

AN INVESTIGATION ON THE EFFECT OF NI-CR COATING THICKNESS ON THE SCRATCH RESISTANCE OF PARTICLE-REINFORCED ALUMINIUM MATRIX COMPOSITE

Siva Prakash Palleda^{1,*} and Kagathur Goud Satish²

Received: March 26, 2023; Revised: July 10, 2023; Accepted: September 11, 2023

Abstract

Composite materials are best suited for many engineering applications due to their high strength-to-weight ratio. Metal matrix composites have drawn attention due to their superior mechanical qualities and economics in preparation. This study uses stir casting to prepare aluminum 6065 with SiC particles in varied concentrations. Scanning electron microscopy (SEM) was used to examine the effects of particle content (8 to 12 wt%), loading variables, and Ni-Cr coating thickness (100 and 200 microns) on the scratch resistance of the composites. Scratch tests were also used to examine the friction coefficient and scratch morphology of the aluminum matrix composites. When compared to lower particle concentrations in the matrix material, it has been found that more significant particle content provides more excellent scratch resistance.

Keywords: Aluminium matrix composite; Ni-Cr coating; Scratch test; SiC particles

Introduction

The aircraft, aerospace, and automotive sectors frequently use aluminum matrix composites (AMCs) reinforced with ceramic particles due to their high stiffness, strength-to-weight ratio, low coefficient of thermal expansion, and exceptional wear resistance (Yuan *et al.*, 2016). Excellent casting qualities make aluminum alloy a popular choice for complicated geometries. These cast components are subjected to cyclic loading in engineering practice, which may cause fatigue failure (Hosseini *et al.*, 2015). Al/TiB₂ nano-composites were created using the powder metallurgy method by first pressing aluminum

powder with varying TiB₂ volume ratios, and then sintering them between 620°C and 690°C (Suryanarayana, 2001; Kumar and Balasubramanian, 2010; Chen *et al.*, 2015). Haghighi *et al.* (Haghighi *et al.*, 2012) considered Al-5 by vol% and Al₂O₃ by equal channel angular pressing and extrusion and compared the physical and mechanical properties. Studies are conducted on preparing the AMCs reinforced by two sizes of alumina particles by hot forward extrusion and wet attrition milling processes (Khorshid *et al.*, 2010).

Duirs *et al.* (Deuis *et al.*, 1996) evaluated the fracture toughness of constituent phases by means

¹ Department of Mechanical Engineering, GM Institute of Technology, Davangere, Karnataka, India. E-mail: palleda@gmail.com

² Department of Mechanical Engineering, UBDT College of Engineering, Davangere, Karnataka, India. E-mail: kgsati@gmail.com

* Corresponding author

DOI: <https://doi.org/10.55766/sujst-2023-06-e0864>

Suranaree J. Sci. Technol. 30(6):030154(1-7)

of a scratch test with an increasing force. The phase was not considered due to the escalating level of pressure. This approach distinguished the shift from ductile to brittle abrasion based on the onset of lateral cracking. It was observed that the ratio of fracture hardness to toughness was determined to investigate whether the material was ductile or brittle.

In numerous scratch investigations, abrasive materials (quartz and alumina) were utilized instead of the usual diamond indenter to simulate abrasive wear in dual-phase alloys. Further studies on the use of diamond indentors and Al_2O_3 in scratch experiments on Co-based alloys to investigate the mechanisms for removing the material are being investigated (Prasad *et al.*, 1986).

The cohesion or adhesion bond strength of thin and thick coatings can be evaluated in the laboratory using a variety of test procedures. (Heimann, 1996). However, each one has its own set of advantages and limitations. The scratch test is easy to use and doesn't need any further specimen preparation, despite the fact that it is not as accurate as other techniques. Scratch testing is a remarkable tool for optimizing plasma spraying settings. It has been used for a while to figure out how well a coating adheres to its base. (Bull and Berasetegui, 2006). The adhesion and failure processes of thin layers (20 microns) have previously been investigated by scratching the coating's surface. The faults introduced during composite processing can reduce fatigue performance and cause early failure. Thus, a method for quantitatively evaluating these flaws that take into account both safety and economics needs to be developed (Yang *et al.*, 2022).

