Microstructure, hardness and machinability analysis of gravity cast AA6061/SiC composites

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KEYWORDS

Metal Matrix Composites,
Hardness,
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ABSTRACT

In the present work, machinability analysis of AA6061/SiC composites developed using gravity die casting technique. The microstructure of composites and the chip formed are studied using optical and electron microscopes. Brinell hardness measurements were carried out to check the effect of varying SiC particle content for both the composites. The machinability analysis was carried out by varying feed rate, depth of cut and speed for all composites. From optical studies it was confirmed that addition and increase in SiC content led to grain refinement of AA6061 matrix. The hardness of composites was found to higher than that of unreinforced owing to addition of SiC particles. Machinability studies revealed that increase in feed rate, depth of cut and cutting speed led to increase in the tangential force. The increase in tangential force was attributed to increase in chip thickness and width during the machining operation.

1. Introduction

More than dozens of aluminium alloys are being used for variety applications in different areas of manufacturing and technology. These alloys are available in the form of wrought products like plate, sheet, bar and angle in the market in and later cut or welded or machined according to the requirements of components. In particular, AA6XXX and AA7XXX alloy series in which Mg, Zn, Cu and Si are principal alloying elements are known for low density, high strength and better corrosion resistance. Take for example the complex architectural parts and structural members are made up of AA6XXX series as they are known for high compressive and tensile strength. Similarly AA7XXX series which possess high strength and high toughness is used in making aircraft wing structures. Further AA6XXX and AA7XXX alloy series are heat treatable and their strength can be enhanced by precipitation hardening by opting different temper conditions [1, 2]. But due to increase in the popularity of light metal matrix based composites and their possible applications in the almost all fields of engineering has led to lot of advancements. Compared to pure and unreinforced metals, metal matrix composites are known to have low density, high strength and high stiffness to weight ratio. In this regard AA6XXX and AA7XXX alloys are widely being tried as matrix material in the manufacturing of composites as they are easy to process and possess good mechanical properties. Variety of reinforcements like graphite, TiC, SiC, Al_2O_3, TiB_2, Si_3N_4, TiO_2 and flyash are used to reinforce these aluminium alloys [3-10]. After addition of reinforcements the aluminium composites showed improvement in mechanical and tribological properties. However, selection of appropriate reinforcement and processing technique is very crucial and highly dependent on the type of application.

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Machining is the most important and major manufacturing process in which final shape to a component is given by turning, milling, drilling or other miscellaneous operations. As aluminium alloys and its composites have huge role in the manufacturing of various automotive and aircraft parts it is necessary to understand their machining performance especially when a new type of reinforcement or thermal treatment is given. The effect of processing conditions like secondary deformation processing, heat treatment, addition of alloying elements and filler materials like SiC into aluminium alloys has created considerable apprehension due to lack of information on machining attributes. In their work Bansal and

