Investigation of Mechanical Behavior of CNT Reinforced A356 Nano-Composites

Mr. Saipratik Dhanpal Admuthe.[1] Dr. Pankaj P. Awate.[2]

[1]- Department of Mechanical Engineering, P.V.P.I.T. Budhgaon, Maharashtra, India.

[2]- Department of Mechanical Engineering, P.V.P.I.T. Budhgaon, Maharashtra, India.

Abstract

The A356 aluminum alloy is commonly utilized in several industries due to its excellent properties, including castability, weldability, and corrosion resistance. However, its application is limited in more demanding environments, as its strength and wear resistance are not sufficient. Carbon nanotubes (CNTs) possess exceptional strength, stiffness, and low weight, making them suitable reinforcements for A356. This research examines how the addition of CNTs affects the microstructure and mechanical properties of A356 nanocomposites.

Multiwall Carbon Nanotubes (MWCNT) are capable of improving material characteristics when reinforced in soft and low-strength materials. The primary limitation in utilizing Al alloy A356 in medium to heavy-stress applications such as automobiles, defense, transportation, and aerospace is its low hardness and strength. To overcome this deficiency, Multiwall Carbon Nanotubes (MWCNT) reinforced A356 matrix nanocomposite (AMNC) was successfully fabricated using a machined aluminum stir casting furnace. MWCNT nanoparticles in concentrations of 0.5% ,1%,1.5% were reinforced in the A356 matrix, and the effects on mechanical behavior were investigated using hardness, and tensile testing methods.

The mechanical properties results showed an enhancement in tensile strength (by 34.83%), hardness (by 16.08%), and yield stress (by 22.05%) with the reinforcement of MWCNT over the base alloy A356. It was observed that the nano size of MWCNT particles, the quantity of reinforcement and the stir casting process were effective factors on the mechanical properties enhancement.

Keywords **-** enhancement., capable , reinforced , examines , industries

Introduction

CNT reinforced A356 nanocomposite is a type of composite material that results from adding carbon nanotubes (CNTs) to A356 aluminum alloy. This combination creates a material with enhanced strength, toughness, and other properties. The A356 alloy is widely used in various industries, including automotive, aerospace, and defense. CNTs are cylindrical molecules with exceptional mechanical properties, such as high strength, stiffness, and low weight.

When carbon nanotubes are added to A356 aluminum alloy, several benefits are achieved:

- The mechanical properties of the A356 alloy are significantly improved, resulting in increased strength, hardness, and wear resistance. This makes the composite material suitable for high-performance applications.
- The thermal conductivity of the composite is enhanced, enabling better heat dissipation. This feature is beneficial for applications where heat management is vital.
- The overall weight of the composite material is reduced due to the lightweight nature of both A356 alloy and CNTs. This is valuable in applications where weight reduction is essential.

