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Effect of Heat Treatment on the Mechanical Properties of Aluminium 6063 Reinforced with Alumina, Titania, and Hybrid Powders

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Abstract**:** *The research examines the mechanical behaviour changes of alumina and titania-reinforced Aluminium 6063 composites after T6 heat treatment. The stir casting method combined with 3 wt% or 6 wt% reinforcement followed by a heat treatment solution at 520°C for 2 hours, then water quenching and artificial aging at 180°C for 8 hours. Tensile properties and hardness were enhanced through heat treatment such that peak hardness reached 116 HRB in 6 wt% TiO_2 composites. Tensile strength increased by 44.8% in 3 wt% TiO_2 composites (192.8 MPa), and peak hardness reached 116 HRB in 6 wt% TiO_2 samples. The impact strength of materials decreased with reinforcement addition, but heat treatments introduced marginal improvements when working with low reinforcement amounts. The research findings present essential knowledge to improve Aluminium 6063 composites for automotive and aerospace sector applications.*

Keywords**:** *Aluminium 6063, Reinforcement, Tensile Strength, Impact Toughness, Metal Matrix Composites*

1. INTRODUCTION

The use of Aluminum matrix composites (AMCs) has increased over recent years due to their exceptional blend of characteristics encompassing strengthened weight proportion with enhanced wear qualities and augmented thermal and electrical performance [1]. Modern structural projects, aerospace applications, and automotive needs utilize the aluminium 6063 from the 6xxx series as their primary alloy choice [2]. Current engineering requirements call for improved mechanical properties of these alloys because existing requirements keep growing.

The mechanical properties of aluminium matrix composites (AMCs) have substantially improved from the use of ceramic reinforcements. Incorporating ceramic reinforcements such as Al_2O_3 and TiC into aluminium has been shown to improve tensile strength, hardness, and wear resistance [3]. Numerous ceramic particulates serve as reinforcing elements in AMCs that can be manufactured using stir casting along with friction stir processing and pressure infiltration [4]. The integration of such reinforcements enhances their stiffness together with specific strength and wear resistance, along with improved fatigue property levels relative to traditional materials [5]. The properties demonstrate improved bonding strength between matrix and reinforcement, which enables efficient load transfer [6]. The technology faces issues regarding particle distribution together with agglomeration, which require solutions [5]. Research confirms that ceramic-reinforced AMCs have potential as industrial materials for automotive and aerospace applications, along with military purposes, because of their exceptional mechanical and tribological properties [6].

Al 6063 stands out because of its good extruding properties and smooth finishes as a medium-strength material [7]. Heat treatment of Al 6063 creates strength by magnesium and silicon elements that form Mg_2Si precipitates [1]. Different studies investigated the property enhancements that occur when Al 6063 receives different additives during processing. Adeosun et al. investigated Al 6063 reinforced with SiC, and their study demonstrated that the material showed better tensile strength and enhanced hardness, according to their published findings [7]. Reinforced composites using these ingredients produce increased hardness as well as enhanced tensile strength and yield strength compared to standard aluminium alloys. Environmental conditions combined with selected reinforcements control the corrosion resistance modification of these materials [8]. The fabrication techniques of stir casting and ultrasonic-cavitation-assisted casting yield uniform reinforcement distributions according to references [9], [10]. The current focus of technology developers lies in making composite materials because they satisfy industrial needs in the automotive aerospace and manufacturing sectors and explore environmentally friendly crab shell particles [9].

In alumina-reinforced composites, such as those with alumina added to zirconia or aluminium, alumina improves hardness, strength, wear resistance, and thermal conductivity. The performance benefits of nano-sized alumina particles in materials are significant, yet achieving uniform particle distribution is still tricky when using higher volume percentages [10], [11]. High-temperature slow crack growth resistance depends on alumina's form as either particulate or platelet reinforcement elements [10]. The distribution of reinforcing particles at high-volume fractions faces significant obstacles to achieving uniform distribution [11].

Research shows interest in Titania as a reinforcement agent because of its high strength and low density, along with its effective bond with aluminium matrices [10], [12]. The study by Reddy et al. showed that Al-TiO_2 composites gained better tensile strength and improved hardness after TiO_2 inclusion [13]. Kumar et al. documented that Al-TiO_2 composites showed improved wear durability as well as decreased sliding friction when compared to aluminium without ceramic reinforcement [13], [14] .

Heat treatment is a fundamental process that improves the mechanical behaviour of aluminium alloys and their composites. Alabi et al. [15], [16] have shown through this study on low-alloy and AISI 4135 steels that quenching conditions and temperature play a critical role in shaping microstructure and hardness. Although their studies were conducted on steel material, the insights provided are equally valuable for understanding how thermal parameters influence phase formation and mechanical behaviour in aluminium matrix composites. T6 heat treatment provides a better improvement in the strength and hardness of 6xxx series alloys [17]. Ozturk et al. investigated the effect of T6 heat treatment on Al 6063/SiC composites and found that there was a significant improvement in tensile strength and hardness after heat treatment [18]. Solution treatment and ageing artificially enhance to a great extent the hardness, tensile strength, and elongation of the aluminium alloys and their composites [19], [20]

Heat-treated materials develop refined structures with dispersed finer precipitates, which improve their mechanical properties [21]. Different aluminium alloy series exhibit distinct responses to heat treatment where heat-treatment capability applies to 2XXX, 6XXX and 7XXX series [22]. The heat treatment of Al6061 composites leads to enhanced hardness yield strength and ultimate tensile strength [21]. The optimal heat treatment testing conditions depend on alloy composition and reinforcing materials, where temperature duration and cooling speed determine desired properties [20], [22]. The T6 heat treatment using solution treatment followed by quenching and artificial ageing demonstrates remarkable effectiveness for strengthening 6xxx series aluminium alloys [17]. This heat treatment process allows for the formation of fine, coherent precipitates that impede dislocation motion, thereby increasing the overall strength of the material [23].

