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Research Article

Efficacy of heat treatment on the material properties of aluminium alloy matrix composite impregnated with silver nano particle/calcium carbonate Al –AgNp/$CaCO_3$

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Abstract
Most innovative industries, for example, have begun to look for new engineering materials with better qualities. Aluminium metal matrix (AMCs) has been successfully used as "high tech" materials in a variety of industrial applications due to their improved functional properties. The aluminium-based composites with nano reinforced particulates is a promising material with good thermal stability, light weight, higher strength, increased stiffness, better fracture toughness, enhanced corrosion resistance, enriched fatigue, wear and tensile behaviour. It is a highly sorted material utilized in marine, automobile, as well as aerospace industries. In this study, the effect of heat treatment on the material properties of aluminium alloy matrix composite impregnated with silver nano particle/calcium carbonate (Al–AgNp/$CaCO_3$) was investigated. The stir casting technique has a proven record for the production of a homogenous mixture of aluminium alloy (AA 6063) matrix composite. The samples cast include S1, S2 and S3 consisting of varied weight of AgNp + CaCO3 at 2%, 4%, 6%, respectively, while samples S4, S5 and S6 consist of calcium carbonate ($CaCO_3$) at 2%, 4% and 6% composition respectively as well as the Control sample 'C'. A portion of each sample was heat-treated at 522 °C for 60 minutes and rapidly cooled in water to produce a T4 temper. The hardness, impact behaviour and tensile strength of the heat-treated materials were evaluated. The results established were compared with that of the unheated and C (control) samples. It was established that the hardness of the heat-treated samples increased with the addition of AgNp + $CaCO_3$ at 2% and 6% only. Similarly, the hardness of tempered samples impregnated with $CaCO_3$ particles only increased only at 6% composition. The impact strength of the heat-treated samples increased when reinforced with 4% and 6% of AgNp + $CaCO_3$. The addition of $CaCO_3$ has the same effect on the heat-treated samples at 2%, 4% and 6% composition. The major achievement of this research is establishing the optimum composition of reinforcement particle of AgNp and $Caco_3$ that have positive effects on the mechanical properties of heat treated AA6063 alloy matrix. Further heat treatment work is recommended in the area of annealing and quenching in different media and also varying the composite percentage above 6%.

Keywords
Aluminium alloy matrix, Calcium carbonate, Rockwell hardness, Impact strength, Silver nano particle, Tensile strength.

1.Introduction
It is pertinent to note that the selection of material properties played a vital role in engineering applications. It has been established that aluminium (Al) is one of the materials that was sought after globally because of its remarkable properties. Because of its availability and favourable characteristics, aluminium has found significant use in a variety of sectors.

Aluminium alloys have adequate strength characteristics, high corrosion resistance as well as high thermal conductivity, more so, it is ductile in nature, easy to be recycled with high tensile strength. As a result, it is widely used in a variety of industries,

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including maritime endeavours, aviation sectors as well as structural and automobile industries [1−3].

This research work aims to manufacture Al6063 alloy hybrid composites reinforced with the varied weight of silver nanoparticle and calcium carbonate. It characterizes the efficacy of heat treatment on the materials properties of the casted composites. It also determines the optimum weight composition of the reinforce material to yield better hardness property, improved impact strength (IS) and superior tensile behavior. This research investigation is envisaged to contribute to the current knowledge on metal matrix composites (MMCs), advanced stir casting technique and serve as an avenue for new research prospect in the area of material modification and innovations. It is expected to provide a new option for engineers in the aeronautical, automobile, construction and marine industries. However, the research investigation is limited to a specific choice of the matrix material (AA6063), and reinforcement particles (AgNp/ $CaCO_3$), heat process parameters (tempering) and characterization techniques (hardness, impact and tensile tests). It is designed to replace monolithic materials such as ferrous, aluminium, titanium alloys, as well as polymer-based composites in a wide engineering application, particularly in the aerospace, automotive, construction, and marine industries.

1.1Metal matrix composites (MMCs)

MMC has shown to be a viable option for modifying and improving the characteristics of aluminium and its alloys by adding reinforcement particles to monolithic metal. MMC occurs when two or more dissimilar materials (metal matrix and reinforcements) are joined to generate a superior and unique material, according to researchers [4−7]. Metal qualities like as stiffness, hardness, wear resistance, density as well as strength is improved by using reinforcements. Compared to monolithic aluminium, reinforced aluminium composites have several distinct advantages. Metal-ceramic composites (MCCs) are meant to combine the benefits of metals and ceramics. Metal, which forms a percolating network and is referred to as the matrix phase, is one of the elements of the composite material.