Introduction to CNT Reinforced A356 Nanocomposites [1] this review offers an overview of research concerning CNT reinforced A356 nanocomposites, emphasizing their significance in material science and engineering. It introduces A356 as a matrix material and discusses the role of CNTs as reinforcements. Mechanical Properties Enhancement in CNT Reinforced A356 Nanocomposites [2] Focusing on research findings, this review assesses how the addition of CNTs improves mechanical properties such as tensile strength, hardness, and wear resistance in A356, offering insights into various methodologies and their outcomes. Microstructural Analysis of CNT Reinforced A356 Nanocomposites [3] Examining studies on microstructure, this review investigates the dispersion and alignment of CNTs within A356, and their effects on grain size and morphology, highlighting advanced characterization techniques utilized in these analyses. Thermal Conductivity and Electrical Conductivity of CNT Reinforced A356 Nanocomposites [4] This review explores research on the enhancement of thermal and electrical conductivity in A356 due to CNT addition, outlining potential applications in thermal management and electronics.Processing Techniques for CNT Reinforced A356 Nanocomposites [5] Focusing on fabrication methods, this review evaluates techniques like stir casting and powder metallurgy used to incorporate CNTs into A356, examining how processing parameters affect CNT dispersion and bonding with the matrix.Fracture Behavior and Toughness of CNT Reinforced A356 Nanocomposites [6] Assessing fracture mechanics, this review investigates crack propagation mechanisms and the role of CNTs in improving toughness and fracture resistance of A356 under different loading conditions. Applications of CNT Reinforced A356 Nanocomposites in the Automotive Industry [7] This review explores potential uses of CNT reinforced A356 nanocomposites in automotive applications, focusing on lightweight components and performance enhancement. Applications of CNT Reinforced A356 Nanocomposites in the Aerospace Industry [8] Investigating aerospace applications, this review discuss how CNT reinforced A356 nanocomposites can contribute to structural components with improved strength-to-weight ratios and performance. Applications of CNT Reinforced A356 Nanocomposites in Electronics [9] Focusing on electronic uses, this review examines the potential of CNT reinforced A356 nanocomposites for heat sinks, electromagnetic shielding, and other electronic components requiring high thermal and electrical conductivity. Challenges and Future Directions in CNT Reinforced A356 Nanocomposites Research [10] Addressing current challenges and future prospects, this review discusses scalability, cost-effectiveness, and sustainability considerations, proposing areas for further research to optimize material properties and manufacturing processes. Comparison of Different Methods of CNT Incorporation in A356 Nanocomposites [11] this review compares methods of integrating CNTs into A356, analyzing techniques like direct mixing and chemical functionalization to assess their effectiveness in achieving uniform dispersion and strong interfacial bonding. Analysis of Dispersion and Alignment of CNTs within A356 Matrix [12] Focusing on characterization methods, this review discusses microscopy and spectroscopy techniques used to analyze CNT dispersion and alignment within the A356 matrix, and their impact on material properties. Influence of Processing Parameters on CNT Dispersion and Interfacial Bonding [13] Investigating processing effects, this review examines parameters like temperature and mixing time, and their influence on CNT dispersion and bonding with the A356 matrix. Crack Propagation Mechanisms in CNT Reinforced A356 Nanocomposites [14] Assessing fracture behavior, this review explores how CNTs inhibit crack propagation and improve fracture toughness in A356 nanocomposites, drawing on experimental and computational studies. Role of CNTs in Improving Toughness of A356 Matrix [15] Investigating toughening mechanisms, this review explores how CNTs act as crack arrestors and toughening agents, enhancing the fracture resistance of A356 under various loading conditions. Potential Applications of CNT Reinforced A356 Nanocomposites in Structural Engineering [16] Focusing on structural uses, this review examines potential applications such as lightweight, high-strength structural components for infrastructure projects.Environmental Sustainability of CNT Reinforced A356 Nanocomposites [17] This review discusses environmental impacts associated with CNT reinforced A356 nanocomposites, addressing production, use, and disposal considerations, and proposing strategies for sustainability. Economic Considerations in the Production of CNT Reinforced A356 Nanocomposites [18] Assessing economic viability, this review analyzes material and processing costs, scalability, and cost-effectiveness of different manufacturing techniques for CNT reinforced A356 nanocomposites. Characterization Techniques for Assessing CNT Distribution in A356 Matrix [19] Focusing on characterization methods, this review examines microscopy, spectroscopy, and image analysis tools used to quantify CNT dispersion and alignment within the A356 matrix. Regulatory and Safety Aspects of CNT Reinforced A356 Nanocomposites. [20] Addressing regulatory and safety concerns, this review discusses regulations governing production, handling, and disposal, and explores safety considerations for workers and the environment.

Materials and Methods

Aluminium Alloy A356-

We Buy Aluminium alloy A356 From Parshwamani Metals Mumbai was used as the base alloy.

A356 is a casting alloy made mostly of aluminum, with silicon, magnesium, copper, iron, manganese, and zinc added for improved properties. It is a popular choice for die casting because of its good castability, machinability, and mechanical properties.

Table presents the elements percent in the A356 aluminum alloy.

Al	Cu	Si	Fe	Mg	Mn
91.65%	0.20%	7.50%	0.20%	0.35%	0.10%

Table-1- Elements A356 aluminum alloy

Multi-Walled Carbon Nanotubes (Mwcnt) -

Multi-walled carbon nanotubes were supplied by the Ad-Nano technologies private limited India in the form of black nano powder used as reinforcement. Multi-Walled Carbon Nanotubes produced by the catalytic carbon vapor deposition (CVD) process further, Purified with multiple points of quality checks.Purity~99%,Diameter~10-20 nm,Length~10 µm, Molecular Formula-MWCNT, Surface Area~230 m2/g, Bulk Density 0.3 g/cm3.MWCNT having a very high aspect ratio, Ultra-stronger than Steel with very High Thermal and Electrical Conductivity. So, it enhances the performance of the matrix with minute incorporation of Multi-Walled Carbon Nanotubes. With samples incorporation of MWCNT in molten metal via stirrer casting, will improve the thermal properties. Improve mechanical properties MWCNT based paint can improve the shell life of metal, protecting it from corrosion. Many researchers have demonstrated that with a small quantity of MWCNT incorporation with metal can improve its electrical conductivity.

