Enhancing Mechanical Properties of Aluminium Alloy 7075 using Nano-Titanium Dioxide Reinforcement

1.Dr. Girish.K.B

Professor

BGS Institute of Technology

girish.kn03@gmail.com

2.Yashwanth.M. V

ygowda07@gmail.com

BGS Institute of technology

3. Dr.Manjunath.S.H

Professor

BGS Institute of technology

hodme@bgsit.ac.in

4. Dr.Narendra.B.K

Principal and Dean

BGS Institute of technology

b_k_narendra@yahoo.com

Abstract:

The goal of this work is to develop and analyse Al7075-nano TiO_2 composites using the stir casting method. To achieve uniform dispersion, titanium dioxide (TiO_2) nanoparticles were methodically incorporated into the liquid state of the aluminium alloy Al7075. The microstructural analysis revealed the presence of a more refined grain structure due to the incorporation of nano TiO_2. In comparison to the original Al7075 alloy, the mechanical properties of the nanocomposites showed significant improvements in microhardness, ultimate tensile strength (UTS), and impact energy. Increased nano TiO_2 concentrations resulted in higher microhardness values, which can be attributed to improved nanoparticle dispersion and dislocation strengthening. The thermal conductivity of the material under study increased linearly with the concentration of nano TiO_2, peaking at a remarkably high value at 6% nano TiO_2 content. Furthermore, the incorporation of nano TiO_2 particles into Al7075 resulted in a significant increase in impact energy absorption, making these composites well-suited for applications requiring impact resistance.

Keywords: Al7075, TiO_2, Microstructure, Mechanical properties, Impact energy.

1.0 Introduction:

Various manufacturing sectors have seen an increase in demand for materials with high strength and low density in recent decades. For improved performance and efficiency, industries such as aerospace, automotive, marine, and mining have increasingly relied on lightweight materials such as titanium, magnesium, and aluminium and their alloys [1, 2]. Because of their superior thermal and electrical conductivity, high corrosion resistance, workability, and impressive strength-to-weight ratio, aluminium alloys in particular have gained significant popularity [3]. The construction industry, which consumes a significant portion of global aluminium production, benefits from the versatility of aluminium alloys in forming intricate shapes for unusual projects [4]. Furthermore, because of their exceptional corrosion resistance and low maintenance requirements, they are ideal for marine environments and other difficult applications [4]. Innovative aluminium structural systems have emerged as a result of ongoing technological advancements, demonstrating superior economic and environmental performance when compared to traditional steel and concrete structures, contributing to sustainability and climate change mitigation [5]. Aluminium alloys from the

7xxx series, particularly Al-zinc (Al-7xxx class alloy), have proven to be especially suitable for applications requiring a high strength-to-weight ratio [6, 7]. The exceptional properties of Al 7075 alloys, such as high yield strength and elongation at failure, benefit components used in aerospace, aircraft, marine, and military applications such as missile tail cones, helicopter blades, and engine casings [8, 9]. Researchers have turned to the development of advanced aluminium matrix composites (AMCs) to improve the mechanical and functional properties of aluminium alloys [10]. Metal matrix nanocomposites (MMNCs) reinforced with nanoparticles has shown significant promise in outperforming conventional micron-scale reinforcements. These MMNCs have demonstrated exceptional mechanical strength, creep resistance, and fatigue life at high temperatures [11-13].

