



# Microstructure Characterization, Mechanical and Wear Behavior of Silicon Carbide and Neem Leaf Powder Reinforced AL7075 Alloy hybrid MMC's

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**ABSTRACT.** The demanding material quality criteria in the automotive and aerospace industries have recently had an impact on the development of lightweight aluminium alloys. The choice and application of metal-matrix composites as structural materials in this context are known to offer a variety of benefits. These benefits include the ability to combine high elastic modulus, toughness, and impact resistance; minimum sensitivity to change in temperature or thermal shock; durability of the surface is good; moisture absorption leads to a potential issue while minimum exposure which leads to environmental degradation; and improved fabricability with conventional metalworking equipment. Aluminium metal matrix composites (AMMCs) are a potential material for advanced structural, aviation, aerospace, marine, and defense applications, as well as for the automotive sector and other related fields, due to their outstanding combination of qualities. The stir casting procedure is used to create an aluminium metal matrix composite (AMMC), which is the most efficient way to do so. In this study, the aluminium alloy 7075 is strengthened using neem leaf powder and SiC. The Vickers hardness examination method is used to govern the hardness of hybrid composites. Eventually, the mechanical and tribological properties of the composites were assessed, and their relationship to the composites' matching microstructure and wear was addressed.

**KEYWORDS.** Al7075 alloy, SiC, Neem Leaf Powder, Stir Casting, Wear, Metal Matrix composites.



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## INTRODUCTION

Composite materials are widely adopted because, in comparison to metallic elements, they possess more specialized characteristics (characteristics/weight unit) of robustness and rigidity, which present intriguing design possibilities for new products. Composite materials, which can be made of two or more components, have features that cannot be obtained from a single material. In the composite, one of the constituent elements serves as the reinforcement and another one serves as the matrix. The matrix material has three purposes: to guard the strengthening materials, to transmit stress to the reinforcing materials, and to give the composite part its final shape. The purpose of the reinforcements is to strengthen the matrix in desired directions while also giving the composite strong mechanical properties. A composite material's properties are determined by the matrix's nature, the reinforcement's form (particles or fibers), and the reinforcement's relative concentration. Aluminum and its alloys are the most often used matrix in metal matrix composites (MMCs).

Aluminium alloys have great features due to their low density, lightweight, exceptionally high strength, remarkable corrosion resistance, and good thermal and electrical conductivity. Two prominent series of aluminium alloys are the heat-treatable Al6061 and Al7075. Al6061 alloy is frequently employed in the construction (building and roadway), automotive, and shipbuilding industries because of its high level of corrosion resistance, outstanding extricability by nature, and moderate strength. Because it has a very high strength and toughness factor, aluminium alloy 7075 is widely used in the automotive and aviation industries. Due to their high strength, fracture toughness, wear resistance, and stiffness, aluminium alloy composites are of great interest to a lot of individuals. These composites are superior for applications involving high temperatures when reinforced with ceramic particles. Metal matrix composites based on aluminium are increasingly used in many different industries as a result of topical manufacturing progress in the automotive and aircraft industries.

Authors, casting process Reference No	Matrix Material	Reinforcement	Average Mechanical Property			
			Hardn ess	UTS	YS	% Elgn
M.B.A. Shuvho, et.al [13] stir casting	Al 6063 alloy	TiO <sub>2</sub> (1%), Al <sub>2</sub> O <sub>3</sub> (1%), SiC (2.5-10% in steps of 2.5)	86.16	132.1	97.9	5.75
P. Pugalenth, et.al [14] stir casting	Al7075 alloy	SiC (2%), Al <sub>2</sub> O <sub>3</sub> (3-9% in steps of 2)	99.25	354.3	---	3.72
N. Lokesh, et.al [10] stir casting	Al6063 alloy	TiO <sub>2</sub> (10%), Cu (5-15% in steps of 5)	48.30	105.4	---	17.4
Manoj Singla, et.al [12] stir casting	Al alloy	SiC (5-30% in steps of 5)	42.65	----	---	----
Dipankar Dey & Ajay Biswas [22] stir casting	Al2024 alloy	SiC (5%), TiB <sub>2</sub> (5%)	----	212.0	---	----
Karakoc H, et.al [23] Powder metallurgy	Al6061 alloy	SiC (3-12% in steps of 3), B <sub>4</sub> C (3-12% in steps of 3),	62.4	180.6	---	----
Dipankar Dey et al. [24] stir casting	Al2024 alloy	SiC (3-9% in steps of 3)	49	215	---	----

Table 1: A brief overview of the literature.

The focus for structural applications has shifted in new years to discontinuously reinforced Metal matrix composites based on aluminium alloy. The Al 6063 TiO<sub>2</sub>-Cu metal matrix composite's mechanical properties and microstructure have been studied by scientists and researchers in detail [1-3] with regard to the mechanical evaluation of metal matrix composites with discontinuously reinforced Al alloy. The findings demonstrated that stir casting is regarded as a low-cost casting technique due to its low cost and minimal reinforcement damage [4-7]. The manufacture of MMC utilizing the liquid casting process was covered in their work. They used Al<sub>2</sub>O<sub>3</sub> as reinforcement and AA7075 as the base metal. The parameters were optimized using the Taguchi technique, and the optimal AA7075/Al<sub>2</sub>O<sub>3</sub> composite was selected using the "smaller the

best" guiding concept [8-10]. It was noted that when the processing temperature was between 7500C and 8000C, the dispersion of reinforcement particles was homogeneous. When making the composite, Mg particles are added. The results indicate that Al-SiC is more wettable. The study demonstrated that wettability was enhanced by fine-sized reinforcing particles. DM Singla and others [11-13]. SiC particles were added to the Al alloy in weight percentages ranging from 5 - 20%, and the mechanical characteristics of the resulting composites were studied. The results showed that raising the volume % of SiC increases ultimate strength. According to a review of the literature, adding reinforcements such as SiC, Mg, Al<sub>2</sub>O<sub>3</sub>, etc. has improved the mechanical properties of aluminium alloys [14-16]. Also, effective properties of composite materials can be studied using micromechanical models, such as homogenization models for FGMs which are a combination of ceramic and metallic phase materials, by many researchers [17-21].

There hasn't been any research done on the mechanical properties of SiC powder and neem leaf ash reinforced Al-7075 alloy. In this study, Al-7075 alloy-based metal matrix composites reinforced with SiC and neem leaf ash powder are made, and their mechanical properties are examined.