Studies have examined the joint impact of reinforcement addition and heat treatment, yet many peer-reviewed works study them independently. Sharma et al. examined how T6 heat treatment affects Al 6061/SiC composite materials by uncovering beneficial combined improvements in their mechanical properties [24]. However, few studies explore the mechanical behaviour of Al6063-based composites reinforced with Al_2O_3 and TiO_2, especially in combination with T6 heat treatment. This highlights a significant research gap: the synergistic effects of dual ceramic reinforcement systems specifically Al_2O_3 and TiO_2 on Al6063 composites under T6 heat treatment remain poorly understood. Hybrid reinforcements may offer a strategic advantage by combining the hardness benefits of Al_2O_3 with the tensile strength and toughness of TiO_2.

This study aims to bridge this gap by evaluating the mechanical properties of Al6063 composites reinforced with individual and combined (hybrid) ceramic particles following T6 heat treatment. The findings will provide insights into optimizing aluminium matrix composites for structural applications in the aerospace and automotive sectors.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

In this study, the Al6063 alloy served as the matrix material due to its favourable properties, and it was reinforced with two types of ceramic particles. Specifically, alumina (Al_2O_3) particles with an average size of 20 µm and titania (TiO_2) particles averaging 15 µm were used to enhance the composite's performance. The chemical composition of the Al6063 alloy was carefully determined using optical emission spectroscopy, and the findings are summarized in Table 1.

Table 1: Chemical Composition of Al6063 Alloy (XRF Analysis)

Element	**Mg**	**Al**	**Si**	**Ti**	**Cr**	**Mn**	**Fe**	**Ni**	**Cu**	**Zn**	**Sr**	**Pb**	**Sn**	**Sb**
Content (%w)	7.84	91.65	0	0	0.0078	0.038	0.0769	0.0519	0	0.1245	0	0.0016	0.0595	0.1352

2.2 Composite Fabrication

Composites were produced through stir casting. The ingots of Al6063 alloy were melted in a graphite crucible in the heat of an electric resistance furnace at approximately 750°C. For better wettability and to drive out moisture, the reinforcement particles were preheated at 200°C for 1 hour. The melt was stirred at 450 rpm using a graphite impeller to form a vortex, into which the preheated particles were slowly introduced. It was stirred for 10 minutes to ensure that the reinforcement was evenly mixed. The molten composites were then cast into preheated steel moulds and allowed to solidify at room conditions. Four types of composites were prepared:

i. Al6063 reinforced with 6 wt% Al_2O_3

ii. Al6063 reinforced with 6 wt% TiO_2,
iii. A hybrid composite of Al6063 reinforced with 3 wt% Al_2O_3 and 3 wt% TiO_2
iv. Unreinforced Al6063 served as the control sample. Al6063 + 6 wt% Al2O3

2.3 Heat Treatment

In this research, heat treatment operations on Al6063-based composites followed the T6 method through solution treatment followed by quenching before artificial ageing.

2.3.1 Solution treatment

The composites in the first stage underwent an initial solution treatment at 530°C for one hour. This procedure allows the alloying elements to blend into the aluminium matrix through solution treatment before producing a homogeneous solid solution. The research utilized an appropriate 530°C solution treatment temperature outside the conventional 400°C-500°C range for 6xxx series aluminium alloy to achieve effective dissolving of alloying constituents [25].

2.3.2 Quenching

Rapid water quenching at room temperature took place right after the solution treatment ended. Rapid cooling functions as a necessary step because it secures the supersaturated solid solution, which forms solution treatment while stopping early alloy element precipitation [25].

2.3.3 Artificial aging

Artificial ageing began at 175°C for eight hours, which represented the concluding step of the process. The artificial ageing process applies standard procedures from the 6xxx series aluminium alloy field through temperature exposure at 140°C to 180°C for 1 to 8 hours. Controlling mechanical properties demands the artificial ageing step because it enables the directed precipitation of the alloying elements [25].

During artificial ageing, the alloying elements form ordered arrays of atoms in the aluminium matrix, known as GP zones, which significantly strengthen the material. This process optimizes the mechanical properties of the composites, enhancing their strength and hardness.

The T6 heat treatment process delivers notable mechanical property advancements when used with material in its as-cast state. The treatment produces elevated tensile strength, yield strength, and hardness but might cause minor reductions in alloy ductility [7], [26].

It is essential to recognize that the exact heat treatment parameters profoundly affect the final characteristics of the composites. In this study, the selected conditions were designed to strike an optimal balance between strength and ductility for Al6063-based composites reinforced with alumina, Titania, and hybrid powders.

