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The influence of nickel on the mechanical and tribological properties of AA2219-CNT composites made by stir casting

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AA2219 aluminium alloy matrix composite enhanced with CNTs(Carbon nanotubes) was investigated for its mechanical and tribological properties. Stir casting was used to add nickel to the aluminium matrix, and the homogenization procedure was then used to homogenise the mixture. It was found that the interdimeric portions of the interdimeric CNT and aluminium compounds had a block-shaped structure. There was an increase in tiny needle-shaped Aluminum precipitates near interdimeric zones when nickel was added up to 1.5 wt%; additional nickel addition reduced their abundance in this location. It was found that the needle-shaped Carbon Interdimeric nanotube precipitates disappeared following normalisation treatment with nickel up to 4.5 wt%. Ni and CNT intermetallic were converted to CNT by adding nickel and homogenization. Furthermore, the aluminium matrix generated aluminium precipitates instead of al-Ni precipitates when nickel concentration increased from 3 to 4.5 wt%. Composite's coefficient of friction and wear rate were lowered by 13 percent and 12 percent compared to a control sample without nickel, while its strength was increased by roughly 42 percent.

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1. Introduction

Many industries have recently found aluminium to be a viable replacement to metals or cast iron because of the need for light and strong materials [1]. As a result, aluminium and its alloys are expected to have distinct properties. Making aluminium matrix composites (AMCs) with ceramic reinforcements is one method of achieving such qualities like strength and durability. Production of these materials may be accomplished through a variety of processes, the most common of which being powder metallurgy and metal casting. Powder metallurgy, as an example, is a costly process. When it comes to casting, there are several drawbacks, including the difficulty of inorganic nanoparticles to wet composite [2–7]. It is possible to cover the ceramic particles with a metal to alleviate this issue. Aside from that, rigid reactive products that form amongst matrix and filler weaken the composite's mechanical characteristics. Another approach is to strengthen the aluminium matrix using technologies. Compared to the prior procedure, the reactive compounds utilised here are more stable and produce a genetic flaw surface. To put it another way, high temperatures are required for the reactions to take place. For the manufacturing of reinforcing particles like CNT, aggressive infiltrate is another method relying on the reactivity of nanoparticles with aluminium composites. These approaches, however, need the use to manufacture AMCs, the process requires high temperature increases and complicated machinery, which is a challenge [8–10]. Researchers are now studying the effects of metal particles on molten aluminium. Nickel, titanium, and tungsten are examples of metal particles that have low aluminium solubilities and high aluminium solubilities, respectively, in terms of aluminium solubility (such as zinc) [11–15,36,37].

A reinforcing material in aluminium matrix composites, the first group has a lower melting point than aluminium. Nickel strengthened aluminium metal matrix composites may be made utilising filming procedures by several researchers [16]. Copper particles were used in the fabrication of A356 composites. Stir casting was

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used to create the composite. It was determined that AMC containing copper particles had a greater hardness, fracture toughness, yield stress, young's modulus, and flexibility than A356 alloy [17–19]. The mechanical characteristics of Al-Cu(p) composites made by stir casting were examined to see if copper content affected their mechanical properties [20]. Around 5–10 wt% copper boosted the performance, but more than 15 wt% copper lowered the performance, due to a build up of Strengthened materials [21]. The microstructure and hardness of the material were also enhanced by increasing copper. Stir-casting the AA6061 matrix composite with steel chips increased its mechanical qualities and wear resistance compared to the alloy without steel chips, according to [22]. CaCl2 was incorporated into the AA7178 alloy to observe the results.

The AMC was made using a combination of stir casting and moderately casting techniques. In comparison to the composite, the AA7178 matrix alloy was shown to be weaker and less able to withstand strain [23–25]. The composition of an A390 / 10 % Mg composite was studied using the semi-solid casting technique to see how the ageing thermal treatment and agitation speed influenced it [26]. The composite matrix was found to include spherical grains of -Al as a result of ageing heat treatment. Grain sizes became more spherical as a result of longer stirring times. In high-temperature applications, the excess of Zr and Sc to A356 alloy raised the toughness of the materials [27]. Al-Si matrix alloy was shown to have a tensile strength and ductility increase of up to 470 MPa and 9%, respectively, when stainless-steel granules were added to the Aluminium-Silicon matrix and the casting pressure was increased to around 110 MPa. They are an ideal reinforcement for AMCs because of their excellent strength, corrosion and oxidation resistance, and elastic modulus [28]. CNT intermetallic compounds were produced through the stir casting procedure, resulting in an increase in the micro - hardness and abrasion resistivity of the AA7075 matrix composite enhanced with Nickel. The corrosion behaviour of Ni powder-strengthening stir-cast AA6061 matrix composites was explored in this work to see how a T6 heat treatment process affected it [29].

