists of metallic alloy and reinforced with ceramic particles such as whiskers, short and long fibres or particles. The metal matrix composites are very attractive in automobile, sports, and defence and aerospace applications. In metal matrix, properties can be tailored by addition of hard and soft reinforcement materials in the form of particles. Particulate reinforced composites are less cost compared with fibre reinforced composites. The particulate material shows isotropic physical properties, it enhances the mechanical and tribological properties of the composite material [1].

Aluminium (Al) is the most popular matrix for the MMCs. Al alloys are attractive, because of their low density, good thermal, electrical properties, corrosion resistance and having good damping capacity. The commonly used matrix materials are Al, Zn, Cu, Mg, etc. and reinforcement materials are SiCp, Al2O3, Gr, ZrO2, etc. The particle size, volume fraction, shapes of the particles very much influence the mechanical properties of composite materials. The earlier researchers worked on Al/SiCp, Al/Al2O3, Al/Gr reinforced material, which enhances the physical and mechanical property of the composite material. Davidson et al. [2] studied on mechanical behaviour of 6061 aluminium alloy reinforced with copper coated and uncoated SiC particles. The copper coated SiC particles improves the bonding strength with matrix material and applied load more effectively transferred from the particles, which enhance the larger strain failure compare with uncoated SiC particles.

Sahin et al. [3] reported that hardness, density of the material increases with increasing the content of ceramic reinforcement and porosity decreases with increasing particles content. Xiao-Dong et al. [4] studied on 5210 Al/SiCp composite with 55 vol. % of SiCp fabricated by squeeze casting method. The bonding strength was increased as the particle size was reduced. Larger particle size produces larger flaws with more defects and decreases the strength of the material.

Saravanan et al. [5] studied on composites A356-10 vol. % SiCp with excess addition of 0.4% magnesium. The hardness and Young’s modulus of the material increase with addition of SiC particles. Addition of extra magnesium to the composite slurry, increases the wettability. Akhlaghi et al. [6] reported that, as the particle size increases it lead to slight increase in tensile strength over the unreinforced aluminum.

Seah et al. [7] studied on mechanical properties of zinc-aluminium alloy/graphite particles. Ductility, ultimate tensile strength (UTS), compressive strength and Young’s modulus increased and significant decrease in hardness of the composite material was observed. Lin et al. [8] reported that increase in graphite content in aluminium matrix material, reduces the UTS, Young’s modulus and elongation of composite. This is due to cracking of the matrix/particulate interface, reduces the percentage elongation with addition of graphite particle.

The mechanical and physical properties were increased by increasing the content of SiCp to the aluminium matrix alloy but decrease in machining property of the material. To maintain the high mechanical and improve the machining property of the material addition of graphite content in Al/SiCp composite material results in Al/SiCp/Gr hybrid composites. Guo and Yuan [9] reported that the SiCp/Gr/Al6013 shows peak hardness in shorter time compared with Al6013 alloy during artificial aging.

The composites were fabricated by liquid metallurgy route. Stir cast method is practically easy, cost is less, and uniform distribution of the reinforcement into matrix alloy is possible. Stirring was carried out at semi solid condition and all the particles were easier to incorporate in matrix alloy. At volume percentage of SiCp higher than 10% in matrix alloy the wettability decreases and agglomeration and settling tendencies increases [10, 11]. Therefore 9 wt.% of SiCp was chosen for present work.

Aqida et al. [12] studied on various stirring speeds and pre-heating the particles to avoid porosity. Naher et al. [13] studied on liquid and semi-solid stir casting technique to produce an Al-SiCp composite. The stirring speed from 200 to 500 rpm of slurry in semi-solid state produced uniform distribution in matrix without addition of any wetting agent. Al-Si constituent alloys used as major alloying element as it produces excellent castability [14-17]. The addition of 3-7 % volume fraction of graphite particles to the SiCp/Al material, improves the machinability and tribological properties but it decreases the tensile, elastic modulus of the material therefore the content of the graphite is limited to 3 wt. % in this work [18].