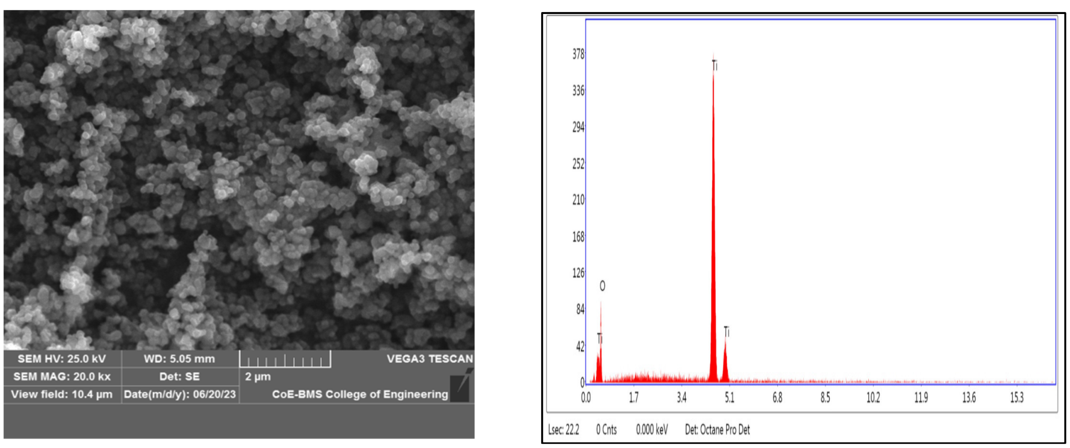
Dhanabalakrishnan et al.'s work [14] focused on the development of Al7075-nano TiO2 composites using the traditional stir casting technique. The paper investigates the microstructural interface properties between Al7075 and nano-TiO2, along with Vickers hardness and tensile/elongation measurements. The study demonstrates a notable enhancement in ultimate tensile strength (UTS), hardness, and elongation's strength over the parent material. The research conducted by Harsha et al. [15] explored the fabrication of nano composites of Al 356 reinforced with ZrO2 nanoparticles. The study investigated the morphological and mechanical properties of the resulting composites, revealing improvements in hardness and tensile strength with the addition of ZrO2 nanoparticles. AbuShana and Moustafa [16] utilized friction stir processing (FSP) to reinforce AA 2024 with Al2O3 nanoparticles. The study investigated the effect of process variables on wear resistance, mechanical properties, and hardness behavior of the MMNCs. The findings showed significant improvements in hardness and wear resistance, making them ideal for aerospace and automotive applications. Karunanithi et al. [17] studied the synthesis of Al 7075/TiO2 nanocomposites through mechanical milling, cold compaction, and sintering. The research demonstrated that nanocomposites exhibited superior compressibility and hardness compared to micro composites. The absence of age hardenable characteristics and the suppression of GP zones made these nanocomposites promising for various engineering applications. Kishore and Channabasavaraj [18] explored the impact of cryogenic treatment on Al7075/TiO2 nanocomposites prepared through liquid metallurgy. The study investigated the wear rate of the specimens, with varying weight percentages of TiO2. Taguchi's approach was utilized to validate experimental results for wear rate.

On the other hand, Nano-titanium dioxide (TiO_2), in particular, has emerged as a promising reinforcement for aluminium alloys, particularly Al7075 [19]. Nano-sized TiO_2 particles have low specific gravity, high hardness, and a high melting point, making them suitable for wear-resistant applications such as automobile pulleys and linkages [20-21]. To incorporate nano-TiO_2 particles into the aluminium matrix, various fabrication techniques such as spray technique, powder metallurgy, and mechanical alloying have been used. Despite the growing interest in aluminum-nano TiO_2 composites, research into their mechanical and tribological properties remains limited. As a result, there is a need to investigate and comprehend the effects of incorporating nano-TiO_2 particles in Al7075 composites at various volume fractions. The mechanical properties of Al7075 composites reinforced with nano-TiO_2 particles at volume fractions of 5% and 10% were investigated in this paper using the stir casting process. Stir casting has shown promise as a method for dispersing nano-sized TiO_2 particles uniformly in liquid aluminium without causing agglomeration [21-22]. The study's goal is to contribute to the development of advanced lightweight materials that combine aluminum's exceptional properties with the advantages of nanometer-scale reinforcement. The materials and methods used in this study will be presented in the following sections of this paper, followed by the results and discussions of the mechanical properties of the Al7075-nano TiO_2 composites. The paper will conclude with a summary of our findings and their implications for future research on advanced aluminium matrix composites.

2.0 Materials and Methods

The aluminium alloy Al7075 was chosen as the matrix material for the preparation of the nano composite system. The ingots of the desired alloys were requested from Fenfee Metallurgical in Bangalore, India. The reinforcing phase for the Al7075 matrices was nano TiO_2 with an average particle size of 40 to 70 nm. Figure 1 shows an elemental dispersive spectroscopy (EDS) image of nano TiO_2 particles acquired with a scanning electron microscopy (SEM). The morphology of nano TiO_2 particles is sharp and irregular in shape, according to scanning electron microscopy (SEM). The EDS analysis of the particles reveals only two major peaks, which correspond to the elements titanium and oxygen. The nano composite was created through the stir casting process, in which an Al7075 alloy was melted at 750 degrees Celsius in a graphite crucible. The Al7075 alloy was melted in an electrical resistance furnace that was also equipped with a mechanical stirrer.