The exterior damage to the surfaces of the components may happen throughout the processes of manufacturing, repairing, and providing services owing to accidents like the fall of tools or scratches by sharp objects. One of the most dangerous surface

flaws is the scratch caused by accidents. A study (Doremus *et al.*, 2015) reported that a small scratch can significantly reduce the fatigue life of aluminum alloys. Many factors associated with the scratch may influence the fatigue performance. These factors can be classified as, morphology and configuration of the scratch, residual stresses around the scratch, and microstructure characteristics of the material in the vicinity the scratch. (Feng *et al.*, 2014). (Nishimura *et al.*, 2018) conducted torsional fatigue tests and rotating bending fatigue tests on specimens with scratches, and pointed out that when the direction of a scratch is perpendicular to the maximum principal stress, the fatigue performance is degraded most.

Materials and Methods

The aluminum 6065 makes it an ideal choice for aircraft frames, fuselages, and wings where weight savings are important considerations. It is also used in the automotive industry for engine parts such as pistons, cylinder heads, and other components like suspension arms and steering knuckles. 6065 aluminum is a 6000-series aluminum alloy: there is significant alloying with both magnesium and silicon, and the alloy is formulated for primary forming into wrought products. 6065 is the Aluminum Association (AA) designation for this material. In European standards, it will be given as EN AW-6065.

Among many materials, aluminum suits most applications because of its agility to take different forms, lightweight, low melting temperature, good mechanical properties, availability, and ease of handling. The following Table 1 shows the composition of the aluminum 6065 alloys.

Stir casting method

Stir casting is widely regarded as a low-cost approach for fabricating aluminum metal matrix composites (AMMCs) in the commercial world. Its advantages are its ease of use, adaptability, and suitability for large-scale production. This method is the most cost-effective of all the AMMC manufacturing methods, and it enables the fabrication of extremely large components. Figure 1 shows the arrangements of the stir-casting process. Between the reinforcement and the matrix alloy, there is no chemical interaction. Good wettability is a critical property that defines the quality of bonding between constituents and, as a result, has a substantial impact on the properties of composite materials (Hashim *et al.*, 1999; Naher *et al.*, 2003).

Table 1. Composition of 6065-Aluminium alloy

%Al	%Bi	%Si	%Fe	%Cu	%Zn
94.4-98.5	0.5-1.2	0.4-0.8	0-0.7	0.15-0.4	0-0.25

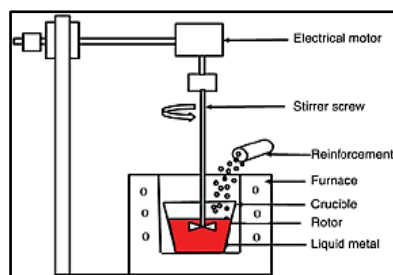


Figure 1. Stir casting arrangement

Preheating the reinforcements improved good wettability and reduced the porosity by allowing moisture to escape and produce the sound casting. The researchers observe that preheating the moulds positively impacts the final casting. Many variables influence the composites' final mechanical and microstructure properties. The stirrer speed, stirring time, and pouring temperature play a vital role in producing a structurally sound casting (Soltani *et al.*, 2017). The aluminum 6065 bars were melted in a furnace SiC particles were added by 30, 60, and 120 microns by weight percentages to the molten metal for each melt. Under constant stirring at 700 rpm for up to 10 minutes, the liquid metal is poured into the preheated EN 19 mould.

Specimen preparation

The solidified casting is machined by end milling operations and coated for varying thicknesses, as shown in Figure 2, for the given specimen dimension as per the ASTM G-117 standards.

Ni-Cr Plasma coating

Thermal spraying is one of the most versatile hard-facing techniques available for the application of coating materials used to protect components from abrasive wear, adhesive wear, erosive wear or surface fatigue, and corrosion. Figure 3 shows the coating process in which powders of the coating materials are fed into the plasma jet at around 10,000-15,000°C, at which the coating materials melt and are sprayed over the substrate to be coated. Ni-Cr materials are being coated to the surface of the composites. A 100 and 200 microns coating thickness is considered for the test.