1.2Aluminium metal matrix composites (AMC)

AA6063 was selected as the suitable matrix alloys because of it comparatively easy to process, light weight, which helps in weight reduction and other unique combination of properties such as higher strength with improved stiffness, abrasion and wear resistance and also tailored electrical and thermal performance. By integrating sufficient reinforcement in a suitable volume fraction, it is feasible to change numerous technological properties of aluminium/aluminum alloys by more than two-three orders of magnitude. No other monolithic materials can match with the combination of attributes provided by AMC material systems today. The application of AMCs in numerous industries is driven by performance, environmental, and economic benefits. The main advantages of AMCs in the transportation sector are noise reduction, fuel efficiency, and decreased airborne emissions. As environmental regulations become more stringent and an emphasis on increasing fuel efficiency becomes more significant, the use of AMCs in the automotive industry will become required and desirable in the foreseeable future [8].

1.3Reinforcements

To complement a specific matrix material, appropriate reinforcement materials must be chosen. The choice of reinforcement is dictated by several factors like intended application, the process to be used, availability and cost-effectiveness. Particles not only increase the material properties of a matrix by strengthening dispersion, but they also prevent dislocation movement [9, 10]. The most commonly used reinforcements are fibres, whiskers and particles. The particles addition, as a reinforcement component imparts isotropic properties, whereas whisker and fibres, provide a certain amount of directionality [11].

1.4Stir casting

This technique involves the mixing of the preheated ceramic particles to the molten metal using a mechanical stirrer. This process was developed by Prasad et al. and later on, modified by Lloyd in which the preheated ceramic particles were added in a vortex of molten alloy created by the rotating impeller [12, 13]. The modified version of this technique is used commercially for the production of a variety of metal composites. The cast composites are occasionally extruded again to decrease porosity, refine the microstructure, and ensure that the reinforcement is distributed evenly. The main difficulties with this technique are the segregation of the reinforcing particles produced by surface or settling of the reinforcing particles while melting and casting. Wettability between the matrix and the reinforcement is a variable that determines the composite's characteristics. The position of the impeller, geometry, speed as well as the material properties of the added particles are all influencing factors during the particle distribution in the molten matrix [14].

2.Literature review

Different strategies for enhancing the metallurgical characteristics of aluminium and its alloys have been developed and implemented [15]. The approach utilised to modify the material is determined by the desired qualities and application region. Stir casting has shown to be an effective method for altering the characteristics of aluminium and its alloys. Stir casting is widely regarded as a viable method for producing MMC. It has various advantages over other approaches, including simplicity, ease of use, cost effectiveness, versatility as well as adaptability to large-scale production [16]. The stir casting method is mostly used to create particle reinforced metal matrix composites (PMMC). The technique entails dispersing reinforcement particles into the molten matrix melt and stirring continuously to ensure smoothness and prevent air bubble entrapment. Because the molten metal matrix might react with atmospheric air and suffer oxidation, consequently compromising the characteristics of the composites material, the molten metal matrix is normally subjected to degassing by a suitable liquid before the inclusion of the reinforcing material into the mould. [17].

MMC offers higher ductility than that of the ceramic matrix and better environmental stability than the polymer matrix composites. MMCs offer considerable improvement in thermal, electrical, as well as mechanical properties. Due to improved resistance to erosion and abrasion, MMCs are making great inroads into several sectors of industry. Lightweight, metal-matrix composites have been attracting growing interest and introduced into the most important applications in the automotive industry. Because MMCs may be custom-made based on the nature of the application, these novel materials have opened up limitless possibilities for current material science and development [18, 19].

Silicate, silver, copper, alumina, graphite, silicon carbide, carbon, boron etc., are the common reinforcement materials used in developing the composite for the desired specific applications. The reinforcement not only helps in weight reduction but also improves the component properties. The advantages of the composite material over the metals and alloys are the increased young’s modulus, tensile strength, creep resistance and reduced thermal elongation. MMCs are extensively used in the automotive, transportation, construction and leisure industry not only because of the improvement in mechanical and wear behavior but the affordable cost is also an essential factor [20].

Depending on the application for which the composite is to be utilised, numerous factors must be considered before selecting the MMC. Continuously reinforced matrix composites are used to effectively transfer load to the reinforcing filament, resulting in increased matrix toughness. When more strength than the composite's toughness is required, discontinuously reinforced composites are preferable. The performance of a composite is determined by the response between the matrix and the reinforcement during processing or in service. Thermal stresses are created by the substantial difference in coefficient of thermal expansion between the matrix and the reinforcement, which modifies the mechanical behaviour of the composite. The mechanical properties of the composite are also affected by the matrix fatigue performance on the cyclic response [21−23].