Hexachloroethane tablets, also known as C2C16, were used in the degassing process to ensure the highest quality molten Al7075. After the degassing process was completed, the molten metal was stirred, and heated nano TiO_2 particles were gradually introduced to the melt while it was stirring. To ensure that the nano TiO_2 particles were distributed evenly throughout the molten metal, the particles were added very slowly. Throughout the experiment, the concentration of nano TiO_2 particles was increased by 2% increments from 0% to 6%. Brinell hardness testing was performed on cast composite samples in accordance with the ASTM E10 standard. The hardness of the polished surfaces of all composites is tested. A 500 kg load was applied with a 10 mm hardened steel ball for 30 seconds of dwell time. Ultimate Tensile Strength (UTS) studies were carried out at room temperature using the standard technique outlined in ASTM-E8. Castings were sectioned along a track that corresponded to the specimens' longitudinal axis. The UTS and ductility were determined by testing and measuring three samples from each composition's castings. An ASTM E23-16a impact test was performed on nanocomposite materials made of Aluminium 7075 and reinforced with TiO_2 . The experiment's goal was to determine the material's ability to withstand loads that were suddenly applied to it.



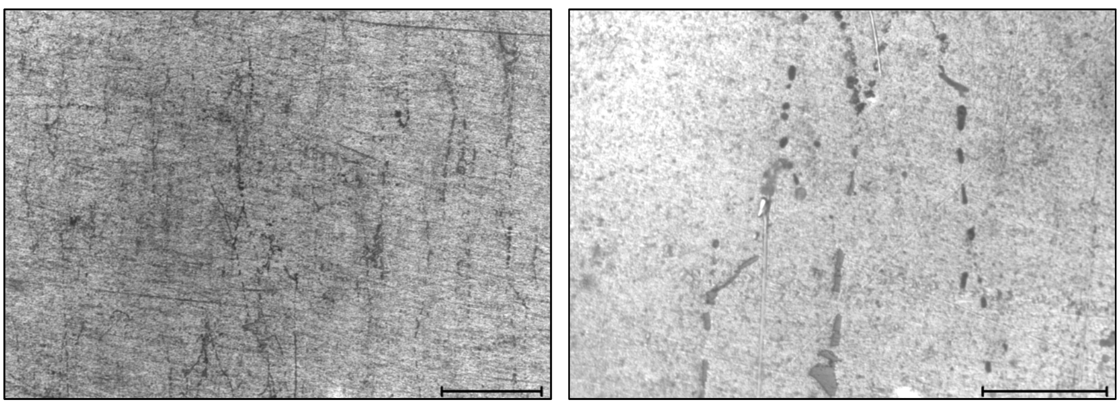
(a) **(b)**

Fig. 1 (a) SEM image and (b) EDS of nano TiO_2 particles

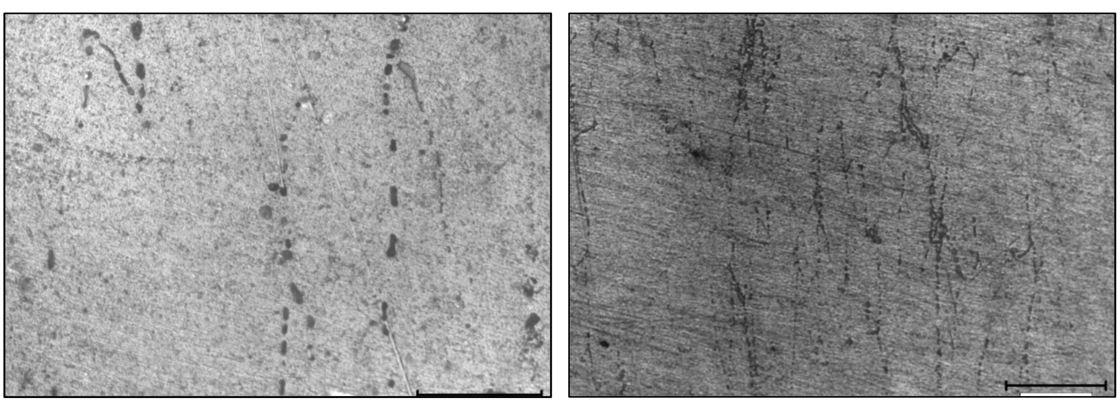
3.0 Results and Discussions

3.1 Microstructure

Figure 2 depicts the microstructure of stir cast Al7075/nano TiO_2 nanocomposites. Figure 2 depicts optical micrographs of Al7075 alloy and nanocomposites containing 2, 4, and 6 weight percent nano TiO_2 . The microstructures of stir cast Al7075 alloy (a), Al7075/2%nano TiO_2 nanocomposites (c), and Al7075/4%nano TiO_2 nanocomposites (e) are shown in Figure 2. The microstructure produced by the casting process is characterised by the dominance of dendritic eutectic phases; the stir casting process produces a noticeably more refined microstructure. This is depicted in Fig. 2 (a). Grain refining is significantly aided by the incorporation of nano TiO_2 nanoparticles, as illustrated in Figure 2(c). The grain size decreases even more when the percentage of nano TiO_2 increases from 2% to 4%, as shown in Fig. 2 (b-d). Because the Al7075 alloy lacks a grain inhibitor, the grains in it grow to be fairly large while maintaining their equiaxed shape.



(a)Al7075 alloy **(b)Al7075+2wt%TiO_2**



(c)Al7075+4wt%TiO_2 **(d)Al7075+6wt%TiO_2**

Fig.2(a-d) Optical microstructure of Al7075 alloy and its nano composites

