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Fabrication and Characterization of Al/MoS_2/Gr Composites

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A B S T R A C T

The aluminium alloy of grade Al-1120 is commonly used in automobile and contraction industries for making various components. The fabrication of an Al/MoS_2/Gr composite and an examination of composite properties are the goals of this study. Stir casting was used to fabricate the composites. In this work, the composite's tensile strength, impact strength, and wear behavior were assessed and documented. It was discovered that the presence of Gr and MoS_2 in the matrix material (Al-1120) enhanced the composites' tensile strength and wear resistance. Nevertheless, the composites' impact strength and % elongation declined. The tensile strength of Al/1% Gr composite found higher amongst the all composite which is 73.45 % higher that of matrix material whereas percentage elongation decreased by 28.32 %. The wear resistance property of Al/1% MoS_2 is higher than the other composites.

1. INTRODUCTION

Aluminium matrix composites (AMCs) are a class of lightweight metal matrix composites. Generally, Al and Mg are used as matrix materials for the fabrication of light-metal matrix composites. AMCs have gained value over matrix composites due to their ease of fabrication. Due to their good wear resistance and high strength-to-weight ratio, AMCs are widely used in the automotive and aerospace industries for the fabrication of various components. The properties of AMCs depend on factors such as the processing route of the composite, reinforcement properties, and the presence of their weight in the matrix material, and properties of the matrix material [1,2]. The reinforcement used in AMCs is generally oxides, carbides, and nitrides of ceramic materials such as SiC, SiO_2, Si_3N_4, Al_2O_3, B_4C, ZrO_2, WC, TiC, TiO_2, TiB_2, ZrO_2, WC, etc. The Gr, CNT, Molybdenum disulfide, etc., are also used as reinforcements to fabricate composites for wear applications [3]. Industrial waste and ash from agricultural materials are used to fabricate cost-effective AMCs. The size of the reinforcement particles can range from the micro scale to the nano scale. Stir casting is one of the most popular methods for making AMCs, despite the drawback of particle settling during solidification. Stir casting is a low-cost, easy way to make AMCs. The special attention that must be given in this process is to the stirrer rpm and the stirring time, because over-stirring increases the porosity of the composite. Various researchers reported the effects of reinforcement, fabrication methods, and processing parameters on the properties of the fabricated composites. Al-Salihi et al. [3] fabricated Al_2O_3 reinforced Al 7075 alloy matrix composites with varying percentages of Al_2O_3 through the stir casting process. It was found that the composite's wear resistance and hardness improved relative to the matrix material. Abdizadeh et al. [4] studied the influence of reinforcement percentage and processing temperature on the B_4C-reinforced aluminum matrix composite. They observed that excessive processing temperature led to the formation of an oxide layer between the matrix and the reinforcement. This oxide layer reduces wetting of B_4C in aluminium, thereby affecting the composite's properties. They suggested the optimal casting temperature and reinforcement volume percentage for fabricating an Al/B4C composite. Farooqi et al. [5] fabricated hybrid AMCs by reinforcing 0.5 wt% carbon nano-tubes and 5.0 wt% zirconium dioxide through the powder metallurgy route. They compared the properties of a hybrid composite with individually reinforced composites. It was found that the mechanical performance of the hybrid composite was superior to that of the individual reinforcement composite. Guo et al. [6] found that TiC wetting with Al alloys plays an important role in the preparation of reinforced TiC Al-matrix composites. It was found that Si promotes the formation of Al_4C_3, accelerates fluid dispersion, and improves TiC wetting with aluminium, thereby improving the uniform distribution of TiC in the Al/TiC composite. Bhasha et al. [7] have fabricated a hybrid composite of Al/RHA/TiC by varying the weight percentages of RHA and TiC from 3 to 9 via casting and analyzed its mechanical properties. The result showed that a 7 wt% reinforcement-fabricated hybrid composite exhibits tensile strength and hardness that are 31% and 18% higher than those of the matrix material, respectively. Ramadoss et al. [8] worked on the influence of B_4C and silicon carbide reinforcements on the tribological behaviour of fabricated composites. The result shows that the Al/SiC composite exhibited higher wear resistance than the Al/B_4C composite. Bakke et al. [9] fabricated an Al alloy/Cu composite by die casting. They found that Al–Cu inter-metallic phases were present in the fabricated composite. Furthermore, a significant increase in hardness was observed in the vicinity of the Al–Cu intermetallic phase layer. Peng et al. [10] fabricated braking pad materials