Visual Abstract

Investigations on tensile fractography and wear characteristics of Al7075-Al_2O_3-SiC Hybrid Metal Matrix Composites routed through liquid metallurgical techniques

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ABSTRACT. The Al_2O_3-SiC reinforced Al7075 Metal Matrix Composite (MMCs) is fabricated through liquid metallurgical technique. Ceramic particulates were amalgamated into the aluminium alloy to achieve improved mechanical properties and wear resistance. Al-7075/Al_2O_3/SiC hybrid MMCs were produced by reinforcing 2%, 3%, 4% and 5% of Al_2O_3 and 3%, 5% and 7% of SiC particles. Microstructural analysis was carried out to evaluate the uniform dispersal of reinforcing particulates within the base matrix. The output results indicate that the mechanical properties of the hybrid MMCs are enhanced by increase the wt. % of ceramic particulates. Tensile fractography results show the internal fracture structure of the tensile test specimens in which the particulates fracture and pullouts were observed. The wear characteristics of developed composites are studied using the pin-on-disc apparatus. The high wear resistance is observed at 5% Al_2O_3 + 7% SiC reinforced MMCs.

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INTRODUCTION

Metal Composites find valuable to use as modern material in high temperature applications. Al-based MMCs are being extensively used in various engineering industrial applications due to higher strength, higher thermal conductivity, & better wear resistance. The selection of ceramic reinforcements in the matrix material has played an important role in the manufacturing of MMCs but major challenges handled by metal matrix composite researchers to get optimized results from several alternatives of innovative organic and inorganic reinforcements [1]. Generally, reinforcing materials used for these MMCs are SiC, Al_2O_3 and Gr in the form of whiskers or particles [2]. The mechanical and wear behavior of metal matrix composites depend on their type of reinforcement, microstructure, weight percentage of reinforcement, size of the particulates, interfacial bonding, sliding distance, average load and sliding speed etc [3]. Several composites with the incorporation of particulates were made by adding particulates, as in rheocasting, with the result that spherical primary particles were embedded in the matrix. Aluminum composites are usually made by the stir casting (liquid casting) process. The stir-casting process can be carried out at a minimum cost [4 & 5]. In this process, the ceramic particulates are mixed at the melting temperature of the alloy. However, in others, for example compo casting, the particulates are added into the semisolid slurry alloy. Continuously reinforced composites are highly expensive to manufacture compared to discontinuously reinforced composites. The performance of the base matrix is less expensive with particle reinforcement when compared with the fiber reinforcement [6 & 7]. AMMCs which are reinforced by ceramic particulates show improvements in mechanical properties as compared to matrix alloy and they are most widely used in tribological applications due to the improved wear resistance, stroke density and high ratio of strength [8]. This is the inducement for increased focus on the use of the direction of particles reinforced Al alloy MMCs for tribological applications [9]. Furthermore, researchers had also studied the immense potential in their properties of Al/SiC/Al_2O_3 based materials such as better machinability, superior weldability, formability, good castability and better corrosive resistance at high temperature and pressure [10]. Based on the recent research survey, it can be considered that SiC-Al_2O_3 particulates reinforced composites are useful in automotive applications, for the manufacture of camshafts, pistons, bearing surfaces, braking systems and cylinder liners and also used in aerospace-applications, for the manufacture of wings of the aircraft structure, exhaust systems and engine components. From the literature studies, for Al composites it was observed that by addition of hard reinforcements into the matrix increases the tensile strength, hardness and wear resistance of the MMCs. Veeresh et al. [11] in their research on Al 7075-Al_2O_3 MMCs stated that the mechanical strength (tensile) of MMCs are found to be high compared to Al7075 alloy. The hardness and wear resistance of the MMCs improved by increasing filler content [12]. Radhika et al. [13] examined the wear characteristics of Al-Gr-Al_2O_3 MMCs and observed that addition of the Al_2O_3 particulates had a significant influence on the wear resistance of the MMCs. Alaneme and Bodunrin [14] investigated the mechanical properties of Al6063-Al_2O_3 composites. The obtained results indicated the mechanical properties enhanced by the addition of hard ceramic particulates. At the same time it was observed that the fracture toughness and strain to fracture also decreased by increasing wt. % of Al_2O_3. Al 2024/Al_2O_3 composites produced by the vortex method showed an increase in mechanical properties and density when the Al_2O_3 content was increased [15]. Mahdavi et al. [16] investigated the effect of SiCp reinforced MMCs and reported that, wear behavior improved by the addition of SiC in the matrix. Prashant et al. [17] observed that reinforcement of SiC content reduces the wear behavior of the Al 6061 composite. Sharma et al [18] studied the effect of SiCp reinforcement on the unlubricated wear characteristics of ZA27 alloy composites. Experimentations were conducted by varying the sliding speeds and applied loads. The observed results indicated that Al alloy exhibits a high wear rate when compared to reinforced MMCs and by increasing wt. % of reinforcing particles, the wear rate decreased. Vedrtnam [19] studied the wear behavior of Al-SiC-Cu composites. They observed that the wear resistance of the MMCs was improved by increasing wt. % of the reinforcing particulates. Komai and Minoshima [20] examined the tensile strength of Al/Zn/Mg reinforced by SiC produced by a PM (powder metallurgy) method. It is revealed that the strength of the SiC-Al7075 composite was higher compared to unreinforced material. Sourabh Gargatte et al. [21] studied the wear behavior of Al-SiC composites. The SiC particles enhance the hardness of MMCs and also increase the wear resistance. However, from the literature review it can be concluded that adequate data is not available on the tensile strength, hardness properties and wear behavior of Al 7075 MMCs. Therefore, the present research study aims at investigating wear behavior, hardness and tensile strength of the

Al7075+Al_2O_3+SiC hybrid MMCs having various wt. % of particulates. The output results of this research are adequate information about mechanical, wear behavior and fractography of the surface are analyzed through SEM and EDAX analysis and also their results to inspire better and operative application based on the studies.

