Visual Abstract

Analysis of the influence of reinforcements on the microstructure and mechanical characterization of the Al-Flyash composites

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ABSTRACT. The aim of this work is to investigate the influence of the addition of silicon carbide and molybdenum disulfide on the microstructure and the tensile strength of the Al-Flyash hybrid composites prepared using the stir casting technique. The composite with aluminum 6061 alloy as the matrix and flyash as the reinforcement, with different weight fractions, is investigated to study its microstructure and the tensile strength. The same has been compared with the hybrid composites with Aluminum-Flyash/SiC and Aluminum-Flyash/MoS_2 for different weight fractions of the reinforcements. The tensile tests were conducted as per ASTM standard testing procedures at room temperature. From the results it is identified that tensile strength of the Al6061-Flyash composite is lesser than the Al6061-Flyash/SiC and Al6061-Flyash/MoS_2 hybrid composites. It is also observed that increment in the composition of the SiC and MoS_2 causes the increment in the tensile strength of the hybrid composite. This increment in the tensile strength is due to good interface bonding and uniform distribution of the reinforcements in the composite.

KEYWORDS. Flyash; Tensile strength; Molybdenum disulfide; Silicon carbide; Microstructure.

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INTRODUCTION

Materials selected so far are particulate reinforced metal matrix composites (MMCs) which have the advantage that they are nearly isotropic [1]. Silicon carbide, Al_2O_3, boron carbide (B_4C), and graphite are common reinforcements for aluminum matrices. However, the flyash as reinforcement in the aluminum matrix has the wide range of scope in area of mechanical behavior [2-3] of the composites. Aluminum matrix with flyash particulate reinforced composite has also a lower density than aluminum which leads to weight reductions in the areas of aerospace and automobiles. However the increment in the flyash leads to decrement in the strength of the aluminum composite. Thus it is recommended to use the hybrid aluminum metal matrix composites such that the other reinforcements gives the better strength to the composites.

Many authors prepared the metal matrix composites using stir casting route [4-5] however the stir casting route is also utilized to prepare the hybrid MMCs [6-9]. Since, stir casting method was considered to be of low cost and effective method and also gives the uniform distribution of the reinforcement even at higher weight percentages.
Mechanical properties, tensile fracture behavior of aluminum matrix composites with Graphite [10-11], Fly ash [12] etc was studied by the different authors and many authors made an attempt to compare the obtained results with the unreinforced aluminum alloy. Some authors studied the aluminum matrix composites with single reinforcement [10-12] and concluded that the required results were not obtained. E. Gikunoo et al [12] studied the Al-Fly ash composites and found that the density of the composite decreases thus the weight reduction is possible however the tensile strength of the composite decreases. Thus, many researchers concentrating on the research in the field of hybrid metal matrix composites [13-14]. To keep the reduced weight of the composite one reinforcement used such as flyash [15-18], rice husk ash [19] and to increases the strength of the composites second reinforcement such as graphite [15-17], silicon carbide [18-19] has been utilized. The main idea to utilize the graphite in the metal matrix composites is to gain the reduced co-efficient of friction of the composites. Since the graphite act as the self lubricant material, the wear rate of the composite has been reduced.
Researchers [20-23] utilized the molybdenum disulfide (MoS_2) as the reinforcement in aluminum matrix composites. However, adding of MoS_2 more than 5wt% in the aluminum matrix decreases tensile as well as wear properties of the composites [22-23]. Thus the hybrid metal matrix composites were utilized in order to increases the tensile strength using the silicon carbide and reduce the wear rate using the self lubricants such as graphite [24-25] and MoS_2 [26-30]. Researchers also compared the Al-SiC MMCs with hybrid Al-SiC/MoS_2 MMCs and recommended that hybrid MMCs have better mechanical properties in contrast with the single reinforced MMCs.
It is identified from the literature that more research work has been done on the mechanical behavior of aluminum matrix reinforced with silicon carbide or graphite [31-32], TiB_2 [33] particulate and laminated [34], polymer [35] composites. On the other hand it is also observed that the systematic evaluation of mechanical behavior of hybrid aluminum matrix composites has to carry out. In this background, there is a scope for the study the mechanical characterization of hybrid aluminum composite with fly ash as reinforcement. Through this investigation, an attempt has been made to investigate effect of addition of the SiC and MoS_2 separately on the microstructure of the Al6061-Flyash hybrid composites. Through the material characterization an attempt has been made to compare the Al6061-fly ash composite with Al6061-FA/SiC and Al6061-FA/MoS_2 hybrid composite.

METHODOLOGY

The methodology adopted in this work is mentioned below:
(1) The stir casting method will be used to prepare the aluminum matrix composites for the various compositions of the reinforcement/s. The compositions considered in this work are *Composite A* - Al6061-Fly ash for 4, 8, 12, 16, and 20wt.% of the reinforcement; *Composite B* - Al6061-FA/SiC composite for the 2, 4, 6, 8, and 10wt.% of flyash, and 1, 2, 3, 4 and 5wt.% of SiC; and *Composite C* - Al6061-FA/MoS_2 composite for the 2, 4, 6, 8 and 10wt% of flyash and 1, 2, 3, 4 and 5wt% of MoS_2.
(2) The energy-dispersive x-ray spectroscopy (EDX) experimental setup, shown in Fig.1(a), will be utilized to determine the presence of reinforcing elements in the composites. The scanning electron microscope (SEM) analysis will be used to analyze the microstructure of the composites. These analysis techniques will be utilized to study the microstructure of the said composites due to the availability, low cost, ease to examine and analyze, etc.
(3) For all the compositions of Composite A, Composite B and Composite C, hardness, tensile test specimens will be prepared as per the ASTM standard testing procedure.
(4) To analyze the failure of the composites, the fractography examination will be carried out using SEM.

MATERIAL AND PREPARATION

The materials chosen in this work are aluminum alloy 6061 as matrix material, particles of flyash, and silicon carbide/molybdenum disulfide as reinforcements. The motivation to use fly ash as the reinforcement is to gain the advantage of its weight reduction properties. The use of SiC gives the increased hardness, tensile, impact strength, etc. The addition of MoS_2 gives better wear resistance properties to the aluminum composite.
It is identified that the addition of the flyash reinforcement to the aluminum decreases the density of the composites [12-16]. Thus this can be utilized in applications in automobile industries where it requires weight reduction properties. On

the other hand, the increment in the weight percentage of flyash increases the hardness and strength of the composites whereas there is a decrement in the same has been observed after 10wt% of the fly ash reinforcement. Hence in the present investigation, the weight percentage of the flyash is considered are 2, 4, 6, 8, and 10wt%.

From the literature, it is also observed that the addition of a higher percentage of SiC in the aluminum matrix has not given significant hardness and tensile properties and also increases the weight of the composite. Whereas the lower weight fractions of the SiC will give the better properties of the composites. Also at a low weight fraction of SiC will give the increased hardness, lower density, reduced weight, increased strength of the composites. Hence in the present investigation, the weight percentage of the SiC is considered to be 1, 2, 3, 4, and 5wt%.