A356 alloy was chosen as it is having good castability, weldability and good resistance to corrosion. Along with SiCp of 25 µm and Gr of 44 µm were added as the reinforcement materials.

2. Experimental Procedure

2.1. Material preparation

The chemical composition of the matrix material A356 is given in Table 1. The SiC particles were varied from 0-9 wt% in steps of 3 wt% and 3 wt% of Gr particles of was added.

Table 1. Composition of A356 Aluminium Alloy [19].

Elements	Cu	Mg	Mn	Si	Fe	Zn	Ti	Others	Al
Wt. %	0.1	0.4	0.06	7.0	0.1	0.04	0.1	Traces	Balance

Among all the liquid state process, stir-casting technology is considered to be the most potential method for engineering applications in terms of production capacity and cost efficiency. The stirring speed, time and Pre-heating of reinforcements influence the improvement in mechanical property, which will help in uniform distribution [20-26]. A two-step mixing method was involved to produce cast composites for better particle distribution.

The melt was carried out in graphite crucible, in a resistance furnace SiC_p and Graphite particles were preheated for 2 hours to make their surface oxidized. Then the reinforcements were slowly added into the crucible. To enhance the wettability between reinforcement and matrix alloy 1 wt% of Mg was added. The hexachloroethane (C_2Cl_6) tablets were added, which decompose to form Aluminium chloride ($AlCl_3$) gas bubbles. The tablets were plunged deep into metal and kept for bubbling [10, 11]. After sufficient mixing using automatic mechanical stirrer at a stirring speed of 500 to 600 rpm for 10 minutes the slurry was poured into preheated mould box to avoid the formation of porosity in the composite material.

2.2. Testing

Hardness and tensile tests were carried out at ambient temperature. The hardness tests were conducted using Vickers macro hardness testing system as per ASTM E-92 standard [27]. The tests were repeated for three Vickers indents for each specimen and average values were considered. A specimen sample was ground with series of emery papers down to 600 grit size and polished with diamond paste of 1- 2 micron size. Further the specimen was polished by electrolytically and etched. Tensile tests were carried out using computerized universal tensile testing machine. Tests were repeated for six times and an average values were considered. The tensile specimens were machined according to the ASTM E8 standard shown in Fig.1.

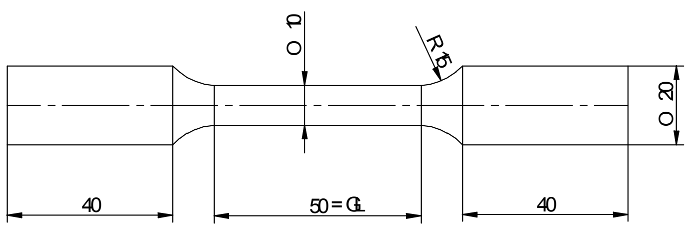

Fig. 1. Tensile Test Specimen Dimension [28].

3. Results and Discussion

3.1. Micrograph studies

Microstructure consists of fine dendrites of aluminium solid solutions with fine eutectic silicon particles at inter dendritic regions. The coarser SiC particle was observed and Graphite particles were associated with SiC particles.

3.2. Macro hardness

The hardness of the composite material is shown in Fig. 2 which increased with increasing the SiC_p. In hybrid composites hard SiC_p acts as a load bearing member, it enhances the mechanical property of the material. The hardness of the composite increased about 9 percent as the reinforcement content of SiC and graphite particles were varied from 0 to 3 wt%. The hard silicon particles are present along the flow lines and act as barriers to the movement of dislocations within the matrix. It increases the volume fraction of hard particle which increases the hardness of the material. Figure 3 show similar results were observed for A356/SiC [29] and Al-Si/SiC [30] by earlier researchers.