RAW MATERIALS AND TECHNIQUES

Reinforcements and instruments

Al7075 (bright extruded rod) was purchased from M/s Perfect Metal Works, Bengaluru, Karnataka. Al_2O_3 and SiC were purchased from M/s The Prince Chemical Co. Bengaluru, Karnataka. The casting facility was used from M/s Aluminium Fabrications, Bengaluru. Tensile strength was studied using a UTM machine (load capacity of 400 KN) and a Vickers hardness tester was used to measure the microhardness at M/s Raghavendra Spectro Metallurgical Laboratory, Bengaluru, Karnataka. Tribological tests were evaluated by using pin and disc apparatus at Bangalore Institute of Technology, Bengaluru, India. The Scanning Electron Micrographs (SEM) were studied using Hitachi S-3400 SEM apparatus, Manipal Academy of Higher Education (MAHE), Udupi, Karnataka.

Fabrication technique

Liquid metallurgical technique helps to improve the wettability of the metal matrix composites by avoiding the formation of gaseous and oxide layers on the surface of liquid metal and also avoids agglomeration of the particles in the matrix material. In this technique, the fluidity can be sustained, like cleaning the melt from suspended oxides, reducing the rate of heat transfer by mold material [22]. The composite was reinforced by 3%, 5% and 7% SiC & 2%, 3%, 4% and 5% Al_2O_3 of particle size: 100 meshes with ph value between 6.5 to 7.5 and SiC particulates with mesh size of 220. It was fabricated by a stir-casting method. Al7075 alloy was meltssed by using a coke furnace at 800ºC. The reinforcement (preheated) was mixed with Al alloy. De-gassing tablets were used to eliminate gases from the molten melt. While adding reinforcements, stirring was done at 100 rpm for 5-6 min and later the melt was poured into the preheated mold box. The cast samples were removed from the mold box after the solidification. Cast samples were prepared as test specimens by using the CNC machining process. The chemical composition of Al 7075 and SiC in wt. % is as in Tab. 1 and 2. The Wt. % of Al 7075 and ceramic particulates used for the fabrication of composites is as in Tab. 3. The hybrid composite test samples are depicted in Fig. 1.

Content	Al	Cu	Mg	Si	Fe	Mn	Ni	Pb	Sn	Ti	Zn	Cr
Wt. %	Rem	1.480	2.306	0.059	0.256	0.052	0.052	0.023	0.012	0.052	5.424	0.280

Table 1: The chemical composition of Al 7075 in wt. %.

Content	Si	P	Ca
Wt. %	99.41	0.32	0.26

Table 2: The chemical composition of SiC in wt. %.

Tensile behavior

Tensile testing was performed as per the ASTM standards E8. Tensile tests were performed by subjecting the test specimen to axial or longitudinal load at a particular extension rate of increase of load till failure of the specimen occurred. Test trials were carried out by using UTM with a maximum load of 390-400 KN of capacity.

Hardness

The hardness of composites was studied according to standards E92 using Vickers-micro hardness testing equipment. The diamond indenter of 10 mm under the load condition of 0.5 kg with 15 seconds of duration was applied on the test specimens. Hardness tests were carried out under the room temperature of 27ºC. The hardness of the composite was determined at 3 different places and the average of hardness values was recorded.

Wear behavior

The pin on disc testing equipment was used for measuring the wear loss. The wear tests were performed as per the ASTM standards under the fixed sliding-speed of 1.66 m/s and the constant load of 3 kg against EN-32 steel disc. For testing purposes, the specimens of length, 30 mm and 8 mm ϕ were prepared. The weights of the composite specimens were measured initially by using the digital weighing machine. The specimens were vertically rotated on a hardened steel disc. Wear test was conducted when the specimen surfaces interface with the flat steel disc surface. After each test, specimens were removed from the fixture, and later acetone was used to clean the surface of the specimens. Finally, the wear behavior was studied by considering the initial and final weight difference techniques.

Composite	Al7075 alloy (Wt. %)	SiC (Wt. %)	Al_2O_3 (Wt. %)
Specimen - 1	95	3	2
Specimen - 2	94	3	3
Specimen - 3	93	3	4
Specimen - 4	92	3	5
Specimen - 5	93	5	2
Specimen - 6	92	5	3
Specimen - 7	91	5	4
Specimen - 8	90	5	5
Specimen - 9	91	7	2
Specimen - 10	90	7	3
Specimen - 11	89	7	4
Specimen - 12	88	7	5

Table 3: Weight percentage of Al7075 alloy and ceramic particulates for the developed composites.

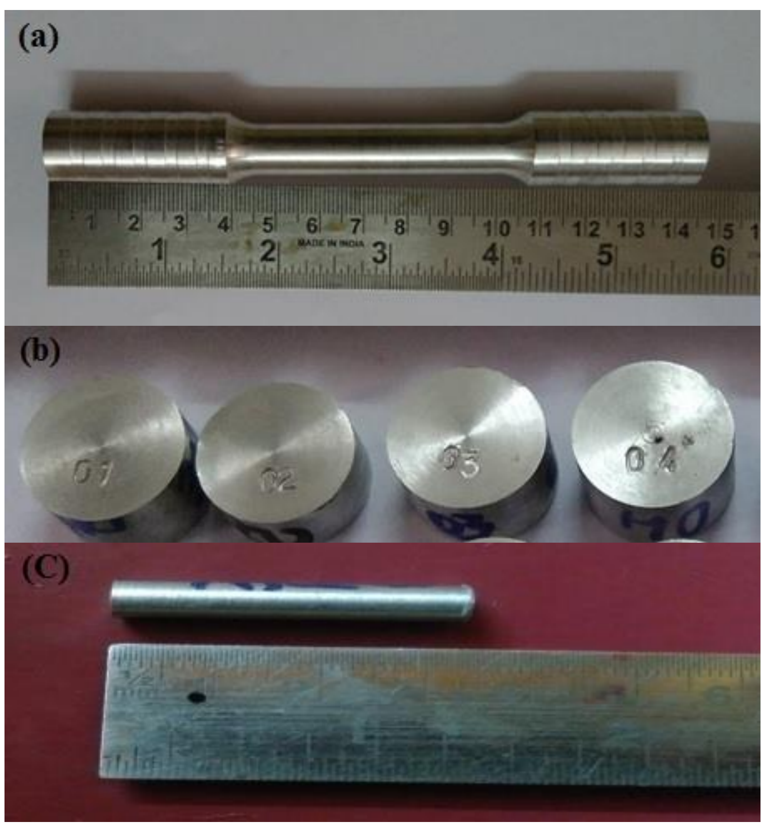
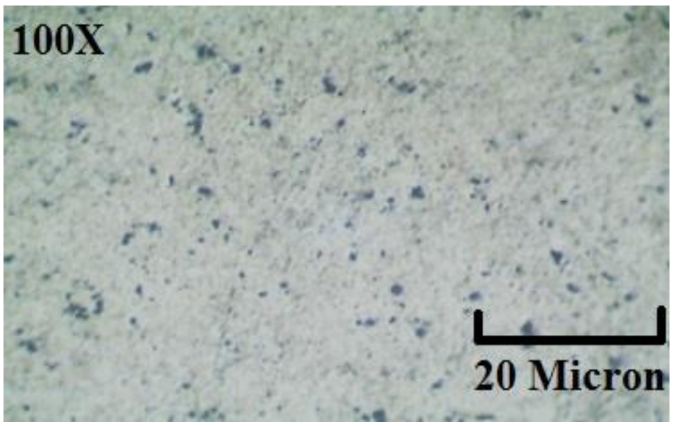