The nano TiO_2 particles present in Al7075/nano TiO_2 nanocomposites, on the other hand, are visible both at the grain borders and within the grains themselves. The nano TiO_2 particles are forced to the grain boundaries during the casting process, where they are then maintained. The discovery of nanoparticles deep within the grains lends support to the theory that some of the particles were drawn in by the solidification front and became trapped inside the grains. The presence of nano-sized TiO_2 nanoparticles, which perform well as efficient nucleation sites throughout the solidification process, can be attributed to the grain refinement observed in nanocomposites. The grain size of the nanocomposites has been significantly reduced due to the abundance of nucleation sites provided by the nano TiO_2 nanoparticles. The microstructural investigation demonstrates that the use of the stir casting technique and the incorporation of nano TiO_2 nanoparticles significantly improves the microstructure of the Al7075 alloy. If the individual grains in the material are made smaller, Al7075/nano TiO_2 nanocomposites may be more useful for a wider range of engineering applications.

3.2 Hardness

Figure 3 depicts the results of Brinell microhardness tests performed on cast Al7075 alloy and its nanocomposites supplemented with varying amounts of nano TiO_2 . As the graph clearly shows, cast alloys and nanocomposites always have extremely high microhardness values. When microhardness tests on as-cast Al7075 alloys were performed, a value of 34 BHN was discovered. The microhardness values for the cast nanocomposite with a nano TiO_2 concentration of 2% were determined to be 37 BHN. When it was cast, the nanocomposite had a significantly higher microhardness than the alloy. When the nano TiO_2 concentration was increased from 0% to 6%, the microhardness of cast nanocomposites increased even more. We measured microhardness values as high as 46 BHN in the cast nanocomposite containing 6% nano TiO_2 . The microhardness of the cast nanocomposite increased by approximately 72.67% when compared to the alloy. The higher microhardness values found in the cast alloy and nanocomposites are most likely due to reduced clustering of nano TiO_2 nanoparticles and enhanced dispersion of these particles. The increased microhardness of the nanocomposites is due in part to the high hardness of nano TiO_2 nanoparticles and their ability to create dislocations in the material matrix. Because hard nano TiO_2 nanoparticles are not susceptible to the localised plastic deformation caused by indentation, the material's hardness can reach impressively high levels. The formation of dislocations is caused by a mismatch in thermal expansion between the Al7075 matrix and the nano TiO_2 nanoparticles, which contributes to an increase in the material's microhardness. According to the results of microhardness tests, nano TiO_2 -reinforced cast Al7075 has a significantly higher microhardness than the alloy itself. The fact that the microhardness values increased as the nano TiO_2 concentration increased demonstrates the promise that these nanocomposites hold for improved mechanical characteristics and performance in a wide range of engineering applications.