Scratch testing

Tests are conducted for constant normal load and ramp load using the 45° diamond indenter on the digitally controlled scratch tester. DUCOM Scratch tester TR-101 model, as shown in Figure 4, is used for generating scratches on the surface of the composite. Different loading types, such as constant load and ramp load with different intensities, have been analyzed. A diamond indenter with a 45° angle is used for the test.

The specimens are fixed on the table with attachments; after fixing the specimen, types of loads and intensity, stroke length, and set distance can be selected. After parameters are set, the indenter will move above the specimen. The scratch will be initiated and the traction force v/s stroke length graph will be shown on the display provided. After the scratch, the camera captures the high-definition image of the scratch and stores it for analysis. For each specimen, the above steps are



Figure 2. Scratch test specimen of 8, 10, 12% SiC for 100 µ coating thickness



Figure 3. Plasma spray coating of ceramic coating onto a metal substrate



Figure 4. DUCOM Scratch tester TR-101 model

repeated until all specimens are being tested against scratch resistance

A scratch test was carried out for varying reinforcement concentrations and coating thickness. A constant load of 30N and a stroke length of 10 mm is considered for the testing. From the result, it was observed that as loading increases, the scratch resistance increases. Also, for ramp loads, the resistance offered by the materials increases, and in the case of constant load, the traction force increases initially up to a certain length of the stroke and remains constant throughout the stroke. From the scratch test, it was observed that the effort required to produce the scratch on the specimen reduced with the increase in the coating thickness. SEM images show the track of the scratch test; the coating materials are deformed to allow the indenter to move with minimum resistance.

Results and Discussion

Effect of 8% SiC Particle Concentration on Constant Load

To investigate the effect of the constant load, 30N is applied to the indenter, and the traction force required to make a scratch on the surface is shown in Figure 5. The difference between the traction force and the normal load is the force required by the indenter to overcome the resistance of the material for the scratch to be developed on the surface of the material.

Initially, high resistance is offered by the material. This can be observed in the graph up to 0.8 mm, the rise in the traction force required. As the material deformed, it flows outwards to make a way

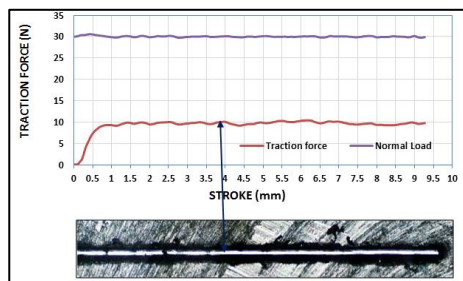


Figure 5. Effect of 8% SiC particle for 30N constant load on scratch resistance: Traction force

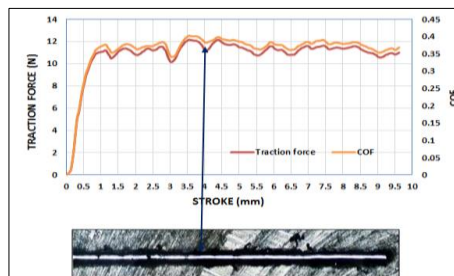


Figure 6. Effect of 8% SiC particle for 30N constant load on scratch resistance: COF & Traction force

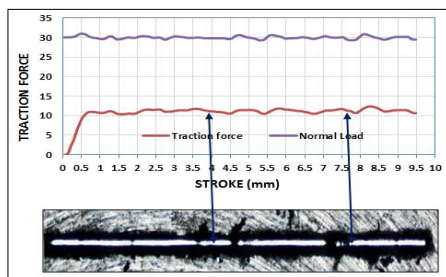


Figure 7. Effect of 10% SiC particle for 30N constant load on scratch resistance: Traction force

for the scratch to be developed, this reduces the force required to overcome the resistance of the deformed material and maintains the constant traction force around 10N throughout the 10 mm stroke length.

It is further observed in Figure 6 that at nearly 4.15 mm stroke, there is a peak in the traction force, which is illustrated in the above image. Similarly, many such peaks on the graphs show the particle resistance for the scratch. This also indicates the particles have distributed throughout the length of the stroke, the value of the traction force indicates the extra force required to overcome the resistance of the particle in the track of the indenter for the tested composite specimen.