## MATERIALS, COMPOSITES FABRICATION AND TESTING

**Z**inc serves as the primary alloying element in an aluminium 7075. It possesses excellent mechanical properties along with great ductility, high strength, toughness, and decent fatigue resistance. Although it is significantly more resistant to corrosion than the alloys from the 2000 series, micro segregation makes it more brittle than many other aluminium alloys. It is one of the most widely utilized aluminium alloys for extremely high-stress structural applications and is extensively employed in aviation structural parts. This study used Al7075 as its matrix material, which has a theoretical density of 2.810 g/cm<sup>3</sup>. The matrix material's chemical composition is listed in Tab. 2 [25]. SiC particles with an average size of 25 microns and neem leaf powder were utilized as reinforcement. In order to improve the wettability between the matrix and the reinforcements, mg is used as a wetting agent during the creation of hybrid composites. The neem tree, scientifically known as *Azadirachta indica*, is a South Asian native that is now grown all over the world for its therapeutic benefits. Neem leaf powder (NLP) was once used as a form of contraception. Currently, it is used in makeup, detergents, and creams. NLP is the byproduct of the neem oil extraction process, which is done on neem leaves. The usage of this NLP waste as reinforcement may be advantageous for the composites. Neem leaves were dried for this project for five days outside, then burned to create ash power. SiC powder is synthesized and used as an abrasive. For composite materials, this can serve as reinforcement. The industry provided SiC powder with a 25 mm average particle size. Before being used as reinforcement, it was dried out in a furnace to eliminate any moisture. Fig. 2 displays the SiC powder picture that was provided by the sector.

Element	Zn	Cu	Mn	Mg	Fe	Cr	Ti	Si	Al
Weight%	5.4	1.42	0.12	2.42	0.42	0.21	0.11	0.13	Bal.

Table 2: Chemical composition of Al7075 [25].

## FABRICATION OF AL7075-SiC-NLP MMCs

**T**he stir-cast furnace has been mounted on the floor and the temperature of the furnace has precisely been measured and controlled to achieve sound quality of the composite. Two thermocouples, one PID controller have been used for this purpose. As mild steel materials are having high temperature stability, they have been selected as stirrer rod and impeller. This stirrer, which has been connected to 1 HP DC motor through flexible link, has been used to stir the molten metal in semi solid state. The screw operator lift has been used to bring the stirrer in contact with the mixing materials. The melt has been maintained at a temperature between 750 to 800°C for one hour. Prior to transfer the SiC and NLP particulates into the matrix, they were pre- heat in an electrical furnace and introduced to the melt while being continuously mechanically churned for about 10 minutes at a speed of 300 rpm. After complete addition of the particulates into the molten Al alloy for each combination, the molten slurry has been tilted and poured into the preheated (300°C) permanent steel die and finally allowed to cool in atmospheric conditions (room temperature). The composite has been solidified in die in the form of a cylindrical bar of diameter 15 mm and height 130 mm. Also, weight percentages of SiC and NLP are mentioned in Tab. 3.

Sl. No	Description	SiC (Wt.%)	NLP (Wt.%)	Al-7075 (Wt.%)
1	S0	----	----	0
2	S1	5	5	90
3	S2	7.5	7.5	85
4	S3	10	10	80

Table 3: Weight % of reinforcements in fabricated AMMC.

## PREPARATION OF SAMPLES

Samples were cut from the cast circular section for mechanical and tribological characterization, including tensile, hardness, wear, and morphology. The tensile strength of the manufactured composite sample was measured using a UTM, which was also prepared as per ASTM E8 standards. Vickers hardness testers were used to test the specimens' hardness on samples prepared as per ASTM E92 standards. The samples were worn using a pin-on-disc device following ASTM G99 guidelines. The produced composites' morphology is studied using a scanning electron microscope.

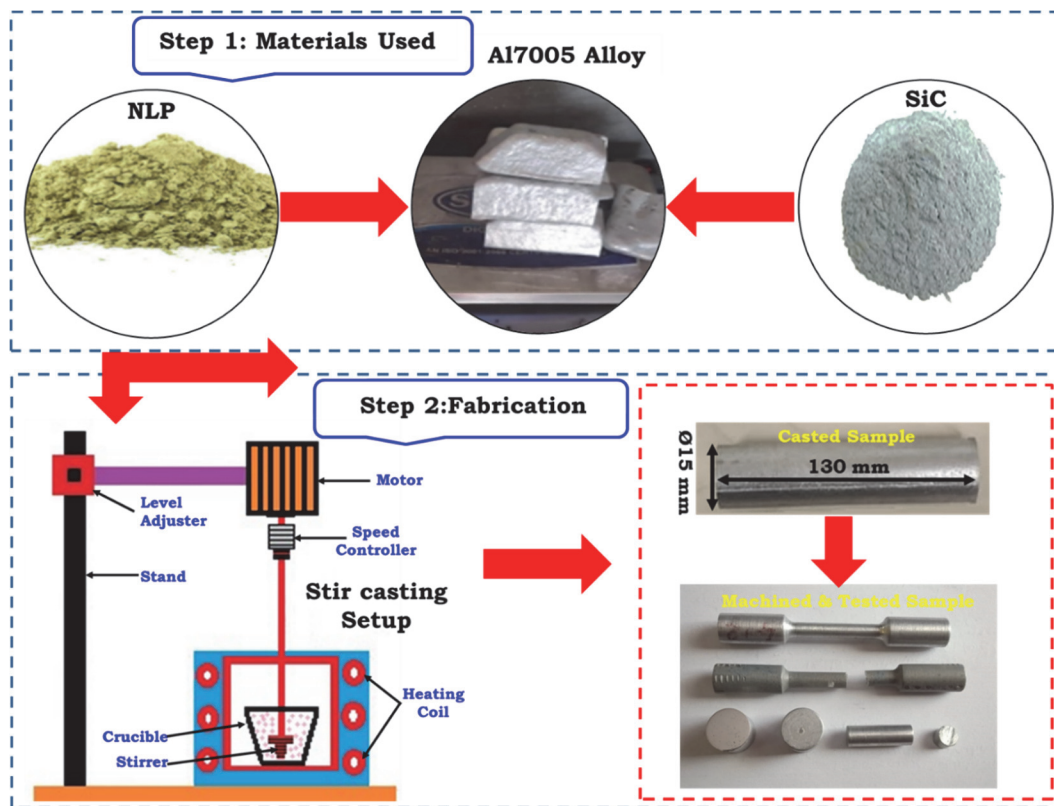


Figure 1: Flowchart depicting materials, fabrication technique and samples used in current study.