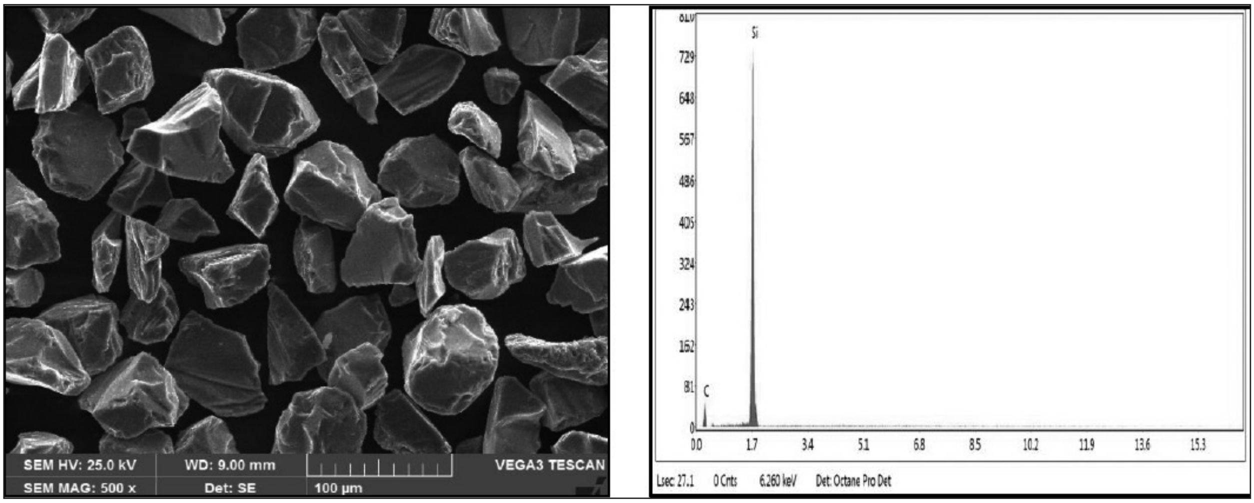

Fig. 1. (a) SEM image and (b) EDS of SiC particles.

Upadhyay [11] studied the effect of machining parameters of material removal rate, tool wear and surface roughness of alumina reinforced Al2124 composites. It was found that increase in feed rate and speed led to increase in tool wear and material removal rate. However, surface roughness was found to decrease with the increase in the values of speed. Kumarasamy et al [12] reported the machinability behavior of flyash and graphite reinforced aluminium composites. Using Taguchi factorial design 27 experiments pertaining turning operation was conducted and optimal cutting parameter for obtaining better surface roughness was analyzed using S/N ratio. The results showed significant influence of reinforcement content and cutting on surface finish of aluminium hybrid composites. In another work, Suresh et al [13] reported optimization of machining parameters using grey-fuzzy algorithm. Aluminium alloy LM25/SiC/Gr composites fabricated using compo-casting technique was subjected to machinability analysis by following Taguchi's L27. Composite with 10% SiC/Gr content showed better machinability for cutting speed of 200 m/min and feed rate of 0.075 mm/rev.

Taking a clue from various research work an attempt is made to study the machinability of important aluminium alloy AA6061 reinforced with SiC particles. The composites are developed using gravity die casting and subjected to microstructure and hardness studies. Further machinability studies were conducted by varying machining parameters like speed (180 – 280 rpm), feed rate (0.1 – 0.6 mm/rev) and depth of cut (0.3 – 0.6 mm). The results obtained are presented and analyzed with respect to other works.

2. Experimentation

2.1 Composite manufacturing

In the present work, AA6061/SiC composite was developed using gravity die casting technique with varying SiC content. Although the reinforcement, SiC particle is the reinforcing phase and AA6061 alloy is the continuous matrix phase. AA6061 was chosen as the matrix material for preparation of composite system. The ingots of the alloy were procured from Fenfee Metallurgicals, Ramanagara, India. The reinforcing phase, silicon carbide (SiC) had average particle size of ~75 µm. Scanning electron micrograph (SEM) of procured SiC particles is shown in Fig. 1 along elemental dispersive spectroscopy (EDS). The morphology as per SEM of SiC particles is found to be sharp and irregular in shape. The composite system was fabricated by gravity die casting method in which AA6061 alloy was melted in graphite crucible at a temperature of 750°C. In order to melt the alloy, electrical resistance furnace with mechanical stirrer was used for this purpose. After completion of melting, degassing of the molten AA6061 was carried out using hexachloroethane tablets (C_2C_{16}). Once the degassing is done, the stirring of molten metal was carried out and in due course of time the preheated SiC particles were added to it. The SiC particles are added slowly to the molten metal so that uniform dispersion can be obtained. Here SiC particle content was varied from 0% to 8% in the even steps of 2%. The molten metals along with SiC particles are stirred for 20 minutes for uniform mixing of particles with the melt. Once mixing for 20 minutes is done the molten metal is poured into the permanent mould.