The composite's unique property parameters were determined by the use of a specific type of matrix reinforcement and a manufacturing technology that has given the metal matrix an almost limitless range of engineering uses. High electrical and thermal conductivity is sometimes important requirements for selecting a matrix, in addition to strength. Aluminium, magnesium, titanium, copper, iron and zinc alloys can be used as a matrix material to produce composites. The reactivity of magnesium and iron with the atmosphere makes processing difficult. The high reactivity of titanium results in the formation of inter-metallic with many reinforcement materials which makes titanium based MMCs much more difficult to produce than Al, Zn and Copper composites. Because of the growing demand for lightweight and high-strength components, aluminium and its alloys have become popular as matrix materials [24, 25].

Even the intermetallic-matrix and carbon matrix composites have also emerged recently. MMCs are attractive for brake rotors, bearings, cylinder liners, bushings as well as other applications due to their good wear resistance, high thermal conductivity as well as reduced coefficient of thermal expansion as compared to unreinforced alloys. With the usage of a large proportion of these MMCs, the weight of the next-generation aircraft will be reduced by 65 percent due to lightweight composite materials. The athletic and bicycle industries are two industries where composite materials are used commercially. Not only must automobile components are lighter, but they must also be cost-effective, according to industry standards. Because of the consistency of qualities in commercial components and the ability to meet specifications with high yields at a reasonable cost, particle reinforced MMCs will become a widely used engineering material [26].

Several methods had been employed in developing MMCs. The microstructure of the matrix phase depends on the technique used for processing the composite. The process used to develop composite affects the tribological properties because it influences matrix microstructure, the distribution of reinforcement and the bonding between the matrix and the reinforcement. Solid-state and liquid state processing routes are generally used for the fabrication of composites which are described below [27, 28].

Addition of reinforcement to the metal alloy modifies the microstructure and also influences the interface between the matrix and the secondary reinforcing phase. The interface adhesion developed due to the chemical reaction and interaction plays a crucial role in the performance of composite materials. Interfacial reactions in the aluminium metal matrix are predominantly determined by the nature, shape, size and volume fraction of the reinforcement. For the higher temperature applications, the microstructure of the composites needs to be stable for a longer period. The interfacial reaction and precipitation effect alters the microstructure which adversely affects the thermal stability of the composite. Porosity also influences the interfacial reactions due to the increase in surface area which further promotes the reaction. The surface cleanliness of the raw materials and casting parameters like temperature and holding time accelerate the interfacial reaction which damages the microstructure of the composite. To achieve the desired microstructure and properties care needs to be taken in the selection of the matrix by conducting appropriate surface treatment of the reinforcement and choosing the controlled processing parameters [29].

An enhancement in the mechanical properties of a composite is the important aspect which needs more attention during the preparation of the composite. Homogeneous distribution of particle in the matrix increases the hardness and decreases the ductility of the material, but at the same time alters the tensile and compressive strength. In several applications, materials experience compressive load. Characterizing the response of the material under compression requires its behaviour under compression before use. Tensile testing is widely used to study the mechanical behaviour of material to know its elastic, yield point and plastic deformation and its fracture properties. These studies are limited up to the region of necking under certain circumstances. So, compression tests are the alternative approach to understand the behaviour of the materials under the large plastic strains during the deformation processes to make the measurements beyond the tensile necking limit [29].

Extensive research works have been experimented and reported on aluminium metal matrix using different types of reinforcement particles. Some of these research investigations with their key findings are briefly reviewed in this section. Monolithic metals like aluminium metal have found several applications in both industry and research sectors due to favourable mechanical, electrochemical, tribological and metallurgical properties [30].

However, due to rapid and evolving advancement in the production of new equipment, the needs for engineered materials with specific functional and superior properties is on the rise. Addition of reinforcement particles to these monolithic metals can help develop new materials with improved and superior, corrosion resistance, mechanical, chemical, and metallurgical properties that can withstand the harsh and aggressive working environment [31].

Stir casting technique is a potential and promising technique to produce MMC is owing to its favourable properties over other techniques. Since Silver nanoparticle is known to be excellent reinforcement particles, stir casting techniques will be used to produce MMC with aluminium acting as the matrix and silver nanoparticle serving as the reinforcement particles [32].

This research is aimed at characterizing the effect of heat treatment on the material properties of Al6063 alloy hybrid composites reinforced with silver nanoparticle reinforcements and calcium carbonate powder. The study tends to fulfil the following objectives:

1. Vary the weight composition of the reinforcement particles to determine the optimal composition of the reinforcement particles.
2. Investigate the hardness, tensile strength, and impact behaviour of the casted composite.
3. Determine the effect of heat treatment on the material properties evolution from the casted AA6063/AgNp.