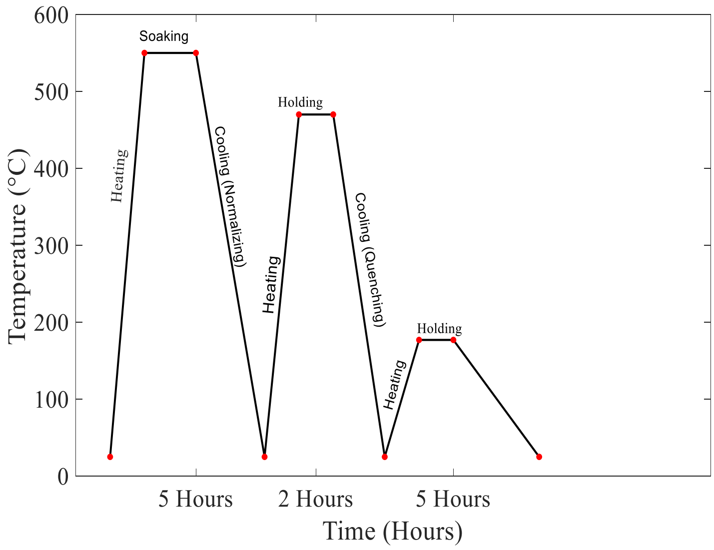

Figure 1: Time–temperature profile of the T6 heat treatment process applied to Al6063 composites, showing the solution treatment, quenching, and artificial ageing stages

2.4 Characterization and Testing

A set of standardized tests provided complete information for analyzing the material sample. The sample underwent tensile tests, which followed ASTM E8 procedures, through a universal testing machine to measure its strength behaviour and deformation properties. Complete hardness analysis occurred using a Vickers hardness tester that applied 5 kg force to study material indentation resistance. The Charpy impact test machine evaluated the impact toughness to determine the sample's energy-absorption capability in sudden impacts. All mechanical tests were conducted in triplicate to ensure statistical reliability. The various testing methods provide a comprehensive assessment of the mechanical attributes of the examined material.

3. RESULTS AND DISCUSSION

3.1 Hardness

Figure 4 shows the Vickers hardness values of the composites after heat treatment. The hardness test confirmed that heat treatment effectively improved the mechanical properties of Aluminium 6063 composites. The material hardness was as high as 116 HV owing to the reinforcement of Titania at a concentration of 6%, which provided considerable improvement in material hardness. Hybrid composites containing 3% and 6% reinforcement showed considerable improvement in hardness, as alumina was effective in reinforcement with Titania.

Mechanical tests indicated that composites containing 6% Al_2O_3 exhibited a modest enhancement in hardness, with nearly hybrid composite hardness values. In contrast, the base alloy exhibited the least hardness value among the examined samples since reinforcement and heat treatment enhance the mechanical properties of materials.

At 6% TiO_2, the material is made harder through the blocking of dislocations by ceramic particles and its capacity to resist loads. The aging phase used in heat treatment led to smaller precipitates that hardened the microstructure and improved the material's wear protection.

The hybrid of alumina and Titania reinforcement gave a good balance in hardness because they complemented each other. The hybrid composites have better mechanical properties because they embody the benefit of both alumina and Titania reinforcements without loss of strength. The alumina composites were more potent than the pure alloy but did not achieve the highest hardness shown in other composites. This result supports what Nazeer and Safiulla (2020) observed in similar composites, where the presence of TiO_2 noticeably improved hardness by reinforcing the matrix and resisting surface indentation [17].

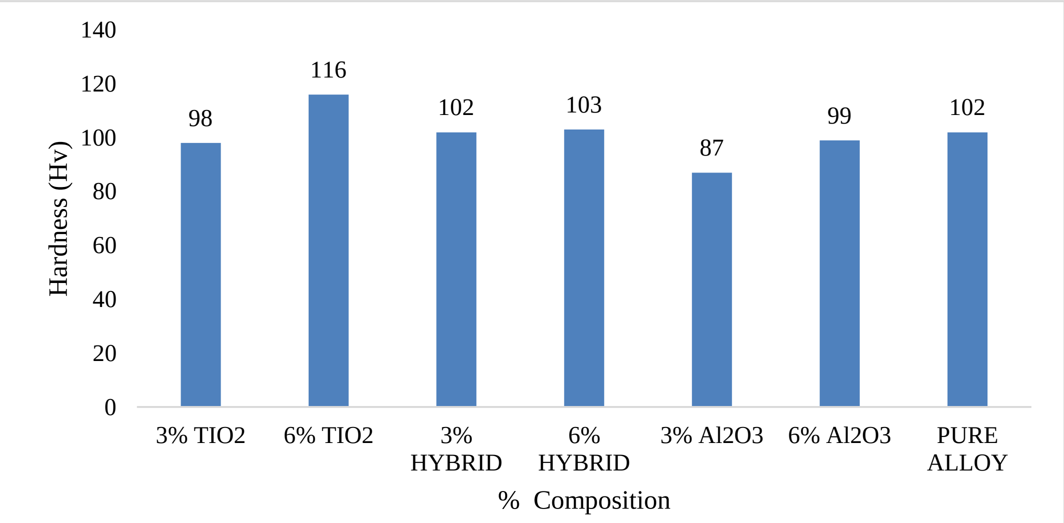

Figure 2: Vickers hardness values of Al6063 composites with various reinforcement types and concentrations after T6 heat treatment.