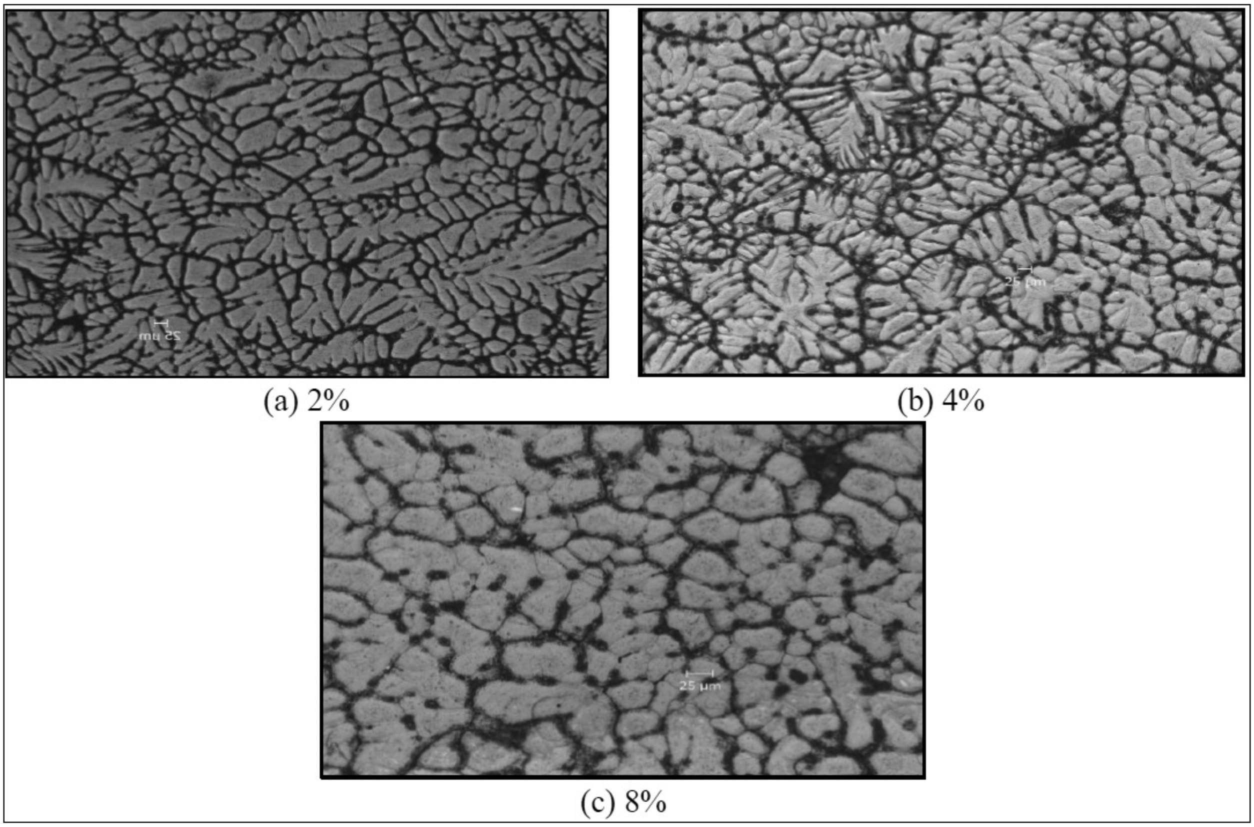

Fig. 2. Optical microstructure of AA6061/SiC composites.

2.2 Characterization and testing

The cast AA6061/SiC composite was subjected to metallographic polishing and etching process as per ASTM E-3 standard. A Keller reagent combination of 90 ml water, 4ml H_2SO_4, 2g C_rO_3 and 4ml of HF was used to etch the composite samples to reveal microstructural features. Olympus metallurgical microscope was used take the optical micrographs on polished etched surface of cast composites. Further SEM (Make: JSM 840a Jeol) was used to check the SiC particle morphology and microstructure of cast composites. The Brinell hardness test was carried out on cast composite samples as per ASTM E10 standard. The hardness test is carried out on the polished surface of all composites. A hardened steel ball of 10 mm diameter was used to apply a load of 500 kg for a dwell time of 30 seconds. A strain gauge type of lathe tool dynamometer (Make: UNITECH, Model: UIL-15, 500KG, XYZ) was used to measure vertical and horizontal forces during machining operations. Conventional type universal lathe machine was used for machining studies. For machinability analysis was carried out using single point cutting tool (HSS) with the feed rate (0.1 – 0.4 mm/rev), speed (180 – 280 rpm) and depth of cut (0.3 – 0.6 mm). The cutting tool holder PNR 25M16 was used for experimentation. The results obtained are presented in the form of tangential force for all composites.