## RESULTS AND DISCUSSION

### Microstructural analysis

Fig. 2 displays SEM (Scanning Electron Microscope) micrographs of varied SiC and Neem leaf powder contents of strengthened aluminium matrix composites. Microstructure showed that reinforcements particles are uniformly distributed throughout the matrix. Greater strength and a reduced wear rate are obtained in a metal matrix composite when reinforced particles are dispersed intergranularly as opposed to intergranularly. The duration of solidification has a considerable impact on the intergranular dispersion of reinforcing particles. Because of its Al7075/SiC/neem Leaf powder

surfaces' poor wettability, significant agglomeration of reinforcement, and pore nucleation, Fig. 7(a) exhibits some porosity. Increasing the temperature of the molten material while stirring can significantly minimize this porosity [26-28]. aggregates of reinforced particles that, when firmly bound to the matrix, enhance cast composite materials. a collection of reinforced particles held together by a molten matrix and with minimal to no microcracks or vacancies [29-30]. In addition, these aggregates provide the cast composite with its strength. It has been noted that a SiC and neem leaf powder dispersed composite with a lower weight percentage is less porous and less obstructed than a composite with a higher weight percentage of reinforcements, and that the fluidity of the composite slurry is developing, allowing for a better drive of the ceramic reinforcements and clustering with some porous content [31].

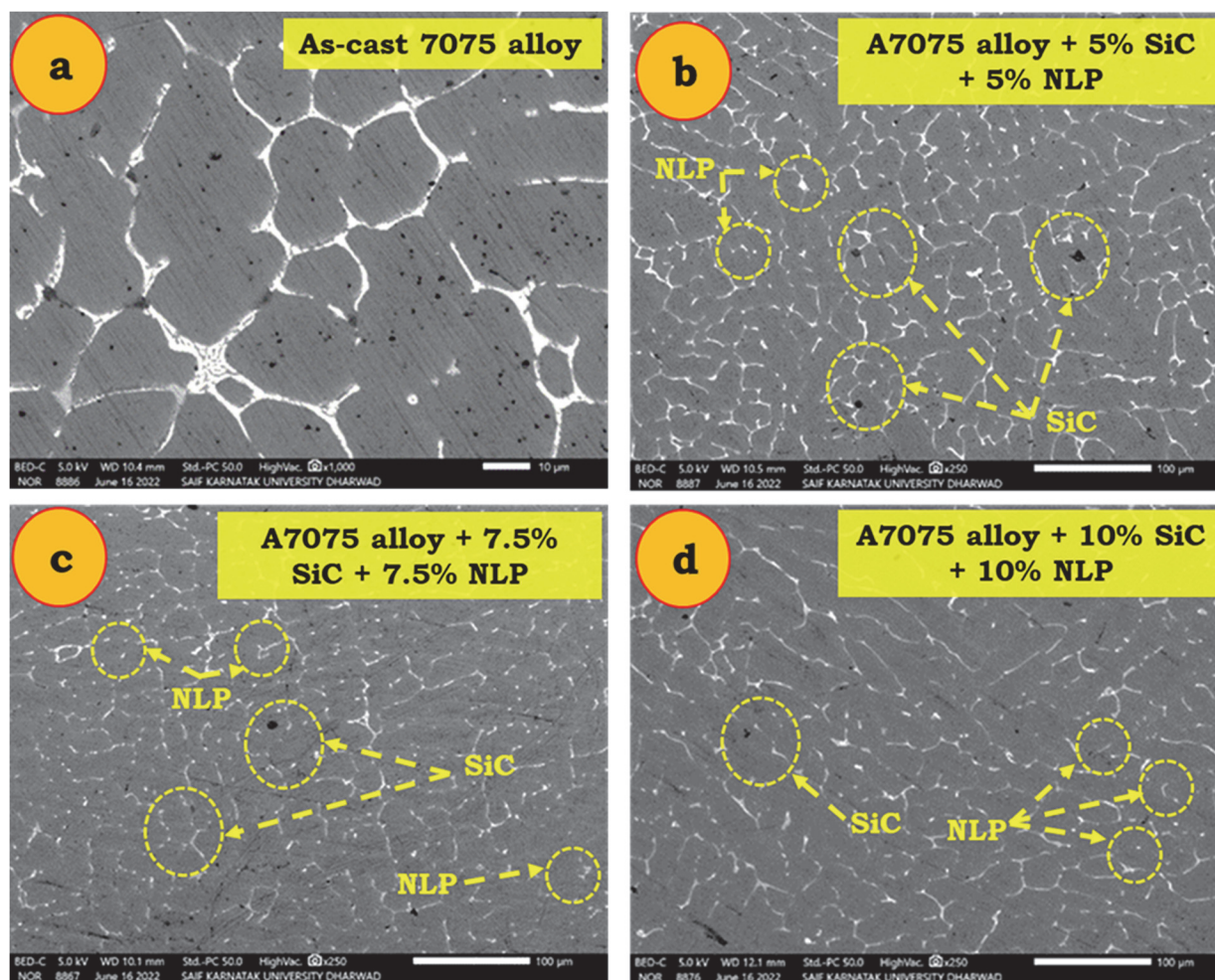


Figure 2: Microstructural Analysis of Al7075-NLP-SiC hybrid-MMCs.

### Hardness test results

Fig. 3 illustrates the hardness test of Al7075-NLP-SiC hybrid MMCs. It is clear from Fig. According to Fig. 3, a rise in the weight% of SiC up to 7.5% and Neem Leaf Powder (NLP) has been associated with an upward trend in hardness. Hardness improvement is responsible for SiC's higher hardness and the fact that the composite's hardness was increased by SiC's addition. SiC has a higher hardness than other materials, and its inclusion in a composite increases its hardness. This can be attributed to hardness enhancement. When SiC content reached 10%, excessive porosity, and microcracks started to occur, which is the main cause of the decrease in hardness. The following elements are accountable for the enhancement in the hybrid composites' hardness values: (1) Powder particles of SiC and eutectic Si particles enhance the matrix's grain structure. (2) SiC, a hard ceramic material, is dispersed in a softer, ductile matrix, which causes the matrix to stiffen. (3) Particle strengthening of the composites via dislocation density strengthening and plastic strain limit implications [32-33].

### Tensile test results

Fig. 4 illustrates the tensile strength of Al7075-NLP-SiC hybrid-MMCs. Compared to single-reinforced composites, hybrid composites have better UTS values. Since SiC particles are a bit tougher than neem leaf powder (NLP) particles, this results



from the synergistic manner in which particle and dispersion strengthening mechanisms work together. The temperature mismatch between the low-expansion ceramic reinforcements and the high-expansion metal matrix is another problem. An efficient transfer of stress from the matrix to the reinforcements, interactions between particulates and dislocations (strain hardening effect), and matrix grain refinement may be the reason for enhancement in strength. By enhancing grain refinement through the impacts of the nuclear site and particle grain pinning, the addition of SiC particles helps to refine the primary Si in the Al-Si alloy. The short fibrous form Si in composites results from the refinement of primary Si. By regaining ductility, the Si particles' refining enhances their tensile characteristics. Also, by serving as a second phase, the tiny Si particles increase strength. The dislocation density rises as a result of the matrix and particle's incompatibility in terms of elastic modulus and thermal expansion. The strength of the composites is improved by the rise in dislocation density (dislocation strengthening). Moreover, the non-deforming SiC particles during the deformation produce localized strain in the matrix, which strengthens through local plastic constraint. SiC particles, which are tough and stiff, serve as load-bearing components in composites and increase their strength [34-35].