Molybdenum disulfide is silver black in appearance, occurs as molybdenite. MoS_2 is unreactive and unaffected by dilute acids. It is similar to graphite in appearance, and also it is used as a solid lubricant as it has a low coefficient of friction. It is also reported in the literature that the density of the MoS_2 is 5.06 g/cc. Thus the addition of the higher weight fractions of the MoS_2 increases the weight of the composites as well as the tensile strength also decreases [22]. Hence in the present investigation, the weight percentage of the MoS_2 is considered to be 1, 2, 3, 4, and 5wt%.

From the literature [13] it is identified that flyash has higher silicon oxide. Thus it gives better properties when mixed with aluminum. In the present work, the flyash is used as main reinforcement with 2, 4, 6, 8, and 10wt% with silicon carbide/MoS_2 as additional reinforcements 1, 2, 3, 4, and 5wt% in the aluminum hybrid MMCs.

Most of the researchers [4-9] utilized stir casting method in the fabrication of particulate hybrid MMCs. Tab. 1 shows the various configurations of materials and the casting parameters used to prepare the composites.

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Sl no	Al6061	Flyash	SiC	MoS_2	Composite	Temperature	Stirring speed
1	96, 92, 88, 84 and 80%	4, 8, 12, 16 and 20wt%	-	-	Al6061-FA	720°C	500rpm
2	97, 94, 91, 88 and 85%	2, 4, 6, 8 and 10wt%	1, 2, 3, 4 and 5wt%	-	Al6061-FA/SiC	720°C	500rpm
3	97, 94, 91, 88 and 85%	2, 4, 6, 8 and 10wt%	-	1, 2, 3, 4 and 5wt%	Al6061-FA/MoS_2	720°C	500rpm

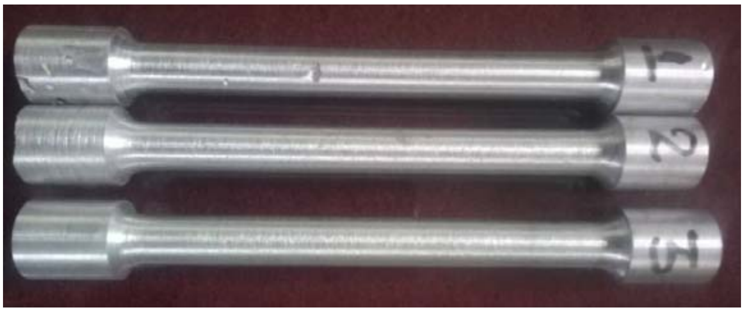
Table 1: Material compositions and the processing parameters

The Al6061 is super heated to the temperature 720°C in a graphite crucible. While stirring, with four blade stirrer, at 500rpm the reinforcements such as flyash and SiC particles were added to the molten aluminum. Since the Al6061 in liquid state is very reactive to oxygen, thus stirring is done in the closed chamber with nitrogen gas. The degasifier and flux has been added to remove the gases from the liquid melt (if any) and magnesium is added to increase the wettablitiy of flyash particles. The liquid melt is poured to the graphite mold and allowed to solidify. The Al6061-FA/SiC composite bars taken from the mold were machined to prepare the testing specimens (EDX, SEM, hardness, tensile test specimens). The similar casting experimentation is repeated to prepare the composite A and Composite C for the said compositions.

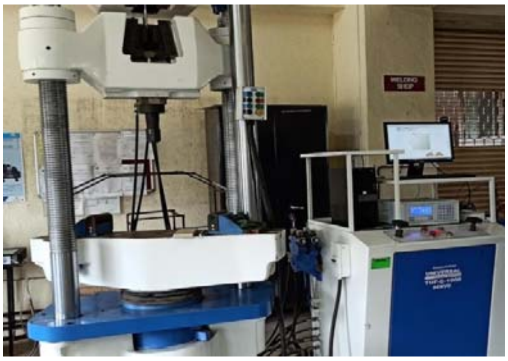
EXPERIMENTATION

In this experimental work on Al6061-Fly ash, Al6061-Fly ash/SiC, and Al6061-Fly ash/MoS_2 particulate composite, for various weight percentages of reinforcement/s. These composites produced using the stir casting technique to determine the mechanical properties such as hardness, tensile strength.For all the combinations, i.e. Composite A, Composite B, and Composite C,specimens are prepared to examine the material properties. Fig.1(b) shows the experimental setup for tensile testing whereas Fig.1(c-d) shows the tensile test specimens of Al6061-Flyash composites before and after a fracture.

(a): EDX and SEM experimental setup



(c): Before test



(b): Tensile testing experimental setup

(d): After test

Figure 1 (a): EDX and SEM setup, (b) Tensile testing setup, (c-d): Tensile test specimens Al6061-Flyash composites.

RESULTS AND DISCUSSION

EDX Analysis

To confirm the formation of Al6061-FA, Al6061-FA/SiC, and Al6061-FA/MoS2 composites, EDX analysis was performed. The existence of these composites generally influences the mechanical properties of Al6061-FA hybrid composites. To confirm the formulation of the Aluminium-flyash composites the analysis of different areas was focused, corresponding peaks, and results are shown in Fig.2(a-c). The microstructure of the composite demonstrates the uniform distribution of flyash content in the aluminum matrix.

Fig.2(a) shows the EDX analysis of the Al6061-flyash composite with 8wt% of the reinforcement. The table inside the figure shows the elements present in it. The presence of aluminum is common whereas the presence of Si and Mg shows that, the aluminum used is Al6061 alloy. The elements Fe and O indicate the presence of the flyash reinforcement. The main constituents in the flyash are SiO_2, Al_2O_3, and Fe_2O_3, it also has a little quantity of MgO. However the Si and Mg in the Al6061 alloys were 0.6 to 0.8%, and the increased percentage of those elements shows the addition of flyash in the composite.

Fig.2(b) shows the EDX analysis of the Al6061-flyash with SiC as the additional reinforcement in the hybrid composite with 8wt% of the reinforcement. The table inside the figure shows the elements present in it. The presence of the percentage of Al, Si, and Mg shows that the aluminum used is Al6061 alloy. The elements Fe and O indicate the presence of the flyash reinforcement and the increased percentage of the Si is obtained from the addition of the SiC reinforcement. Element C shows the presence of carbide obtained from the SiC which gives the strength to the said composite.

Fig.2(c) shows the EDX analysis of the Al6061-flyash with MoS_2 as the additional reinforcement in the hybrid composite with 8wt% of the reinforcement. The table inside the figure shows the elements present in it. The presence of the percentage of Al, Si, and Mg shows that the aluminum used is Al6061 alloy. The elements Fe and O indicate the presence of the flyash reinforcement and the increased percentage of the Si is obtained from the addition of the flyash reinforcement. The element Mo and S show the presence of reinforcement MoS_2. However, the presence of sulfide is not obtained from the EDX profile, because in the hot condition the MoS_2 reacts with oxygen and forms the molybdenum trioxide and sulfur oxide. The presence of molybdenum gives the increased ductility, density and provides a little increment in the hardness.