3. Results and Discussion

In this section effect of SiC on microstructure, Brinell hardness and machinability is studied and presented with appropriate discussions.

3.1 Microstructure and hardness

Fig. 2 shows the optical micrographs of AA6061/SiC composites for varying SiC content of 2%, 4% and 8% respectively. From Fig. 2 (a) and (c), it can be seen that AA6061 composites contains typical α-Al as primary phase and dendritic eutectic phase. The primary phase is seen to have quite refined and while the dendritic phase is quite uniformly dispersed. The formation of cast microstructure largely depends on the cooling rate which in turn defines the grain size. The dendritic microstructure in case of composites with lower SiC content (2%) showed coarse grains while the one with higher SiC content (8%) showed smaller grain size. The AA6061/SiC composite with 2% SiC content show the vast dendritic structure which gradually turns to equi-axed structure as the SiC content is increased to 8%. The main reason for obtaining equi-axed grain structure is due to nucleation of new grains and limited the grain size by inhibiting their growth. In addition to this the SiC particles also increases the solidification rate due to which helps in the formation of equi-axed grain structure. The SiC particles are seen to be dispersed at the grain boundaries which are quite clearly visible from the optical micrographs Fig. 2 (b) and (c). One can see that with the increase in SiC particle content the dendritic phase is quite changed to equi-axed grains. Further the grain size of composites is found to decrease considerably with the increase in SiC particle content.

Brinell hardness values of the Al6061/SiC composite system is presented in the Fig. 3. It is found that the hardness of composites tend to enhance with the increase in the SiC content. As shown in Fig. 4 the hardness of AA6061/SiC composites tends to increase gradually and highest value is noted for composite with 8% SiC content. For AA6061 alloy and AA6061/8%SiC

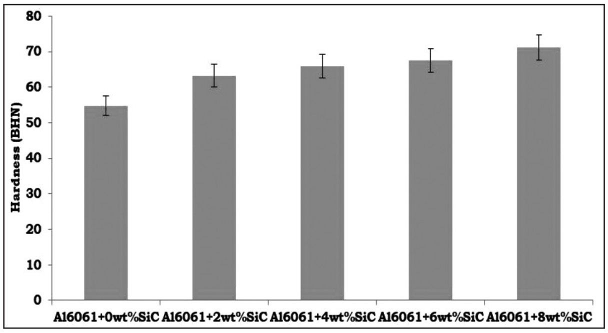

Fig. 3. Brinell hardness of AA6061/SiC composite.