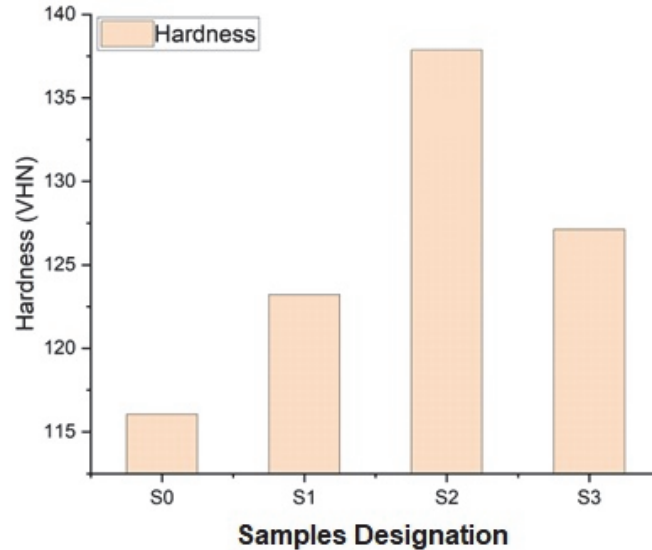


Figure 3: Hardness Test results of Al7075-NLP-SiC hybrid-MMCs.

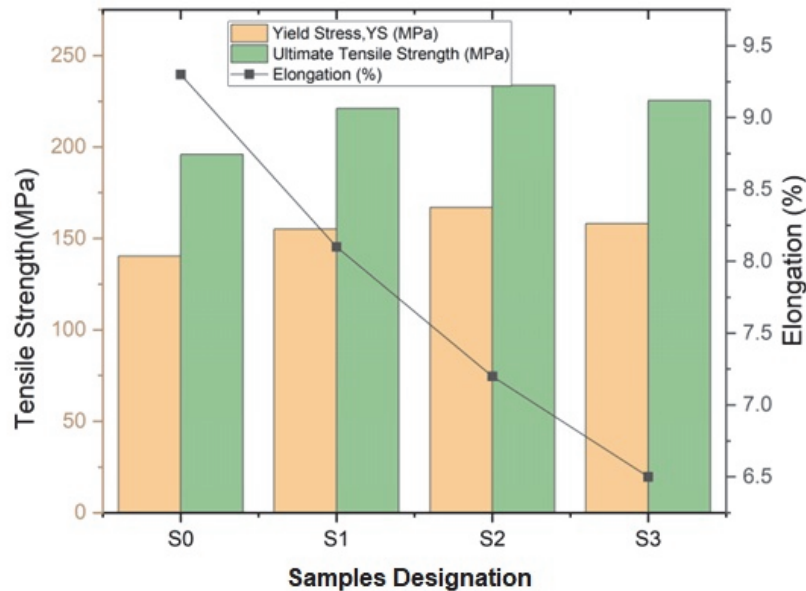


Figure 4: Tensile strength (TS) results of Al7075-NLP-SiC hybrid-MMCs.

#### Fracture test results

Fig. 5 shows the fracture surface analysis of Al7075-NLP-SiC hybrid-MMCs. Fig. 5(a) depicts a fractography of Al7075 alloy displaying a fern-like structure, a flat fracture surface made up of tiny crack portions, and rupture patterns indicating ductile

fracture [33]. Fig. 5(b), 5(c) and 5(d) to depicts fractograph of Al7075-NLP-SiC hybrid-MMCs. River-like structures, cleavage facades, and voids with plenty of cavities and lower dimples after reinforcements have uneven tearing troughs, and less ductile failure can be observed throughout the images indicating brittle fracture [36-37]. and has a quasi-cleavage feature mode-cleavage feature mode. Materials with lower elongation values frequently exhibit quasi-cleavage fracture. Large SiC particles or broken Al-Si eutectic particles may be to blame for this. The form and size of the particles have a significant impact on the tensile properties, as is well known. The Al-Si eutectic particles in the 7075 alloy are big and elongated, making them more brittle and susceptible to cracking. Thus, the inter-dendritic cracking and silicon particle cracking dominate the fracture process in the 7075 alloy. While in composites, the dislocations accumulate close to the SiC particles, creating stress fields that in turn induce local fluctuations that eventually cause the SiC particles to shatter. It is significant to notice that SiC particles broke under tensile loading rather than debonded due to the strong link between the 7075 matrix and the SiC particles. The interfacial connection between the SiC particles and 7075 matrix is crucial in cases of tensile loading. When loading circumstances are present, it attempts to keep the SiC particles in the matrix if the interfacial bonding is strong. Because to the high interfacial bonding, however, as the load increases, the SiC particles fracture rather than debond. Hence, the nature of fracture in composites is brittle [36-37].

