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Mechanical and Morphological Investigation of Aluminium 7075 Reinforced with Nano Graphene / Aluminium Oxide / Inconel Alloy 625 Using Ultrasonic Stir Casting Method

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ABSTRACT

Aluminium Hybrid Metal Matrix Nano Composites (AHMMNCs) are finding widespread use in the aerospace, marine, defence, and automotive industries due to its high stiffness, high strength-to-weight ratio, and outstanding wear resistance. Hybrid nano composite materials are commonly used in engineering applications due to their proper mechanical organisation. Mechanical property improvement of hybrid nano composites is now a prominent field of research in materials and industrial technology. Aluminium alloy 7075 was reinforced with 0.5, 1.5%, and 2.0 wt. percent of nano-graphene (20-30nm), 2,4,6,8 wt percent of aluminium oxide (50m), and 2,4,6,8 wt percent of Inconel alloy 625 and 1wt percent of magnesium utilising an ultrasonic stir casting process in this study. Mechanical characteristics of the hybrid nano-composite material were evaluated using tension, compression, hardness, and flexural tests. SEM was used for morphology inquiry examination.

1. INTRODUCTION

Recent study investigates nano composite material as an emerging method for generating a material with a low density and a high strength-to-weight ratio [1] Example 1. A comparative investigation of the hardness derived from synthesised composites is conducted, and it is discovered that the hardness MMNC progressively increases as the concentration of reinforcing agent increases (SiO_2). Hardness values are highest in MMNC (AA2024-T351/3 wt percent SiO_2) with increasing concentrations.Using SiO_2 nanoparticles as a reinforcing agent. The results show that increasing the concentration of reinforcing particles greatly boosts tensile strength and impact energy (SiO_2). It is also discovered that when the concentration of nanoparticles in the matrix increases, the elongation of the produced composite decreases. 2. Tensile strength and hardness improve with increasing reinforcement weight %. Even with inadequate CNT dispersion in the composite, combining varied weight proportion reinforced particles by stir casting technique results in a roughly 25% improvement in tensile and hardness strength. These composites may be utilised in vehicle parts such as car, truck, and engine internals. They may also be utilised in turbines, aerospace sectors, defence submarines, tanks, and other applications where a high strength-to-weight ratio is required. The stir casting process is used to make metal matrix composites with the use of mechanical stirring. The matrix material was melted in an electrical furnace, and the warmed reinforcements were then combined with the matrix material. According to the literature, particle temperature, degasing, stirring speed, pouring time, and pouring temperature stirring temperature are all critical aspects that impact the characteristics of metal matrix composites [2]. Aluminium-nickel intermetallic composite these composites were successfully created by stir casting. The micro hardness characteristics of matrix material improved with increasing nickel concentration, rising from 100.95HV to 182.72HV (15 percent Ni). After T6 heat treatment, the greatest micro hardness value attained was around 248 HV (for 15% Ni), reflecting a 36% increase. In a drysliding wear test, this result showed that T6 heat treatment improved the wear resistance of Al7075+15 percent nickel reinforcement [3]. The AA7075 matrix composites reinforced with GNPs were created using the non-contact ultrasonic vibrations aided stir casting process. GNPs have been found to have an effect on the mechanical and physical characteristics of known composites. Experiments have demonstrated that adding GNPs to an aluminium matrix increases the microstructure, tensile strength, hardness, and tribological aspects of the composites generated. T6 heat treatment's influence on mechanical characteristics was also studied. When produced composites were compared to cast base metal matrix, they demonstrated an improvement in micro hardness and tensile strength of around 37% and 27%, respectively [4]. Tribological and mechanical qualities have been the focus of recent study [5]. Various forms of reinforcement, including as ceramic reinforcement, waste from manufacturing industries, and waste from agriculture industries, have been shown to be employed in the synthesis of aluminium matrix composites [4]. For the same process settings, the tribological behaviour of Al–boron carbide and Al–silicon carbide composites manufactured using the stir-casting technique was examined. Al–boron carbide exhibited a lower wear rate and coefficient of friction than Al–SiC composites, they observed. In recent investigations, micro-sized boron carbide particles were employed to enhance the mechanical characteristics of AMCs. The poor ductility and fracture toughness of micro-sized ceramic particle-reinforced aluminium metal composites with increasing ceramic particle concentrations, on the other hand, have limited their usage [6]. Using a stir casting technique, the mechanical behaviour and wear properties of boron carbide and graphite reinforced aluminium hybrid composites were investigated. It was discovered that the hardness and tensile strength of the fabricated composites were significantly improved when compared to AA6061 alloy [7].