Figure 1: (a) Composite specimen for tensile test (b) Composite specimen for hardness test and (c) Composite specimen for the wear test

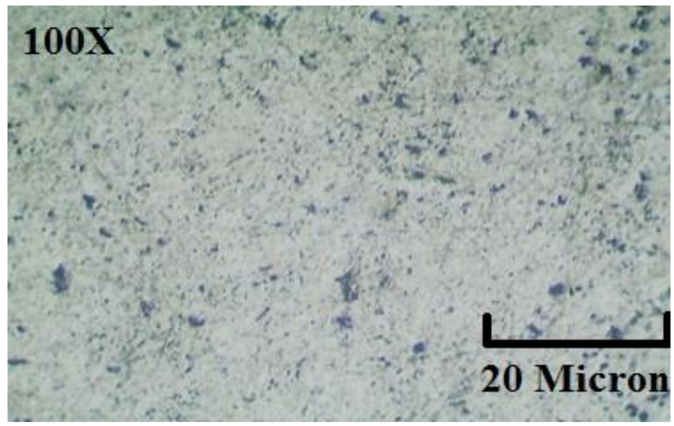
OUTCOMES AND DISCUSSIONS

Metallographic study

The metallographic of fabricated MMCs are depicted in Fig. 2. Fig. 2(a) depicts the micrographic view of base material and Fig. 2(b) depicts the micrographic view of Al_2O_3 and SiC reinforced Al composite. From the metallographic study, uniform dispersal of particulates within the base matrix was observed. The reinforced particulates inhibited the dendritic development, which exhibited improved mechanical properties. Micro-structure of composites showed the interface which specifies superior bonding of Al_2O_3-SiC particulates and base matrix. The uniform distributions of particulates are desired for obtaining enhanced mechanical properties and wear performance. The stirring of molten melt (slurry) affects extreme strain-rate and therefore resulted in uniform dispersal of the reinforcing particulates in melt alloy. As the reinforcement content increased, the decreased grain-size within the matrix was observed. The virtuous dense and cast defect-less microstructure generally produced excellent properties of the material.



(a)



(b)

Figure 2: Microstructure images of composites: (a) 2%Al_2O_3 + 3%SiC (b) 5%Al_2O_3 + 7%SiC

Influence of reinforcements

The influence of hard ceramic particulates (Al_2O_3 and SiCp) on the mechanical behavior of the MMCs obtained from tensile and hardness tests are depicted in Figs. 3 and 6. The UTS with varying Al_2O_3 and SiC is depicted in Fig. 3. The obtained result indicates that the tensile strength is increased by increasing the wt. % of alumina content. It is due to the resistance to dislocations and hence the strength of hybrid composite increased by increasing wt. % Al_2O_3 particulates. This type of observation conforms with the results of most hard particles reinforced in MMCs [23]. Abhishek Kumar et al. [24] studied the mechanical behavior of MMCs reinforced with Al_2O_3 and SiC particulates. They observed that the solidification process of MMCs increased by the amount of reinforcement in the matrix material. It is due to the intricacy in the addition of Al_2O_3 and SiC particulates that creates obstacles to the dislocation of movement through the matrix material. The evaluation of the stress v/s strain graph for the developed composite sample is as shown in Fig. 4. One of the main reasons for the increase in stress is "direct strengthening outcomes from load transfer of matrix to reinforcement through shear stresses at an interface among the components". From Fig. 3 it is observed that composite with 5% Al_2O_3 and 7% SiC possesses better tensile strength as compared with other composition specimens. The combination of hard ceramic particulates (Al_2O_3 and SiC) makes the composite stronger so that it can withstand higher loads. From the graphical representation of the stress-strain curve depicted in Fig. 4, it is also revealed that composite with 5% Al_2O_3 and 7% SiC withstands maximum stress. The stress-strain curve indicates the improved toughness apart from high tensile strength. This is significant. Meanwhile, most strength improvement methods cause decreasing ductility.