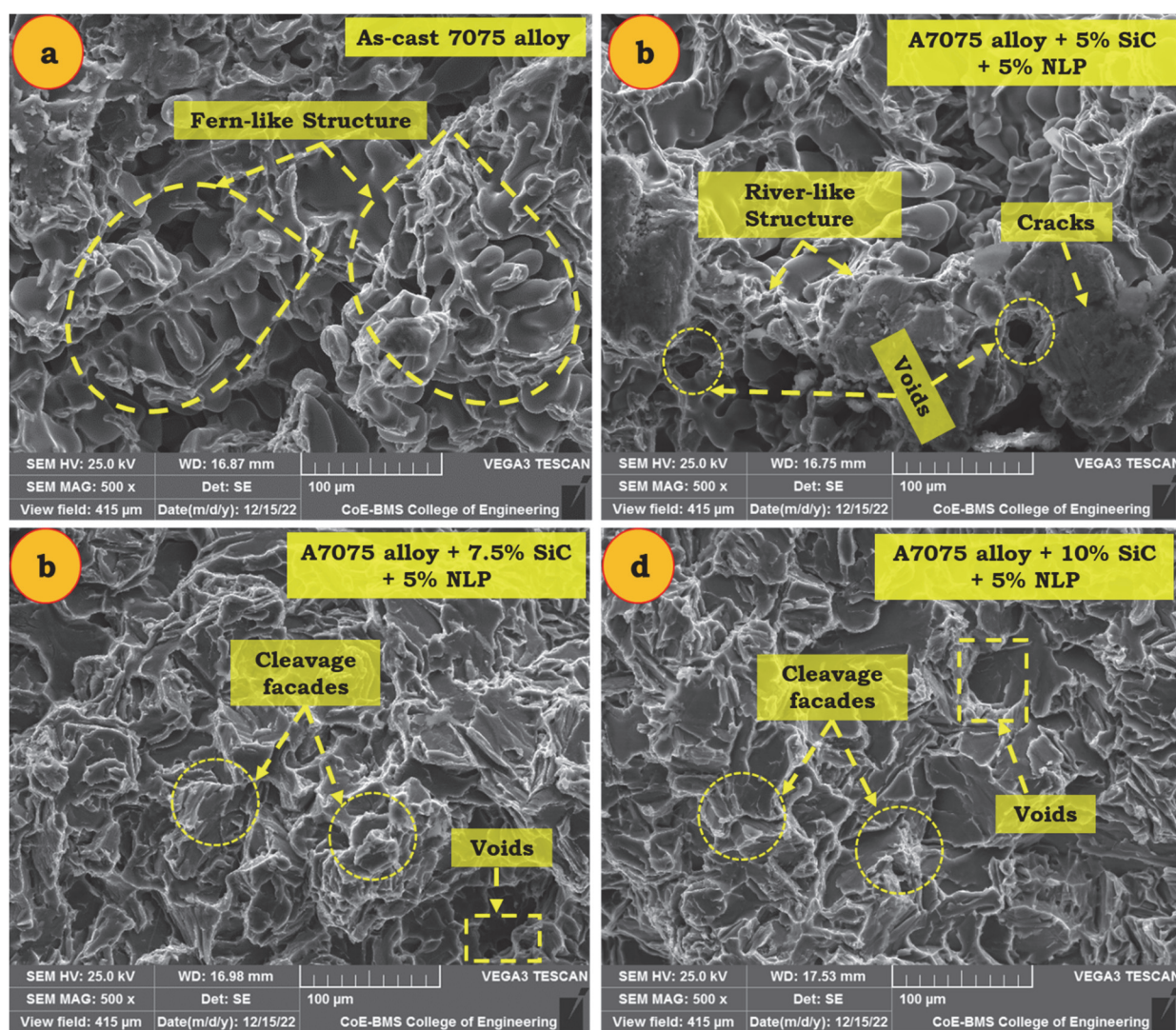


Figure 5: Fracture Analysis of Al7075-NLP-SiC hybrid-MMCs.

### *Wear test results*

Wear tests of prepared compositions were conducted with applied loads, sliding speeds, and sliding distances, and all the parameters are shown in Tab. 3.



S/No	Parameters	Values
1	Normal Load Applied (N)	19.62
2	Test Duration (mins)	3
3	Speed (rpm)	500
4	Pin Dia (mm)	8
5	Track Radius (mm)	60
6	Sliding Distance (m)	565.487
7	Sliding Velocity (m/s)	3.14159

Table 3: Wear Test Parameters of Current Studies.

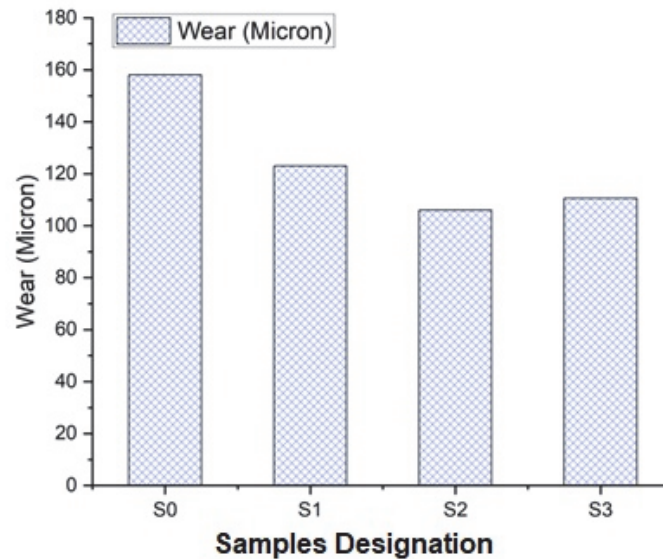


Figure 6: Wear test results of Al7075-NLP-SiC hybrid-MMCs.

Adhesive, abrasive, delamination, and abrasion wears remain the most common wear processes that can occur in composites made of Al/SiC and NLP. Variations in reinforcement weight percentage, load, sliding speed, and distance are the causes of these wear mechanisms [38]. The main sources of various wear mechanisms include metallurgical characteristics, environmental conditions, and disc surface characteristics. For S1 wear is more this is due to the part adhesion and delamination are the main causes of wear mechanisms and more wear when compared to the S2 and S3. The S2's primary wear processes are abrasive, with adhesion and plastic deformation coming in second and third. S3 exhibits extremely low wear compared to S1 and S2 due to the Al- 10%SiC, and neem leaf powder specimens' existence of tiny craters, which reduced wear loss. In contrast to the other two composites, the mechanically mixed layer (MML), which forms on top of the composite with 10 weight percent SiC and Neem Leaf powder, serves as a protective layer and a solid lubricant. The development of this tribolayer or oxide layer reduces wear loss [22,38-39].

### *Wear track analysis*

Fig. 7 shows the wear track analysis results of Al7075-NLP-SiC hybrid-MMCs. The proportion of particulate (SiC & NLP) in composites affects wear rate and contributes to augmenting the composites' wear adhesion. Fig. 7(a) displays the wear track of Al7075 alloy depicting abrasive wear. Throughout the surface, thick grooves and craters are observed. Fig. 7(b) shows the wear track of Al7075 alloy reinforced with 5% SiC and 5% NLP revealing adhesive wear. All over the surface, scuffs and craters are observed; compared to Fig. 7(a), Fig 7(b) displays less wear-out surface due to the presence of reinforcement particles. Fig. 7(c) displays the wear track of Al7075 alloy reinforced with 7.5% SiC and 5% NLP revealing adhesive wear. All over the surface, scuffs and craters are observed in a few spots along with thin grooves; compared to Figs. 7(a) and 7(b), Fig 7(c) displays less wear-out surface due to the presence of reinforcement particles. Fig. 7(d) displays the wear track of Al7075 alloy reinforced with 10% SiC and 5% NLP revealing adhesive wear.