Al7075 has several uses in the automotive, aerospace, mechanical, and marine sectors because to its high strength-to-weight ratio, high tensile strength, high yield strength, and high elongation at failure. Al7075 alloy is utilised directly or as part of a metal matrix composite in the above-mentioned industry. As a consequence, the Al7075 alloy is intriguing and was chosen as the foundation material for our research [8]. The mechanical characteristics of hybrid composites Al7075/Aluminum oxide/Graphite were investigated. Ceramic particles mixed with solid lubricants were stir cast into an aluminium alloy matrix to decrease wear resistance and friction factor. The hybrid Al 7075/Al2O3/graphite composites were created with 5% graphite reinforcements and 2, 4, 6, and 8% aluminium oxide with an average particle size of 16 m. The amount of abrasive phase enhances the flexural, tensile, compressive, and hardness characteristics of hybrid composites [9]. Due to its exceptional mix of qualities such as low friction, chemical inertness, absence of intrinsic abrasiveness, film forming capabilities on metal surfaces, and environmental friendliness, graphite was the most often used solid lubricant. An appropriate quantity of graphite particles added to Aluminium Matrix Composites (AMCs) can minimise the wear rate of the aluminium metal composites. Acoustic cavitation is the formation and dissolution of thousands of microbubbles in molten aluminium liquids caused by cyclic high intensity ultrasonic waves. The break downing of micro-bubbles in molten aluminium produces transient micro-hot spots that can have pressures of approximately 1010 atm and heating and cooling rates exceeding 1015 K/s. Transient cavitation could result in robust impact joining with the local high temperatures. It is sufficient to disperse nanoparticles, refine grains, remove gas, and homogenise reinforcement material dispersion. Based on the observations above, it can be concluded that only a few studies on the mechanical properties of ceramic particulates reinforced Al7075 metal matrix nano composites have been conducted [10, 11]. Aluminum matrix composites (AMCs) outperform any other monolithic material on the market today in terms of property combination. Aluminum matrix composites have been created and used for structural and functional purposes in a variety of engineering areas. The advantages of employing AMCs in various industries are around performance, cost, and the environment. AMCs improve transportation sectors by lowering fuel consumption, noise, and airborne pollution [12]. By altering the amount or percentages of matrix and reinforcements on their own, MC characteristics can be improved. A blend of nano-SiC and aluminium particles with average particle sizes of 50 nm and 16 nm was employed as reinforcement. The Al/SiC ratio was used to calculate the needed quantity of SiC. Previous research refers to this combination preparation as Particle reinforced aluminium matrix composites, which have been demonstrated to greatly increase the strength and hardness of aluminium and its alloys. Plasticity and ductility, on the other hand, can be greatly decreased at the same time. This will have a substantial influence on the safety and dependability of Al matrix composites (AMCs) components [13]. It was discovered that adding particles to the aluminium matrix enhanced indentation resistance. The resistance to indentation dropped abruptly when the amount of particle was raised to a greater percentage than typical. It is produced by the creation of clusters, which results in porosity and a drop in hardness value. As a result, large reinforcement levels lower the hardness value in Al Metal matrix composites [14]. The results unveil that the effect of graphite reinforcement over Al7075 alloy has a significant impact on static mechanical properties such as tensile, compressive strengths as well as hardness. The combination of SiC and graphite ceramic particles should be responsible for this massive gain in characteristics. Graphite particles tend to strengthen the link between the matrix and reinforcement, whereas SiC particles increase the ductility of the material, which finally improves the mechanical properties. Stir casting leads in uniform reinforcement distribution, which increases compression and hardness qualities. However, reinforcing of hBN provides better wear characteristics than other reinforcements, however when comparing both tensile and wear characteristics, Al7075 alloy reinforced with SiC and graphite ceramic particles is more lucrative, resulting in good mechanical and wear characteristics [15].