The fracture surface of composites test specimens is as depicted in Fig. 5. From Fig it is found that the fracture is mainly dimple rupture. Generally, this is normally due to the overload failure and failure by merging of micro-voids process. From the composite (2% Al_2O_3 + 3% SiC) it is observed that, the size of dimples has reduced noticeably. Fine dimples in the matrix region are present among the particulates. The numerous cuplike dimples are also observed in fractured image of 5% Al_2O_3 + 7% SiC composite material. Formation and coalescence of micro-voids resulted in the dimples at localized strain regions (grain boundaries). Fracture image of 5% Al_2O_3 + 7% SiC composite material shows that the number of dimples observed is more and in smaller sizes indicating the development of micro-voids. It specifies good bonding among the matrix and the reinforcements. Generally, the grain size and shape of reinforcing particulates determine the bonding ability. Generally, the dimple size shows the directly proportional relationship with composite strength. A fracture surface of tensile test specimens indicates the combination of hard ceramic particulates at the interface. A combination of particulates fracture and pullout was stated to be a fracture mechanism. The mode of fracture in the matrix alloy which has changed from ductile to cleavage nature was dominated by voids and micro-crack nucleation and propagation, as depicted in Fig. 5. The fracture analysis of MMCs showed that, at higher wt. % of reinforcement content, nucleation of void took place at huge participates also of reinforcement into the matrix material whereas at lower wt. % of reinforcement, the fracture indicates the breakage of the particulates.

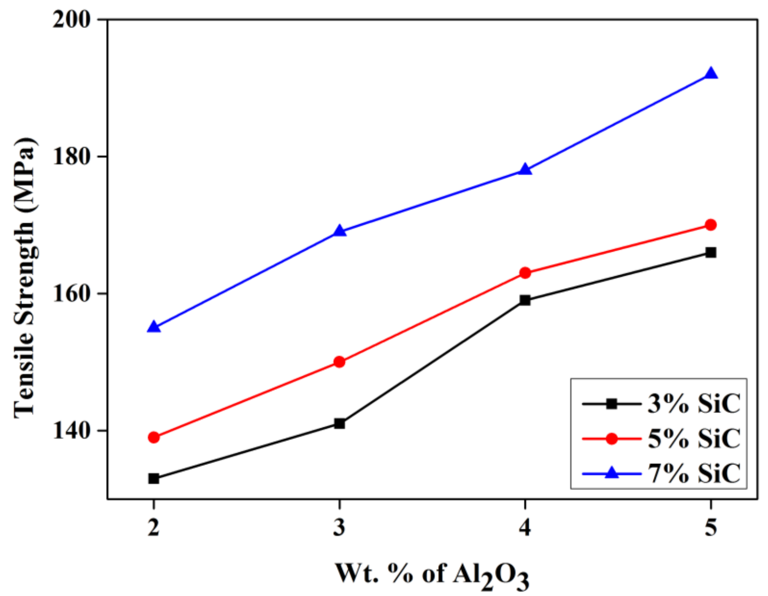


Figure 3: Tensile strength with varying contents of Al_2O_3 and SiC.

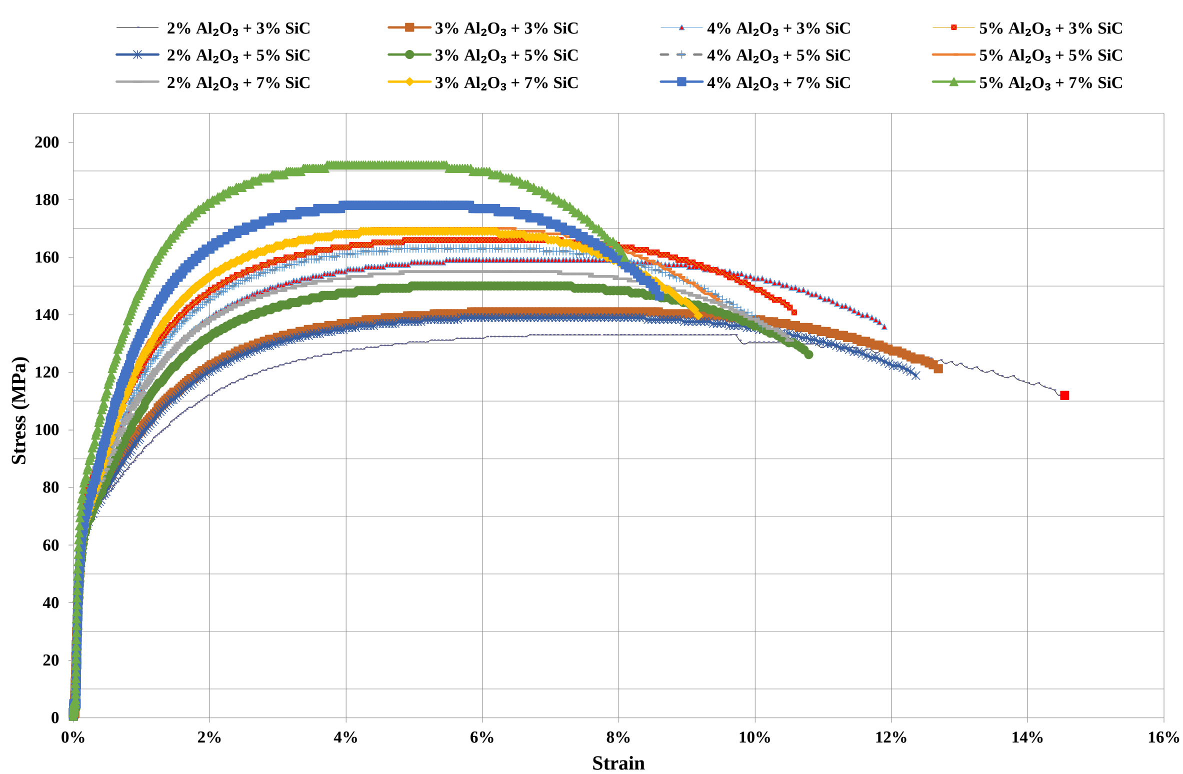


Figure 4: Stress-strain curve for all the composition.