This investigation is envisaged to contribute to the current knowledge on MMC and stir casting and serve as an avenue for new research prospect in the area of material modification. For industrial applications, it is expected to provide a new option for engineers to select their choice of materials for ever-demanding engineering gadgets with high heat resistance. It will also expand research area and open new windows of opportunities for further research areas and innovations. This research study contributes to the area of composite material and material modification techniques. However, the research investigation is limited to a specific choice of the matrix material (AA6063), reinforcement particles (AgNp and CaCO), process parameters (tempering) and characterization techniques (hardness, impact and tensile tests).

3.Methods

The metal matrix used in this research study is AA6063 with the chemical composition depicted in *Table 1* of about 7000 g obtained in billet form at Iron and Steel Market Gate, Ibadan in Oyo State. Two different types of reinforcement were used for this research study. AgNp about 300g and $CaCO_3$ about 420g with 99.9% purity were used as the reinforcement particles. Only Nano-Silver particles sourced from South Africa all required materials were procured locally.

Table 1 Elemental composition of AA6063

Element	Cr	Cu	Ti	Fe	Mn	Zn	Si	Mg	Al
Wt. %	0.01	0.01	0.008	0.19	0.04	0.01	0.26	0.51	Balance

3.1Preparation of samples

In this study, the preparation of the samples was carried out in three different stages, which are the preparation of Nano material, the preparation of Al composites as well as the heat treatment of aluminium composites.

3.1.1Nano material preparation

Different weight compositions of the reinforcement particles were added to the metal matrix as illustrated in *Table 2*. 300g of AgNp was impregnated with 300g of $CaCO_3$. The main purpose of $CaCO_3$ is to serve as a binder without changing the composition or properties of AgNp or the base metal. 300g of AgNp and 300g of $CaCO_3$ was measured and put in a beaker and mixed thoroughly into slurry at 2000 rpm using Heidolph RZR 20121 automatic stirring machine. The slurry was spread on a nylon and left in the sun for six hours to dry and solidify. To get fine and even particle size, the dried mixture was ground into powder in a crucible and sieved through a 600 mesh sieve.

3.1.2Preparation of aluminium composites

AA6063 alloy was used in this research. About 7000g of this aluminium billet were purchased. The modified AgNp and $CaCO_3$ were used to prepare MMC of Aluminium-nano-silver particles (Al-AgNp) by stirred melting technique.

Stir casting was chosen for large scale production because of its ease of use, versatility in matrix management, and, most crucially, cost effectiveness. Due to the stirring action, combined with optimal processing settings, it delivers stronger matrix reinforcement bonding than other standard procedures [33, 34]. The degree of homogeneity, which should be significantly higher, determines the optimal mechanical and physical properties of composite materials.

The stir casting method has recently evolved to include a two-step mixing phase. The metal is heated to a temperature above that of liquids, then cooled to a semi-solid condition, upon which point preheated ceramic particles are introduced and homogenized. Further, it is heated to the high temperature followed by the mixing of particles with the impeller moving up and down, resulting in more uniform microstructure than the conventional stirring [35]. The purpose of two- step heating is to break the gas layers around the particle surface which also improves the wetting between the matrix and the ceramic reinforcement.

The mixing ratio of the base metal and reinforcement is illustrated in *Table 2*. The following procedures were adopted in the preparation of aluminium composite via stir casting. The aluminium billets were divided into seven (7) portions, measured with sensitive weigh balance and labelled as samples S_1, S_2, S_3, S_4, S_5, S_6 and S_C (control sample) as shown in *Table 2*. Each billet segment was firstly heated to 450°C before being melted in a crucible furnace at 750°C to integrate the modified AgNp. The modified AgNp was then weighed and preheated at 100°C for 20g, 40g, and 60g before being mixed with 980g, 969g, and 940g of molten aluminium billets, respectively. The liquid was well mixed for 10 minutes at 180 rpm before being put into a 20mm by 300 mm cylindrical moulds. At the same percentage weight fraction, same operations were repeated for Al-CaCO3 as indicated in *Table 2*.

Table 2 Substrate (aluminium) to reinforcement formulation ratio (AgNp, $CaCO_3$)

Sample	Mass of composite (g)	Mass fraction of Al (g)	Reinforcement fraction (AgNp + $CaCO_3$)		Reinforcement fraction ($CaCO_3$)	
			%	Mass (g)	%	Mass (g)
S_1	1000	980.00	2.00	20.00	-	-
S_2	1000	960.00	4.00	40.00	-	-
S_3	1000	940.00	6.00	60.00	-	-
S_4	1000	980.00	-	-	2.00	20.00
S_5	1000	960.00	-	-	4.00	40.00
S_6	1000	940.00	-	-	6.00	60.00
S_C	1000	1000.00	-	-	0.00	0.00

3.1.3Heat treatment of aluminium composites

Each casted sample was divided into two portions of equal size (150mm each). For heat treatment, one portion of each sample was chosen. During the heat treatment process, each sample was aged and tempered. The sample S1 AA6063 alloy was heat treated at 522°C (970°F) and soaked for 60 minutes in a muffle furnace. After that, the alloy elements are quenched in water for quick cooling to avoid precipitation. T4 temper is produced as a result of this process. The procedure was repeated for another six samples.