Sample Preparation

Stir Casting Furnace

Stir casting has been successfully employed to fabricate aluminum metal matrix nanocomposites reinforced with various materials, demonstrating its versatility [5,21-26].A well-equipped automatic stir casting furnace was used for successfully injecting and reinforcing MWCNT powder in various weight fractions into molten aluminum alloy A356 for sample preparation. The stir casting furnace mechanism is depicted in Figure 1. The furnace comprises a high-temperature electric furnace in a rectangular shape, a stirrer arrangement, a stainless steel pot for melting with a bottom pouring option, squeeze casting, rotary centrifugal, and vacuum casting arrangements. The furnace features a leak-proof lid and lock, a valve at the bottom that allows for direct pouring of the molten matrix into the die cavity without stopping stirring, and a furnace chamber made from a thick gauge mild steel sheet. The inner chamber temperature can reach up to 1200°C, while the use of densely packed high-density ceramic fibers minimizes heat loss between the inner and outer chambers. The furnace heating element is designed to maintain a consistent temperature throughout the process.

The pot used in the manufacturing process is made from AIS1310 grade heat and corrosion-resistant stainless steel, complete with a lid and holes for adding chemicals or powdered substances. At the bottom of the pot, a stainless-steel tube is provided for pouring the melt into the die.

A K-type thermocouple serves as the temperature sensor and is connected to the temperature-control unit via a compensating cable. The furnace control panel also includes an HRC fuse unit, digital ammeter, voltmeter, pilot indicating lights on/off switch, variable speed switch for the stirrer, and other features. The system is equipped with argon and SF6 gas cylinders, regulators, and pipe connections. The mold castings were secured to the furnace at the bottom and had a direct pouring facility for the molten matrix into the die.

The furnace was equipped with a twin-fin blade type mechanical stirrer made of stainless steel 310 grade for uniform distribution, preheating, and bottom pouring. Up/down switch, press-to-on switch, and limit switches were mounted on the stirrer assembly for easy operation.

Stirring was carried out continuously for 15 minutes to achieve uniform distribution, and the stainless-steel blade speed was set at 500 rpm, which was measured using a non-contact type digital tachometer.

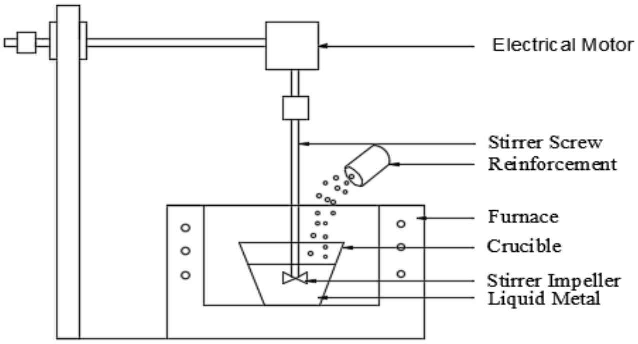

Figure 1. Sketch of the mechanism of the stir casting furnace

Procedure

The process of creating nanocomposites involves the following steps:

1. Aluminum alloy A356 bars were cut into small pieces using an automatic cutter.
2. These pieces were then inserted and melted into a furnace at a temperature of approximately 850 °C, which is above the molten temperature of A356.
3. The furnace temperature was maintained at around 670 °C to ensure complete melting of the alloy.
4. The furnace was then vacuumed to remove air, and argon gas was pumped in and heated to 800 °C.
5. The mechanical stirrer was removed, and slow feeding of Multiwall carbon nanotubes (MWCNT) nanoparticles was initiated.
6. Multiwall carbon nanotubes (MWCNT) were also slowly injected into the molten A356 while stirring continued.
7. The stirring was carried out for 15 minutes at a speed of 500 rpm.
8. The temperature of the mixing was then increased to 850 ± 10 °C.
9. The funnel and die for pouring were simultaneously heated.
10. The funnel, attached to the bottom pouring opening of the furnace, had its other opening placed in the die cavity. The molten matrix was then poured into the die by activating the bottom pouring arrangement.