During the testing of the above specimen, the coefficient of friction (COF) was recorded. This value represents the amount of friction offered for the movement of the diamond indenter in the surface.

COF is the representation of friction. It is observed that at the same place at nearly 4.15 mm stroke length where the particles have obstructed the movement of the indenter, the COF has increased as observed from Figure 6. It is also shown in the image that the material is undisturbed, which indicates the resistance offered by the composite for the scratch to progress.

Effect of 10% SiC Particle Concentration on Constant Load

To analyze the effect of the constant load, 30N is applied to the indenter, and the traction force required to make a scratch on the surface is shown in Figure 7. Initially, high resistance is offered by the material; this can be observed in the graph up to 0.7 mm, the rise in the traction force required. As the material deformed, it flows outwards to make a way for the scratch to be developed, this reduces the force required to overcome the resistance of the deformed material and maintains the constant traction force around 10N throughout the 10 mm stroke length.

It is further observed in Figure 8 that at nearly 8.2 mm stroke, there is a peak in the traction force. This is reflected in the image of the scratch below the graph. Similarly, many such peaks nearly at 1.25 and 5.75 mm are observed on the graphs this shows the particle resistance for the scratch. This also indicates the particles have distributed throughout the length of the stroke.

For the above testing, the coefficient of friction (COF) has been recorded. This value represents the amount of friction offered for the movement of the diamond indenter in the surface. COF is the representation of friction. It is observed that at the same place at nearly 8.2 mm stroke length where the

particles have obstructed the movement of the indenter, the COF has increased, as observed in Figure 9. It is also shown in the image that the material is ununiformly distributed, this causes resistance by the composite for the scratch to progress.

Effect of 12% SiC Particle Concentration on Constant Load

To investigate the effect of the constant load, 30N is applied to the indenter, and the traction force required to make a scratch on the surface is shown in Figure 9.

The difference between the traction force and the normal load is the force required by the indenter to overcome the resistance of the material for the

scratch to be developed on the surface of the material.

Initially, high resistance is offered by the material. This can be observed in the graph up to 1.1 mm, the rise in the traction force required. As the material deformed, it flows outwards to make a way for the scratch to be developed, this reduces the force required to overcome the resistance of the deformed material and maintains the constant traction force around 10N to 14N throughout the 10 mm stroke length. It is further observed in Figure 10 that at nearly 3.0 mm stroke, there is a peak in the traction force. This is reflected on the image of the scratch below the graph. Similarly at 7.00mm there is a valley to indicate the particle is removed and the load required is very less hence the valley to show less force is required to overcome the scratch resistance is observed. Many such minor peaks on the graphs shows the particle resistance for the scratch. This also indicates the particles have distributed throughout the length of the stroke. The value of the traction force indicates the extra force required by the indenter to overcome the resistance of the particle in the track of the indenter.

During the testing of the above specimen, the coefficient of friction (COF) was recorded. This value represents the amount of friction offered for the movement of the diamond indenter in the surface.

COF is the representation of friction. It is observed that at the same place at nearly 3 mm stroke length where the particles have obstructed the movement of the indenter, the COF has increased, as observed from Figure 8. It is also shown in the image that at 7.00 mm, the removal of clustered particles has less resistance to offer, and hence the value is reduced.

Effect of Coating on Scratch Resistance for 8% SiC with Constant Load

Tests were further conducted for nickel-chromium coating for 100 and 200 microns thickness. Similar loading parameters were used, and the results are shown in Figure 11. The traction force for without coating and with coating for varying thickness are plotted. It is observed that the coating is well adhered to the substrate, and it has not peeled out. It is the strong bonding between the substrate and the coating which allows better surface characteristics of the coated specimen. The traction force required for 100 micron thickness is much lower than the uncoated specimen, as the depth of penetration is not enough to scratch through the surface and into the substrate. The increases in the coating thickness show that the material offers less resistance to scratches.