All over the surface, scuffs, specks, and craters are observed in a few spots, along with a combination of thick and thin grooves. Wear tracks of Figs. 7(b) to (d) are almost identical, with scuffs, thick and thin grooves throughout the area. Overall, it can be analyzed that as sliding wear occurs, interfaces amongst dislocations and reinforcement particles (SiC & NLP)



inhibit crack propagation from expanding. The temperature difference between the aluminium alloy and SiC particles generates strain zones around the SiC particles during solidification. These strain zones oppose the cracks' ability to spread and the subsequent material loss they cause. SiC particles are evenly distributed, producing Orowan strengthening [39-40]. At all load settings, the 7075 alloy showed the highest rate of wear, which is primarily the result of direct metal to metal contact. Several factors, such as more subsurface deformation and ensuing delamination wear, simpler removal of load-bearing particles, increased friction because of more touch couple surface asperities interlocking, material softening and matrix oxidation because of friction-precipitated temperature rise, and faster tribolayer technology and elimination, are chargeable for the growth in put on loss with an increase in load. greater factors come into play as the load increases, inflicting a fast acceleration of wear rate above the important load [41-42].

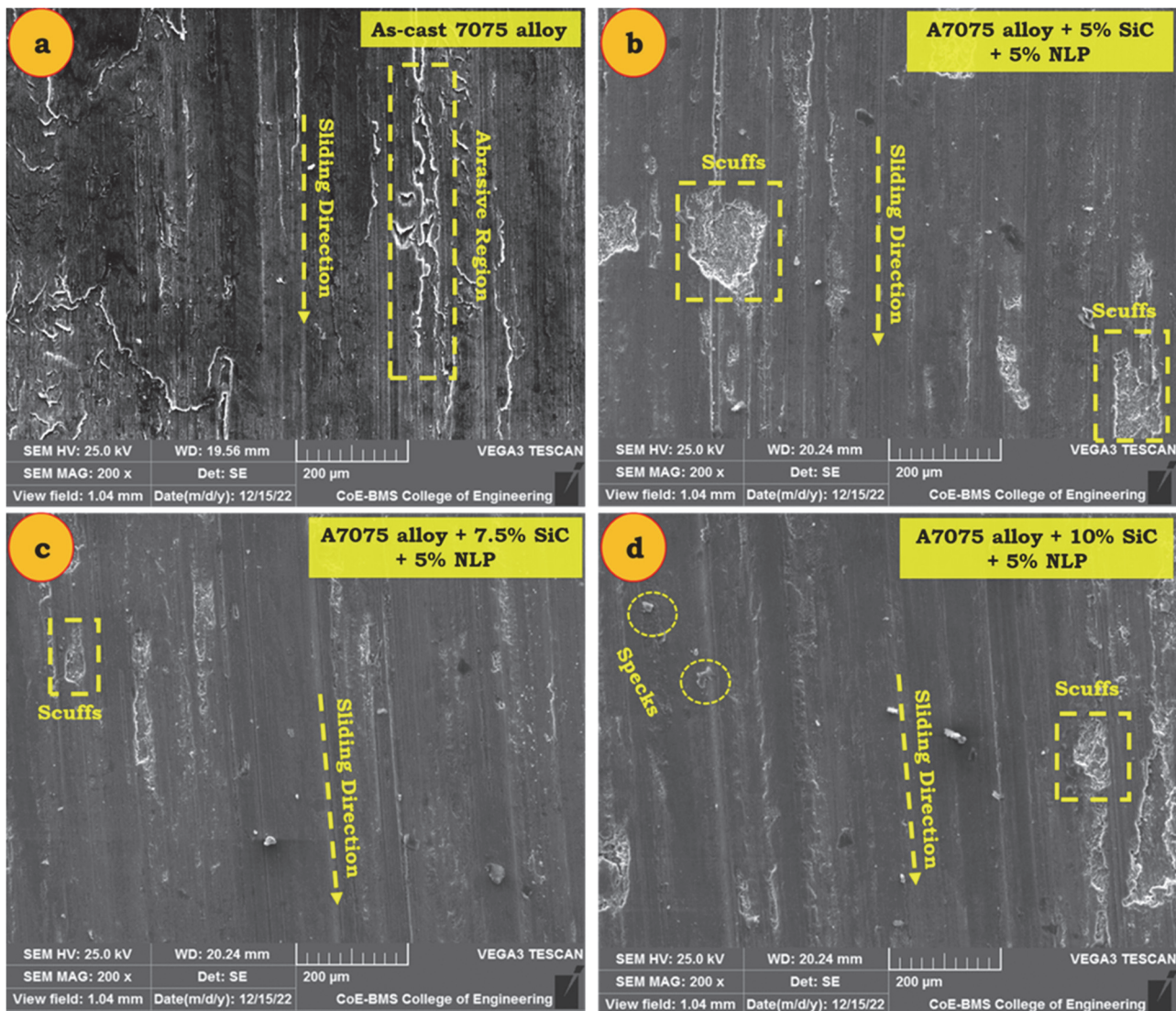


Figure 7: Wear track analysis results of Al7075-NLP-SiC hybrid-MMCs.

## CONCLUSIONS

In the present investigation, the stir casting method is used to produce hybrid MMCs made of aluminium 7075/SiC/Neem Leaf powder with varied weight percentages (5,7.5 & 10). Composites containing 10 wt.% SiC and neem leaf powder exhibited strong resistance with relation to friction coefficient and wear loss. Because the matrix and reinforcement have a strong interfacial bond, the Al/7.5wt%SiC and neem leaf powder composite displayed increased hardness. A SEM examination revealed how uniformly dispersed SiC particles all over the matrix improved the various



properties of the composite material by increasing interfacial bonding, including the use of mg powder during melting, preheating the reinforcement before pouring, and employing the right stirring time and speed during mixing.