3.2Mechanical characterization of heat treated samples

In this study, the following mechanical characterizations such as hardness test, impact test as well as tensile strength test were carried out in the heat-treated samples.

3.2.1Hardness test procedures

All polished specimens were subjected to a hardness test using an Atico Rockwell hardness tester in line with the American society for testing and materials (ASTM) E384 standard. The specimen was thoroughly washed and cleaned, and was made free from any foreign materials such as dirt and grease. The specimen was then placed one after the other on the anvil and allowed to make contact with the indenter. 980 N was selected on the load selector.

The Load/Unload liver was used to apply the load (900 N) to the specimen, and the scale deflector was allowed to rest for 15 seconds before recording the reading. To verify reproducibility and correctness of the results, the experiment was repeated three times. Equation 1 was used to calculate the average Rockwell hardness (HRC) number for each specimen.

$$\text{HRC}=\frac{HR1+HR2+HR3}{3} \quad (1)$$

3.2.2Impact test procedures

In the same vein, Impact test was carried out to assess the brittle fracture specimens and to determine their impact strength. Atico Charpy Impact Tester was used to carry out the test in accordance with ASTM E23. The samples were cut into standard Charpy test specimens of 55mm length and 10 mm breathe with thickness of 5 mm. A 45° V-notch of 2 mm depth and 0.25 mm root radius was cut at the center of each specimen. Each specimen was cleaned and placed in the impact testing machine's vice in such a way that the notch was at the center and backing the hammer. The pendulum was moved up to its locked position and ensured that it was locked at pre-swing angle. The path of the swing of the pendulum was cleared and ensured all safety guards are in place. The scale pointer was reset to zero, and precautionary measures were checked. The pendulum was launched, and then allow to strike the specimen in the middle. It was then fracture and the impact energy absorbed 'E1' (in joules) was recorded immediately from the scale. The experiment was repeated for the second specimen, and E2 was also recorded. The average impact absorbed energy (AvgIE) (in Joules) and Impact Strength 'IS' (in Joules/m2) for the specimen was also calculated using Equation 2 and Equation 3.

$$\text{AvgIE} = (\text{E1} + \text{E2})/2 \quad (2)$$

$$\text{IS}=\frac{\text{AvgIE}}{\text{A}} \quad (3)$$

Where A is the area of the impact specimen (L × B × H) in m^2.

3.2.3Tensile test procedures

The standard tensile specimen was machined from each sample and Hi-Tech Universal Tester HSM58 was used to carry out the tensile test in line with ASTM E8 standard test. It was noted that 90 mm was measured to be original length while 20 mm was recorded as diameter. The specimens were inserted into the machine's test grips one after the other and properly fastened at both ends. Also, a strain measuring device was attached to it. The load was applied; the record of the load versus elongation data was taken. Tensile test was carried out until fracture occurs. For all specimens that were later analysed, the machine recorded yield strength, stain, ultimate strength, elongation as well as stress. Readings were taken more frequently as yield point is approached. The final length and diameter of the specimens were also measured.

4.Results

This section presents a detailed discussion of the results and analysis conducted on the AA6063/AgNp samples. The section is divided into different subheadings based on the characterization techniques results.

4.1Hardness test results

Table 3 shown the result of the Rockwell Hardness Test conducted on the specimens. The HRC was calculated using Equation (1). The result has been presented graphically in *Figure 1*.

Table 3 Result of Rockwell hardness test conducted on tempered AA6063/AgNp Samples

S. No.	Sample	HR_1	HR_2	HR_3	HRC
1	S_1 (2% AgNp + $CaCO_3$)	53.5	52.5	57	54.3
2	S_2 (4% AgNp + $CaCO_3$)	48	45	48.5	47.17
3	S_3 (6% AgNp + $CaCO_3$)	46	54.5	55.5	52
4	S_4 (2% $CaCO_3$)	48.5	51.5	53.5	51.17
5	S_5 (4%$CaCO_3$)	47	53	53.5	51.17
6	S_6 (6%$CaCO_3$)	54.5	50.5	56	53.67
7	C (100% AA6063)	50.5	51	54	51.83