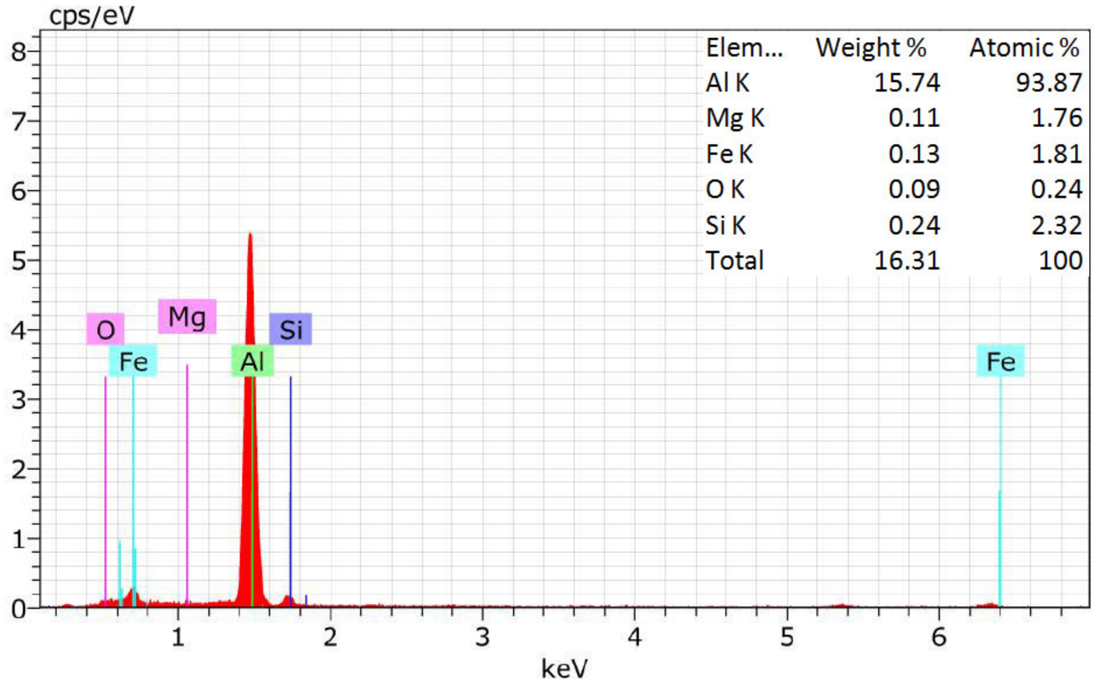


Figure 2(a): EDX spectrum of the Al6061-8wt%Flyash

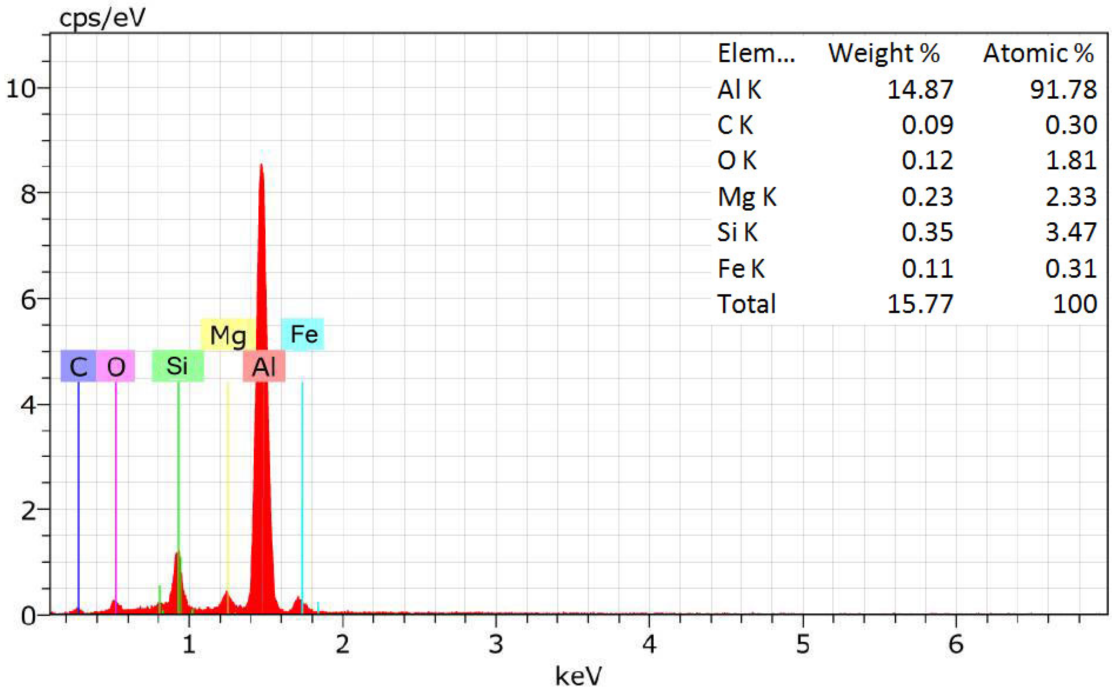


Figure 2(b): EDX spectrum of the Al6061-6wt%FA/ 3wt%SiC composite.

From the EDX spectra, it is seen that the interface is very smooth and it also shows the existence of the elements aluminum, carbon, silicon, magnesium, Mo, O, and Fe phase at the interface. From the SEM/EDS spectrum analysis, the results confirm the required composition of the tailored composites. Fig 3(a-d) shows the EDX spectrum respectively at the marked location at the particle-matrix interface of flyash particles, Al6061-8wt.%Flyash, Al6061-6-wt.%FA/3wt.%SiC, and Al6061-6wt%FA/3wt%MoS_2 composite respectively. From Fig 3 (b-d), through the mapping of particles, it is clear that the distribution of the reinforced particles (SiC and MoS_2) in the aluminum-flyash composites is uniform. Hence, the uniform distribution of the reinforced particles may give improved mechanical properties.