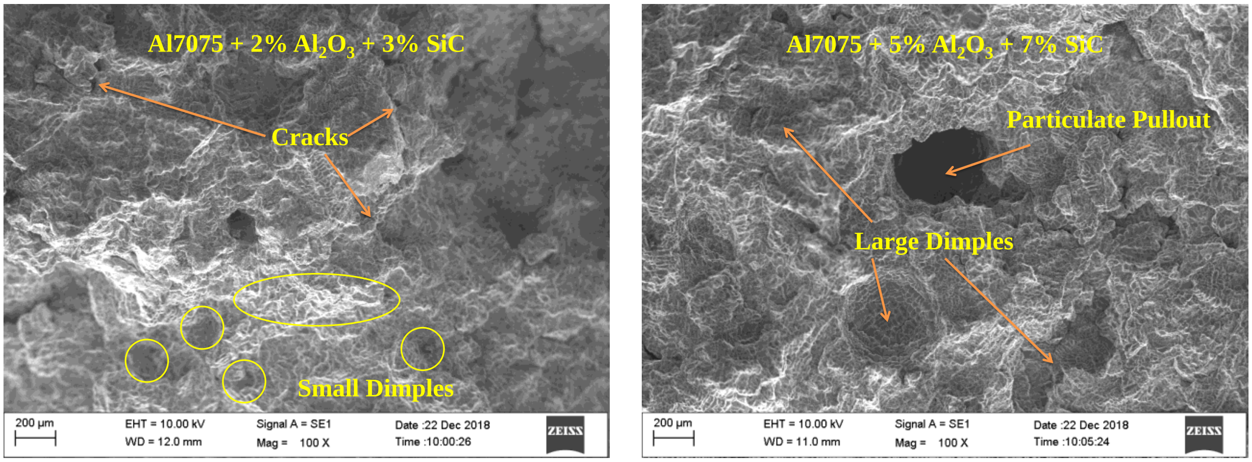


Figure 5: Fracture images of the tensile specimen with different compositions .

The variation of hardness with varying Al_2O_3 and SiC is as depicted in Fig. 6. The hardness of the composite increased due to the addition of Al_2O_3 and SiC particulates. The improvement in the results is occurred due to the reinforcement of hard ceramics, which act as obstacles in the movement of dislocations [25]. The increased hardness of the MMCs can also be clarified based on dislodgment densities. By increasing the SiC content in the matrix, the dislodgment density of MMCs increased which resisted the plastic deformation during sliding [26].

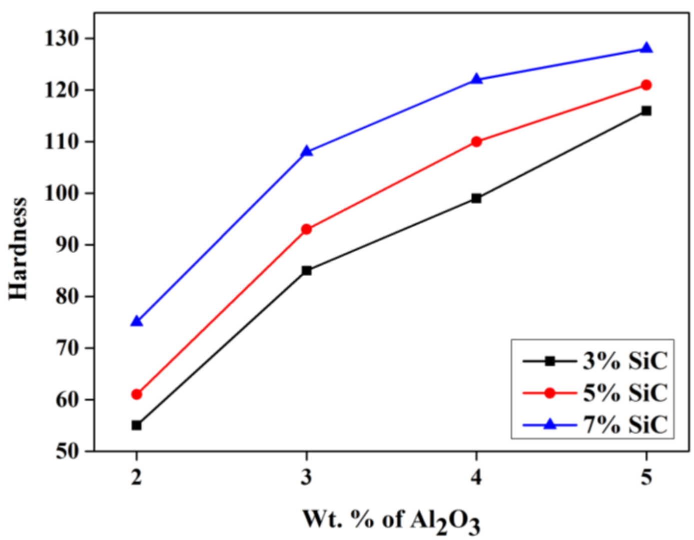


Figure 6: Vickers hardness of varying contents of Al_2O_3 and SiC.

It was observed that the hardness value is maximum at 5 % Al_2O_3 + 7 % SiC reinforced MMCs. In many earlier research works on ceramic reinforced MMCs, it has been shown that there is an optimum range of reinforcement's percentage for which the mechanical characteristics show maximum values. The piling up of the huge number of dislocations at the interface of particulates and matrix during the solidification because of the low coefficient of thermal expansion in SiC - Al_2O_3 when compared with base alloy is the main reason for attaining better hardness in composites [27]. The hardness increased with increasing Al_2O_3 and SiC particulates and the maximum hardness was found at 5 % of Al_2O_3 and 7 wt. % of SiC reinforced composite. Optimum values of UTS and Vickers hardness for the composite were obtained at 5 % of Al_2O_3 + 7 wt. % of SiC reinforced composite. As the number of particulates in the matrix increased, the corresponding matrix/particle interfacial areas also increased. It is observed that the ceramic particulates increase the mechanical properties of the MMCs. Hence it is evident that tensile strength and hardness of Al composite increased by adding of Al_2O_3-SiC particulates [28].

Wear behavior of the MMCs

Wear loss of the MMCs (Al7075/Al_2O_3/SiC) is depicted in Fig. 7. The wear loss of hybrid composite decreased due to the addition of Al_2O_3 and SiC. From the results it is observed that high wear resistance was exhibited in 5 wt. % Al_2O_3 - 7 wt. % SiC reinforced hybrid composite. It is noticed that, the wear resistance of the MMCs would increase by increasing the wt. % of hard ceramic particulates [29, 30]. When the Al_2O_3 particulates are intensely (strongly) bonded with the Al matrix, they protect the composite surfaces against the destructive action of the counter face which results in less wear. The matrix and reinforcement particles interface is an extremely imperative constraint. Meanwhile, inter-faces might be discreetly weak due to the interfacial reactions as well as poor wettability. Better bonding among reinforcing particulates and the matrix increases the wear resistance of MMCs continuously due to an increase in the wt. % of reinforcements. In the case of Al composites, the depth of dispersal by hard asperities of hard steel disc is generally directed by the protruding the hard ceramic reinforcements. The major part of the load applied is carried by SiC particulates. The effect of reinforcing particulates is to withstand the contact-stresses and prevent high plastic deformation thereby reducing the amount of material worn out [26]. Observation revealed that the Al_2O_3 and SiCp-reinforced MMCs increased the hardness and thus increased the wear resistance. Similar outcomes have also been observed in the literature survey [15]. The wear loss of 2% Al_2O_3 + 3% SiC reinforced MMCs were higher than 5% Al_2O_3 + 7% SiC reinforced MMCs. This is due to the variation in the reinforcement properties. Whereas the toughness of Al_2O_3 is less than that of SiCp and as a result of this fragmentation of Al_2O_3 particulates occurred at an earlier phase than SiCp, resulting in an improved in wear characteristics of Al_2O_3 reinforced MMCs [27].