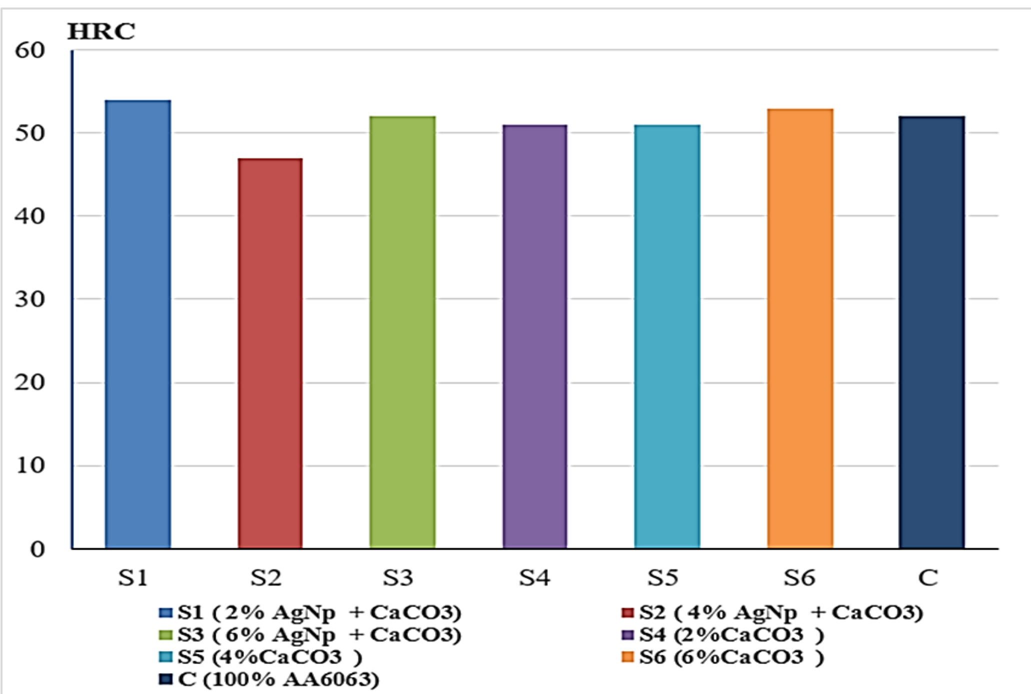

Figure 1 Comparison of hardness properties of tempered AA6063/AgNp composites

Figure 1 revealed that S_2 (impregnated with 4% AgNp + $CaCO_3$) has negative impact on the hardness properties of the base material (AA6063). It reduces the hardness by 10%. While S_3 (6% AgNp + $CaCO_3$),

S_4, and S_5 impregnated with 2% and 4% of $CaCO_3$ only respectively at has no significant impact on the hardness property of the base material. But at 6%, both $CaCO_3$ and AgNp+$CaCO_3$ individually increases the hardness value of the base metal by 6%.

4.2Impact test results

Table 4 shows the results of the Charpy Impact Test performed on the specimens. Equations (3) and (4) were used to calculate the average impact absorbed energy (Avg IE) and impact strength (IS).

From the analysis of the Charpy Impact test shown in *Figure 2*, reinforcement of the base material with AgNp + $CaCO_3$ only increases the Impact Energy (IE) at 6% (S_3) by 4 Joules. The impact strength reduces as the percentage reduces. Impregnating the sample with 2% AgNp + $CaCO_3$ also reduces the impact strength of the matrix by 4 Joules.

Table 4 Impact test results on tempered AA6063/AgNp samples

S. No.	Sample	IE_1 (J)	IE_2 (J)	Avg IE (J)
1	S_1 (2% AgNp + $CaCO_3$)	31	34	32.5
2	S_2 (4% AgNp + $CaCO_3$)	35	37	36
3	S_3 (6% AgNp + $CaCO_3$)	35	44	39.5
4	S_4 (2%$CaCO_3$)	38	42	40
5	S_5 (4%$CaCO_3$)	36	40	38
6	S_6 (6%$CaCO_3$)	34	42	38
7	C (100% AA6063)	34	37	35.5