by reinforcing TiC and Al_2O_3 in copper and studied the effect of reinforcements on the behaviour of the developed braking pad material at various braking speeds. They found that, at braking speeds up to 250 km/h, both composites exhibit lower frictional heat. Furthermore, frictional heat increases with both higher braking speed and higher reinforcement volume percentage in the composite. Gupta [11] presented a summary of important controlling factors in the fabrication of aluminium matrix composites in his study. The effects of the process route, composite fabrication methods, and reinforcement materials on mechanical and tribological properties were discussed in detail. Jaber et al. [12] studied the electrical, magnetic, and mechanical behaviour of an Al/TiO_2 composite fabricated by stir casting. They found that adding TiO_2 to the matrix material improves the electrical conductivity, magnetic properties, and tensile strength of the prepared composites. Adediran et al. [13] studied the mechanical behaviour of aluminium matrix rice husk ash (10 wt. %) reinforced composites prepared through a double stir-casting process. Peter et al. [14] presented a review of ceramic- and bio-based hybrid-reinforced aluminium matrix composites. Based on this review, AMCs have excellent physiomechanical properties and tribological properties. These materials could be useful for advanced applications in the automotive and aviation industries. Bembalge et al. [15] investigated the thermal stability and mechanical properties of 6063/SiC composites, using varying reinforcement sizes. Cheneke et al. [16] studied the effect of solution treatment on the mechanical properties of TiB_2 reinforced composites fabricated by semi-solid casting. Subramanian et al. [17] have investigated wear properties of Al/Bagasse ash/SiC hybrid composites. The results show that Bagasse ash and SiC improve the mechanical and wear properties of the matrix material. Sabry et al. [18] developed Al6061/SiC/Gr composite by reinforcing varying % of SiC and Gr. They found that the hardness and strength of the composite SiC (15%) + Gr (10%) improved by 32% and 50%, respectively, compared to Al 6061.Ravikumar et al. [19] fabricated Al2O3/SiC particulate-reinforced composite using the stir casting method. They reinforced Al_2O_3 with 2, 4, and 6 wt. % and SiC with 3, 6, and 9 wt. %. The wear properties of the composite were studied. The Al_2O_3-reinforced composite exhibited better wear resistance than the SiC-reinforced composite. Sree Manu et al. [20] fabricated aluminium hybrid composites by reinforcing dispersoids of Si3N4, aluminosilicate fiber, and carbon through a direct squeeze-infiltration process. They have found that an aluminosilicate fiber-reinforced composite shows slightly higher wear resistance than other composites due to the presence of fibers that are difficult to detach. Yu et al. [21] reinforced carbon nano-tubes (CNTs) into Al and its alloys to improve Young's Modulus properties. Kaushik et al. [22] optimized the wear properties of 6063/SiC fabricated via a matrix composite stir-casting route using a Taguchi-based GRA-integrated approach. UI Haq [23] studied the wear properties of Si_3N_4-reinforced aluminium matrix Composite fabricated by stir casting. Dodo et al. [24] studied the effect of granite particles on the properties of Al/Granite Composites. They have found the hardness of the composite. However, the tensile and impact strengths of the composites decreased with increasing granite weight percentage. Abdulajees et al. [25] fabricated hybrid composites via a stir-casting route by doping varying wt. % of graphite and iron powders reinforcement in Al7075 alloy. It was found that the tensile strength of the fabricated composite increased with increasing wt. % of reinforcement in Al7075. Afkham et al. [26] studied the effects of coating on the wettability of SiC and Al_2O_3 in aluminium melt during the fabrication of a composite. The SiC and Al_2O_3 were coated with nickel and copper material before being reinforced in the matrix. The microstructure of the fabricated composite shows that the coating improves wettability and enhances the uniform distribution of particulates. A similar result was reported by Huang et al. [27] in the case of Graphite Flake/Si/Al Hybrid Composites. Gupta and Rakesh [28] studied the effects of reinforced particulates on AMCs properties. They presented a detailed overview of the effects of reinforcement, mechanical, physical, and chemical properties on the properties of AMCs. They also discuss the effects of reinforcement wettability in the matrix material on the developed composite properties. Loto et al. [29] examined the corrosion-resistant properties of the Al/SiC compound. They found that high SiC grain size increased resistance to corrosion by reducing galvanic corrosion during intermediate intermetallic precipitates. Sardar et al. [30] studied the wear resistance of Al_2O_3 reinforced composite using the Taguchi technique. It was found that the 20 wt. % particulates composite exhibited better wear resistance under all investigated wear conditions.