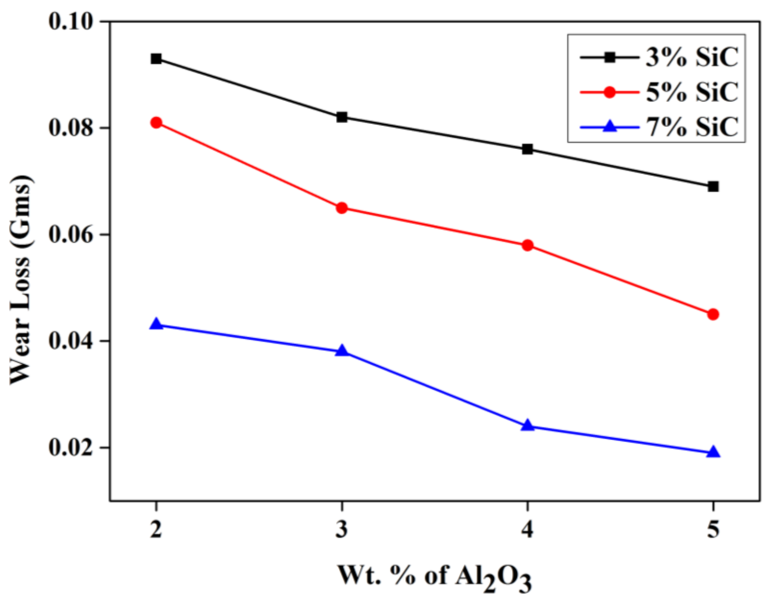


Figure 7: Wear rate of varying contents of Al_2O_3 and SiC

Morphological analysis

A uniform dispersal of Al_2O_3 and SiC particulates in the MMCs has been detected. The uniform dispersal of the particles in the base alloy is essential to produce MMCs with better wear resistance and mechanical characteristics. The results reveal that the agglomeration of particulates was small. The worn surfaces of the composites led to the development of iron-rich layers [31]. Scanning electron microscopy was done on composite samples as shown in Fig. 8 and 9 which depicted the uniform distribution of reinforcements. Here (Fig. 9), Al_2O_3 particles are seen as white (whitish phases) as well as SiC particles are been observed in dark (black) phases within the base matrix structure. Surface damages like detachments and de-cohesion of the material were also observed. The formation of grooves was noticeable in the path of sliding. Fig. 9 shows the worn-out surfaces of Al7075 with 5 % of Al_2O_3 + 7 % SiC reinforced MMCs. The plastic deformation was resisted in the base matrix due to the existence of hard ceramic particulates. Grooves and minor patches are also noticed. Due to the load applied, Al_2O_3 and SiC caused wrapping on the surface. These ceramic particulates acted like wrapping material on sliding surfaces and offered wear resistance. In the present investigation, Al_2O_3-SiC particulates were exposed to have valuable properties of the wear behavior of MMCs. Al_2O_3-SiC particles avoided the penetration of steel disc into the MMCs and enhance the wear resistance. The Al_2O_3-SiC particulates may get crushed to powder form to maintain the wear resistance as detected in the results of wear rate [32, 33]. Similar results have been noticed [5] and it is concluded that, from the analysis it is seen that, the SEM analysis of worn-out surfaces of the MMCs (Al7075 + 2%Al_2O_3 + 3%SiC) is different from that of Al7075 + 5%Al_2O_3 + 7%SiC composite.

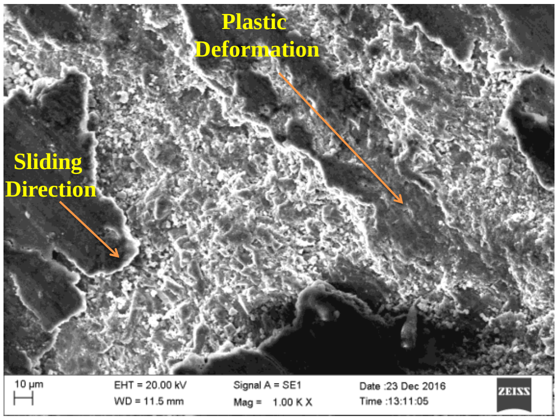


Figure 8: SEM analysis of wornout surface composite sample (Al 7075 + 2% Al_2O_3 + 3% SiC)

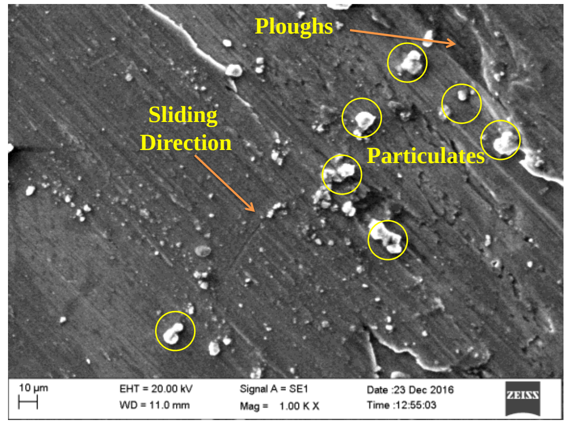


Figure 9: SEM analysis of wornout surface composite sample (Al 7075 + 5% Al_2O_3 + 7% SiC)

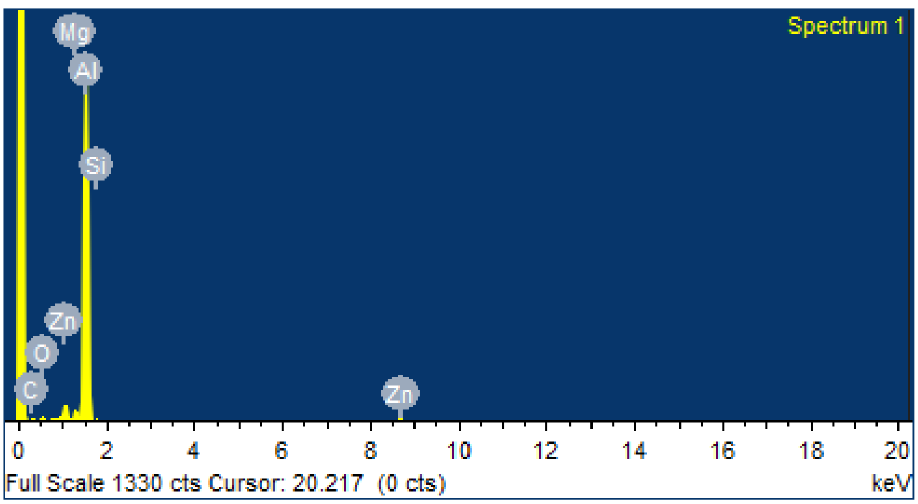


Figure 10: EDS spectrum of composite specimen (Al + 5% Al_2O_3 + 7% SiC).