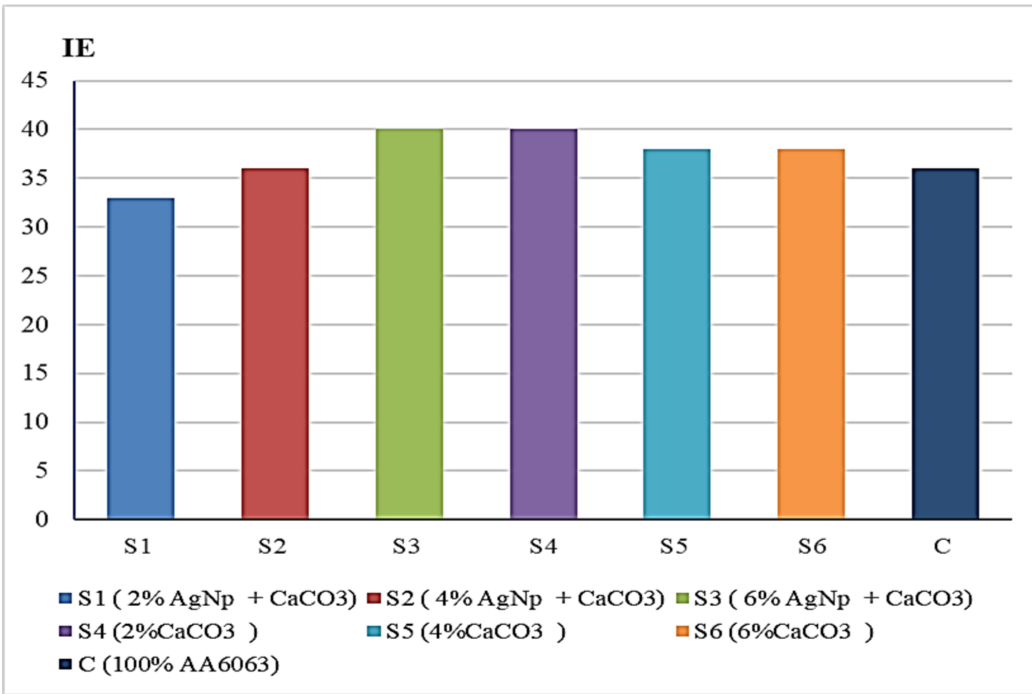

Figure 2 Comparison of impact absorbed energy (IE) of tempered AA6063/AgNp

4.3Tensile test results

Table 5 shows the results of the Tensile Test performed on tempered AA6063/AgNp samples.
Figure 3 shown that AA6063/AgNp has great effect on the tensile strength of samples S_1, S_2 and S_5. The greatest impact was on S_5 impregnated with 4% $CaCO_3$ which increased the tensile strength by 26MPa (27% Increase) followed by S_1 impregnated with 2% AgNp + $CaCO_3$ increased the tensile strength by 14Mpa (15% increase) and S_2 (4% AgNp + $CaCO_3$) with 3Mpa or 3% increase.

Table 5 Tensile test results on tempered AA6063/AgNp samples

S. No.	Sample	Length (mm)	Diameter (mm)	Tensile strain at break (Standard)	Tensile strain at maximum tensile stress	Tensile stress at yield (Zero Slope)
				(mm/mm)	(mm/mm)	(MPa)
1	S_1	30,000	4	0.06421	0.03777	110.23
2	S_2	30,000	4	0.0645	0.04633	98.873
3	S_3	30,000	4	0.07532	0.0583	90.112
4	S_4	30,000	4	0.0665	0.05327	93
5	S_5	30,000	4	0.09282	0.08406	122.003
6	S_6	30,000	4	0.06456	0.05312	80.101
7	Control	30,000	4	0.0757	0.06438	96.001