## REFERENCES

- [1] Surappa, M.K. (2003). Aluminium matrix composites: Challenges and opportunities. *Sadhana* 28, pp 319–334. DOI: 10.1007/BF02717141.
- [2] Naher, S., Brabazon, D., Looney, L. (2004). Development and assessment of a new quick quench stir caster design for the production of metal matrix composites, *J. Mater. Process. Technol* 165(3), pp 430-439. DOI: 10.1016/j.jmatprotec.2004.09.043.
- [3] Seo, Y.H., Kang, C.G. (1999). Effects of hot extrusion through a curved die on the mechanical properties of SiCp/Al composites fabricated by melt-stirring. *Compos. Sci. Technol*, 59(5), pp 643-654. DOI: 10.1016/S0266-3538(98)00123-7.
- [4] Shivalingaiah, K., Nagarajaiah, V., Selvan, C.P., Kariappa, S.T., Chandrashekarappa, N.G., Lakshmikanthan, A., Chandrashekarappa, M.P.G., Linul, E. (2022). Stir Casting Process Analysis and Optimization for Better Properties in Al-MWCNT-GR-Based Hybrid Composites”. *Metals* 2022, 12, 1297. DOI: 10.3390/met12081297.
- [5] Praveen, K. S., Shantharaja, M., Manjunath, P. G. C., Lakshmikanthan, A., Danil, Y. P., Khaled, G., and Munishamaiah, K. (2021). Corrosion Behaviour of High-Strength Al 7005 Alloy and Its Composites Reinforced with Industrial Waste-Based Fly Ash and Glass Fibre: Comparison of Stir Cast and Extrusion Conditions. *Materials*, 14(14), 3929. DOI: 10.3390/ma14143929.
- [6] Lakshmikanthan, A., Mahesh, V., Prabhu, R.T., Patel, M.G.C., Bontha, S. (2021). Free Vibration Analysis of A357 Alloy Reinforced with Dual Particle Size Silicon Carbide Metal Matrix Composite Plates Using Finite Element Method. *Archives of Foundry Engineering*, 21(1), pp. 101 – 112, DOI: 10.24425/afe.2021.136085.
- [7] Lakshmikanthan, A., Ram, P. T., Bontha, S. (2016). The Effect on the Dry Sliding Wear Behavior of Gravity Cast A357 Reinforced with Dual Size Silicon Carbide Particles, *Applied Mechanics and Materials*, Trans Tech Publications, Switzerland, 829, pp. 83-89, DOI: 10.4028/www.scientific.net/AMM.829.83
- [8] Zhou, Z.M. (1997). Casting of SiC reinforced metal matrix composites, *J. Mater. Process. Technol*, 63(1-3), pp 358-363. DOI: 10.1016/S0924-0136(96)02647-7.
- [9] Kevorkijan, V.M., Sustarsic, B. (1997). A New Production Technology for Discontinuously Reinforced Al-SiC Composites, *Key Eng. Mater.*, 127-131, pp 471-478. DOI: 10.4028/www.scientific.net/KEM.127-131.471.
- [10] Lokesh, N., Manoj, B., Srikanth, K., Varunkumar, P., Ramanayya, P.K.V., Venkateswara R. M. (2018). Mechanical Characterization of Stir Cast Al 6063 TiO<sub>2</sub>-Cu Reinforced Hybrid Metal Matrix Composites, 5(9), pp 18383-18392, DOI: 10.1016/j.matpr.2018.06.178.
- [11] Jayashree, P.K., Gowri, S. M.C., Kini, A., Sharma, S., Shetty, R. (2013). Review on Effect of Silicon Carbide (SiC) on Stir Cast Aluminium Metal Matrix Composites, *Int. J. Curr. Eng. Technol.*, 3(3), pp 1061-1071.
- [12] Singla, D.M., Dwivedi, D., Singh, L., Chawla, V. (2009). Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite, *J. Miner. Mater. Charact. Eng.*, 8(6), pp 455-467, DOI: 10.4236/jmmce.2009.86040.
- [13] Shuvho, M.B.A., Chowdhury, M. A., Kchaou, M., Roy, B. K., Rahman, A., Islam, M. A. (2020), Surface characterization and mechanical behavior of aluminum-based metal matrix composite reinforced with nano Al<sub>2</sub>O<sub>3</sub>, SiC, TiO<sub>2</sub> particles, *Chem. Data Collect.* 28, 100442, DOI: 10.1016/j.cdc.2020.100442.
- [14] Pugaleti, P., Jayaraman, M., Natarajan, A. (2015). Evaluation of Mechanical Properties of Aluminium Alloy 7075 Reinforced with SiC and Al<sub>2</sub>O<sub>3</sub> Hybrid Metal Matrix Composites, *Appl. Mech. Mater.* 766–767, pp 246–251. DOI: 10.4028/www.scientific.net/AMM.766-767.246.
- [15] Emamy, M., Mahta, M., Rasizadeh, J. (2006). Formation of TiB<sub>2</sub> particles during dissolution of TiAl<sub>3</sub> in Al–TiB<sub>2</sub> metal matrix composite using an in-situ technique, *Compos. Sci. Technol.* 66 (7–8), pp 1063–1066. DOI: 10.1016/j.compscitech.2005.04.016.
- [16] Chelladurai, S.J.S., Kumar, S.S., Venugopal, N., Ray, A.P., Manjunath, T.C., Gnanasekaran, S. (2021). A review on mechanical properties and wear behaviour of aluminium based metal matrix composites, *Mater. Today: Proc.* 37, pp 908–916. DOI: 10.1016/j.matpr.2020.06.053.
- [17] Sihame, A.Y., Lemya, H.H.A., Zakaria, B., and Abdelouahed, T. (2018). Effect of homogenization models on stress analysis of functionally graded plates. *Structural Engineering and Mechanics*, 67(5), pp. 527-544, DOI: 10.12989/sem.2018.67.5.527.