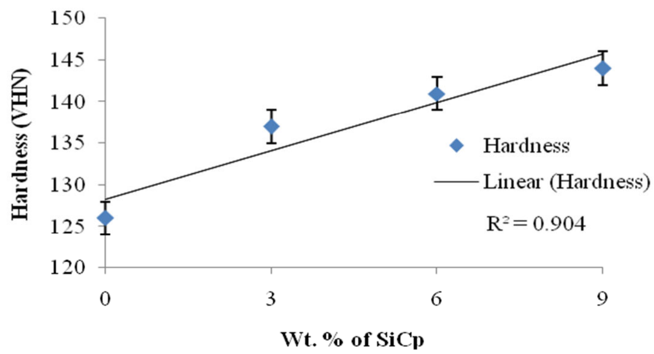

Fig. 2. Variation of Hardness with Increases in SiCp.

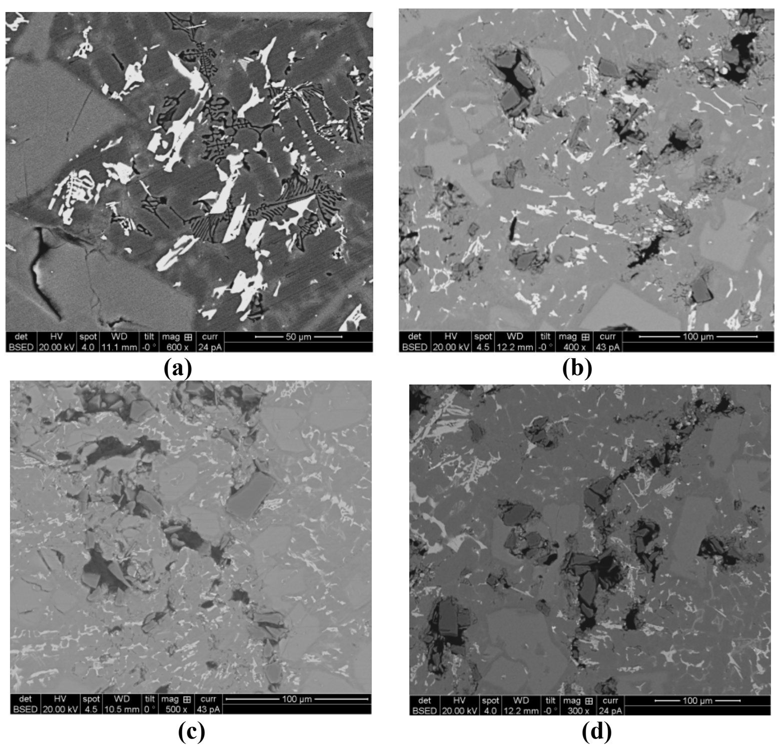

Fig. 3. SEM of (a) A356 alloy. (b) A356-3%Gr-3%SiC$_p$. (c) A356-3%Gr- 6%SiC$_p$. (d) A356-3%Gr-9%SiC$_p$.

Hardness of the specimen increases with increase in SiC [3, 5] and decrease in the hardness were observed with reinforcement of Gr [7]. Inclusion of both SiC and Gr will not yield as good result when compared with SiC alone [31, 32].

The hardness was measured by Vickers diamond indenter, the indentation formation is shown in Fig. 4.

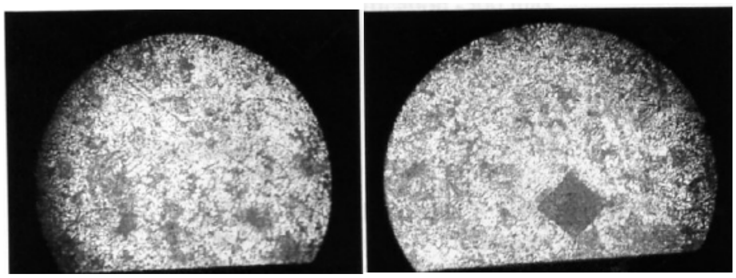

Fig. 4. (a) Before Indentation at 100x (b) After Indentation at 100x.

3.3. Tensile strength

The tensile strength of the composite increased with increase in SiC_p particles shown in Fig. 5. The tensile strength of the composite material improved by 5%, with an addition of 3 wt% of SiC and graphite particles. The reinforcement of the particle in alloy plays a significant role in overall strength of the composite. The increase in strength of the matrix enhances the mechanical properties of the composites. The presence of reinforcement in the alloy generates dislocation across the span of lattice. Dislocation motion is controlled by either the dislocation interactions, direct dislocation particulate interaction with the matrix structure. The generation of dislocation as a result of heavy pile up of dislocations at the grain boundary as well as the particle-matrix interface which causes the increase in strength of the composites.