The ideal pressure employed in the squeeze casting of aluminium alloys and composites for superior microstructural refinement and mechanical characteristics is 100 MPa. The size of the reinforcing particles used in the squeeze casting process determines the material's strength. The smaller the grain size, the better the property improvement. The recommended melt and die temperatures for aluminium alloys and composites during squeeze casting are 600°C to 700°C and roughly 250°C, respectively. Due to the high pressure level in the squeeze casting process, there is a refinement in the microstructure with the combined impact of undercooling and a greater cooling rate. Mechanical characteristics are enhanced for both alloys and composites when manufactured using the squeeze casting technique under regulated process settings [16]. FSP was used to create superficial Al-Mo MMC. The approach under consideration appears to be appropriate for producing a dispersion of Mo particles in a superficial layer on the top surface of an Al sample. The results revealed that the Mo particles were well dispersed on the top surface of the samples, but no molybdenum powders were found in the cross section. In conclusion, it appears that the examined approach is effective for producing a superficial layer with increased performance due to powder dispersion to surface metal matrix composite [17]. This paper summarises the most recent state of knowledge in graphene manufacturing and processing methods for graphene reinforced metal matrix composites (GRMMCs). They can be separated from those seen in CNT-containing MMCs. The current work reveals that nano Graphene can improve different aspects of GRMMCs, however no investigations on the influence of Graphene flakes' size distribution on GRMMC attributes were conducted. Furthermore, the performance of graphene at high-temperature working circumstances is unknown and must be investigated. There is still a lot of work to be done in order to optimise their processing. GRMMCs provide up a whole new world of multifunctional and improved properties with a wide variety of applications [18]. Microstructural characterisation, mechanical property assessment, and corrosion experiments on AMMNCs were all successful in this work. The castings were made with varied amounts of Nano Al_2O_3 reinforcement ranging from 2 to 8%. According to the findings of the investigation, the presence of 6 percent nano Al_2O_3 particles in AMMNC exhibited excellent tensile strength (increased by 25.69 percent) and hardness (increased by 26.31 percent) in comparison to the rest of the nano Al_2O_3 particles in an account of structural strength established at 6 percent nano Al_2O_3 particles. It was discovered that the AMMNC with 2 wt. percent Nano Al_2O_3 had a larger weight loss than the other; hence, a high corrosion rate was produced with 2 wt. percent AMMNCs. When compared to the other AMMNC combinations, AMMNC with 6 wt. percent Nano Al_2O_3 demonstrated much higher corrosion resistance [19]. AA6061 matrix material was successfully created utilising SiC as the primary reinforcement material and RHA as the secondary reinforcement material using the mechanical stir casting technology. Tensile strength and hardness were increased by utilising SiC and RHA reinforcing materials concurrently, according to the results. Ductility and toughness were lowered by incorporating SiC and RHA reinforcement particles into the AA6061 matrix material. After heat treatment, the mechanical characteristics of the composite were enhanced [20]. The wear test findings for Al7068 alloy with various Mg percent composition reveal that the specimen with 3 percent Mg wears the least compared to other specimens at a load value of 2 kg, indicating that applications needing lower rates of wear require a high Magnesium content at moderate loads. The impact test on the alloy Al7068 with changing Mg percent composition results in the specimen with the maximum impact energy absorbed of 3.9J, indicating that the low percentage content of magnesium boosts the impact strength of the alloy and therefore its performance [21]. Al 6061 with 5%, 10%, and 15% weight increases hardness and tensile strength while decreasing percent elongation, indicating low ductility. The inclusion of ceramics into the matrix of Al 6061 increases the plain strain fracture toughness somewhat. The combination of alumina and zirconia in Al 6061 seems to reduce material wear. The material with the highest wear resistance has 15% zirconia and alumina additives [22]. The hardness range demonstrates the influence of the preheating procedure. Because preheating ensures effective bonding of TiB2 and Al7075. The addition of TiB2 improves the tensile characteristics as well as the strength of the AMMC. The optimal speed of the Pin on Disk results in the lowest wear rate (210rpm). The wear resistance in AMMC demonstrates that 15% -TiB_2 particles affect maximum wear reduction. Microstructural examination, such as porosity and worn surface inspection, is also utilised to validate the composite's surface quality [22]. In this literature review few research work had been performed by using Aluminium 7075 and Inconel alloy 625 hence these two material chosen as a matrix and reinforcement for this research work. Inclusion of the reinforcements increase the mechanical property of hybrid composite material. In this resaerch work mechanical properties of the nano compsoite material determined by using various test such as tensile, compression, hardness, flexural test.SEM analysis conducted to indentify morphological study of the hybrid nano compsoite and density and porosity of the composite was determined. Tensile strength increases from 116Mpa to 179 Mpa and hardness enhanced from 127 BHN to 170 BHN. Compression strength of the composite improved from 219Mpa to 264 Mpa and flexurnal strength of the composite material enhanced from 229Mpa to 450 Mpa. In previous reserch study not emphasis on flexural and comperssion strength property enhancement. This research work significantly focuses on flexural and compression strength property enhancement. There is no other research on the assistance of Aluminium alloy 7075 with three distinct reinforcements, namely aluminium oxide/Nano graphene/Inconel alloy 625, in the literature. No metal matric composite research work had been conducted using Inconel alloy 625 as a reinforcement and very few research work performed by utilizing ultrasonic stir casting fabrication method, this research work emphasis on fabrication of nano hybrid composite by using ultrasonic stir casting fabrication method.

2. EXPERIMENTAL PROCEDURE

Figure 1 depicts a stir casting machine. In this study, the aluminium alloy Al 7075 was used as the foundation material, with Nano graphene, aluminium oxide and Inconel alloy reinforcement. The hybrid nano composites were made using (0.5,1,1.5,2) Nano graphene, aluminium oxide (2,4,6,8), and Inconel alloy 625 (2,4,6,8) weight percent reinforcement. In a graphite crucible, the matrix material 7075 metal weighing 1250g of aluminium was heated and melted into liquid condition. Magnesium is used with an aluminium alloy 7075 to increase wettability between the base metal and reinforcements. Within 10 minutes at 860°C with mechanical agitation at 650 rpm, the reinforcing mixture and 1% magnesium were added to the melt. An ultrasonic probe constructed of stainless steel was used to generate a frequency of 20 kHz with a power of 2 kW. The titanium probe had a diameter of 15 mm and a length of 250 mm. Following the mechanical agitation, the ultrasonic agitation procedure was done for 15 minutes. The mould was warmed to 450°C before pouring molten aluminium into the prepared die at 870°C casting temperature. The die's dimensions are 300x100x15mm.