Prior studies have focused on widely used as Al-6061 and Al-7075 aluminium alloys as matrix materials for composites fabrication. The Al-1120 has received little attention. Furthermore, previous studies have mostly focused on single reinforcements (either Gr or MoS_2), with little attention paid to hybrid combinations (Gr + MoS_2) and their combined effects on Wear and mechanical qualities of the developed aluminum matrix composite. The current study's objectives are to fabricate Al-1120-matrix composites by stir casting, reinforce them with different weight percentages of graphite (Gr), MoS_2, and hybrid combinations of Gr and MoS_2, and assess the mechanical characteristics and tribological behavior of the developed composites.

2. MATERIAL AND METHODS

Al/MoS_2/Gr composites were made using commercial aluminum alloy of grade Al-1120 as the matrix material. Al-1120 contains Al 98.76% while alloying elements like Fe, Mg, Si, Ca, Mn, and Cu 0.43, 0.26, 0.18, 0.12, 0.03, and 0.22 weight percent, respectively. Powdered molybdenum disulphide (MoS_2) and graphite (Gr) were employed as reinforcing materials. The particulate size of graphite powder (Gr) and molybdenum disulphide were 5 μm and 20 μm respectively. Fig. 1 displays the picture of MoS_2 and Gr obtained by scanning electron microscopy (SEM).

Stir casting was used to fabricate Al/Gr/MoS_2 composites with different weight percentages (wt %). In a closed furnace stir casting machine, the matrix material (Al-1120) was heated to 850 degrees Celsius for melting. To eliminate moisture, the reinforcements were warmed to 350 degrees Celsius. The metal was cooled to 650 degrees Celsius. A vertex was formed inside the molten metal after it was agitated with a stirrer set to 400 rpm. The MoS_2 and Gr reinforcements were introduced into molten material vertex and continued to rotate the mixture for 5 minutes to distribute reinforcements uniformly in molten matrix material. To increase the fluidity of the molten material and the wettability of the reinforcements, 0.5% magnesium powder was added to the melt. A cast-iron mold that had been warmed to 150 degrees Celsius was filled with the combined molten mixes. Composites of the single reinforcement and hybrid reinforcement types were fabricated. In the category of single reinforcement composites, reinforcements in matrix materials were varied as 1% MoS_2, 2% MoS_2 and 1% Gr for the fabrication of single particulate reinforced composites. However hybrid composite was fabricated of 1% (Gr+MoS_2) reinforced composite. The composition of developed composites is listed in Table 1.