3.3 Ultimate Tensile Strength

Figure.4 compares the ultimate tensile strength of Al7075 alloy and its composites with various nano TiO_2 particle weight percentages. The graph clearly shows that the ultimate tensile strength of the material increases in direct proportion to the fraction of nano TiO_2 particles present in the material. The ultimate tensile strength of the Al7075 alloy was found to be 121 MPa, while the Al7075/2% nano TiO_2 composite had 144 MPa and the Al7075/6% nano TiO_2 composite had 155 MPa. When compared to the unreinforced Al7075 alloy, the Al7075/4% nano TiO_2 composite demonstrated an astonishingly significant increase in ultimate tensile strength. This remarkable improvement can be attributed to the addition of very small TiO_2 particles to the Al7075 alloy. It has been shown that the ultimate tensile strength increases dramatically up to a weight percentage of 4% nano TiO_2 , but then begins to decrease slightly after that point. The tensile strength of a composite made of Al7075 and 6% nano TiO_2 was 161 MPa, according to the researchers' findings. Multiple processes work together to increase the strength of Al7075 composites. The amount of nano TiO_2 particles present in Al7075 composites was found to increase the material's tensile strength. The primary contributors to this improvement were grain refining and dislocation strengthening.

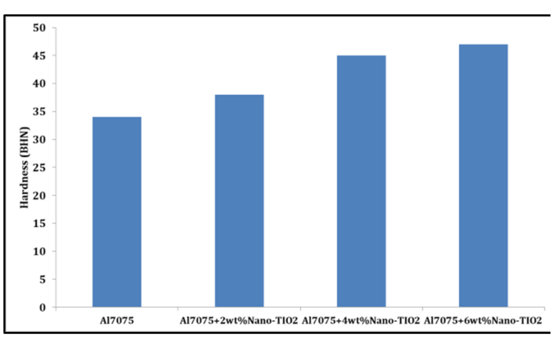


Fig.3 Variation of hardness with nano TiO_2 particles

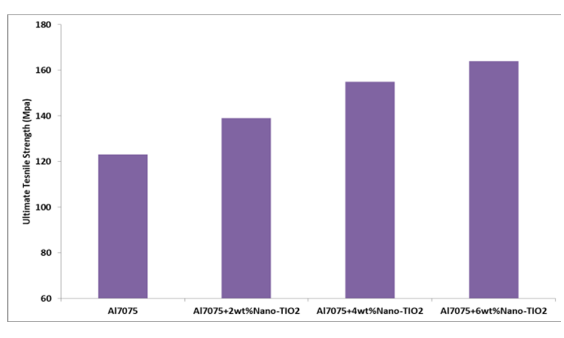


Fig.4 Variation of Ultimate Tensile Strength with nano TiO_2

3.4 Ductility

The percentage elongation of Al7075 alloy and its composites with varying weight percentages of nano TiO_2 particles is shown in Fig. 5. The figure shows that the percentage elongation decreases significantly as the weight percentage of nano TiO_2 particles increases. The percentage elongation of the Al7075 alloy is found to be 8%, while that of the Al7075/2% nano TiO_2 and Al7075/6% nano TiO_2 composites is 4.4% and 3.2%, respectively. When compared to the unreinforced Al7075 alloy, the Al7075/6% nano TiO_2 composite had a 69.33% decrease in percentage elongation value. This significant decrease in percentage elongation can be attributed to the addition of irregularly shaped and sized nano TiO_2 particles to the Al7075 alloy. Similarly, the percentage elongation values of the Al7075 composites were found to decrease as the nano TiO_2 particle content increased. Because of the irregular shape and size of the nano TiO_2 particles, the plastic deformation process may be hampered, resulting in a reduction in the percentage elongation of the composites. The decrease in percentage elongation is a common occurrence in particle-reinforced composites, as the presence of hard particles can restrict dislocation movement and reduce material ductility.When nano TiO_2 particles are added to the Al7075 matrix, the percentage elongation decreases significantly, indicating reduced ductility. This behaviour is typical of particle-reinforced composites, and the findings highlight the trade-off between increased strength and decreased ductility in such materials. The Al7075/nano TiO_2 composites have higher strength but lower elongation, making them suitable for applications where strength is more important than ductility.