The composite with 2% Al_2O_3 + 3% SiC showed wide and also narrow grooves on the worn-out surfaces. Whereas, fine grooves were observed in MMCs of 5% Al_2O_3 + 7% SiC. This remark supports the lower wear loss of MMCs. Fig. 8 shows the material removed in the form of intensive plastic flow. It is witnessed that, the MMCs have been subjected to severe plastic deformation. Though, the extent of the plastic deformation in 5%Al_2O_3 + 7%SiC composites seems to be less when compared to that of 2%Al_2O_3 + 3%SiC reinforced composite. Further, it is noticed that the size of the grooves is high in 2%Al_2O_3 + 3%SiC reinforced composite, but no such morphologies are observed in 5%Al_2O_3 + 7%SiC reinforced composite, which shows the improved ability of MMCs to endure applied load during wear test. The EDS (Energy Dispersive Spectroscopy) analysis of Al-Al_2O_3-SiC particles is depicted in Fig. 10. The results reveal the existence of Mg, Al, Si, Zn, O and C in the interface layer. The small volume of oxygen was noticed in EDS due to the development of the oxide layer [34]. From the results, it is inferred that oxygen (O) noticed in EDS is probably due to the presence of oxide (Al_2O_3) during sample preparation. Also, the presence of a "Si" peak was observed. This indicates that the presence of SiC particulates in the composite. The peaks are shown in Fig. 10, the EDS configurations are indexed to a combination of different elements and other small peaks attributed to the impurity [27, 35, 36].

Conclusions

In the present investigation, the Al 7075-Al_2O_3-SiCp hybrid MMCs were effectively produced using the liquid metallurgical technique. The effect of Al_2O_3-SiC reinforcement on mechanical properties and wear characteristics were studied and the outcome of the results is as follows:

- The UTS of the hybrid metal matrix composite was enhanced due to increasing of 5% of Al_2O_3 and 7% of SiC content.
- The fractographic studies show that the changes in the mode of failure occurred from ductile to brittle due to an increase in the wt. % of hard ceramic particulates such as Al_2O_3 & SiC content.
- Maximum hardness of the produced composites was obtained at 5% of Al_2O_3 and 7% of SiC content.
- The wear loss of the hybrid metal matrix composite decreased drastically with an increase in the content of Al_2O_3 and SiC particulates.
- The SEM images reveal that, the plastic deformation is resisted in the matrix due to the existence of hard ceramic particulates which acted as a barrier within the movement of dislocation, resulting in improved wear resistance.
- EDS spectrum indicates the existence of elements like Al, Mg, Si, Fe, and O.

References

[1] Nikhilesh, S., Belokar. R. M. and Walia, R. S. (2020). A critical review on advanced reinforcements and base materials on hybrid metal matrix composites. Silicon, DOI: 10.1007/s12633-020-00853-z.

[2] Dharmalingam, S. and Subramanian, R. (2010). Analysis of dry sliding friction and wear behavior of aluminum alumina composites using taguchi's techniques. Journal of Composite Materials, pp. 1-17.

[3] Mulugundam, S. S. and Gugulothu, S. K. (2021). Fabrication, mechanical and wear characterization of silicon carbide reinforced aluminium 7075 metal matrix composite. Silicon, DOI: 10.1007/s12633-021-00992-x.

[4] William, C. and Harrigan. (1998). Commercial processing of metal matrix composites. Materials Science and Engineering. A244, pp. 75-79.

[5] Ramesh, C. S., Keshavamurthy, R., Channabasappa, B. H. and Pramod, S. (2010). Friction and wear behavior of Ni–P coated Si_3N_4 reinforced Al6061composites. Tribology International, 43, pp. 623-634.

[6] Deuis, R. L., Subramanian, C. and Yellup, J. M. (1997). Dry sliding wear of aluminium composites-a review. Composites Science and Technology, 57, pp. 415-435.

[7] Sannino, A. P. and Rack, H. J. (1995). Dry sliding wear of discontinuously reinforced aluminum composites: review and discussion. Wear, 189, pp. 1-19.

[8] Dorward, R. C. and Pritchett, T. R. (1988). Advanced aluminium alloys for aircraft and aerospace applications. Materials & Design, 9, pp. 63-69.

[9] Chellman, D. J. and Langebeck, S. L. (1992). Aerospace application of advanced aluminum alloys. Key Engineering Materials, 77, pp. 49-60.

[10] Reddy, P. V., Kumar, G. S., Krishnudu, D. M. and Rao, H. R. (2020). Mechanical and wear performances of aluminium-based metal matrix composites: a review. Journal of Bio-and Tribo- Corrosion, 6(83), pp. 2-16.

[11] Veeresh Kumar, G. B., Rao, C. S. P., Selvaraj, N. and Bhagyashekar, M. S. (2010). Studies on Al6061-SiC and Al7075-Al_2O_3 metal matrix composites. Journal of Minerals & Materials Characterization & Engineering, 9, pp. 43-55.

[12] Straffelini, G., Bonollo, F., Molinari, A. and Tiziani, A. (1997.) Influence of matrix hardness on the dry sliding behaviour of 20 vol. % Al_2O_3-particulate-reinforced 6061 Al metal matrix composite. Wear, 211, pp. 192-197.