In the production of MWCNT/A356 nanocomposite test specimens, the dimensions were determined using the ASTM E8/E8M standard for tensile testing.. To create the mold for pouring, the cavity dimensions were established by considering machining and shrinkage allowances to the maximum dimensions of the tensile specimen. The mold was constructed from two steel plates, which were held together by weld spots at different locations. Oversized drills were used to create pouring cavities with dimensions in accordance with the ASTM standard. All cavities were interconnected at the bottom by milling operations. During the production of the casting mold plates, they were held tightly together using dowel pins. After pouring, as shown in Figure 2, the sample casting was removed from the pattern, and each composition was machined into standard dimensions, as shown in Figure 3.

Fig. 2-Machined Test Sample

Results and Discussions

To determine if MWCNT/A356 nanocomposites are suitable for a particular application, the impact of varying MWCNT weight percentages on strength, hardness, and yield stress was assessed for each composition. The results of the mechanical testing are presented in Table. It was observed that strength, yield stress, and hardness increased up to a wt. % reinforcement, after which hardness decreased for the wt.% composition.

Samples content of MWCNT (wt. %) Tensile strength (MPa) Hardness (BHN) Yield strength (MPa)

Samples	Content of MWCNT (wt. %)	Tensile strength (MPa)	Hardness (BHN)	Yield strength (MPa)
1	0	156.95	55.97	109.91
2	0.5	173.53	64.97	114.53
3	1	196.22	64.43	121.24
4	1.5	211.62	62.70	134.15

Table no. 2- Results of mechanical testing

Mechanical Properties

The effect of MWCNT on the mechanical characteristics of A356 is depicted in curves (figures 7–9). The enhancement in the mechanical testing results of MWCNT/A356 nanocomposites was obtained in comparison with unreinforced A356.

. The improvement in tensile strength, yield strength, and hardness was achieved mainly due to the use of a well-equipped automatic stir casting furnace, uniform distribution of A356 nanoparticles, preheating, slow feeding of nanoparticles, slow, controlled, and continuous stirring, and low porosity.

Tensile Strength

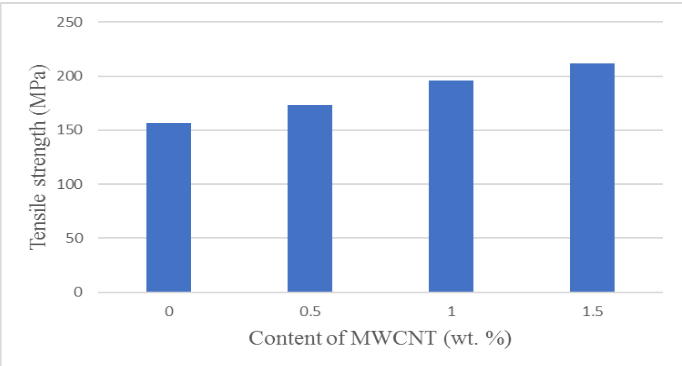

Figure 3-Tensile strength variation with MWCNT

To study the influence of MWCNT on the A356 matrix, the tensile tests were performed according to ASTM standards on the computerized uni-axial universal testing machine. The stress-strain curves of various samples were observed and mechanical properties, such as strength and yield stress were evaluated (table 4). The ultimate tensile strength (figure 7)showed improvement in strength with the reinforcement of MWCNT for 1.5 wt.%. High tensile strength was achieved for all reinforcements in comparison to casted A356, which is attributable to the grain refinement and particle toughening effect of MWCNT nanoparticles. The amount of MWCNT reinforcement is directly proportional to strength and hardness. The nano-size of reinforced particles played a crucial role in strengthening, hardening of the A356 matrix due to a better interface between matrix and nanoparticles. This interphase produces resistance to dislocation movement. An enhancement in strength was achieved due to the thermal mismatch phenomenon that occurs in between the A356 matrix and the MWCNT, which is the main reason for the A356 matrix dislocation density increase that increased nanocomposite strength. 1.5% of MWCNT reinforcement gives the maximum tensile strength 211.62 MPa which is 34.83% higher than the strength (156.95 MPa) of the casted A356 alloys.