3.5 Impact Strength

Figure 6 depicts the results of results of the impact properties of Al7075 matrices supplemented with nano TiO_2 . Because of the importance of this role, it is critical to emphasise that the nano TiO_2 particles that serve as the reinforcing phase play a significant role in determining the impact energy of the composites. During impact testing, the primary load-bearing phase in composite materials is nano TiO_2 . This is due to its exceptional mechanical capabilities as well as its high tensile strain to failure characteristics. These properties significantly contribute to the composites' ability to generate higher impact energy. The incorporation of nano TiO_2 , which is known for its exceptional mechanical properties, into the Al7075 matrix resulted in an increase in the impact energy of the composites produced. The impact energy of unprocessed Al7075 was 28 J, as shown in Figure 6. With only 2% nano TiO_2 added to the Al7075 matrix, the impact energy increased dramatically, rising to 34 J. This represents a 44% increase over pure Al7075 impact energy. When the nano TiO_2 concentration was increased from 2% to 6%, there was a discernible increase in impact energy equal to a factor of 43 J. In comparison to pure Al7075, the Al7075/2% nano TiO_2 composite successfully absorbed approximately 89.7% more impact energy. These findings show how much impact energy can be improved by incorporating nano TiO_2 as a reinforcement into the Al7075 matrix. Nano TiO_2 particles efficiently absorb and spread impact forces within the composite structure due to their high load-bearing capacities, resulting in higher impact energy. The nano TiO_2 particles accomplish this. Because Nano TiO_2 has a high tensile strain to failure, it can absorb more energy upon impact, increasing the impact resistance of the composites.

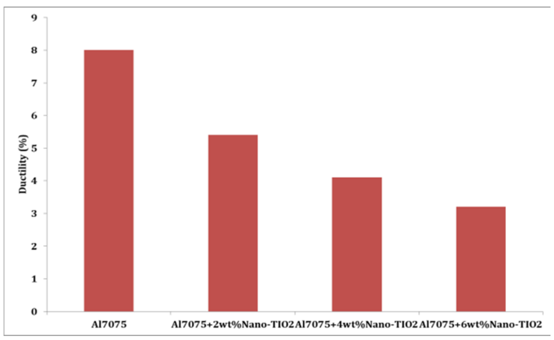


Fig.5 Variation of Ductility with nano TiO_2

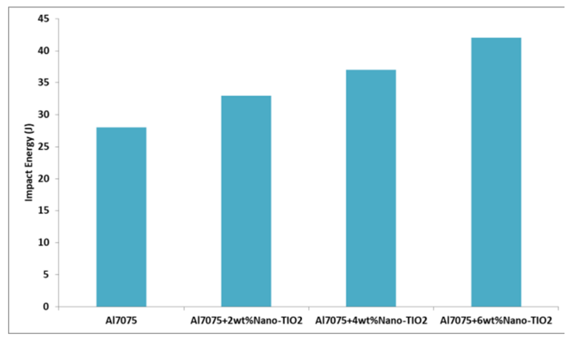


Fig.6 Variation of impact energy with nano TiO_2

4.0 Conclusions

1. Stir casting nano TiO_2 particles into Al7075 matrix improves composite microstructure. Grain refinement and nano TiO_2 nanoparticle nucleation sites reduce grain size, making Al7075/nano TiO_2 nanocomposites suitable for engineering applications.

2. Nano TiO_2 nanoparticles boost Al7075 alloy microhardness. Nanocomposites have higher microhardness due to nanoparticle dispersion and reduced clustering. Nano TiO_2 particles increase hardness by strengthening dislocations.

3. Nano TiO_2 reinforcement linearly increases Al7075/nano TiO_2 nanocomposites' ultimate tensile strength. Nano TiO_2 improves tensile strength up to 6%, demonstrating its effectiveness as reinforcement in composites.

4. As nano TiO_2 weight percentage increases, Al7075/nano TiO_2 composite elongation decreases.

5. Nano TiO_2 particles in Al7075 increase impact energy absorption significantly. Nano TiO_2 's high tensile strain to failure makes composites suitable for impact-resistant applications.