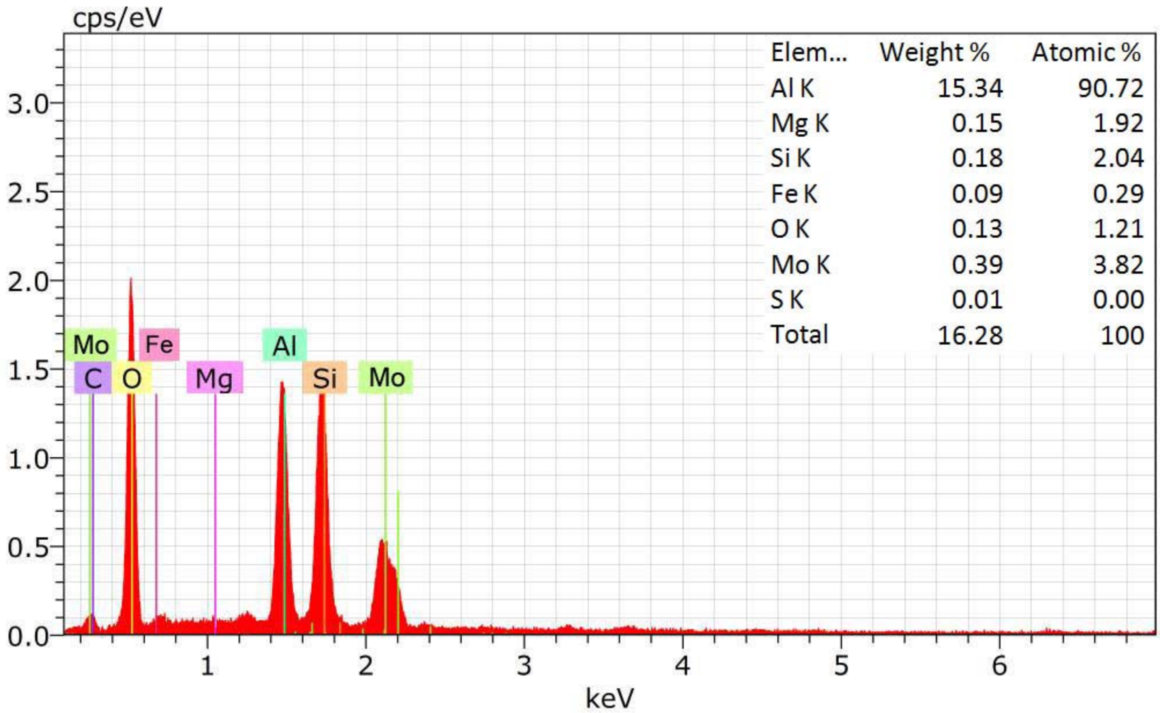
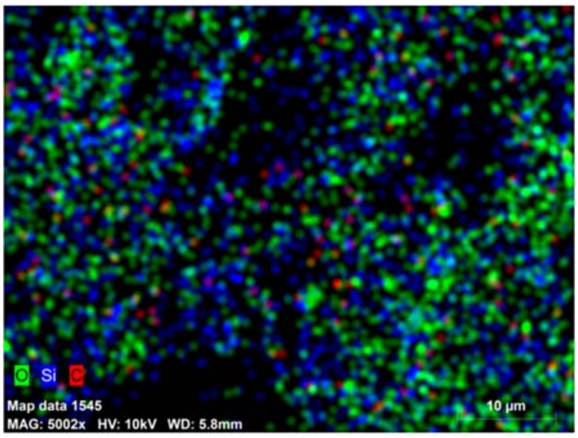
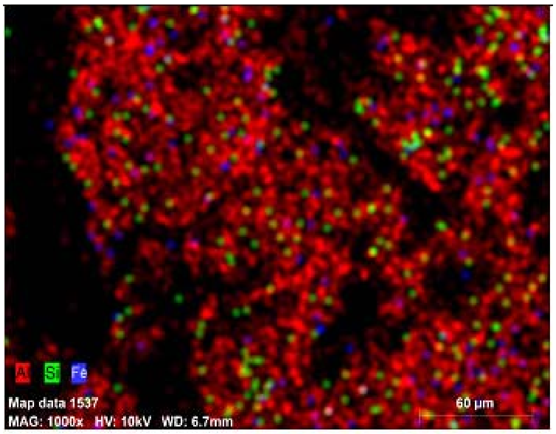


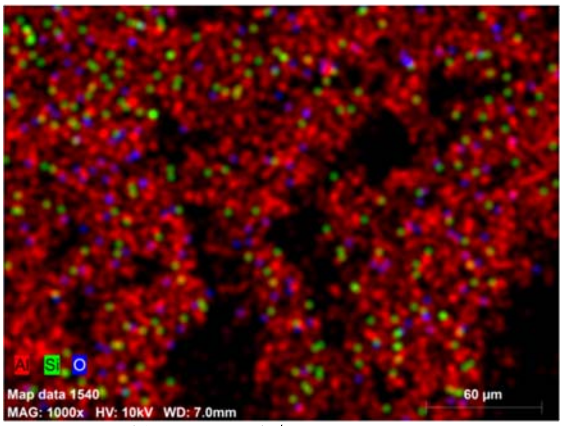
Figure 2(c): EDX spectrum of the Al6061-6wt%FA/ 3wt%MoS_2 composite.



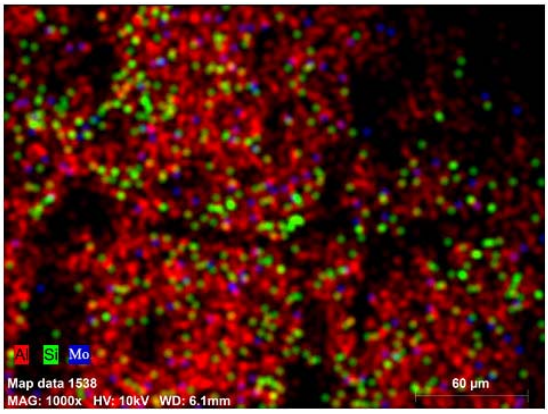
(a) Flyash Particles



(b) Al6061-8%Flyash



(c) Al6061-6%FA/ 3%SiC composite



(d) Al6061-6wt%FA/ 3wt%MoS_2 composite

Figure 3: SEM of hybrid aluminum matrix composites

Density of the hybrid composites

Density values of hybrid composites may increase or decrease from the matrix material. Which is mainly depends on the density of the reinforcement material. The density of the hybrid composites increases with increment in weight fractions of the reinforcements of higher densities whereas, for the lower density reinforcement, it decreases. The density of both SiC and MoS_2 is higher than that of Al6061 whereas the density of the flyash is lesser than that of the Al6061 and other reinforcements. Thus to investigate the effect of the addition of different reinforcements on the hybrid MMC on its density has to be determined. The Archimedes principle is used to determine the same. The result of the experimentation is given in Fig.4. From Fig.4 it is observed that the density of the Al6061-FA composite decreases with increment in the flyash content whereas the addition of SiC in the Al6061-FA maintains the density as equal to the Al6061 and the addition of MoS_2 in the Al6061-FA increases the density of the hybrid composites.