3.2 Impact Test

The Figure 3 indicates the strength of Aluminium 6063 composites upon impact. This is expressed in Joules. The composites contain varying percentages of TiO_2, Al_2O_3, and a combination of the two. The pure alloy is included for comparison. The 6 wt% TiO_2 composite is the strongest with approximately 40 J, and the 6 wt% Al_2O_3 composite follows closely. The hybrid composites (3 wt% and 6 wt%) had moderate impact strength, which proves that the balanced reinforcement method can improve toughness. The monolithic alloy had the lowest impact strength, which shows how vital the reinforcement and heat treatment is to improve the energy absorption of the material under impact. Also, the composites reinforced with 3 wt% TiO_2 and 3 wt% Al_2O_3 had better impact strength than the control sample but lower than the samples with the higher percentage reinforcements.

The higher impact strength of the 6 wt% TiO_2 composite is primarily due to the fact that the Titania particles are able to absorb energy more efficiently. The material could utilize impact energy better due to the barrier mechanisms provided by the particles, which prevent the propagation of cracks. The addition of 6 wt% Al_2O_3 resulted in a significant improvement in the material's impact strength. The behaviour of the hybrid composites suggests that alumina and Titania are compatible with one another. These hybrids were not the most superior in impact strength, but they represent a good compromise, giving a balance of optimum toughness and other desirable mechanical properties. The low impact strength of the neat alloy shows that reinforcement and suitable heat treatment are essential for maximizing the energy absorption capacity of Aluminium 6063 composites. A similar trend was noted by Reddy et al. (2022), who found that TiO_2 particles helped absorb impact energy and reduce crack propagation, leading to better toughness especially at higher reinforcement levels [13].

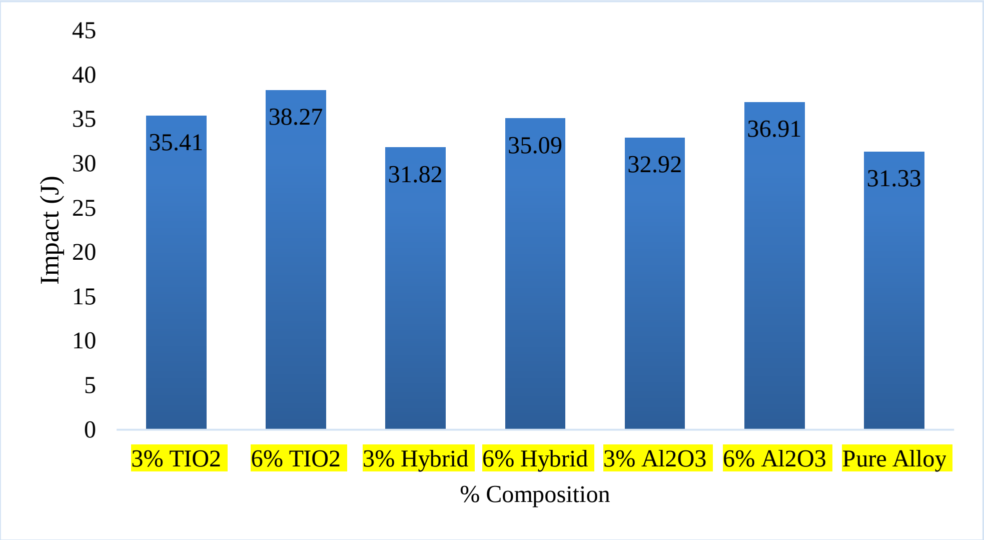

Figure 3: Charpy impact strength of Al6063 composites with different weight percentages of Al_2O_3, TiO_2, and hybrid reinforcements.

3.3 Tensile Properties

3.3.1 Maximum tensile strength

Figure 4 shows the maximum tensile strength values (MPa) for Aluminium 6063 composites reinforced with alumina, titanium oxide, or hybrid powders along with the pure aluminium sample. Tensile strength values are compared between Aluminum 6063 composites reinforced with 3% and 6%.

Tensile strength measurements of the composite material reinforced with 3% titanium oxide reached 200 MPa, which exceeded the strength values of all other reinforced composites and the unreinforced control sample. The tensile strength values of 3% and 6% hybrid composites fell between those of titanium oxide and alumina composites. The addition of 6% alumina reinforcement led to higher tensile strength than using 3% alumina as a reinforcing agent. The unmodified Aluminium 6063 material displayed the minimum tensile strength value, showing that material performance improves through the addition of reinforcements and subsequent heat treatment.