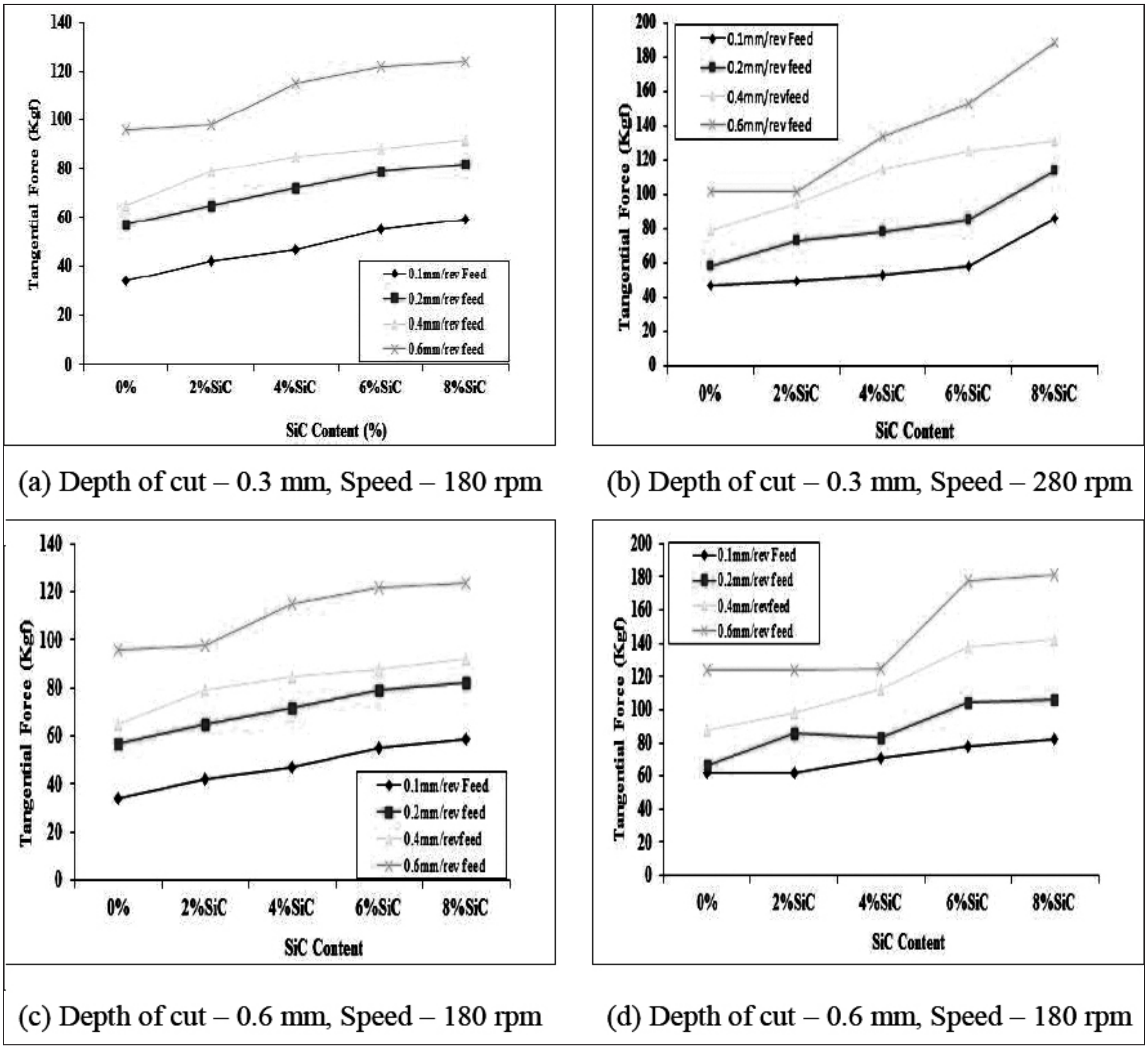

Fig. 4. Tangential force obtained for varying depth of cut, speed and feed rate.

composite the hardness values were 54.76 and 71.25 BHN respectively. The increase in hardness value for AA6061/8%SiC composite is about 30.11% compared to that of AA6061 alloy. The increase in hardness value for composites as compare to unreinforced alloys is due to the resistance provided by SiC particles to the plastic deformation during indentation. In addition to this the grain refinement also contributes to increase in hardness of both the composite systems. Similar observations were reported by Jayakumar et al [14] where they attributed increase in hardness to grain refinement caused by the addition of SiC particles to A319 aluminium composites.

3.2 Machinability analysis

Machinability analysis was carried out by varying the feed rate (0.1 – 0.4 mm/rev), speed (180 – 280 rpm) and depth of cut (0.3 – 0.6 mm). The results obtained are presented in the form of tangential force for all composites.

3.2.1 Effect of feed rate

Fig. 4 shows the tangential force obtained for different feed rates (0.1 – 0.6 mm/rev) for both AA6061 alloy and its composites with varying SiC content. Here, the depth of cut was varied in between 0.3 and 0.6 mm while speed was varied from 180 to 280 rpm. From all tests it was observed that increase in feed rate from 0.1 mm/rev to 0.6 mm/rev, the tangential force was found to increase significantly. For same feed rate the unreinforced AA6061 alloy showed lowest tangential force while AA6061/8% SiC composite showed highest. Take for example from Fig. 4 (a), the tangential force for unreinforced AA6061 alloy at 0.1 and 0.6 mm/rev was 34 and 96 Kgf at 0.3 mm depth of cut and 180 rpm. On the other hand for AA6061/8% SiC composite the tangential force at 0.1 and 0.6 mm/rev was 59 and 124 Kgf respectively. Similarly for other cases of depth of cut and speed as shown in Fig. 4 (b), (c) and (d), the tangential force was found to increase with the increase in feed rate. The main reason for increase in tangential force can be attributed to increase in chip thickness. When the feed rate is increased the chip thickness tends to increase resulting in enhancement in tangential force irrespective of AA6061 alloy or its composites. Senthil et al [15] reported similar observations in their work on Al-Cu composites reinforced with TiB_2 particles.