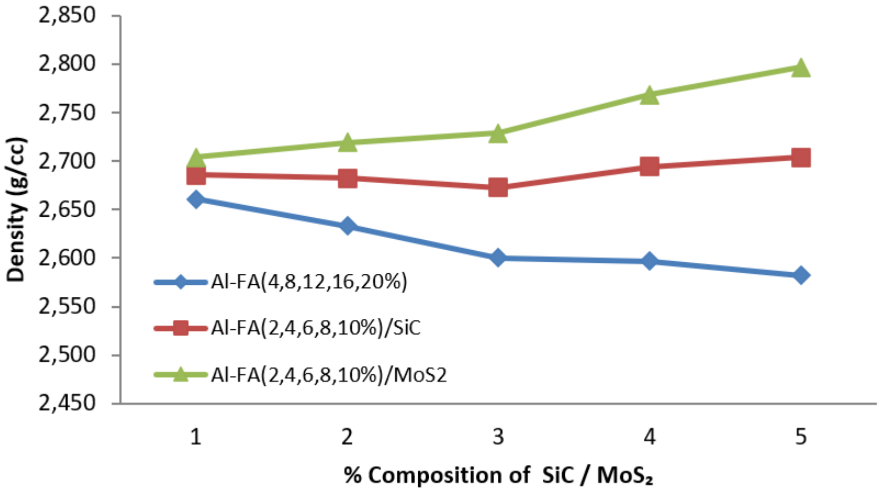


Figure 4: Density of hybrid aluminum matrix composites

Hardness of the hybrid composites

The hardness experimentation has been carried out using the Vickers' micro-hardness testing machine. The result of the experimentation has been shown in the Fig.5 for different composition of the hybrid composites.

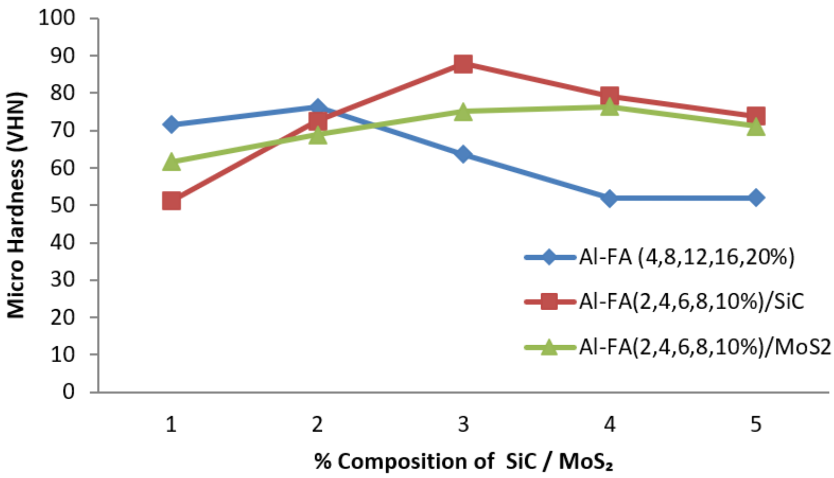


Figure 5: Micro-hardness of hybrid aluminum matrix composites

From Fig 5 it is observed that the hardness of the Al6061-FA composites increases up to 8wt% of the reinforcement and further increment in the flyash decreases the hardness of the composites. This decrement is due to the increased particles of the flyash which forms the clustering and failed to form the uniform distribution which in turn decreases the resistance to the indentation. The hardness of the Al6061-FA/SiC and Al6061-FA/MoS_2 hybrid composites is observed to be higher than the Al6061-FA composites. The hardness of the Al6061-FA/MoS_2 hybrid composite increases with increment in the MoS_2 up to 4wt% and later decreases whereas the hardness of the Al6061-FA/SiC hybrid composite increases up to the 3wt% of SiC and decreases on the further increment of the SiC. However the as compared to the Al6061-FA and Al6061-FA/MoS_2 hybrid composite the hardness of the Al6061-FA/SiC hybrid composite is higher. The maximum hardness obtained, for Al6061-6%FA+3%SiC, is 87.9 VHN and it is 13% higher than the other composites. The addition of the SiC and MoS_2 particles increases the hardness of the hybrid composites. However, the maximum hardness is obtained at the 6 to 8wt% of the flyash, as observed in the Al6061-FA composites.

Tensile strength of the hybrid composites

The tensile test has been carried out using the universal testing machine. The result of the experimentation has been shown in Fig.6 for different compositions of the hybrid composites. From Fig.6 it is observed that the tensile strength of the Al6061-FA composites increases up to 8wt% of the reinforcement and further increment in the flyash decreases the tensile strength of the composites. This decrement is due to the increased particles of the flyash which forms the clustering and failed to form the uniform distribution in the aluminum matrix which in turn decreases the strength.

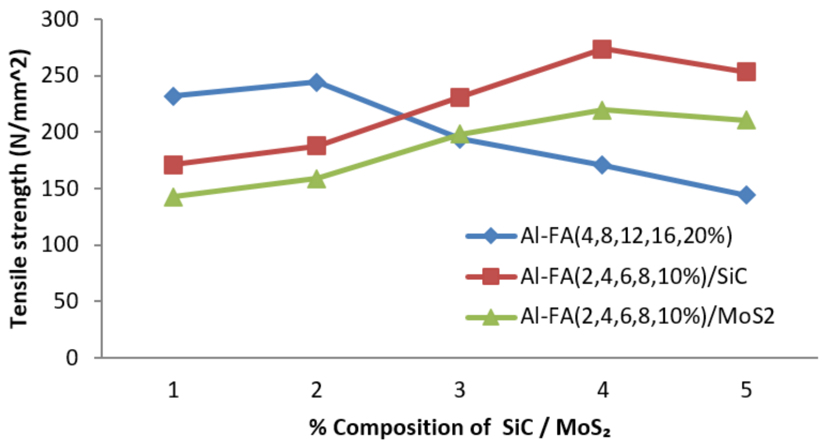


Figure 6: Tensile strength of hybrid aluminum matrix composites.

The tensile strength of the Al6061-FA/SiC and Al6061-FA/MoS_2 hybrid composites is observed to be higher than the Al6061-FA composites. The tensile strength of the Al6061-FA/MoS_2 and Al6061-FA/SiC hybrid composite increases with increment in the MoS_2 and SiC, respectively, up to 4wt% and later decreases. However, as compared to the Al6061-FA and Al6061-FA/MoS_2 hybrid composite the tensile strength of the Al6061-FA/SiC hybrid composite is higher. The maximum hardness obtained, for Al6061-8%FA+4%SiC, is 273.8N/mm^2 and it is 20% higher than the other composites. The addition of the SiC and MoS_2 particles increases the tensile strength of the hybrid composites. However, the maximum tensile strength is obtained at the 8wt% of the flyash, as observed in the Al6061-FA composites.

Thus the addition of the flyash up to 8wt% in the Al6061 matrix increases the hardness and tensile strength of the composites. Fig 7 shows the comparison of the hardness and tensile strength of the Al6061-FA, Al6061-FA/SiC, and Al6061-FA/MoS_2 composites at 8wt% of the flyash reinforcement.