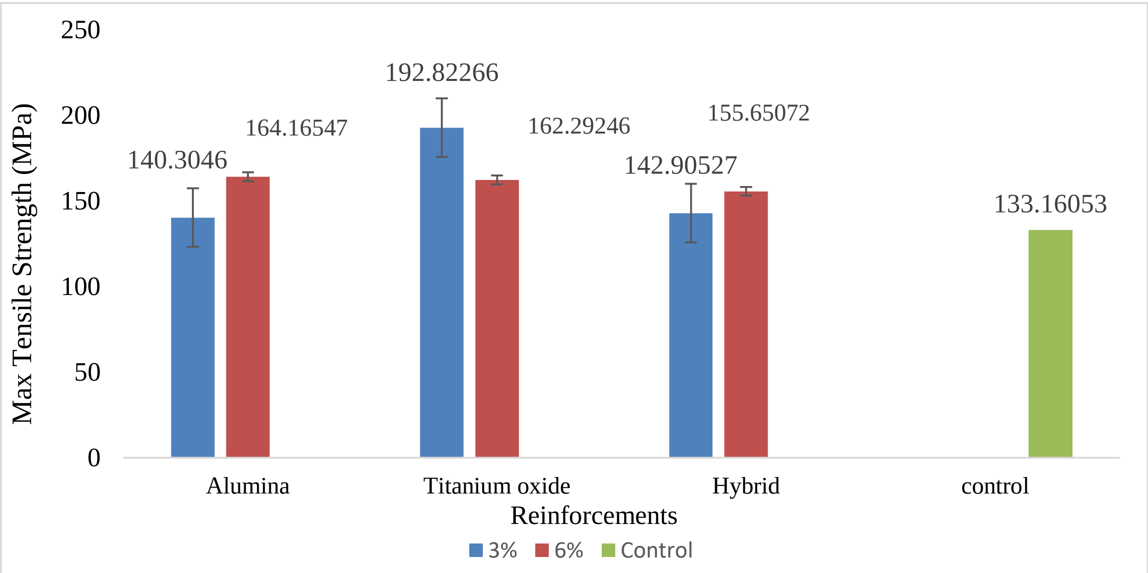

Figure 4: Ultimate tensile strength (UTS) of reinforced and unreinforced Al6063 composites with different ceramic particle additions.

Strong tensile capabilities in the 3% TiO_2 reinforced composite originate from the successful transmission of stress between rigid reinforcement particles and the flexible aluminium matrix. The effects of agglomeration with 6% TiO_2 reinforcement caused a localized concentration of stress points, thereby reducing tensile strength performance.

The hybrid composites produced mechanical properties that blended the favourable aspects of both alumina and Titania reinforcement systems. Through their synergistic material structure, hybrid composites provide applications with both strength benefits and ductile properties, making them suitable for critical mechanical and tough applications.

The tensile strength of alumina-reinforced composites surpassed the strength of the control sample, although it did not exceed the other composites. Tensile strength levels from the sample containing 6% alumina surpassed those of the sample with 3% alumina, indicating improved strength arises from higher alumina concentration, but Titania provides superior benefits.

3.3.2 Maximum tensile modulus

Figure 5 depicts the impact strength results in Joules for Aluminium 6063 composites containing different weight percentages of TiO_2, Al_2O_3 and their combined mixtures together with the impact strength of a single pure Al material. The impact strength measurement indicated that TiO_2 at 6 wt% achieved 40 J while Al_2O_3 at 6 wt% obtained very close results. Hybrid composites which blended both 3 wt% and 6 wt% reinforcements demonstrated average impact strength because balanced reinforcement produces positive effects on material toughness. The pure alloy demonstrated the minimum impact strength, which proves that simultaneous heat treatment and reinforcement are both necessary to improve material energy absorption during impact events. The impact strength of composites blended with 3 wt% TiO_2 together with 3 wt% Al_2O_3 increased relative to the base material, yet the improvement was less substantial than other reinforcement ratios.

The impact strength enhancement in the 6 wt% TiO_2 composite originates from the Titania particles, which provide better energy dissipation ability. These particulate barriers help protect against crack development so the material can spread impact energy better. Impact strength improved notably when using 6 wt% alumina-based composite due to its higher concentration rate, reinforcing the material's sudden force resistance. The experimental data shows that alumina and Titania components achieve performance enhancement through combined effects. The impact strength-enhanced hybrid materials provide an optimal combination of properties because they do not attain peak toughness but achieve balanced mechanical property performance. The low impact resistance of the pure alloy exemplifies that vital reinforcement, along with proper thermal treatment, remains essential for boosting Aluminium 6063 composite energy dissipation capabilities.