- [18] Mehala, T., Zakaria, B., Abdelouahed, T., and Anwar, B.O. (2018). Investigation of Influence of Homogenization Models on Stability and Dynamic of FGM Plates on Elastic Foundations. *Geomechanics and Engineering* 16(3), pp. 257–71. DOI: 10.12989/GAE.2018.16.3.257.
- [19] Zakaria, B., Mohammed, S.A.H., Abdelouahed, T., Mahmoud, S.R., Anwar, B.O. (2014). An efficient and simple higher order shear and normal deformation theory for functionally graded material (FGM) plates, *Composites Part B: Engineering*, 60, pp. 274–283, DOI: 10.1016/j.compositesb.2013.12.057.
- [20] Belabed, Z., Bousahla, A. A., Houari, M. S. A., Tounsi, A., & Mahmoud, S. R. (2018). A new 3-unknown hyperbolic shear deformation theory for vibration of functionally graded sandwich plate. *Earthquakes and Structures*, 14(2), 103–115. DOI: 10.12989/EAS.2018.14.2.103.
- [21] Hadj, M., Kenanda, M. A., Hammadi, F., Belabed, Z. (2023). Free vibration analysis of the structural integrity on the porous functionally graded plates using a novel Quasi-3D hyperbolic high order shear deformation theory, *Frattura ed Integrità Strutturale*, 17(64), pp. 266–282. DOI: 10.3221/IGF-ESIS.64.18.
- [22] Dey, D., Biswas, A. (2020). Comparative study of physical, mechanical and Tribological properties of Al2024 alloy and SiC-TiB<sub>2</sub> composites. *Silicon*, 13, pp 1895–1906. DOI: 10.1007/s12633-020-00560-9.-22
- [23] Karakoc, H., Ovali, I., Dundar, S., Citak, R., (2019). Wear and mechanical properties of Al6061/SiC/B<sub>4</sub>C hybrid composites produced with powder metallurgy technique. *J Mater Res Technol*, 8(6), pp 5348–5361. DOI: 10.1016/j.jmrt.2019.09.002.-23
- [24] Dey, D., Bhowmik, A., Biswas, A. (2020). Effect of SiC content on mechanical and Tribological properties of Al2024-SiC composites. *Silicon*, 14, pp 1–11 DOI:10.1007/s12633-020-00757-y.
- [25] Manikandan, R., Arjunan, T.V. (2020). Mechanical and tribological behaviors of aluminium hybrid composites reinforced by CDA-B<sub>4</sub>C, *Mater. Res. Express*, 7, 016584, DOI: 10.1088/2053-1591/ab6b54.
- [26] Kalaiselvan, K., Murugan, N., Parameswaran, S., (2011). Production and characterization of AA6061–B<sub>4</sub>C stir cast composite. *Mater Des* 32(7), pp 4004–4009. DOI: 10.1016/j.matdes.2011.03.018.
- [27] Selvam, J.D.R., Smart, D.R., Dinaharan, I. (2013). Microstructure and some mechanical properties of fly ash particulate reinforced AA6061 aluminum alloy composites prepared by compo casting. *Mater Des*, 49, pp 28–34. DOI: 10.1016/j.matdes.2013.01.053.
- [28] Ezatpour, H.R., Sajjadi, S.A., Sabzevar, M.H., Huang, Y. (2014). Investigation of microstructure and mechanical properties of Al6061-nanocomposite fabricated by stir casting. *Mater Des*, 55, pp 921–928. DOI: 10.1016/j.matdes.2013.10.060.
- [29] Mahesh, V.P., Nair, P.S., Rajan, T.P.D., Pai, B.C., Hubli R.C. (2011). Processing of surface-treated boron carbide-reinforced aluminum matrix composites by liquid–metal stir-casting technique. *J Compos Mater*, 45(23), pp 2371–2378. DOI: 10.1177/0021998311401086.
- [30] Ma, Z.Y., Tjong, S.C., Li, Y.L., Liang, Y. (1997). High temperature creep behavior of nanometric Si<sub>3</sub>N<sub>4</sub> particulate reinforced aluminium composite. *Mater Sci Eng A*, 225(1–2), pp 125–134. DOI: 10.1016/S0921-5093(96)10870-4.
- [31] Lakshmikanthan, A., Angadi, S., Malik, V., Saxena, K.K., Prakash, C., Dixit, S., Mohammed, K.A. (2022). Mechanical and Tribological Properties of Aluminum-Based Metal-Matrix Composites. *Materials*, 15, 6111. DOI: 10.3390/ma15176111.
- [32] Ravindran, P., Manisekar, K., Narayanasamy, R., Narayanasamy, P. (2013). Tribological behaviour of powder metallurgy-processed Aluminium hybrid composites with the addition of graphite solid lubricant, *Ceram Int*, 39(2), pp. 1169–1182. DOI: 10.1016/j.ceramint.2012.07.041.
- [33] Lakshmikanthan, A., Srikanth, B., Krishna, M., Koppad, P. G., Prabhu, T. R. (2019). Microstructure, mechanical and wear properties of the A357 composites reinforced with dual sized SiC particles. *Journal of Alloys and Compounds*-786(25), pp. 570-580. DOI: 10.1016/j.jallcom.2019.01.382.
- [34] Idusuyi, N., Olayinka, J.I. (2019). Dry sliding wear characteristics of aluminium metal matrix composites: a brief overview. *J Mater Res Technol*, 8(3), pp 3338–3346. DOI: 10.1016/j.jmrt.2019.04.017.
- [35] Majzoobi, G.H., Atrian, A., Enayati, M.H. (2015). Tribological properties of Al7075-SiC nanocomposite prepared by hot dynamic compaction. *Compos Interf*, 22(7), pp 579–593. DOI: 10.1080/09276440.2015.1055955.
- [36] Udoye, N. E., Fayomi, O. S. I. and Inegbenebor, A. O. (2020). Fractography and Tensile Properties of AA6061 Aluminium Alloy/Rice Husk Ash Silicon Nanocomposite, *Materials and Corrosion Advancements, International Journal of Chemical Engineering*. DOI: 10.1155/2020/8818224.
- [37] Rajan, H.B.M., Ramabalan, S., Dinaharan, I., Vijay, S.J. (2014). Effect of TiB<sub>2</sub> content and temperature on sliding wear behavior of AA7075/TiB<sub>2</sub> in situ aluminum cast composites. *Arch Civil Mech Eng*, 14(1), pp. 72–79.



- [38] Veeravalli, R. R., Nallu, R., & Mohiuddin, S. M. M. (2016). Mechanical and tribological properties of AA7075–TiC metal matrix composites under heat treated (T6) and cast conditions. *Journal of Materials research and Technology*, 5(4), pp. 377-383.
- [39] Ravikumar, M., Suresh, R., Reddappa, H. N., Ram Mohan, Y. S., Nagaraja, C. R., and Babu, E. R. (2021). Investigations on tensile fractography and wear characteristics of Al7075-Al<sub>2</sub>O<sub>3</sub>-SiC Hybrid Metal Matrix Composites routed through liquid metallurgical techniques, *Frattura ed Integrità Strutturale*, 15(56), pp. 160–170. DOI: 10.3221/IGF-ESIS.56.13.
- [40] Gouda, S., Veeresh Kumar, G. B., Pramod, R., Prasanna, N. D., Balasubramanya, H. S. and Aradhya, S. M. (2022). Fabrication, Mechanical and Wear Properties of Aluminum (Al6061)-Silicon Carbide-Graphite Hybrid Metal Matrix Composites, *Frattura ed Integrità Strutturale*, 16(62), pp. 134–149. DOI: 10.3221/IGF-ESIS.62.10.
- [41] Chate, G. R., Kulkarni, R. M., Chandrashekarappa, M. P. G., Lakshmikanthan, A., Harsha, H. M., Tophakhane, S., Iranavar, P. (2022). Synthesis and Characterization of Fe<sub>2</sub>O<sub>3</sub> nanoparticles reinforced to recycled industrial aluminium scrap and waste aluminium beverage cans for preparing metal matrix nanocomposites. *Frattura ed Integrità Strutturale*, 16(60), 229-242. DOI: 10.3221/IGF-ESIS.60.16.
- [42] Lakshmikanthan, A., Udayagiri, S. B., Koppad, P. G., Gupta, M., Munishamaiah, K., and Bontha, S. (2020). The effect of heat treatment on the mechanical and tribological properties of dual size SiC reinforced A357 matrix composites. *Journal of Materials Research and Technology*, 9(3), 6434-6452. DOI: 10.1016/j.jmrt.2020.04.027.