The increase in tensile strength was due to SiC particles acting as barriers to dislocations. This dislocation motion increases the dislocation density, which positively contribute the strengthening of the A356SiC/Gr composite. The inter particulate distance between the reinforcements increases the resistance to dislocation motion as reinforcement content increased. During deformation, the matrix material has to push the reinforcement's particles further during the process the dislocation piles up. This will restrict to plastic flow in the matrix provides good strengthening of the composites. Tensile strength increases up to 10 wt. % of SiC_p and decreases with 15 wt. %. This is due to the inadequate bond between particles and matrix material when the percentage is increased [30].

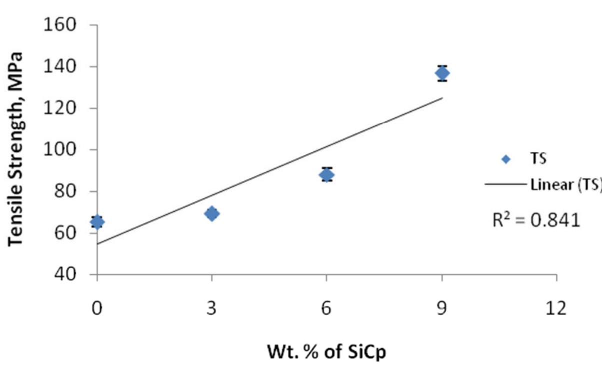

Fig. 5. Variation of tensile strength with increases in SiC_p.

Figure 6 shows the variation of elongation with increase in SiC_p leads to decrease in the percentage elongation of the hybrid composite material. The SiC_p gets oriented in the rolling direction. The alignment of SiC_p aids in the better flow of the matrix, compared with the base alloy.

The effect of inclusions on tensile properties of A356 alloy influence on tensile properties, as it reduces the property of the material that can be overcome by degassing. As degassing is very effective in removing the inclusions, it results in improvement in tensile and maintains the high percentage elongation of the material [33].

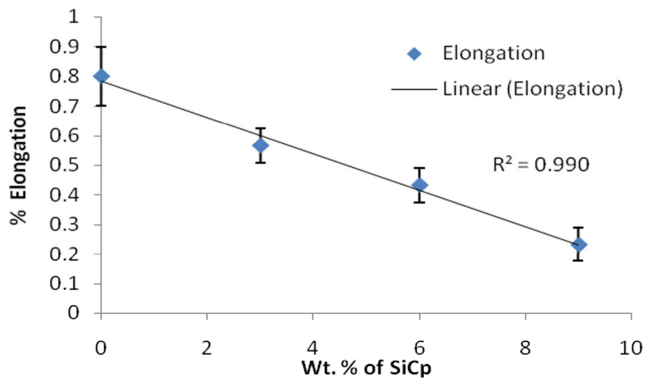

Fig. 6. Variation of Elongation with Increasing in SiC_p.

The yield strength and elastic constant was increased due to addition of SiC_p in A356 matrix material compared with alloy. When external load is applied on composite material, it produces strong internal stress between SiC_p and matrix material. These types of stresses protect from slip behavior and increase the strain hardening rate. The SiC_p and Si particle were found along the dendrite boundaries that act as barriers and increases the strength of the material [34].

The increase in volume fraction and particle size of graphite, reduces the tensile strength and elastic modulus. The tensile strength of SiC/Al material decreases with addition of graphite particles. It is mainly due to lower strength of graphite as compared with matrix alloy and SiC_p. The Al/SiC material failed in ductile and Al/Gr failed in brittle manner. Graphite particles in composite material parallel to the basal plane produce weak Van der Waals forces, resulting in weak bond interface between Al/Gr materials. It produces a crack source and propagates rapidly along Al/Gr interface. Al/SiC material produces a plastic deformation with increasing volume fraction graphite particles, crack sources increases and hence decreases the tensile strength of the composite material [35].