[13] Radhika, N., Subramanian, R. Venkat Prasat, S. (2011). Tribological behaviour of aluminium/alumina/graphite hybrid metal matrix composite using taguchi's techniques. Journal of Minerals & Materials Characterization & Engineering, 10, pp. 427-443.

[14] Alaneme, K. K. and Bodunrin, M. O. (2013). Mechanical behaviour of alumina reinforced AA (6063) metal matrix composites developed by two - step stir casting process. Acta Technica Corviniensis – Bulletin of Engineering, 4, pp. 105-110.

[15] Kok, M. (2005). Production and mechanical properties of Al_2O_3 particle-reinforced 2024 aluminium alloy composites. Journal of Materials Processing Technology, 161, pp. 381-387.

[16] Mahdavi, S. and Akhlaghi, F. (2011). Effect of the graphite content on the tribological behavior of Al/Gr and Al/30SiC/Gr composites processed by in situ powder metallurgy (IPM) method. Tribol Lett, 44, pp. 1-12.
[17] Prashant, S. N., Madev Nagaral. and Auradi, V. (2012). Preparation and evaluation of mechanical and wear properties of Al6061 reinforced with graphite and SiC particulate metal matrix composites. Int. J. Mech. Eng. & Rob. Res, 1, pp. 106-112.
[18] Sharma, S. C., Girish, B. M., Rathnakar Kamath. and Satish, B. M. (1997). Effect of SiC particle reinforcement on the unlubricated sliding wear behaviour of ZA-27 alloy composites. Wear, 213, pp. 33-40.
[19] Ajitanshu Vedrtnama. And Anuj Kumara. (2017). Fabrication and wear characterization of silicon carbide and copper reinforced aluminium matrix composite. Materials Discovery, 9, pp. 16-22.
[20] Komai, K, and Minoshima, K. (1993). Tensile and fatigue fracture behavior and water-environment effects in a SiC-whisker/7075-aluminum composite. Composites Science and Technology, 46, pp. 59-66.
[21] Sourabh, G., Rahul, R. U., Venkatesh, S. D., Srikanth, R. D. and Bhimappa, S. W. (2013). Preparation & characterization of Al-5083 alloy composites. Journal of Minerals and Materials Characterization and Engineering, 1, pp. 8-14.
[22] Sakthivelu, S., Sethusundaram, P. P., Ravichandran, M. and Meignanamoorthy, M. (2020). Experimental investigation and analysis of properties and dry sliding wear behavior of Al-Fe-Si alloy matrix composites. Silicon DOI: 10.1007/s12633-020-00662-4.
[23] Shaik, M. Q., Murthy, B. S. and Pinninti, R. R. (2016). Processing and mechanical properties of Al_2O_3 and red mud particle reinforced AA6061 hybrid composites. Journal of Minerals and Materials Characterization and Engineering, 4, pp. 135-142.
[24] Abhishek Kumar., Shyam, L. and Sudhir Kumar. (2013). Fabrication and characterization of A359/Al_2O_3 metal matrix composite using electromagnetic stir casting method. Journal of Material Research and Technology, 2, pp. 250-254.
[25] Mehdi, R., Nader, P. and Naser, E. (2010). Investigation of particle size and amount of alumina on microstructure and mechanical properties of Al matrix composite made by powder metallurgy. Materials Science and Engineering, A527, pp. 1031-1038.
[26] Padmavathi, K. R., Ramakrishnan, R. and Palanikumar, K. (2019). Wear properties of SiCp and TiO_2p reinforced aluminium metal matrix composites. Indian Journal of Engineering & Materials Science, 26, pp. 51-58.
[27] Yogesh, K. S., Rahul, C., Hitesh, B. and Anil, K. (2015). Wear behavior of aluminum alloy 6061-based composites reinforced with SiC, Al_2O_3 and red mud: a comparative study. The Journal of the Minerals, Metals & Materials Society, 67, 2160-2169.
[28] Pitchayyapillai, G., Seenikannan, P., Raja, K. and Chandrasekaran, K. (2016). Al6061 hybrid metal matrix composite reinforced with alumina and molybdenum disulphide. Advances in Materials Science and Engineering, pp. 1-9.
[29] Majid, H. and Mahmood, M. (2005). Tensile properties of in-situ aluminium-alumina composites. Materials Letters, 59, pp. 3414-3418.
[30] Karamıs, M. B., Cerit, A. A., Burhan, S. and Fehmi, N. (2012). The effects of different ceramics size and volume fraction on wear behavior of Al matrix composites (for automobile cam material). Wear, 289, pp. 73-81.
[31] Rajesh, A. M., Mohamed, K., Saleemsab, D. and Bharath, K. N. (2019). Material characterization of SiC and Al_2O_3-reinforced hybrid aluminum metal matrix composites on wear behavior. Advanced Composites Letters, 28, pp. 1-10.
[32] Altinkok, N., Ozsert, I. and Findik, F. (2013). Dry sliding wear behavior of Al_2O_3/SiC particle reinforced aluminium based MMCs fabricated by stir casting method. Acta Physica Polonica, A124, pp. 11-19.
[33] Sekar, K. (2019). Mechanical and tribological properties of Al7475-SiCp composites by stir casting method and wear rate modeling using RSM. Sadhana, 44:129, pp. 1-8.
[34] Shorowordi, K. M., Laoui, T., Haseeb., Celis, J. P. and Froyen, L. (2003). Microstructure and interface characteristics of B_4C, SiC and Al_2O_3 reinforced Al matrix composites: a comparative study. Journal of Materials Processing Technology, 142, pp. 738-743.
[35] Ravikumar, M., Reddappa, H. N. and Suresh, R. (2018). Study on mechanical and tribological characterization of Al_2O_3/SiCp reinforced aluminum metal matrix composite. Silicon, 10(6), pp. 2535-2545 DOI: 10.1007/s12633-018-9788-1.
[36] AshokKumar, R and Devaraju, A. (2020). Modeling of mechanical properties and high temperature wear Behavior of Al7075/SiC/CRS composite using RSM. Silicon, DOI: 10.1007/s12633-020-00801-x.