Figure 1. Stir casting machine

3. RESULTS AND DISCUSSION

3.1 Tensile test

The test findings in this study show an increase in tensile strength with increasing wt percent of aluminium oxide, Nano graphene, and Inconel 625. The highest tensile strength of the nano composite with 2 wt percent nano graphene +8 wt percent aluminium oxide +8 wt percent Inconel alloy 625 was 179MPa, which was 54.31 percent greater than the unreinforced aluminium matrix alloy 7075. The tensile strength of nano composites is plotted and displayed in Figure 4. In relation to the weight percentage of aluminium oxide, nano graphene, and Inconel alloy. The addition of weight percentage of reinforcements enhances the tensile strength up to 179 MPa, while additional reinforcements decrease the tensile strength of nano composite. as determined by the percentage of elongation shown in Table 1. It was discovered that the elongation of all produced composites ranged from 9.8 percent to 13.5 percent, with a consistent trend to decrease composite ductility. However, the results revealed that the ductility of nano composites deteriorated when reinforcements were added to the matrix material.

Table 1. Mechanical properties of aluminium 7075 alloy reinforced with aluminium oxide, Nano graphene and Inconel 625

Sample No	Wt % of aluminium oxide	Wt% of Nano graphene	Wt % of inconel alloy	Hardness (BHN)	Ultimate tensile strength (MPa)	Elongation (%)
1	0	0	0	127	116	13.5
2	2	0.5	2	134	121	13
3	4	1	4	140	138	12.3
4	6	1.5	6	150	156	10.8
5.	8	2	8	170	179	9.8

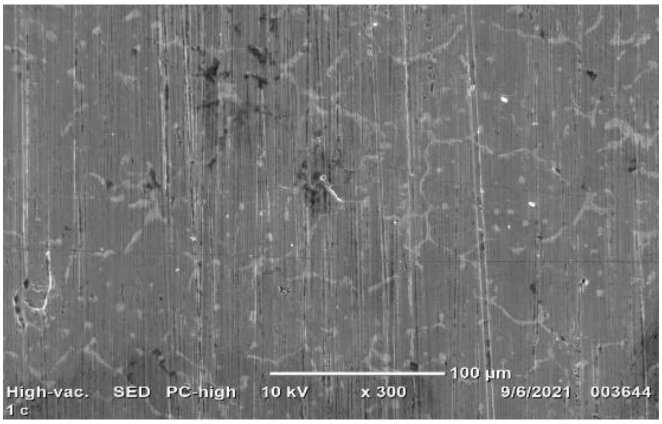
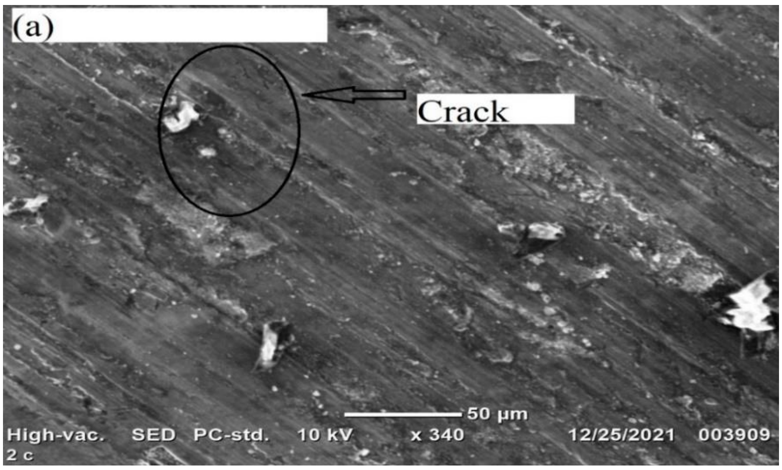
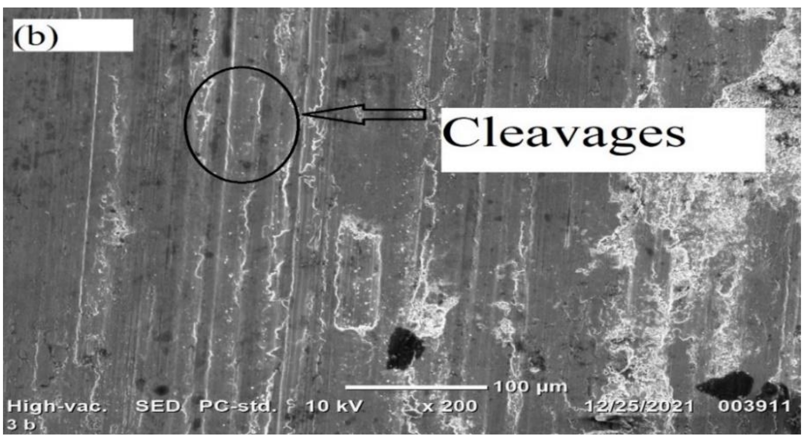