References

1. Michael Rajan HB, Ramabalan S, Dinaharan I, Vijay SJ 2014 Effect of TiB2 content and temperature on sliding wear behavior of AA7075/TiB2 in situ aluminium cast composites Arch Civ Mech Eng. 14 72–79
2. Wu Ruirui, Yuan Zheng, Li Qiushu 2017 Microstructure and mechanical properties of 7075 Al alloy based composites with Al2O3 nanoparticles Int. J. Cast .Met. res. 2 1-4
3. Veeresh Kumar GB, Rao CSP, Selvaraj N 2011 Mechanical and dry sliding wear behavior of Al7075 alloy-reinforced with SiC particles J. Comps. Mater. 0(0) 1–9.
4. Aluminium in construction [Internet]. All about aluminium; 2019 [accessed 1 June 2020]. Available from: https://aluminiumleader.com/application/construction.
5. Aluminum Alloys 101[Internet]. The Aluminum Association; 2019 [accessed 1 June 2020]. Avaliable from: https://www.aluminum.org/aluminum-sustainability.
6. LI Jin-feng, PENG Zhuo-wei, LI Chao-xing, et al. 2008 Mechanical properties, corrosion behaviors and microstructures of 7075 aluminium alloy with various aging treatments Trans. Nonferrous. Met. Soc. China. 18 755-762.
7. Umanatha K, Selvamani ST, Palanikumar K, Niranjanavarma D. Metal to metal worn surface of AA6061 hybrid composites casted by stir casting method. Procedia Eng, 12th GCMM 2014;97:703–12.
8. Bala Narasimha G, et al. Prediction of wear behaviour of Almg1sicu hybrid MMC using Taguchi with grey rational analysis. Procedia Eng, 12th GCMM 2014;97:555–62.
9. Krishna VM, Xavior AM. An investigation on the mechanical properties of hybrid metal matrix composites. Procedia Eng 2014;97:918–24.
10. M.K. Surappa, Aluminium matrix composites: challenges and opportunities, Sadhana 28 (2003) 319–334.
11. S.M. Choi, H. Awaji, Nano composite – a new material design concept, Science and Technology of Advance Materials 6 (2005) 2–10.
12. G. Cao, J. Kobliska, H. Konishi, X. Li, Tensile properties and microstructure of SiC nanoparticle reinforced Mg-4Zn Alloy fabricated by ultrasonic cavitations based

solidification processing, Metallurgical and Materials Transactions A 39A (2008) 880–886.

13. G. Cao, H. Konishi, X. Li, Mechanical properties and microstructure of Mg/SiC nanocomposites fabricated by ultrasonic cavitations based nano-manufacturing, Journal of Manufacturing Science and Engineering 130 (2008) 1–5.

14. G. Cao, H. Konishi, X. Li, Recent developments on ultrasonic cavitation based solidification processing of bulk magnesium nanocomposites, International Journal of Metalcasting, American Foundry Society 2 (2008) 57–68.

15. Jun, Q., Linan, A., and Blau, P.J., STLE/ASME International Joint Tribology Conference, (IJTC 2006, Ser. 2006, ASME, New York, 2006).

16. K.P. Dhanabalakrishnan, N. Mathan Kumar, T. Mothilal, Gori Yatika, H. Mohammed Ali, S. Socrates, "Influence of nano titanium oxide reinforced Al-7075 matrix composites in stir casting method", Materials today: Proceedings, Volume 69, Part 3, 2022, Pages 1381-1386.

17. R.N. Harsha, Mithun V. Kulkarni, B. Satish Babu, "Study of mechanical properties of aluminium/nano-zirconia metal matrix composites", Materials today: Proceedings, Volume 26, Part 2, 2020, Pages 3100-3106.

18. Waheed S. AbuShanab and Essam B. Moustafa, "Effects of friction stir processing parameters on the wear resistance and mechanical properties of fabricated metal matrix nanocomposites (MMNCs) surface", Journal of Material research and Technology, Volume 9, Issue 4, July–August 2020, Pages 7460-7471.

19. R. Karunanithi, K. S. Ghosh and Supriya Bera, "Synthesis and characterization of TiO_2 dispersed Al 7075 micro- and nanocomposite", Advanced Materials Research Vols. 984-985 (2014) pp 313-318.

20. H. Kishore and S. Channabasavaraj, "Influence of wear parameter on Al7075 reinforced with TiO_2 subjected to cryogenic treatment using Taguchi's approach", AIP Conference Proceedings, Volume 2648, Issue 1, 29 November 2022.

21. Fei Chang, Dongdong Gu, Donghua Dai, Pengpeng Yuan. Selective laser melting of in-situ Al4SiC4+SiC hybrid reinforced Al matrix composites: Influence of starting SiC particle size. Surface and Coatings Technology 2015; 272: 15-24.

22. Madeva Nagaral, Pavan R, Shilpa PS, Auradi V. Tensile behaviour of B4C particulate reinforced Al2024 alloy metal matrix composites. *FME Transactions* 2017; 45 (1): 93-96.