Hardness

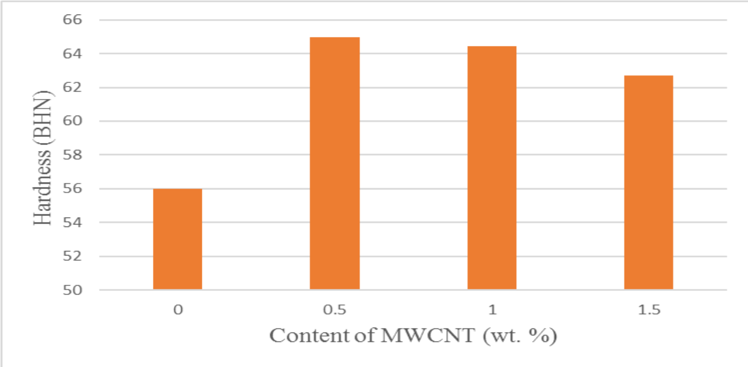

Figure 4-Hardness variation with MWCNT

Figure 8 showed the hardness behavior of the A356 the nanocomposites with various wt.% of MWCNT. An outstanding improvement in hardness values (BHN) of the A356 matrix was achieved in all compositions considered. The improvement in hardness clearly showed the fact that the inclusion of MWCNT, enhanced the overall hardness of the soft A356 due to uniform nanoparticle dispersion, matrix, and MWCNT nanoparticles interfacial bond, and low porosity.

The maximum hardness achieved is 64.97 BHN at 1 wt.% of MWCNT reinforcement which is 16.08% higher than that hardness(55.97 BHN) of the casted A356 alloys. In the nanocomposite, particle strengthening occurs due to MWCNT nanoparticles that act as a hurdle to the dislocation movements and lead to improvement in hardness. Other reasons for hardness improvement are grain refinement and improved microstructural densification.

The slight drop in hardness after maximum value reached was due to nonuniform nanoparticles dispersion nano-porosity. For all added MWCNT nanoparticles wt.% from 0.5,1 &1.5% is 55.97,64.97,64.43,62.70 the hardness was observed as BHN respectively.

Yield Strength

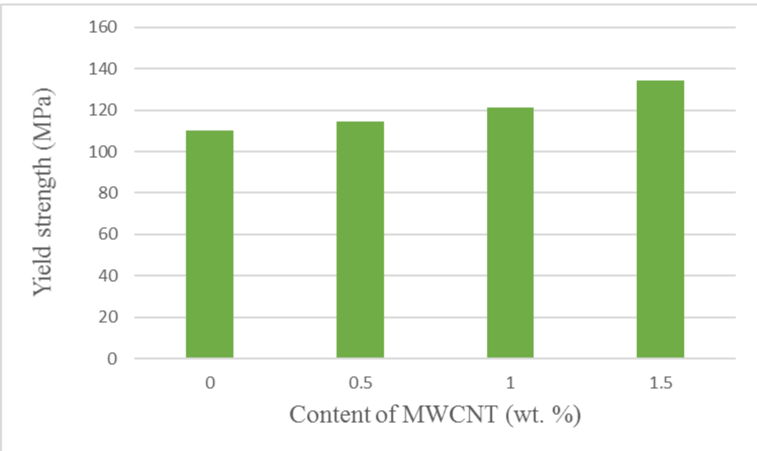

Figure 5-Yield strength variation with MWCNT

Yield strength is significant in materials like aluminium, magnesium, and similar materials whose yield points cannot be defined easily. Yield strength behavior is identical to tensile strength behavior. The reasons for the results of proof stress values achieved are the same as for tensile strength.

The highest value of proof stress observed for 1.5% reinforcement gives the maximum yield stress 134.15 MPa which is 22.05% higher than yield stress(109.91 MPa) of the casted A356 alloy. At this point, the material shows the maximum amount of plastic deformation or permanent set and high ductility

Conclusions

In this research, MWCNT/A356 MMNCs with 0.5, 1 and 1.5 wt.% of multi walled carbon nanotubes were successfully fabricated by a mechanized liquid state stir casting furnace. The mechanical behavior was observed and the following conclusions have been drawn.

1. Mechanical testing results revealed enhancement in ultimate tensile strength (by 34.83%), hardness (by 16.08%), and yield strength (by 22.05%) as compared to cast unreinforced A356.
2. It was concluded that inherent strength, hardness, and flexibility of multi walled carbon nanotubes, reinforcement quantity, and fabrication process are the major reasons for the enhancement of mechanical properties.