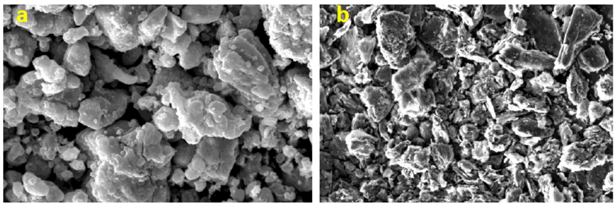

Fig. 1. SEM image of a) MoS_2, b) Gr particulates used in metal powder report.

Table 1. Composites.

S. No.	Composite Category
1.	Al-1120+1 % Gr
2.	Al-1120+1 % MoS_2
3.	Al-1120+2 % MoS_2
4.	Al-1120+1% MoS_2+1 % Gr

As seen in Fig. 2, the testing samples for the tensile, impact, and wear tests were produced in accordance with ASTM standards. All of the experiments were conducted at room temperature. The automated universal testing machine was used to execute the tensile test at a constant cross-head speed of 2 mm/min. The impact tester was used to perform the Charpy impact test. For every composite category, three samples were examined. At room temperature and in a dry state, the wear test of composites was assessed using a pin-on-disk machine. Composites' wear behavior was assessed under various loads, sliding distances, and sliding velocities.

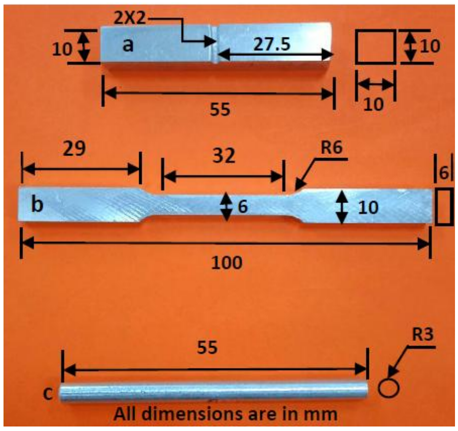

Fig. 2. Specification of testing samples a) Impact, b) Tensile, c) Wear.

3. RESULTS AND DISCUSSION

3.1 Tensile Strength and Percentage Elongation

Table 2 reports the results of the tensile test that was performed on each manufactured composite. Figs. 3 and 4 show the tensile strength and % elongation of the manufactured composites graphically. The ultimate tensile strength (UTS) of all manufactured composites was enhanced by the reinforcement of MoS_2 and Gr particles in the matrix material, as shown in Fig. 3. The composites with 1% MoS_2, 2% MoS_2, 1% (MoS_2+Gr), and 1% Gr had UTS increases of 64.74%, 37.12%, 56.72%, and 73.45%, respectively, compared to the matrix material, as shown in Fig. 3. Furthermore, the composite with 1% Gr reinforcement has the highest UTS. However, the hybrid composite (1%TiB_2 + 1%Gr) had a higher ultimate tensile strength than the 2% MoS_2-reinforced composite. Fig. 4 showed that the percentage elongation of all composites decreased relative to that of the matrix. However, the hybrid composite showed a higher percentage elongation than the other composites. The 1% Gr reinforced composite showed the least percentage elongation. A possible reason for the reduction in percentage elongation may be the brittle properties and larger particle size of the Gr reinforcement [31-32].

Table 2. Tensile Strength of Composites.

Material	UTS N/mm²	Mean UTS N/mm²	% Elongation	Mean % Elongation
Al 1120	162.81	160.61	42.38	41.83
	157.23		38.50	
	161.81		44.63	
Al+1% MoS_2 Composite	291.66	269.41	31.28	30.20
	262.91		31.21	
	253.67		28.11	
Al+2% MoS_2 Composite	211.25	220.24	30.62	31.07
	223.47		31.09	
	226.23		31.15	
Al+1% (MoS_2+Gr) Composite	247.51	251.71	31.25	31.45
	251.94		31.25	
	255.69		31.87	
Al+1%Gr Composite	219.80	278.59	25.46	28.32
	305.27		28.90	
	310.70		30.62	