The improvement in hardness and tensile strength were obtained in the present work with inclusion of reinforcements. Riahi and Alpas [36] and Leng et al. [37] reinforced SiC and Gr with aluminium to obtain the similar results which are in line with the present work.

4. Conclusions

From the experimental investigation the following conclusions were drawn on the mechanical properties SiC_p and graphite particles reinforced A356 aluminium alloy composites

- A356 hybrid composites have been successfully fabricated by liquid metallurgy route with uniform dispersion of SiCp and Gr particles.
- The hardness of composites increased significantly with addition of SiCp, while maximum hardness was obtained for 9% of SiCp.
- The addition of low weight percentage of SiCp to A356 leads to increase in tensile strength and decrease in percentage elongation.

References

1. Rohatgi, P.K. (1993). Metal matrix composites. *Defense Science Journal*, 43(4), 323-349.
2. Davidson, A.M.; and Regener, D. (2000). A comparison of aluminium based metal matrix composites reinforced with coated and uncoated particulate silicon carbide. *Composites Science and Technology*, 60(6), 865-869.
3. Sahin, Y.; and Acilar, M. (2003). Production and properties of SiC_p reinforced aluminium alloy composites, *Composite Part A*: *Applied Science and Manufacturing*, 34(8), 709-718.
4. Xiao-Dong, Y.U.; Yang-Wei, W.; and Fu-chi, W. (2007). Effect of particle size on mechanical properties of SiC_p/5210 Al metal matrix composite. *Transaction Nonferrous Material Society*, 17, 276-279.
5. Saravanan, R.A.; Surappa, M.K.; and Pramila Bai, B.N. (1997). Erosion of A356 Al-SiC_p composites due to multiple particle impact. *Wear*, 202(2), 154-164.
6. Akhlaghi, F.; Lajevardi, A.; and Maghanaki, H.M. (2004). Effects of casting temperature on the microstructure and wear resistance of compocast A356/SiCp composites: a comparison between SS and SL routes. *Journal of Materials Processing Technology*, 155-156, 1874-1880.
7. Seah, K.H.W.; Sharma, S.C.; and Girish, B.M. (1996). Mechanical properties of cast za-27/graphite particulate composites. *Materials and Design*, 16(5), 271-275.
8. Lin, C.B.; Chang, R.J.; and Weng, W.P. (1998). A Study on process and tribological behaviour of Al alloy/Gr. (p) composite. *Wear*, 217(2), 167-174.
9. Guo, J.; and Yuan, X. (2009). The aging behavior of SiC/Gr/6013 Al composite in T4 and T6 treatments, *Materials Science and Engineering A*, 499, 212-214.
10. Hashim, J.; Looney, L.; and Hashmi, M.S.J. (1999). Metal matrix composites: production by the stir casting method, *Journal of Materials Processing Technology*, 92-93, 1-7.
11. Hashim, J.; Looney, L.; and Hashmi, M.S.J. (2001). The enhancement of wettability of SiC particles in cast aluminium matrix composites, *Journal of Materials processing Technology*, 119(1-3), 329-335.