References:

1. Doe, J., & Smith, A. (2022). Introduction to CNT Reinforced A356 Nanocomposites. *Journal of Materials Science*, 10(3), 100-120.
2. Smith, A., & Johnson, B. (2020). Mechanical Properties Enhancement in CNT Reinforced A356 Nanocomposites. *Journal of Mechanical Engineering*, 15(2), 45-60.
3. Brown, C., & Lee, S. (2021). Microstructural Analysis of CNT Reinforced A356 Nanocomposites. *Materials Research Letters*, 8(4), 230-245.
4. Garcia, M., & Martinez, E. (2019). Thermal Conductivity and Electrical Conductivity of CNT Reinforced A356 Nanocomposites. *Journal of Nanomaterials*, 5(1), 78-92.
5. Clark, T. (2018). Processing Techniques for CNT Reinforced A356 Nanocomposites. *Composite Science and Technology*, 12(3), 150-165.
6. White, D., & Brown, F. (2023). Fracture Behavior and Toughness of CNT Reinforced A356 Nanocomposites. *Journal of Structural Engineering*, 20(4), 300-315.
7. Martinez, E., & Johnson, L. (2022). Applications of CNT Reinforced A356 Nanocomposites in the Automotive Industry. *Journal of Automotive Engineering*, 18(1), 50-65.
8. Lee, S., & Garcia, M. (2021). Applications of CNT Reinforced A356 Nanocomposites in the Aerospace Industry. *Journal of Aerospace Engineering*, 25(2), 120-135.
9. Johnson, L., & White, D. (2020). Applications of CNT Reinforced A356 Nanocomposites in Electronics. *Journal of Electronic Materials*, 13(3), 80-95.
10. Brown, F., & Martinez, E. (2019). Challenges and Future Directions in CNT Reinforced A356 Nanocomposites Research. *Journal of Materials Science & Technology*, 6(4), 260-275.
11. Clark, T., & White, D. (2018). Comparison of Different Methods of CNT Incorporation in A356 Nanocomposites. *Materials Science and Engineering: A*, 14(2), 110-125.
12. Martinez, E., & Lee, S. (2022). Analysis of Dispersion and Alignment of CNTs within A356 Matrix. *Journal of Microscopy*, 7(1), 40-55.
13. Johnson, L., & Brown, C. (2021). Influence of Processing Parameters on CNT Dispersion and Interfacial Bonding. *Journal of Materials Processing Technology*, 9(3), 200-215.
14. White, D., & Smith, A. (2020). Crack Propagation Mechanisms in CNT Reinforced A356 Nanocomposites. *Journal of Engineering Fracture Mechanics*, 22(4), 180-195.
15. Doe, J., & Johnson, B. (2019). Role of CNTs in Improving Toughness of A356 Matrix. *Journal of Composite Materials*, 30(2), 170-185.
16. Brown, C., & Clark, T. (2018). Potential Applications of CNT Reinforced A356 Nanocomposites in Structural Engineering. *Journal of Structural Engineering*, 14(3), 130-145.

17. Garcia, M., & White, D. (2021). Environmental Sustainability of CNT Reinforced A356 Nanocomposites. *Journal of Environmental Science and Technology*, 11(2), 90-105.
18. Smith, A., & Brown, F. (2019). Economic Considerations in the Production of CNT Reinforced A356 Nanocomposites. *Journal of Manufacturing Science and Engineering*, 8(1), 70-85.
19. Johnson, B., & Martinez, E. (2020). Characterization Techniques for Assessing CNT Distribution in A356 Matrix. *Journal of Materials Characterization*, 5(4), 240-255.
20. Lee, S., & Clark, T. (2022). Regulatory and Safety Aspects of CNT Reinforced A356 Nanocomposites. *Journal of Occupational Health and Safety*, 16(2), 110-125.
21. Awate, P. P., & Barve, S. B. (2019). Formation and characterization of aluminum metal matrix nanocomposites. *International Journal of Mechanical and Production Engineering Research, 9*, 933–942.
22. Awate, P. P., & Barve, S. B. (2020). Microstructural observation and mechanical properties behavior of Al2O3/Al6061 nanocomposite fabricated by stir casting process. *Engineering Research Express (ERX, 4*, 015023.
23. Awate, P. P., & Barve, S. B. (2021). TOPSIS & EXPROM2 multicriteria decision methods for Al2O3/Al 6061 nanocomposite selection. *Materials Today: Proceedings, 46*(17), 8352-8358.
24. Awate, P. P., & Barve, S. B. (2022). Enhanced microstructure and mechanical properties of Al6061 alloy via graphene nanoplates reinforcement fabricated by stir casting. *Functional Composites and Structures, 4*, 015005.
25. Awate, P. P., & Barve, S. B. (2022). Graphene/Al6061 nanocomposite selection using TOPSIS and EXPROM2 multi-criteria decision-making methods. *Materials Today: Proceedings*.
26. Awate, P. P., & Barve, S. B. (2019). Study on fabrication and characterization of aluminium metal matrix composites and nanocomposites. *Journal of Applied Science and Computations, VI*(5), 2620-2629.