From Fig.7 it is also identified that the hardness of Al-8%FA is nearly the same as the Al-8%FA/4%MoS_2 whereas the tensile strength of the Al-8%FA/4%MoS_2 is lesser than the Al-8%FA. This indicates the addition of MoS_2 has no impact on the hardness and decreases the tensile strength. This decrement in the tensile strength is due to the layered microstructure of the MoS_2 which unable to take the applied load or its interlayer sliding due to the applied stress dissipates the energy. Thus the entire load will act on the matrix and thus reduces the strength of the composite.

In contrast with the Al-8%FA and Al-8%FA/4%MoS_2, the Al-8%FA/4%SiC has high hardness and high tensile strength. This enhancement in hardness and tensile strength is due to the hard particles of the SiC reinforcement, which take the applied load.

From Fig 7 it is observed that, at 8wt% of the flyash, the hardness and the tensile strength of the Al6061-FA/SiC is high in contrast with the Al6061-FA and Al6061-FA/MoS_2 composites. Thus the 8wt% of flyash and 4wt% of SiC is to be considered the optimized composition and can be used as the potential material for the replacement of aluminum-flyash, aluminum-flyash/MoS_2 for automobile applications. Some of the specific applications of flyash composites include pistons, bearings surfaces [4], bushes, cylinder liners, pistons, camshafts [9] as well as the disc brake of two-wheelers.

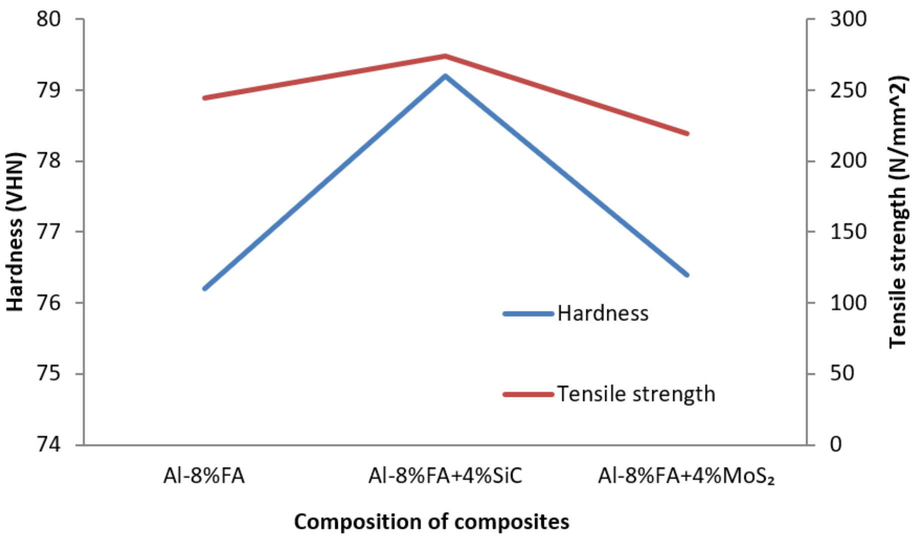


Figure 7: Comparison of hardness and tensile strength of composites at 8wt% of the flyash

Fig 8 shows the fractured surfaces of the aluminum hybrid metal matrix composites for different compositions. Fig.8(a-b) shows the fractured surfaces of the Al6061-flyash composites for 8wt% and 16wt% of the reinforcement. From the fractography, it is clear that the Al6061-flyash composites have microvoids and crack, propagation of those leads to the failure of the matrix. It is also observed that higher percentages of the flyash reinforcement weaken the bonding thus leads to the formation of the cracks at the interfaces.

Fig.8(c-d) shows fractography of Al6061-8%FA/4%SiC and Al6061-10%FA/5%SiC composites. It is observed that al lower percentages of reinforcement the bonding between the matrix and the reinforcement is good and increased reinforcements such as flyash and SiC causes the debonding and voids at the interfaces. Thus decreases the properties of the hybrid composites.

Fig.8(e-f) shows the fractographs of Al6061-8%FA/4%MoS_2 and Al6061-10%FA/5%MoS_2 composites. It is also observed that at the lower percentages of the flyash, up to 8wt%, the voids formed are lesser whereas, at higher percentages, 10wt% of FA and 5wt% of MoS2, the more number of cracks were formed which further leads to the propagation of crack upon loading. Thus reduces the mechanical properties of the said hybrid composites.

CONCLUSIONS

In this experimental work, the influence of the addition of the SiC and MoS_2 on the hardness and tensile properties of the Al6061-FA has been studied. From the results, it is observed that with the addition of SiC and MoS_2 particles in the Al6061-FA composite, the hardness and the tensile strength of the composite increase. However, this increment is limited to the 8wt% of flyash reinforcement in the aluminum matrix. The hardness and the tensile strength of the Al6061-FA/SiChybrid composite are higher than the Al6061-FA and Al6061-FA/MoS_2 composites. Thus for the application like disc brake, which requires lesser weight and high strength and hardness the Al6061-FA/SiChybrid composite can be potential material.In further analysis, for the disc brake application in an automobile, the wear behavior of the Al6061-FA/SiC hybrid composite has to be carried out. In future work, this experiment also be conducted in the thermal environment, to find the effect of temperature on the mechanical properties of the said composites.

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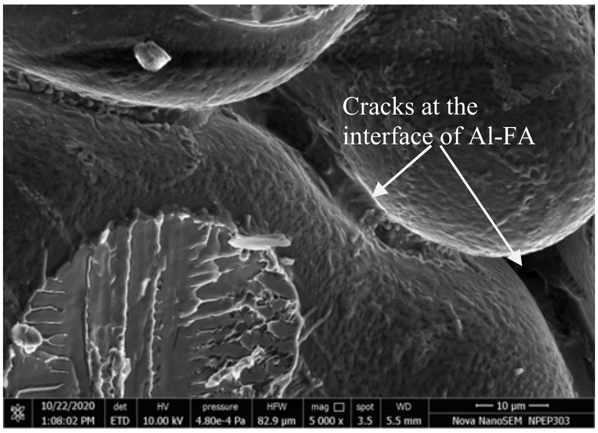
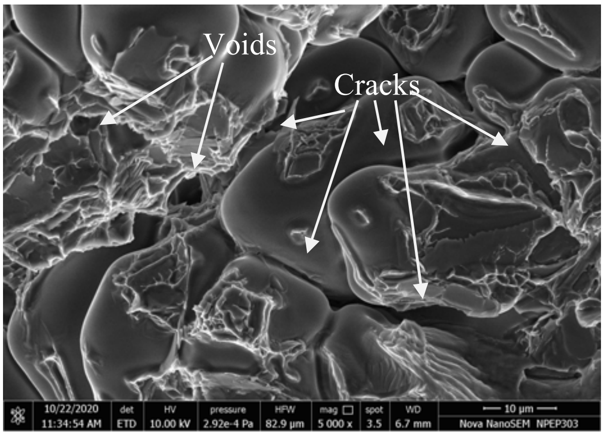
CONFLICT OF INTEREST

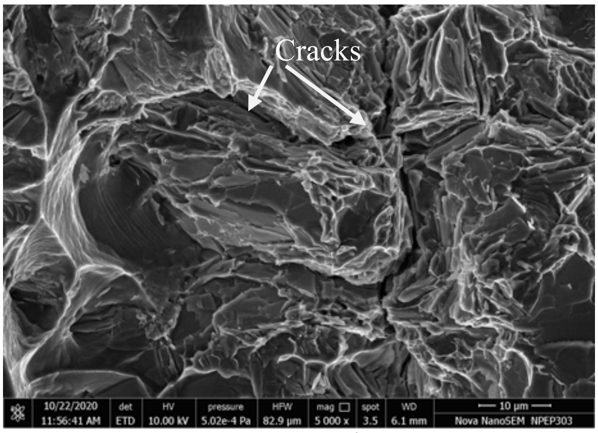
The authors declare that they have no conflict of interest.