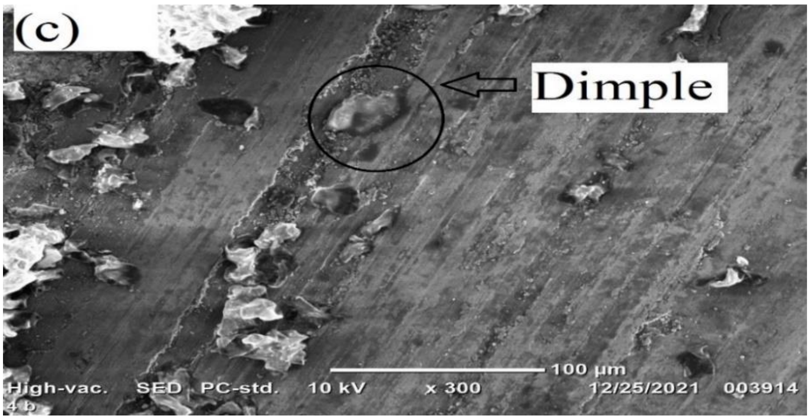
Figure 2. Aluminium 7075



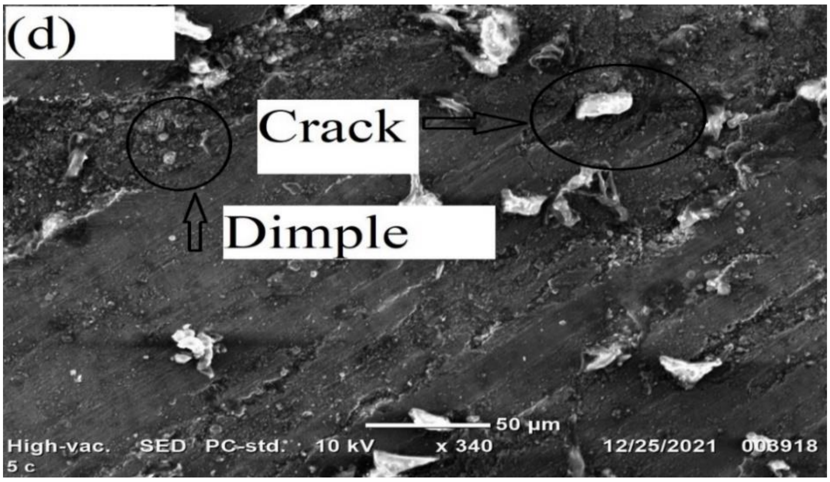
0.5Wt% nano graphene +2Wt% aluminium oxide+2Wt% Inconel alloy 625



1Wt% nano graphene +4Wt% aluminium oxide+4Wt% Inconel alloy 625



1.5Wt% nano graphene +6Wt% aluminium oxide+6Wt% Inconel alloy 625



2Wt% nano graphene +8Wt% aluminium oxide+8Wt% Inconel alloy 625

Figure 3. SEM image of hybrid composite

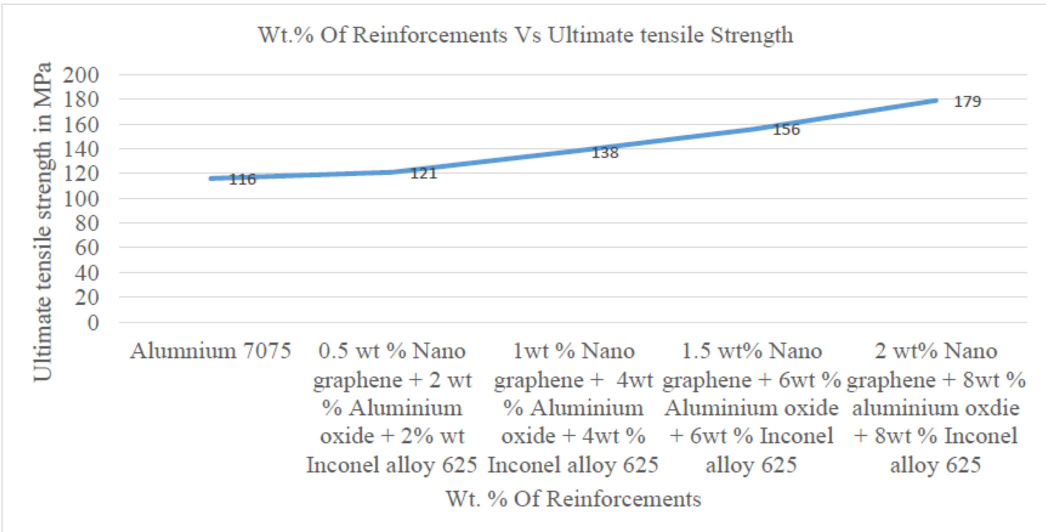


Figure 4. Variation of ultimate tensile strength of nano composite

3.2 Compression test

The compression strength of the specimen as determined by an ASTM E9 compression test using a universal testing equipment. The compression strength increases as the wt percent of hybrid reinforcements increases, with a maximum value of 330 MPa observed at the wt percent of 0.5 percent Nano graphene +2wt percent aluminium oxide and 2wt percent Inconel alloy 625. It was 50.68 percent more expensive than base metal 7075. Figure 5 shows how the compression strength of the enhanceed with the addition of aluminium oxide particles. Which acts as a barrier to dislocation movement. The hard aluminium oxide particles act as fracture barriers in the development plane of the cracks. Aluminum oxide particles exert higher restraint on the plastic flow during deformation, which adds to an increase in compressive strength.