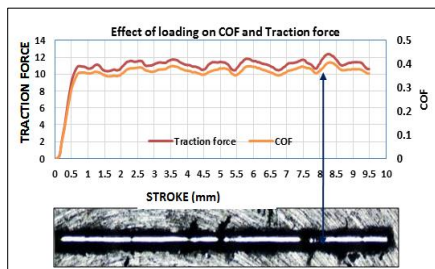


Figure 8. Effect of 10% SiC particle for 30N constant load on scratch resistance: COF & traction force

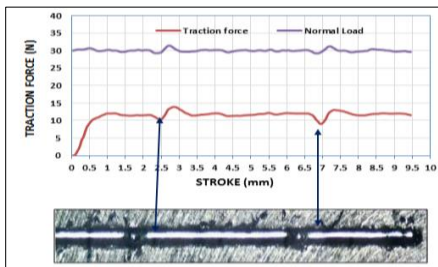


Figure 9. Effect of 12% SiC particle for 30N constant load on scratch resistance: Traction force

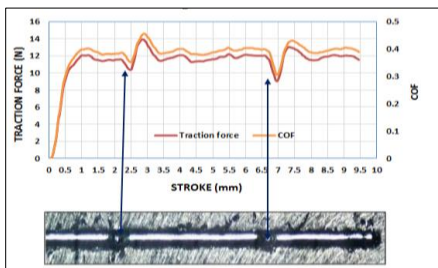


Figure 10. Effect of 12% SiC particle for 30N constant load on scratch resistance: COF & traction force

It is observed from Figure 11 above that the constant traction force increased from 0 to 11.2 N and maintained a steady average value of around 11-12 N. The variations of peaks and valleys over the entire length of travel of the indenter indicate that

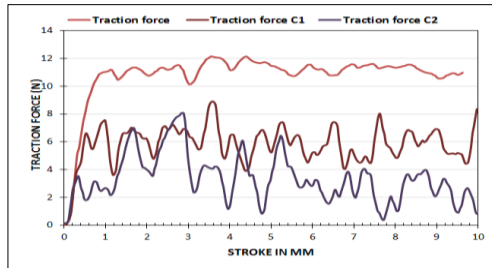


Figure 11. Effect of 100, 200-micron coating thickness on scratch resistance for 8% SiC

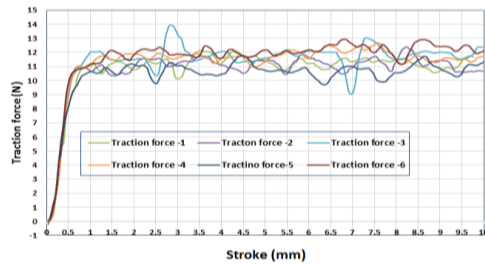


Figure 12. Effect of 100, 200-micron coating thickness on scratch resistance for 8% SiC

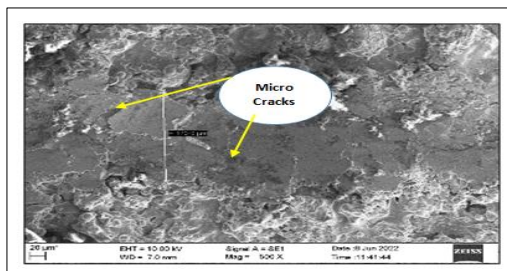


Figure 13. SEM image of 200-micron Ni-Cr coating

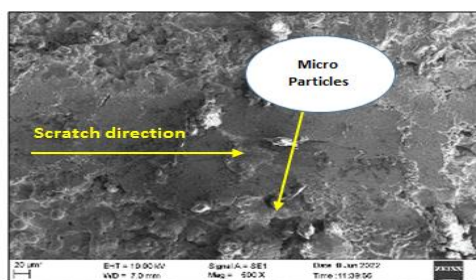


Figure 14. SEM image of 200-micron Ni-Cr coating

the particles have uniformly distributed over the entire surface of the composite specimen. Similarly, the 100-micron coating thickness experiences traction load in a range of 4-7 N. The difference between the normal loads and the traction force is the resistance offered by the coating material.

Effect of Various Concentrations on Traction Force for Constant Load

The traction force for all the concentrations of silicon carbide and alumina is plotted in Figure 12. The variation of the force is as observed earliest that all the values are nearly 10 to 13 N constant load.