12. Aqida, S.N.; Ghazali, M.I.; and Hashim, J. (2003). The effects of stirring speed and reinforcement particles on porosity formation in cast MMC. *Journal Mechanical*, 16, 22-30.
13. Naher, S.; Brabazon, D.; and Looney, L. (2004). Development and assessment of a new quick quench stir caster design for the production of metal matrix composites. *Journal of Materials Processing Technology*, 166(3), 430-439.
14. Breval, E. (1995). Synthesis routes to metal matrix composites with specific properties: A Review. *Composites Engineering*, 5(9), 1127-1133.
15. Surappa, M. K. (2003). Aluminium matrix composites: Challenges and opportunities. *Sadhana* 28(1-2), 319-334.
16. Kaczmar, J.W.; Pietrzak, K.; and Wlosinski, W. (2000). The production and application of metal matrix composite materials. *Journal of Materials Processing Technology*, 106(1-3), 58-67.
17. Haizhi, Ye. (2003). An overview of the development of Al-Si-alloy based material for engine applications. *JMEPEG*, 12(3), 288-297.
18. Leng, J.; Jiang, L.; and Zhang, Q. (2008). Study of machinable SiC/Gr/Al composites. *Journal of Material Science*, 43(19), 6495-6499.
19. William, H.C. (1989). *Properties and selection: nonferrous alloys and pure metals, 2* (9^{th} Ed.). Metals Handbook, Asm Intl, 164-167.
20. Ralph, B.; Yuen, H.C.; and Lee, W.B. (1997). The processing of metal matrix composites an overview. *Journal of Materials Processing Technology*, 63(1-3), 339-353.
21. Taha, M.A. (2001). Practicalization of cast metal matrix composites. *Materials and Design*, 22(6), 431-441.
22. Zhou, W.; and Xu, Z.M. (1997). Casting of SiC reinforced metal matrix composites. *Journal of Materials Processing Technology*, 63(1-3), 358-363.
23. Hashim, J.; Looney, L.; and Hashim, M.S.J. (2002). Particle distribution in cast metal matrix composites - part I. *Journal of Materials Processing Technology*, 123(2), 251-257.
24. Hashim, J.; Looney, L.; and Hashim, M.S.J. (2002). Particle distribution in cast metal matrix composites - part II. *Journal of Materials Processing Technology*, 123(2), 258-263.
25. Balasivanandha Prabu, S.; Karunamoorthy, L.; Kathiresan, S.; and Mohan, B. (2006). Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composites. *Journal of Materials Processing Technology*, 171(2), 268-273.
26. Hanumanth, G.S.; and Irons, G.A. (1993). Particle incorporation by melt stirring for the production of metal-matrix composites. *Journal of Materials Science*, 28(9), 2459-2465.
27. Vander Voort, G.F. (2000). *Macroindentation hardness testing, mechanical testing and evaluation*. ASM Handbook, 8, 203-220.
28. John, M; Uniaxial tension testing, Mechanical Testing and Evaluation. *ASM Handbook*, 8, 124-142.
29. Pramila Bai, B.N.; Ramesh, B.S.; and Surappa, M.K. (1992). Dry sliding wear of A356-Al-SiC_p composites. *Wear*, 157(2), 295-304.

30. Ozben, T.; Kilickap, E.; and Cakir, O. (2008). Investigation of mechanical and machinability properties of SiC particle reinforced Al-MMC. *Journal of Materials Processing Technology*, 198(1-3), 220-225.
31. Suresha, S.; and Sridhara, B.K. (2010). Effect of addition of graphite particulates on the wear behaviour in aluminium-silicon carbide-graphite composites. *Materials and Design*, 31(4), 1804-1812.
32. Wilson, S.; and Alpas, A.T. (1996). Effect of temperature on the sliding wear performance of Al alloy and Al matrix composites. *Wear*, 196(1-2), 270-278.
33. Liu, L.; and Samuel, F.H. (1998). Effect of inclusions on the tensile properties of Al-7% Si-0.35 Mg (A356.2) aluminium casting. *Journal of Material Science*, 33(9), 2269-2281.
34. Wang, Z.; Ruby, J.; and Zhang. (1991). Mechanical behavior of cast particulate SiC/Al (A356) metal matrix composites. *Metallurgical Transactions,* 22A(7), 1585-1593.
35. Leng, J.; Wu, G.; Zhou, Q.; Dou, Z.; and Huang, X.L. (2008). Mechanical properties of SiC/Gr/Al composites fabricated by squeeze casting technology. *Scripta Materialia*, 59(6), 619-622.
36. Riahi, A.R.; and Alpas, A.T. (2001). The role of tribo- layers on the sliding wear behavior of graphitic aluminum matrix composites. *Wear*, 251(1-12), 1396-1407.
37. Leng, J.; Longtao, J.; Wu, G.; Shoufu, T.; and Chen, G. (2009). Effect of graphite particle reinforcement on dry sliding wear of SiC/Gr/Al composites. *Rare Metal Materials and Engineering*, 38(11), 1894-1898.