3.3 Hardness test

Brinell hardness testing machine was used to evaluate the hardness of the hybrid composite material according to ASTM 10 standard. Figure 6 depicts the hardness of 7075 reinforced with Nano graphene, aluminium oxide, and Inconel alloy 625 hybrid nano composite. Each sample's hardness was assessed three times. It implies that the hardness of nano composite material rises with the addition of reinforcement in aluminium alloy 7075. Table 1 shows the hardness of the hybrid nano composite material. The greatest value of 170 BHN was observed at wt% of 2% Nano graphene, 8% aluminium oxide, and 8% Inconel alloy 625. It was 33.85 higher than base metal alloy 7075.

3.4 Flexural test

The flexural strength of the hybrid composite material was determined using an ASTM E290 universal testing equipment with a three-point bending fixture. Flexural strength of 450 Mpa was observed with 1.5wt percent Nano Grapehene +6wt percent aluminium oxide +6wt percent Inconel alloy 625. It was 95.30 percent more than the base metal alloy 7075, with a minimum flexural strength of 389 Mpa observed at 0.5 percent Nano Graphene + 2 wt percent + 2 wt percent Inconel alloy 625. Figure 5 shows how the flexural strength of the hybrid composite material rose as the percentage of reinforcements increased. The three point bending strength test was used to reveal the fracture behaviour of the composites with various weight percentages of aluminium oxide particles in the basic aluminium 7075 alloy. The impact of aluminium oxide and nano graphene on the flexural strength of composites and base alloys is shown in Figure 7. This indicates that the composites have sufficient flexibility to achieve greater strength of 1.5wt% Nano Grapehene +6wt% aluminium oxide +6wt% Inconel alloy 625 in the composites, resulting in an increase in flexural strength of 450Mpa. The small aluminium oxide particles prevent fractures from spreading quickly through the composite and restrict distortion, increasing the flexural strength of the composites.

3.5 Density and porosity

The density of the hybrid composite material increases as the weight percent of reinforcements increases. Figure 8 depicts the fluctuation in density with regard to the weight percent of reinforcements. The greatest density of 2.83kg /mm^3 was seen at wt percent of 1.5 percent Nano graphene, 6% aluminium oxide, and 6% Inconel alloy 625, while the minimum density of 2.81 kg /mm^3 was observed at wt percent of 2% Nano graphene, 8% aluminium oxide, and 8% Inconel alloy 625.