The hills show the resistance offered by the particles in the path of the scratch, and the valleys reflect the blow holes or the removals of the clogged particles, which have no resistance to offer for the scratch.

The hard particle coating resisted less in comparison to the uncoated specimen. Figure 13 shows the scratch on the surface of the 100-micron coating. It is noticed that the indenter has plastically deformed the coating particle, and the surface cracks on the scratch path can be observed. The results were comparable from the work carried out by (Tippeswamy *et al.*, 2023). Similar loading conditions were applied.

The width of the scratch measured is around 170 microns and the indenter moves with less resistance on the coating material.

For 200 microns coating it is observed that the deformation of the coated particles is reduced further as the hardness is increased. This requires less traction load to be applied on the surface of the coating to produce the scratch.

Further observation revealed that the indenter has made less penetration in the coating surface, as shown in Figure 14, that less force is applied on the 200-micron coating in comparison with 100 microns coated specimens. The coating particle and the direction of the scratch are observed in the SEM image.

The scratch direction and the plastic deformation of the particles have shown the resistance offered by the particles for the scratch.

Conclusion

The present study shows that:

I. Aluminum matrix composites reinforced with SiC particles were successfully fabricated by the stir casting method. Initially, for 8% SiC, the traction force is increased up to 10N for a stroke length of 0.8 mm and maintained constant value. A similar trend is being shown by (Tippeswamy *et al.*, 2023).

II. COF values for 8% SiC reflect a similar trend up to 0.8mm stroke length and show some peaks and valleys to represent the presence of the particles in the indenter path travel.

III. Increase in the particle concentration increases the traction force for the given particle size. This can be attributed primarily to the ununiformed distribution of the particles, which causes clusters and requires more force to produce the scratch.

IV. Under the present scratch test conditions, coating of Ni-Cr with 100 microns thickness has reduced the traction force to 6-7N for the scratch as the harder particles have less friction for the movement and more uniform partical distribution.

V. Increasing in the coating thickness has further reduced the traction force to 5-6N for the scratch formation. This is mainly because of better surface characteristics and better wettability between the initial coating and the final coating

VI. Figure 12 shows the variation of traction force for all the particles the hills on the graph show a uniform distribution of the particles along the indenter path.