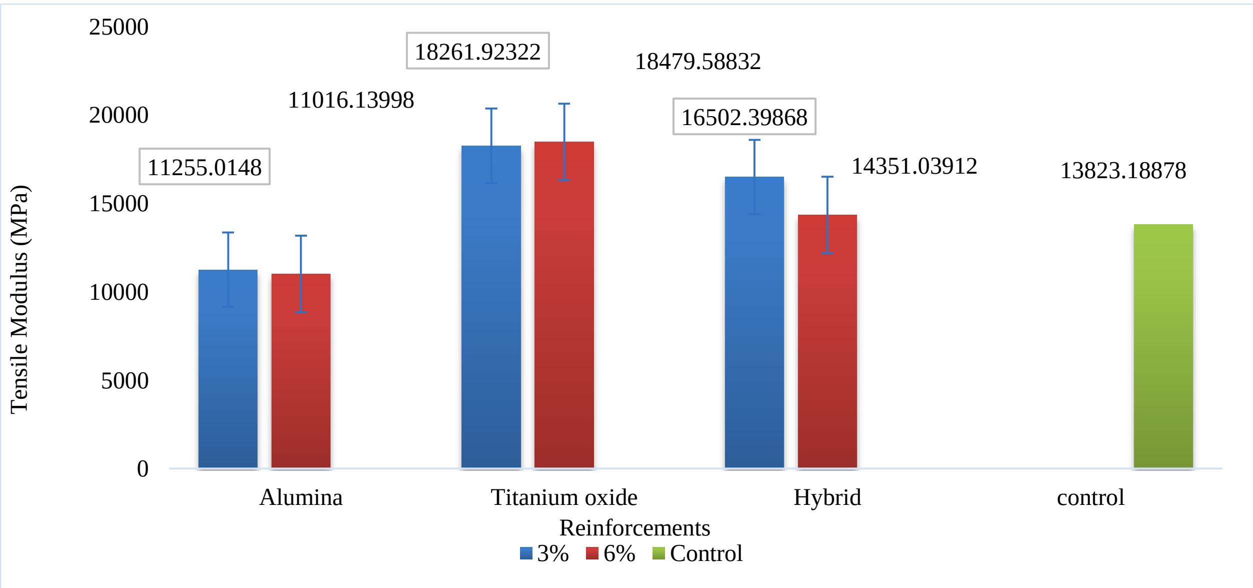

Figure 5: Tensile modulus of Al6063 composites reinforced with Al_2O_3, TiO_2, and hybrid powders, showing stiffness improvements post heat treatment.

3.3.3 Maximum tensile strain

Figure 6 shows the tensile strain values for maximum tensile strength among Aluminium 6063 composites which incorporate either alumina or titanium oxide or hybrid powder additions and shows the unreinforced aluminum specimen. The research data focuses on two reinforcement levels of 3% and 6% which are investigated for the composites.

The composite containing 3% titanium oxide (TiO_2) reached around 0.1 tensile strain. The enhanced ductility performance from 3% reinforcement positions it as the best among all samples due to its ability to protect material ductility. The tensile strain values of the 6% TiO_2 composite demonstrated an inverse pattern to reinforcement content increases since the strain levels decreased significantly.

The combined materials of the composites achieved better overall system performance. The tensile strain evaluation of the 6% hybrid composite outperformed the 3% hybrid variant thus indicating that higher reinforcement mixtures produce optimized alumina-titania interaction effects. The samples containing 6% alumina exhibited a higher tensile strain than the 3% alumina variant but had lesser strain than the hybrid composite samples.

The pure Aluminium 6063 originated from the control sample and demonstrated tensile strain levels which fell in between the titanium-dioxide-enhanced composite and both alumina-reinforced and hybrid composite types. Different reinforcement types and contents demonstrate the pivotal position in controlling the strength vs ductility relationship for Aluminium 6063 composites. This balance between strength and ductility, while reinforcements can lower elongation, the right combination like in our hybrid composites helps maintain a valuable level of flexibility.

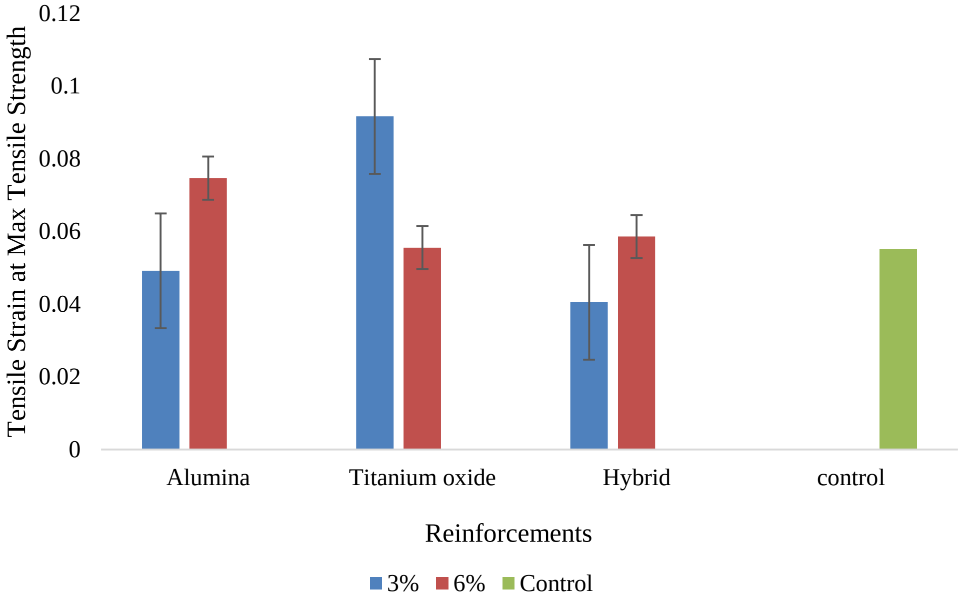

Figure 6: Maximum tensile strain of Al6063 composites, highlighting ductility variations with different reinforcement types and contents

4. CONCLUSIONS

Scientific research examined the mechanical response of Aluminium 6063 metal matrix composites after heat treatment introduced with alumina titanium oxide and hybrid powder additives. It studied the modification to hardness, tensile strength, tensile modulus, and tensile strain of 3% and 6% reinforced composite materials compared to pure Aluminium 6063.

The experiment revealed enhanced hardness performance for every tested composite after heating it through the heat treatment process. The material hardness achieved its peak value of ~116 HV with 6% TiO_2 reinforcement, making titanium oxide particularly successful in material hardening. Hybrid composites yielded balanced enhancements in hardness because the combined effect of alumina and titania reinforcements became apparent. The tensile properties of alumina composites remained similar to control values, yet they demonstrated enhanced hardness properties.

The tensile strength of 3% the TiO_2 composite reached ~200 MPa, surpassing the strength of all other composites. Hybrid composites received improved tensile strength through the synergistic properties resulting from combining alumina and titania components. The addition of 6% alumina to the samples led to superior tensile strength in contrast to 3% alumina, resulting in a positive correlation between tensile strength and alumina content. The observed improvements in tensile strength and hardness highlight the role of reinforcement selection and heat treatment in customizing Al6063 composites for demanding mechanical environments.