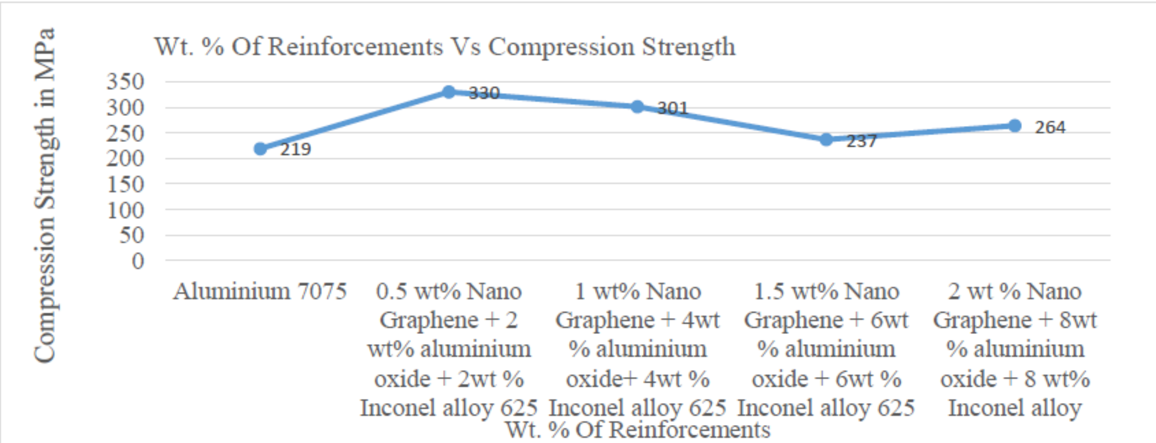


Figure 5. Variation of compression strength of nano composite

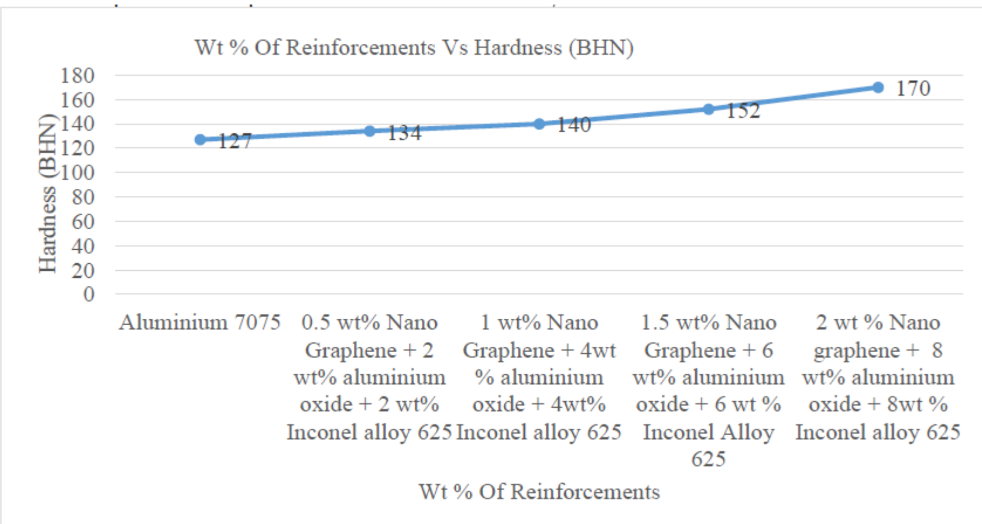


Figure 6. Variation of hardess of nano composite

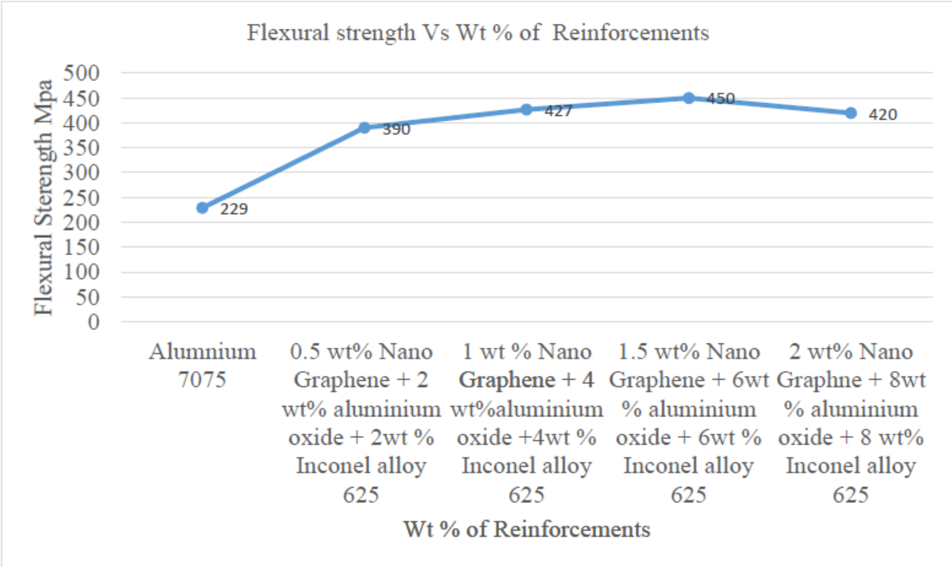


Figure 7. Variation of flexural strength of nano composite

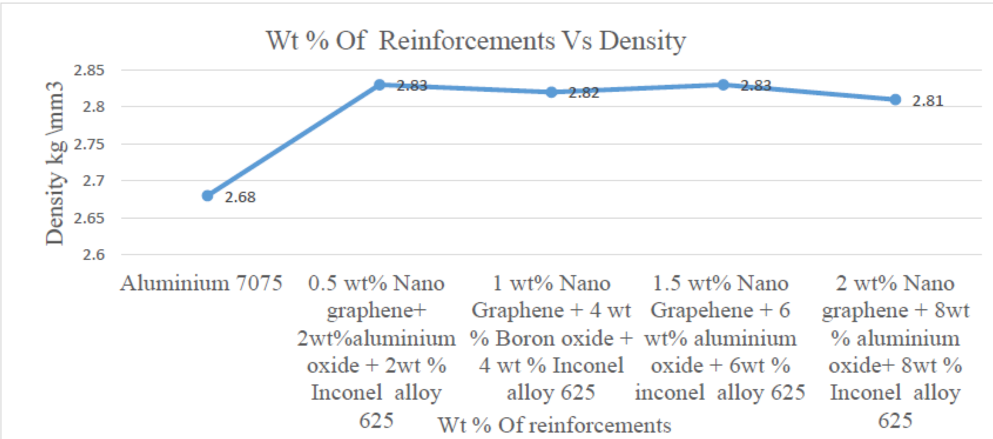


Figure 8. Variation of density of hybrid nano composite

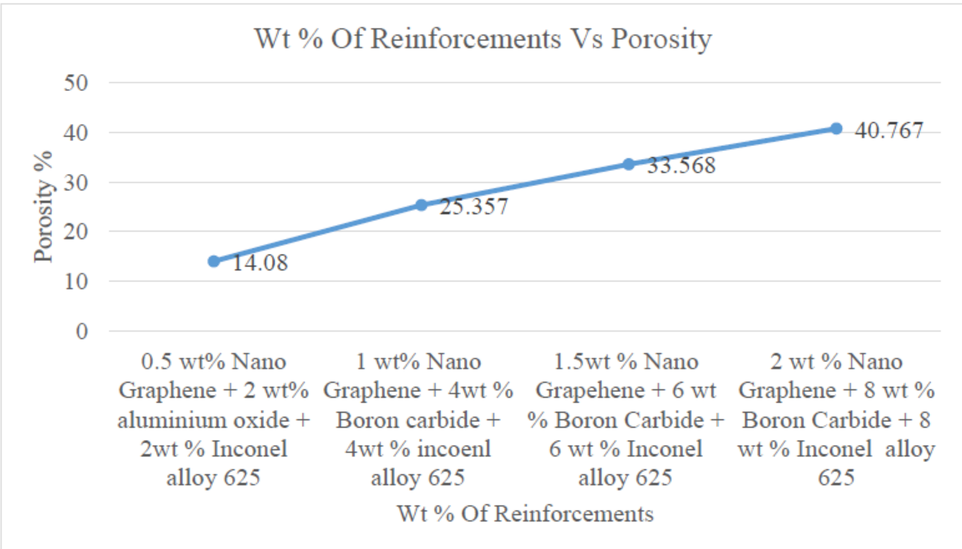


Figure 9. Variation of porosity of hybrid nano composite

Excessive contractions can occur during solidification, resulting in porosity in the composite. The greatest value of 42.767 percent porosity was seen at the wt percent of 2% Nano graphene, 8% aluminium oxide, and 8% Inconel alloy 625 while the minimum value of 16.080 percent porosity was observed at the wt percent of 0.5 percent Nano graphene, 2% aluminium oxide, and 2% Inconel alloy 625. Figure 9 depicts how the porosity of a composite material steadily increases as the weight percent of reinforcement increases. Porosity in nano composite material developed as a result of gas trapping.

4. MICROSTRUCTURE ANALYSIS

The microstructure was studied using a SEM picture to see how aluminium oxide, nano graphene, and Inconel alloy particles were distributed in the matrix. To get microhraphs, specimens with dimensions of 40mm x 40mm x 10mm were polished and mirror finished. Various types of emery paper were used to polish the microstructure specimen. Using a velvet towel, we wiped, dried, and cleaned after each polish cycle. To determine the cast structure, the composite was examined under a scanning electron microscope. Figure 2 depicts unreinforced aluminium 7075 microstructure.

Figure 3 (a-d) depicts the microstructure of an aluminium 7075 hybrid composite reinforced with aluminium oxide, nano graphene, and Inconel alloy 625. The results reveal that the reinforced particles are randomly orientated and that the reinforcement is evenly distributed.

5. CONCLUSION

The hybrid aluminium nano composite material were successfully fabricated by using ultrasonic stir casting method.