3.2.2 Effect of depth of cut

Fig. 4 shows the tangential force obtained for different depth of cut (0.3 – 0.6 mm) for both AA6061 alloy and its composites with varying SiC content. Here the feed rate was varied in between 0.1 and 0.6 mm/rev while speed was varied from 180 to 280 rpm. From all tests it was observed that increase in depth of cut from 0.3 and 0.6 mm, the tangential force was found to increase significantly. From Fig. 4 (a) and (c), the tangential force for unreinforced AA6061 alloy at 0.3 and 0.6 mm depth was 34 and 42 Kgf at 0.1 mm/rev and 180 rpm. On the other hand for AA6061/8% SiC composite the tangential force at 0.1 and 0.6 mm/rev was 59 and 65 Kgf respectively. As it can be observed that the increase in depth of cut from 0.3 mm to 0.6 mm the tangential force increased considerably. Similarly for other feed rates and speed the tangential force is found to increase as well indicating significant influence of depth of cut. The primary reason for increase in tangential force with the increase in depth of cut is the width of chips. On the other the presence of SiC particles in composite makes it harder due to which the force required is high as compared to that of unreinforced AA6061 alloy.

3.3.3 Effect of speed

Fig. 4 shows the tangential force obtained for different speed (180 and 280 rpm) for both AA6061 alloy and its composites with varying SiC content. Here the feed rate was varied in between 0.1 and 0.6 mm/rev while depth of cut was varied in between 0.3 and 0.6 mm. It can be seen from Fig. 4 that with the increase in speed from 180 to 280 rpm there is slight increase in tangential force. Take for example, as seen in Fig. 4 (a) and (b), the tangential force for unreinforced AA6061 alloy was 34 and 47 Kgf for 180 and 280 rpm at 0.1 mm/rev and 0.3 mm depth of cut. On the other hand for AA6061/8% SiC composite the tangential force was 59 and 89 Kgf for 180 and 280 rpm at 0.1 mm/rev and 0.3 mm depth of cut. One can observe that increase in cutting speed led to substantial amount of increase in tangential force. It is well known that the mechanical properties like define the tangential force for different cutting speeds. As it can be seen that the increase in cutting speed is quite marginal and the hardness might be the same as that for lower cutting speed of 180 rpm. In addition to this the accumulation of materials which other known as built up edge causes