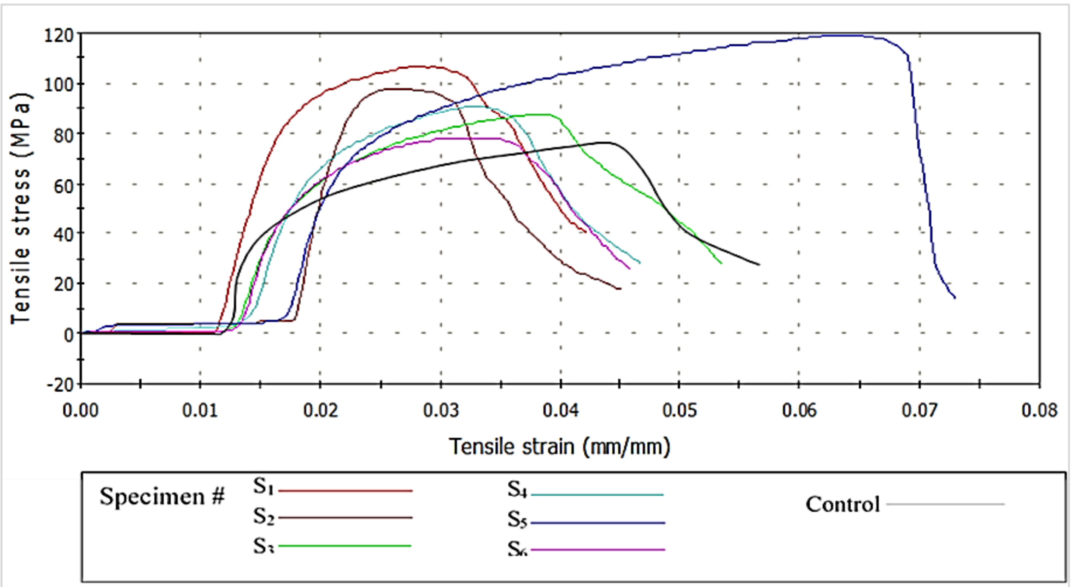

Figure 3 Comparison of tensile strength of tempered AA6063/AgNp samples

5.Discussion

The effect of heat treatment on the Hardness, Tensile and Impact properties of Aluminium alloy matrix composite impregnated with nano-silver particle is presented in *Table 6*. In samples S_1 and S_6 impregnated with 6% AgNp + $CaCO_3$ and 6% $CaCO_3$ respectively, the hardness values increased by 6% each. Impact strength of AA6063 alloy was increased in S3 (impregnated with 6% AgNp + $CaCO_3$) and S4 (impregnated with $CaCO_3$) by 6% each. The impact strength drastically decreases with further addition of $CaCO_3$ reinforced at 4% and 6%. While the impact strength increases with further increase of AgNp + $CaCO_3$ from 2% to 4%.

Nano-Silver particles has great effect on the tensile strength of samples S_1, S_2 and S_5 The greatest impact was on S_5 impregnated with 4% $CaCO_3$ which increased the tensile strength by 26MPa (27% increase), followed by S_1 impregnated with 2% AgNp + $CaCO_3$ increased the tensile strength by 14Mpa (15% increase) and S_2 (4% AgNp + $CaCO_3$) with 3Mpa amount to 3% increase. A complete list of abbreviations is shown in *Appendix I*.

Table 6 Summary of efficacy of heat treatment on the material properties of AA6063/AgNp

S. No.	Sample	HRC	Impact strength (IE)	Max tensile stress (MPa)
1	S_1	54.3	32.5	110.23
2	S_2	47.17	36	98.873
3	S_3	52	39.5	90.112
4	S_4	51.17	40	93
5	S_5	51.17	38	122.003

S. No.	Sample	HRC	Impact strength (IE)	Max tensile stress (MPa)
6	S_6	53.67	38	80.101
7	Control	51.83	35.5	96.001

6.Conclusion and future work

The major achievement of this research is establishing the effect of heat treatment on mechanical properties of AA6063/AgNp alloy matrix impregnated with AgNp + $CaCO_3$ and $CaCO_3$ at varying weights of 2%, 4% and 6% composition. From this study, it was established that the hardness increased when impregnated with 2% and 6% AgNp particle or 6% of $CaCO_3$ particle. The impact strength of the composition increased when reinforced with an AgNp particle (at 4% and 6%) or $CaCO_3$ particles (at 2%, 4% and 6%). But the addition of 2% AgNp particle to the composition reduced the impact energy by 8.5%. The addition of 2% and 4% AgNp + $CaCO_3$ increased the tensile strength of the sample of 14 MPa and 3 MPa, respectively while impregnating the composition with 4% CaCO3 only increased the tensile strength of 26 MPa. It was revealed that the impact strength drastically decreases with further addition of $CaCO_3$ of 4% and 6%. While the impact strength increases with further increase of AgNp + $CaCO_3$ (from 2% to 4%).

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Omolayo M. Ikumapayi: Conceptualization, supervision, writing – review and editing, project administration, correspondence, fund acquisition. **Sunday A. Afolalu:** Writing – review and editing, software, preparation, and fund acquisition. **Ojo P. Bodunde:** Data curation, validation, writing, review and editing. **Chukwuebuka P. Ugwuoke:** Data collection, writing and original draft, methodology, investigation. **Henry A. Benjamin:** Methodology, investigation, writing writing – original draft, analysis, and interpretation of results. **Esther T. Akinlabi:** Supervision, resources, formal analysis, and fund acquisition.

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Appendix I

S. No.	Abbreviation	Description
1	AA 6063	Aluminium Alloy 6000 Series
2	AgNp	Silver Nano Particle
3	AgNp/$CaCO_3$	Silver Nano Particle/Calcium Carbonate
4	Al	Aluminium
5	Al-AgNp	Aluminium-Nano-Silver Particles
6	AMC	Aluminium Metal Matrix Composite
7	ASTM	American Society for Testing and Materials
8	Avg IE	Impact Absorbed Energy
9	$CaCO_3$	Calcium Carbonate
10	HRC	Hardness Number
11	IS	Impact Strength
12	MCCs	Metal-Ceramic Composites
13	MMCs	Metal Matrix Composites
14	PMMC	Particle Reinforced Metal Matrix Composites