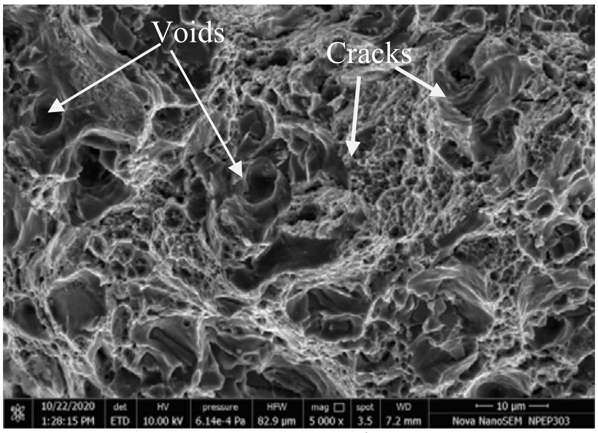
(a) Al6061-8%FA



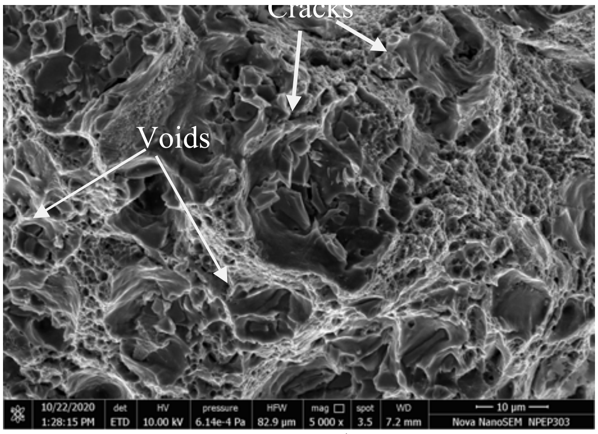
(b) Al6061-16%FA



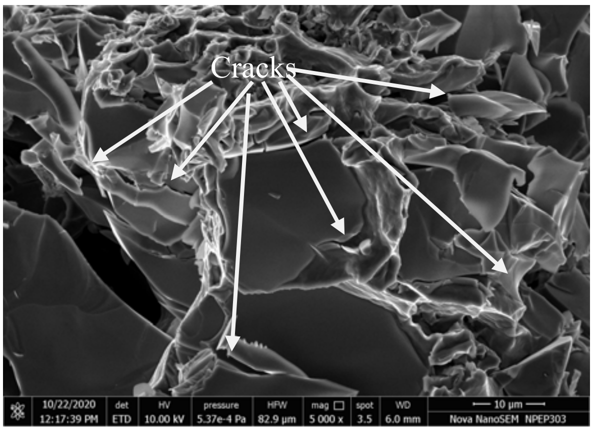
(c) Al6061-8%FA/4%SiC



(d) Al6061-10%FA/5%SiC



(e) Al6061-8%FA/4%MoS_2



(f) Al6061-10%FA/5%MoS_2

Figure 8: SEM of fractured surfaces of the aluminum hybrid composites

REFERENCES

[1] ASM Handbook, Composites, ASM International, 21 (2001).
[2] Anderson, T. L. (2013). Fracture Mechanics-Fundamentals and Applications. 3rd Edition, Taylor & Francis Group, New York.
[3] ASM International (2000). Mechanical Testing and Evaluation, ASM Handbook, 8, pp. 1302-1326.
[4] Doddamani, S. and Kaleemulla, M. (2019). Comparisons of experimental fracture toughness testing methods of Al6061-graphite particulate composites, Journal of Failure Analysis and Prevention, Springer, 19(3), pp.730-737. DOI: 10.1007/s11668-019-00652-8.
[5] Dhummansure, V., Kalyanrao, A. A., Doddamani, S. (2020). Optimization of process parameters for fracture toughness of Al6061-graphite composites, Structural Integrity and Life, 20(1), pp 51–55.
[6] Rajesh, A. M., Kaleemulla, M., Doddamani, S. (2019). Generation of Mechanically Mixed Layer (MML) in Hybrid Aluminum Metal Matrix Composites under As-cast and Age Hardened Conditions, SN Aplied Science, Springer, 1(8), 860. DOI:10.1007/s42452-019-0906-5.
[7] Rajesh, A. M., Kaleemulla, M., Doddamani, S. (2019). Development And Characterization Of Hybrid Aluminum Metal Matrix Composites, Acta Technica Corviniensis – Bulletin of Engineering, 12(3), pp 63-66.
[8] Rajesh, A. M., Kaleemulla, M., Doddamani, S. (2019). Effect of heat treatment on wear behavior of hybrid aluminum metal matrix composites, Tribology in Industry, 41(3), pp.344-354. DOI: 10.24874/ti.2019.41.03.04.
[9] Rajesh, A. M., Kaleemulla, M., Doddamani, S., Bharath K. N. (2019). Material characterization of SiC and Al2O3 reinforced hybrid aluminum metal matrix composites on wear behavior, Advanced Composite Letters, SAGE, 28, pp.1-10. DOI: 10.1177/0963693519856356.
[10] Doddamani, S. and Kaleemulla, M. (2015). Review of experimental fracture toughness (KIc) of aluminium alloy and aluminium MMCs, International Journal of Fracture and Damage Mechanics, Journals Pub, 1 (2), pp.38-51.
[11] Doddamani, S. and Kaleemulla, M. (2016). Indentation Fracture Toughness of Alumnum6061-Graphite Composites, International Journal of Fracture and Damage Mechanics, Journals Pub, 1 (1), pp.40-46.
[12] Gikunoo, E., Omotoso, O. and Oguocha, I. N. A. (2005). Effect of fly ash particles on the mechanical properties of aluminium casting alloy A535, Materials Science and Technology, 21(2), pp-143-152.
[13] Dey, A. and Pandey, K. M. (2016). Characterization of fly ash and its reinforcement effect on metal matrix composites: a review, Rev.Adv. Mater. Sci. 44, pp-168-181.
[14] Imran, M. and Anwar Khan, A. R. (2019). Characterization of Al-7075 metal matrix composites: a review, journal of material research and technology, 8(3), pp.3347–3356. DOI: 10.1016/j.jmrt.2017.10.012.
[15] Kumar, V., Dev Gupta, R. and Batra, N. K. (2014). Comparison of Mechanical Properties and effect of sliding velocity on wear properties of Al 6061, Mg 4%, Fly ash and Al 6061, Mg 4%, Graphite 4%, Fly ash Hybrid Metal matrix composite, Procedia Materials Science 6, pp.1365 – 1375. DOI: 10.1016/j.mspro.2014.07.116.
[16] Haider, U., Bittnar, Z., Kopecky, L., Bittnar, P., Němeček, J., Ali, A., Pokorny, J. (2016). Mechanical behaviour and durability of high volume fly ash cementitious composites, Frattura ed Integrità Strutturale, 38, pp. 289-302. DOI: 10.3221/IGF-ESIS.38.41.
[17] Prakash Kumarasamy, S., Vijayananth, K., Thankachan, T., Pudhupalayam Muthukutti, G. (2017), Investigations on mechanical and machinability behavior of aluminum/flyashcenosphere/Gr hybrid composites processed through compocasting, Journal of Applied Research and Technology 15, pp. 430–441. DOI: 10.1016/j.jart.2017.05.005.
[18] Raja Selvam, D., Robinson Smart, J., Dinaharan, D. S. (2013). Synthesis and characterization of Al6061-Fly Ashp-SiCp composites by stir casting and compocasting methods, Energy Procedia 34, pp. 637 – 646. DOI: 10.1016/j.egypro.2013.06.795.
[19] Ravikumar, M., Reddappa, H.N., Suresh, R., Sreenivasareddy, M., (2021), Experimental studies of different quenching media on mechanical and wear behavior of Al7075/SiC/Al2O3 hybrid composites, Frattura ed Integrità Strutturale, 55, pp. 20-31. DOI: 10.3221/IGF-ESIS.55.02 .
[20] Bizhan Rahmati, A., Sarhan, A. D., and Sayuti, M. (2014). Investigating the optimum molybdenum disulfide (MoS2) nanolubrication parameters in CNC milling of AL6061-T6 alloy, Int J Adv Manuf Technol, 70, pp. 1143–1155. DOI: 10.1007/s00170-013-5334-x.
[21] Geeta Rani, M., ParameswaraRao, Ch.V.S., Rama Kotaiah, K. (2017). Studies on characterization of Al6061/ MoS2 metal matrix composite, International Journal of Mechanical Engineering and Technology (IJMET), 8(8), pp. 998–1003.