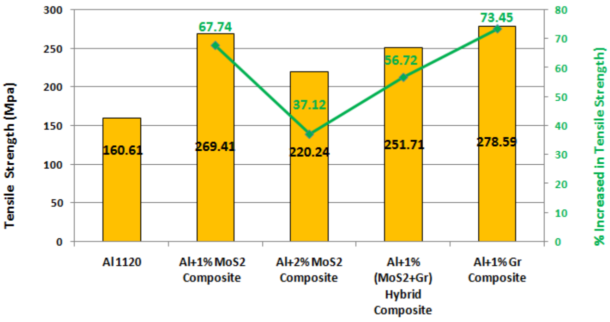

Fig. 3. Effects of Reinforcement on tensile strength.

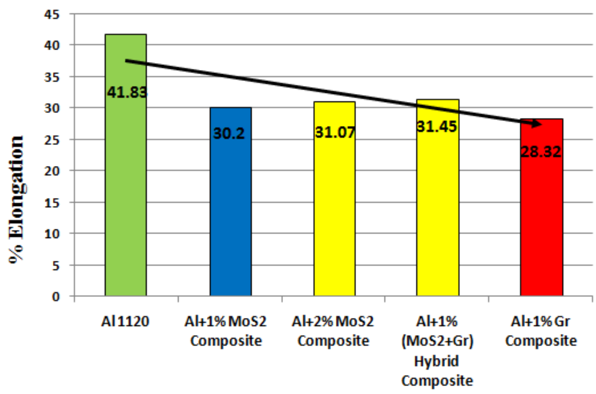

Fig. 4. Effects of reinforcement on elongation.

Fig. 4 showed that the percentage elongation of all composite decreased in comparison to the matrix. However, hybrid composite showed a higher percentage elongation in comparison to other composites. The 1% Gr reinforced composite showed least percentage elongation. The possible reason for the reduction of percentage elongation might be due to brittle properties and bigger particles of Gr reinforcement [28-32].

3.2 Impact Strength

Table 3 reports the testing results for each sample. Fig. 5 shows the tested samples. Fig. 6 shows the average impact strength of composites. Because of the brittle qualities that developed in the manufactured composites, Fig. 6 shows that the impact strength of the manufactured composites decreased in relation to the matrix material. Furthermore, the hybrid composite of Al/Gr/MoS_2 showed higher impact strength compared to other composites. However, Al/Gr showed the least impact strength. The impact strength of the Al/ 1%MoS_2 composite is nearly the same but higher than that of the Al/1% Gr composite.

Fig. 5. Impact tested samples.

Table 3. Impact strength of composites.

Material	Energy (J)	Mean Impact Energy (J)	Impact Strength (J/cm²)	Mean Impact Strength (J/cm²)
Al-1120 (Matrix)	28.20	29.53	36.40	36.80
	30.60		38.70	
	29.80		35.20	
Al+1% MoS_2 Composite	16.3	16.26	20.3	20.3
	16.3		20.3	
	16.2		20.3	
Al+2% MoS_2 Composite	16.3	17.1	20.3	21.36
	17.6		22.0	
	17.4		21.8	
Al+1% (MoS_2+Gr) Composite	23.7	22.1	29.6	27.9
	21.6		27.1	
	21.2		27.0	
Al+1%Gr Composite	10.0	10.03	12.5	12.53
	10.0		12.5	
	10.1		12.6	

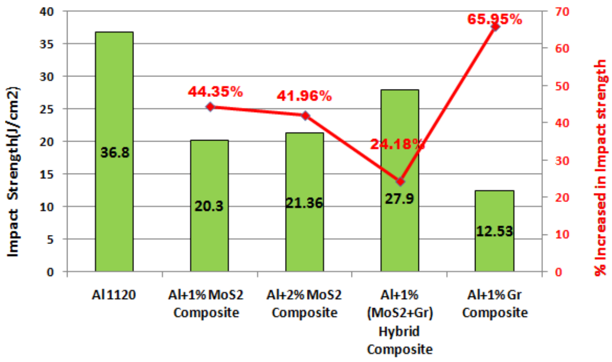

Fig. 6. Effects of reinforcements on impact strength.