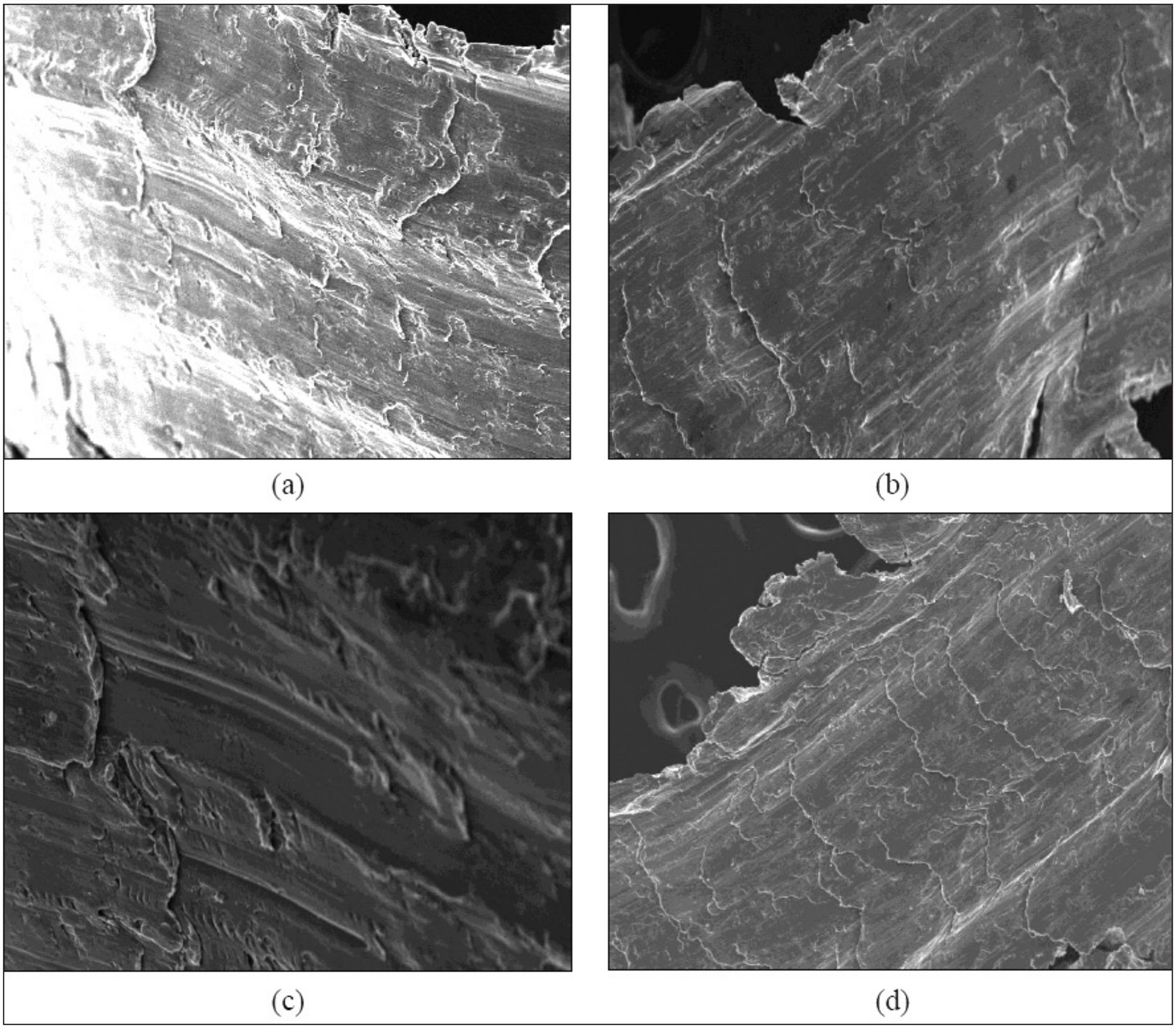

Fig. 5. Chip morphology for (a) 2%, (b) 4%, (c) 6% and (d) 8% SiC reinforced AA6061 composites at depth of cut of 0.3 mm, speed 180 rpm and 0.6 mm/rev.

the seizing of tool tip leading to increase in tangential force.

3.3.4 Chip forms

Fig. 5 (a) – (d) shows the form of chips formed after machining at depth of cut of 0.3 mm, speed 180 rpm and 0.6 mm/rev for AA6061 composites with 2%, 4%, 6% and 8% SiC content. It can be seen from the SEM micrographs that all composites showed lamella kind structures on the free surface of chip which is mainy due to periodic tool-chip contact. Further absence of spherical type of chips here clearly indicates that there was no signfiicant increase in temperature. It is well known that the spherical chips are formed only when there is substantial increase in the temperature during machining while in present case as the cutting speeds are lower one can expect insignificant changes in the temperature. In addition to this, with the increase in SiC content from 2% to 8%, the width of lameller chips was found to increase due to ploughing process. Overall the mechanism responsible for chip formation in all composites is ploughing and shearing.

4. Conclusions

The conclusions drawn from the present work are as follows,

1. The AA6061/SiC composites were successfully developed using gravity die casting technique with varying SiC content.
2. The microstructure studies showed transition of dendritic structure for AA6061 alloy to

equi-axed grain structure for AA6061/SiC composites with significant grain refinement.

3. Hardness of composites was found to be substantially higher than that of unreinforced AA6061 alloy with highest hardness of 71.25 BHN obtained for AA6061/8%SiC composite.

4. Machinability studies revealed increase in tangential force with the increase in feed rate, depth of cut and cutting speed. Increase in chip thickness and width were the primary reasons for increase in tangential force of both alloy and composites

5. Electron microscopy studies revealed ploughing and shearing as the major mechanisms for chip formation in composites.

References

1. Totten, G. E., & MacKenzie, D. S. (2003). *Handbook of Aluminum: Volume 7 Physical Metallurgy and Processes.* Marcel Dekker Inc. New York.