[22] Yadav, R., Prakash Sharma, J., Rekha Yadav, G. (2017). Prediction of Mechanical and Wear Properties of Al-6061/MoS2 (Molybdenum Disulphide) Composites, International Journal of Innovative Research in Science, Engineering and Technology, 6(8), pp. 15839- 15849. DOI: 10.15680/IJIRSET.2016.0608039.
[23] Marachakkanavar, M., Patil, S., Rao, R., Patil, H., Banne, G. (2018). A Review on Tribological and Mechanical Characterization of Al6061 Reinforced with MoS2, Journal of Emerging Technologies and Innovative Research (JETIR), 5(2) pp.244-246.
[24] Vamsi Krishna, M., Xavior, A.M. (2014). An Investigation on the Mechanical Properties of Hybrid Metal Matrix Composites, 12th Global congress on manufacturing and management, Procedia Engineering 97, pp. 918 – 924. DOI: 10.1016/j.proeng.2014.12.367.
[25] Vijaya, M., Srinivas, K. (2019). Investigation on Mechanical Properties of AA6351/SiC and AA6351/SiC/Gr Composites Fabricated by Stir Casting Method, International Journal of Recent Technology and Engineering (IJRTE), 8(1), pp.705-708.
[26] Rouhi, M., Moazami-Goudarzi, M. and Ardestani, M. (2019). Comparison of effect of SiC and MoS2 on wear behavior of Al matrix composites, Trans. Nonferrous Met. Soc. China 29, pp. 1169−1183. DOI: 10.1016/S1003-6326(19)65025-9.
[27] Janbozorgi, M., Shamanian, M., Sadeghian, M. Sepehrinia, P. (2017). Improving tribological behavior of friction stir processed A413/SiCp surface composite using MoS2 lubricant particles, Trans. Nonferrous Met. Soc. China, 27, pp. 298−304. DOI: 10.1016/S1003-6326(17)60034-7.
[28] Maruthi Varun, K. and Raman Goud, R. (2019). Investigation of mechanical properties of Al 7075/SiC/MoS2 hybrid composite, Materials Today: Proceedings, DOI: 10.1016/j.matpr.2019.08.131.
[29] Daniel, S. A. A., Ananth, S. V., Parthiban, A. (2019). Optimization of machining parameters in electro chemical machining of Al5059/SiC/MoS2 composites using taguchi method, Materials Today: Proceedings, DOI: 10.1016/j.matpr.2019.06.750.
[30] Kumar Bannaravuri, P., Kumar Birru, A., Shanker Dixit, U. (2020). Effect of laser surface melting on surface integrity of Al−4.5Cu composites reinforced with SiC and MoS2, Trans. Nonferrous Met. Soc. China, 30, pp. 344−362. DOI: 10.1016/S1003-6326(20)65217-7.
[31] Doddamani, S., Kaleemulla, M., (2017). Fracture toughness investigations of Al6061- Graphite particulate composite using compact specimens, Frattura ed Integrità Strutturale, 11(41), pp. 484-490. DOI:10.3221/IGF-ESIS.41.61.
[32] Doddamani, S., Kaleemulla, M. (2017). Experimental investigation on fracture toughness of Al6061–graphite by using Circumferential Notched Tensile Specimens, Frattura ed Integrità Strutturale, 11(39), pp. 274-281. DOI: 10.3221/IGF-ESIS.39.25.
[33] Bolzon, G., Bocciarelli, M., Chiarullo, E.J. (2009). Mechanical characterization of metal-ceramic composites, Frattura ed Integrità Strutturale, 10, pp. 56-63; DOI: 10.3221/IGF-ESIS.10.07.
[34] Bellini, C., Di Cocco, V, Iacoviello, F., Sorrentino, L. (2019). Experimental analysis of aluminium carbon/epoxy hybrid laminates under flexural load, Frattura ed Integrità Strutturale, 49, pp. 739-747. DOI: 10.3221/IGF-ESIS.49.66.
[35] Nurullaev, E., Ermilov, A. S., Lyubimova, N. Yu. (2017). Dependence of mechanical characteristics from composition and structure and optimization of mechanical fracture energy of polymer composite material based on high-molecular rubbers, Frattura ed Integrità Strutturale, 41, pp. 369-377. DOI: 10.3221/IGF-ESIS.41.48.