1. The microstructure findings show consistent reinforcement distribution and little porosity in the composites. Because of the superior mechanical mechanical characteristics shown by the made hybrid composites, the production of hybrid aluminium matrix composites utilising aluminium oxide, nano graphene, and Inconel alloy 625 has a significant benefit.

2. The addition of reinforcement particles such as aluminium oxide, nano graphene, and Inconel alloy to the aluminium 7075 increases the tensile strength of the composite. The nano composite with 2 wt percent nano graphene +8 wt percent aluminium oxide +8 wt percent Inconel alloy 625 had a maximum tensile strength of 179MPa, which was 54.31 percent higher than the unreinforced aluminium matrix alloy 7075.

3. As the reinforcing content in the matrix rises, the hardness of the composite increases. The greatest value of 170 B.H.N was observed at the weight percentages of 2% Nano graphene, 8% aluminium oxide, and 8% Inconel alloy 625. It was 33.85% more expensive than base metal alloy 7075.

4. The addition of reinforcing particles improves the compression strength of nano composites. The greatest compression strength of 330 MPa is observed at a weight percentage of 0.5 percent Nano graphene +2wt percent aluminium oxide +2wt percent Inconel alloy 625. It was 50.68 percent more expensive than base metal 7075.

5. The flexural strength of nano composites improves as the quantity of reinforcing elements in the aluminium alloy 7075 increases. Flexural strength of 450 Mpa was measured with 1.5wt percent Nano Grapehene +6wt percent aluminium oxide +6wt percent Inconel alloy 625. It was 95.30% more than the basic metal alloy 7075.

The nano size reinforcements (boron carbide and Inconel alloy 625) have the ability of enhancing mechanical properties of nano composite more than micro particulate hybrid composite by uniform distribution of reinforcements in the matrix material.

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