2. Mondolfo, L. F. (1979). *Aluminum Alloys: Structure and Properties.* Butterworth & Co Ltd. London.

3. Keshavamurthy, R., Ugrasen, G., Manasa, R., & Gowda, N. (2014). Estimation of tribological behavior of Al2024-TiB2 in-situ composite using GMDH and ANN. *Applied Mechanics and Materials,* 592-594, 1310-1314.

4. Kumar, G. S., Koppad, P. G., Keshavamurthy, R., & Alipour, M. (2017). Microstructure and mechanical behaviour of in situ fabricated AA6061–TiC metal matrix composites. *Archives of Civil and Mechanical Engineering,* 17, 535-544.

5. Mirjavadi, S. S., Alipour, M., Hamouda, A. M. S., Kord, S., Koppad, P. G., Abuzin, Y. A., & Keshavamurthy, R. (2018). Effect of hot extrusion and T6 heat treatment on microstructure and mechanical properties of Al-10Zn-3.5Mg-2.5Cu nanocomposite reinforced with graphene nanoplatelets. *Journal of Manufacturing Processes,* 36, 264-271.

6. Shivananda Murthy, K. V., Girish, D. P., & Keshavamurthy, R. (2015). Mechanical Characteristics of Hot Forged Al6061-Al2O3 Composite. *Journal of Applied Mechanics and Materials,* 787, 598-601.

7. Shivananda Murthy, K. V., Girish, D. P., & Keshavamurthy, R (2015). Investigation on mechanical Behavior of Hot Forged AL7075-TiO2-flyash Hybrid Metal Matrix Composites. *International Journal of Applied Engineering Research,* 10, 4105-4109.

8. Keshavamurthy, R., Sudhan, J. M., Gowda, N., & Krishna, R. A. (2016). Effect of Thermo-Mechanical Processing and Heat Treatment on the Tribological Characteristics of Al Based MMC's. IOP Conference Series: *Materials Science and Engineering,* 149(1), 012118.

9. Gajakosh, A. K., Keshavamurthy, R., Ugrasen, G., & Adarsh, H. (2018). Investigation on Mechanical Behavior of Hot Rolled Al7075-TiB2 In-situ Metal Matrix Composite. *Materials Today: Proceedings,* 5(11), 25605-25614.

10. Pradeep Kumar, G. S., Keshavamurthy, R., & Prachi Kumari (2016). Influence of Hot forging on Tribological behavior of Al6061-TiB2 In-situ composites. *IOP Conference Series: Materials Science and Engineering,* 149(1), 012087.

11. Bansal, P., Upadhyay, L. (2016). Effect of Turning Parameters on Tool Wear, Surface Roughness and Metal Removal Rate of Alumina Reinforced Aluminum Composite. *Procedia Technology,* 23, 304-310.

12. Kumarasamy, S. P., Vijayananth, K., Thankachan, T., & Muthukutti, G. P. (2017). Investigations on mechanical and machinability behavior of aluminum/flyashcenosphere/Gr hybrid composites processed through compocasting. *Journal of Applied Research and Technology,* 15, 430-441.

13. Suresh, P., Marimuthu, K., Ranganathan, S., & Rajmohan, T. (2014). Optimization of machining parameters in turning of Al-SiC-Gr hybrid metal matrix composites using grey-fuzzy algorithm. *Transactions of Nonferrous Metals Society of China,* 24,2805-2814.

14. Jayakumar, E., Praveen, A. P., Rajan, T. P. D., & Pai, B. C. (2018). Studies on Tribological Characteristics of Centrifugally Cast SiCp-Reinforced Functionally Graded A319 Aluminium Matrix Composites. *Transactions of the Indian Institute of Metals,* 71, 2741-2748.

15. Senthil, P., Selvaraj, T., & Sivaprasad, K. (2013). Influence of turning parameters on the machinability of homogenized Al–Cu/TiB2 in situ metal matrix composites. *The International Journal of Advanced Manufacturing Technology,* 67, 1589-1596.

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