3.3 Wear Behaviour

A pin-on-disc tribometer was used to measure the composites' wear performance, as shown in Fig. 7.

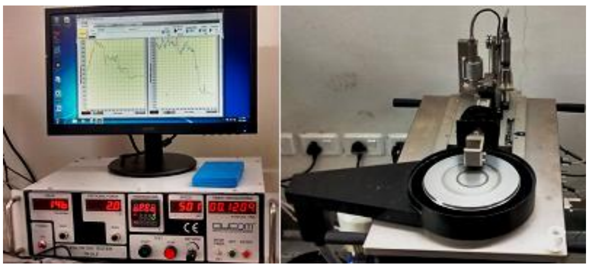

Fig.7. Pin on disk wear tester.

Throughout the test, the worn disk and testing pin come into contact with one another. The testing pin deformed, forming solid joints between the wear disk and the pin, increasing the coefficient of friction and making it harder for the wear disk to slide. Repeated deformation causes the testing pin's contact regions to harden, microcracks to form, the pin to separate from the surface, and wear to occur. Fig. 8 shows the weight loss and rate of Wear of the composites with different sliding distances at a sliding velocity of 3.48 m/s and a load of 10 N. Fig. 8 shows that the composites have improved wear resistance as compared to the matrix material. The presence of MoS_2 and Gr particles in the composite is the primary factor contributing to its improved wear performance. The lubricating nature of MoS_2 and Gr resists the mass deformation of composite materials to the counterpart material [7-8, 11, 18, 20, 28, 33-36]. The weight-loss matrix material was more intense, as shown in Fig. 8. Nevertheless, among the manufactured composites, the composite reinforced with 1% MoS_2 showed the least weight loss. Additionally, the 1% (Gr+MoS_2) hybrid composite outperformed.

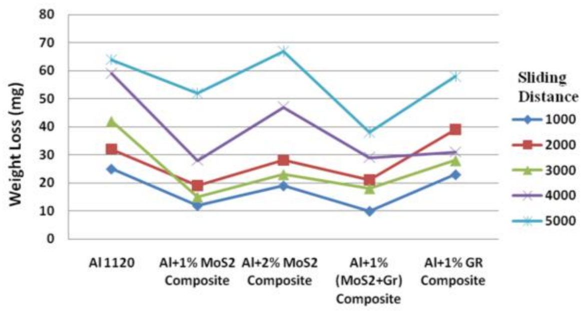

Fig. 8. Weight loss of composites at a varying sliding distance.

4. CONCLUSION

Stir casting was effectively used to produce an aluminium matrix composite reinforced with varying weight percentages of MoS_2 and Gr.

Analysis was done on how reinforcement and its weight percentage affected the composites' mechanical and Wear characteristics. The produced composites' tensile strength, impact strength, and wear resistance were all better than those of Al-1120. The mechanical properties of the 1% Gr-reinforced composite were found to be superior to those of all the other composites. The impact strength and percentage elongation of the composites were lower than those of the matrix material. The wear resistance property of the MoS2 reinforced composite is better than that of the Gr reinforced composites. Additionally, compared to the other composites, the Al/1% (Gr+MoS_2) hybrid composite demonstrated superior wear resistance qualities. However, weight loss and wear rate increased with increasing sliding distance.

Future directions of this research include the use of Gr and MoS_2 nanoparticles for the fabrication of Al-1120 matrix composites. The different combinations of reinforced composites may be fabricated. A comparative analysis of new fabricated composites with existing composites may be conducted to generate more research output.

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