References

- Bull, S.J. and Berasetegui, E.G. (2006). An overview of the potential of quantitative coating adhesion measurement by scratch testing. *Tribology International*, 39(2):99-114. <https://doi.org/10.1016/j.triboint.2005.04.013>
- Chen, C., Guo, L., Luo, J., Hao, J., Guo, Z., and Volinsky, A.A. (2015). Aluminum powder size and microstructure effects on properties of boron nitride reinforced aluminum matrix composites fabricated by semi-solid powder metallurgy. *Materials Science and Engineering: A*, 646:306-314. <https://doi.org/10.1016/j.msea.2015.08.081>
- Deuis, R.L., Subramanian, C., and Yellup, J.M. (1996). Abrasive wear of aluminium composites-a review. *Wear*, 201(1-2):132-144. [https://doi.org/10.1016/S0043-1648\(96\)07228-6](https://doi.org/10.1016/S0043-1648(96)07228-6)
- Doremus, L., Cormier, J., Villechaise, P., Henaff, G., Nadot, Y., and Pierret, S. (2015). Influence of residual stresses on the fatigue crack growth from surface anomalies in a nickel-based superalloy. *Materials Science and Engineering: A*, 644:234-246. <https://doi.org/10.1016/j.msea.2015.07.077>
- Feng, P., Guiqiang L., and Jianfu Z. (2014). Ultrasonic vibration-assisted scratch characteristics of silicon carbide-reinforced aluminum matrix composites. *Ceramics international*, 40(7):10,817-10,823 <https://doi.org/10.1016/j.ceramint.2014.03.073>
- Haghighi, R.D., Jahromi, S.A.J., Moresedgh, A., and Khorshid, M.T. (2012). A comparison between ECAP and conventional extrusion for consolidation of aluminum metal matrix composite. *Journal of materials engineering and performance*, 21:1,885-1,892. <https://doi.org/10.1007/s11665-011-0108-9>
- Hashim, J., Looney, L., and Hashmi, M. (1999). Metal matrix composites: production by the stir casting method. *Journal of Materials Processing Technology*, 92-93:1-7. [https://doi.org/10.1016/S0924-0136\(99\)00118-1](https://doi.org/10.1016/S0924-0136(99)00118-1)
- Heimann, R.B. (1996). Plasma-spray coating principles and applications. First edition. Verlagsgesellschaft. GmbH., 140-143. <https://doi.org/10.1002/9783527614851>
- Hosseini, V.P., Abdizadeh, H., and Baghchesara, M.A. (2015). Fabrication of TiB₂ nanoparticulates-reinforced aluminum matrix composites by powder metallurgy route. *Journal of Composite Materials*, 49(25):3,115-3,125. <https://doi.org/10.1177/0021998314560382>
- Khorshid, M., Tabandeh, S.A., Jenabali, J., and Moshksar, M.M. (2010). Mechanical properties of tri-modal Al matrix composites reinforced by nano-and submicron-sized Al₂O₃ particulates developed by wet attrition milling and hot extrusion. *Materials and design*, 31(8):3,880-3,884. <https://doi.org/10.1016/j.matdes.2010.02.047>
- Kumar, S. and Balasubramanian. V. (2010). Effect of reinforcement size and volume fraction on the abrasive wear behaviour of AA7075 Al/SiCp P/M composites-a statistical analysis. *Tribology international*, 43(1-2):414-422. <https://doi.org/10.1016/j.triboint.2009.07.003>
- Naher, S., Brabazon, D., and Looney, L. (2003). Simulation of the stir casting process. *Journal of Materials Processing Technology*, 143-144:567-571. [https://doi.org/10.1016/S0924-0136\(03\)00368-6](https://doi.org/10.1016/S0924-0136(03)00368-6)
- Nishimura, Y., Yanase, K., Ikeda, Y., Tanaka, Y., Miyamoto, N., Miyakawa, S., and Endo, M. (2018). Fatigue strength of spring steel with small scratches. *Fatigue & Fracture of Engineering Materials & Structures*, 41(7):1,514-1,528. <https://doi.org/10.1111/ffe.12793>
- Prasad, S.V., Rohatgi, P.K., and Kosel, T.H. (1986). Mechanisms of material removal during low stress and high stress abrasion of aluminum alloy-zircon particle composites. *Materials Science and Engineering*, 80(2):213-220. [https://doi.org/10.1016/0025-5416\(86\)90199-0](https://doi.org/10.1016/0025-5416(86)90199-0)
- Soltani, S., Khosroshahi, R.A., Mousavian, R.T., Jiang, Z-Y., Boostani, A.F., and Brabazon, D. (2017). Stir casting process for manufacture of Al-SiC composites. *Rare Metals*, 36(7):581-590. <https://doi.org/10.1007/s12598-015-0565-7>
- Suryanarayana, C. (2001). Mechanical alloying and milling. *Progress in materials science*, 46(1-2):1-184. [https://doi.org/10.1016/S0079-6425\(99\)00010-9](https://doi.org/10.1016/S0079-6425(99)00010-9)
- Tippteswamy, M.S., Arun, K.V., and Naik, S. (2023). Effect of thick film coating on scratch resistance of aluminium 6082-T6 alloy under varied loading conditions. *Materials Today: Proceedings*, 80(Part 2):965-971. <https://doi.org/10.1016/j.matpr.2022.11.449>
- Yang, S., Hu, W., Zhan, Z., Li, J., Bai, C., Yang, Q., and Meng, Q. (2022). Fatigue tests and a damage mechanics-based fatigue model on a cast Al-Si-Mg aluminum alloy with scratches. *International Journal of Fatigue*, 165:107198. <https://doi.org/10.1016/j.ijfatigue.2022.107198>
- Yuan, L., Han, J., Liu, J., and Jiang, Z. (2016). Mechanical properties and tribological behavior of aluminum matrix composites reinforced with in-situ AlB₂ particles. *Tribology International*, 98:41-47. <https://doi.org/10.1016/j.triboint.2016.01.046>