Tensile modulus tests indicated that titanium oxide composites achieved maximum stiffness when their results reached 20,000 MPa. The material stiffness increases due to the addition of TiO_2. Hybrid composites achieved an ideal combination of high material stiffness and favorable ductility characteristics, which makes them suitable for varied applications with specific performance requirements. The contribution of alumina composites to material stiffness was substantially less effective than TiO_2 and hybrid reinforcement additions.

A tensile strain analysis showed that the 3% TiO_2 composite achieved the most excellent ductility level with a measurement of about 0.1. The combination of high tensile strength comes with good ductility behaviour at titanium oxide concentrations below 3%. The tensile strain performance of hybrid composites fell between high flexibility and strength capabilities. The low enhancement in tensile strain from alumina composites demonstrates that their central role in the strengthening process focused on hardness enhancement.

Results demonstrate that titanium oxide (TiO_2) represents the optimum choice as a reinforcement substance because it reaches peak mechanical characteristics, including hardness and tensile strength, as well as stiffness and ductility. Hybrid composites normalize performance among multiple mechanical features, which allows them to serve demanding applications that require mechanical versatility. Alumina additives increased material hardness and wear resistance, although they had lower effects on tensile strength and elastic deformability than titanium oxide.

The data obtained from this study provides important information to industries requiring lightweight yet strong materials in automotive and aerospace applications and structural components. Advanced materials with exact performance characteristics can be designed by carefully selecting reinforcement types and applying heat treatment for mechanical property customization.

These findings provide valuable insights into optimizing the performance of Al6063-based metal matrix composites through appropriate reinforcement selection and heat treatment parameters. Future work should focus on investigating the wear behaviour and corrosion resistance of these composites to further expand their potential applications in various industries.

The combination of 3% TiO_2 reinforcement provided the best outcome for maximized strength alongside ductility, making this combination ideal for use in applications requiring balanced properties. Research identifies heat treatment approaches and reinforcement materials, and their chemical compositions directly impact the creation of advanced metal matrix composites for contemporary engineering purposes. These results provide the mechanical advantage of hybrid and TiO_2 reinforcements in Al6063 and demonstrate their appropriateness for applications demanding strength and restraint on ductility, such as aerospace panels, motor vehicle chassis parts, and building frames.

However, this study is limited by the absence of microstructural analysis (e.g., SEM imaging) and long-term performance testing, which could further clarify the strengthening mechanisms at play. Additionally, only static mechanical properties were assessed. Future research should include study on fatigue life, corrosion and wear resistance of these composites to provide an understanding of their performance under real loading conditions and ambient environments. The addition of nano-reinforcers or hybridization with another ceramic might bring about further performance gains.

REFERENCE

[1] Manjunath, B. & Kumar, H.S.P. (2023). Evaluation of mechanical properties for functionally graded material base metal Aluminum [AL - 6063] when reinforced with silicon carbide [SiC] and titanium dioxide [TiO_2]. *International Research Journal of Engineering and Technology (IRJET)*, 10 (01).

[2] Pattar, J., Ramesh, D., Malghan, R.L., Kumar, A., Kumar, P. & V.H.M. (2024). Investigation of AA6063-based metal–matrix composites reinforced with TiO_2 dispersoids through digitally assisted techniques for mechanical, tribological, and microstructural characterizations. Frontiers *in Mechanical Engineering*, 10. https://doi.org/10.3389/fmech.2024.1393959

[3] Jamwal, A., Vates, U.K., Gupta, P., Aggarwal, A. & Sharma, B.P. (2019). Fabrication and characterization of Al_2O_3–TiC-reinforced aluminum matrix composites. In: *Advances in Manufacturing Technology*, 349–356. https://doi.org/10.1007/978-981-13-6412-9_33

[4] Mathew, G. & Kottur, V.K.N. (2023). Effect of ceramic reinforcements on the mechanical and tribological properties of aluminium metal matrix composites:A review. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.09.099

[5] Iqbal, A.A. & Nuruzzaman, D.M. (2016). Effect of the reinforcement on the mechanical properties of aluminium matrix composite: A review. *International Journal of Applied Engineering Research*. 11(21), 10408-10413. https://api.semanticscholar.org/CorpusID:2346185

[6] Bhaskar, S., Kumar, M. & Patnaik, A. (2019). Mechanical and tribological overview of ceramic particulates reinforced aluminium alloy composites. *Reviews on Advanced Materials Science*, 58(1), 280–294. https://doi.org/10.1515/rams-2019-0033

[7] Adeosun, S.O., Balogun, S.A., Sekunowo, O.I. & Usman, M.A. (2010). Effects of heat treatment on strength and ductility of rolled and forged aluminum 6063 alloy. *Journal of Minerals & Materials Characterization & Engineering 9(8).* http://dx.doi.org/10.4236/jmmce.2010.98054

[8] Alaneme, K.K. & Bodunrin, M.O. (2011). Corrosion behavior of alumina reinforced aluminium (6063) metal matrix composites. *Journal of Minerals and Materials Characterization and Engineering*, 10(12), 1153–1165. https://doi.org/10.4236/jmmce.2011.1012088

[9] Owa, A.F. & Olubambi, P.A. (2024). Enhancing mechanical properties of aluminium 6063 with crab shell particle reinforcement. *Discover Applied Sciences*, 6(7), 337. https://doi.org/10.1007/s42452-024-06035-5

[10] Choi, S.R. & Bansal, N.P. (2013). Alumina-reinforced zirconia composites. *Handbook of Ceramic Composites*. Boston, MA: Springer US, 18. 437-457.

[11] Koli, D.K. & Purohit, R. (2013). Properties and characterization of Al–Al_2O_3 composites processed by casting and powder metallurgy routes (Review). *International Journal of Latest Trends in Engineering and Technology (IJLTET)*, *2*(4), 486-496.
[12] Mukesh Y., Bharathesh, T.P. & Keshavamurthy, R. (2018). Influence of hot extrusion on mechanical characteristics of Al6063-TiC metal matrix composites. *International Journal for Scientific Research & Development*, *4*(3),1-10
[13] Yendapalli, K.K.R., Shaik, A.H., Narahari, V.K.R., Pramanik, S. & Bhaumik, S. (2022). Effect of reinforcements on graphite/titania/aluminium nanohybrid composites. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, 236(2), 217–224. https://doi.org/10.1177/13506501211047741
[14] Hu, Z., Li, P., Fan, C., Xiao, Y., Huang, J. & Ma, W. (2024). Research progress on aluminum matrix composites reinforced by medium and high volume fraction hybrid particles. *Materials Express*, 14(3), 353–369. https://doi.org/10.1166/mex.2024.2673
[15] Alabi, J.S., Heidari, E., Buchely, M.F., Chandrashekhara, K., Lekakh, S.N., O'Malley, R.J. & others (2024). Impact of quenching intensity conditions on using a finite element model to investigate the microstructure and hardenability of low-alloy steel. *Conference Proceedings*, 272–280. https://doi.org/10.31399/asm.cp.ifhtse2024p0272
[16] Alabi, J.S., Heidari, E., Buchely, M.F., Chandrashekhara, K., Lekakh, S.N., O'Malley, R.J. & others (2025). Influence of quenchant temperature on microstructure and hardness in Jominy end quench tests for AISI 4135 steel. *Conference Proceedings*, 96–110. https://doi.org/10.31399/asm.cp.qde2025p0096
[17] Nazeer, A. & Mir Safiulla (2020). Mechanical and wear properties of Al6063 metal matrix composite reinforced with Al_2O_3 particles. *International Journal of Recent Technology and Engineering (IJRTE)*, 8(5), 3955–3960. https://doi.org/10.35940/ijrte.E6732.018520
[18] Semiletov, A.M., Chirkunov, A.A., Grafov, O.Yu. & Kuznetsov, Y.I. (2022). Stability of superhydrophobic layers formed by organic acids on the surface of aluminum alloy 6063. *Coatings*, 12(10), article 1468. https://doi.org/10.3390/coatings12101468
[19] Li, X., Yan, H., Wang, Z.-W., Li, N., Liu, J.-L. & Nie, Q. (2019). Effect of heat treatment on the microstructure and mechanical properties of a composite made of Al-Si-Cu-Mg aluminum alloy reinforced with SiC particles. *Metals*, 9(11), 1205. https://doi.org/10.3390/met9111205
[20] Rahmalina, D., Sukma, H., Rokhim, A. & Suhadi, A. (2021). Mechanical properties of SiC/Gr reinforced hybrid aluminum composites after heat treatment. *Materials Science Forum*, 1042, 111–115. https://doi.org/10.4028/www.scientific.net/MSF.1042.111
[21] Pradeep, A.D. & Rameshkumar, T. (2024). Effect of heat treatment on metallurgical and mechanical properties of an aluminium 6061 hybrid composite. *Materiali in Tehnologije*, 58(5). https://doi.org/10.17222/mit.2024.1149
[22] Kumar, N.M.S., Dhruthi, Pramod, G.K., Samrat, P. & Sadashiva, M. (2022). A critical review on heat treatment of aluminium alloys. *Materials Today: Proceedings*, 58, 71–79. https://doi.org/10.1016/j.matpr.2021.12.586
[23] Zhao, J.-R., Hung, F.-Y. & Chen, J.-H. (2024). Effects of heat-treatment and cold-rolling on mechanical properties and impact failure resistance of new Al 6082 aluminum alloy by continuous casting direct rolling process. *Materials*, 17(4), 805. https://doi.org/10.3390/ma17040805
[24] Padmavathi K R, Ramakrishnan R, Karthikeyan L, & ChezhianBabu S (2020). Mechanical characterization of aluminium–titania metal matrix composites. *In Intelligent Systems and Computer Technology (633-639)*. https://doi.org/10.3233/APC200214
[25] Mohammadi, M. & Ashtiani, H.R. (2021). Influence of heat treatment on the AA6061 and AA6063 aluminum alloys behavior at elevated deformation temperature. *Iranian Journal of Materials Science and Engineering*, 18(2), 1–17. https://doi.org/10.22068/ijmse.1890
[26] Özyürek, D., Tunçay, T. & Kaya, H. (2014). The effects of T5 and T6 heat treatments on wear behaviour of AA6063 alloy. *High Temperature Materials and Processes*, 33(3), 231–237. https://doi.org/10.1515/htmp-2013-0060