A greater degradation current and a lower polarisation resistance were observed for as-cast and samples that were heated, accordingly, when nickel content was increased. In contrast, the as-cast composites demonstrated higher corrosion resistance than the heat-treated samples. Stir-cast Ni-reinforced AA6061 matrix composites provide protection against corrosion was shown to increase with increasing nickel atomic percentages in intermetallic compounds examined by [30]. These results show that an Al4Ni intermetallic compound-containing composite specimen has greater corrosion resistance than other similar composite specimens. The solidification of the CNT composite changed the liquid-solid interface transition, which affected the CNT phase development. By employing the stir and squeeze casting technique, [31] created the AA1100-Al3Ni in-situ composite. They found that the composite's mechanical and tribological characteristics were improved by increasing the Al3Ni content.

Another research said that squeeze cast materials had superior characteristics than stir cast materials. [32] investigated the effects of in-situ synthesis of Al3Ni on nickel addition to aluminium melt during the stir casting process. Increasing the temperature and time of stirring lowered the size of the Al3Ni particles. The (Al2CuMg) and (Al2Cu) precipitates of AA2219 aluminium alloy are the main strengthening components in this family of Al-Cu-Mg alloys. Nickel aluminides may be highly hard and robust with the addition of nickel [33–34]. Thermal instability at high temperatures is a problem with Al-Cu-Mg alloys. Incorporation of nickel aluminides into the aluminium matrix, which has a high thermal stability, can enhance such alloys. An investigation into the mechanical characteristics of nickel aluminides has looked at how nickel powder is introduced to aluminium melt and how the composite is stir cast [35].

2. Materials and methods

An aluminium alloy known as AA2219 with a chemical constitution of 0.2 percent Si, 6.8 percent Cu, 0.4 percent Mn and a balance of Al was chosen as a composites for the experiment (all weight percents). Particle sizes between 20 and 70 μm were also used as reinforcement. Fig. 1 shows the tensile specimen from stir casting procedure An motor with a horsepower of three was used to stir cast the metal Speeding up to 300 rpm At such a temperature of 750 °C, the stirring was done for 20 min. A graphene chamber was used to melt the material in an oven at a temperature. Here, you can see what happens throughout the stir casting technique. Fig. 2 shows Schematic view of Stir casting technique. Addition of nickel powder to the aluminium melt in amounts of 1.5, 3, and 4.5 wt% the purpose of this study is to examine the effect of nickel content on the performance of the product. An argon-carrying gas was utilised to infuse the molten iron with the argon gas. When the molten metal was ready, it was poured into a 200-mm-long, 22-mm-diameter cylindrical mould. There were S-0 (no nickel), S-1.5 (1.5%), S-3 (3.5%), and 4.5 (4.5%) nickel samples. The structural properties of samples were examined after a 24-hour standardization thermal treatment at 500 °C. A sample of the as-cast rod was collected after the molten metal had cooled down for testing. Tensile test samples is assessed for mechanical properties and Vickers hardness were subjected to a 15 kg force for 10 s in order to measure the composites. An ASTM G99-15 tribometer wear test was carried out at a distance of 1000 m under the 10 N load, in line with ASTM G99-15. In terms of diameter and length, the pin measured six millimetres in diameter and thirty millimetres in length. A bearing surface disc made of AISI/SAE 52100 steel hardened to 60 HRC moved the pin at a constant speed of 50 cm/s. The pore size distribution of the composites was measured in the following way:

3. Results and discussion

It possessed eutectic structure and intermetallic compounds developed in the interdimeric areas in sample S-0, which was as-cast. The needle-like precipitates were also seen in interdimeric areas. The eutectic structure was lost during homogenization heat treatment, although interdimeric areas remained showed block-shaped intermetallic complexes. Precipitates were formed in the dendrites as a result, resulting in an interdimeric space that was devoid of precipitates. Thus, the composite coatings produced in inter - granular zones were no longer connected and became isolated islands of metal. As-cast samples have a eutectic structure considerably decreased and disappeared when nickel was increased from 1.5 to 4.5 wt% in the melt. Samples of composite samples, like sample S-0, have interdimeric areas with block-shaped intermetallic compounds at the as-cast condition. As a result, tiny needle-shaped precipitates near the interdimeric areas rose when nickel was added up to 1.5 wt%; additional nickel diminished the number of these precipitates in this area. Compounds generated in interdimeric zones after homogenization treatment no longer had an interconnected structure and were distinct structures.

In contrast, the percentage of these intermetallic compounds grew as nickel content increased. Interdimeric needle-shaped structures disappeared after homogenization treatment when nickel was introduced. Nickel precipitated in the inner zone of dendrites. Intermetallic dark mixtures in S-4.5 did not lose their slip form next standardization. In the interdimeric areas, a copper-

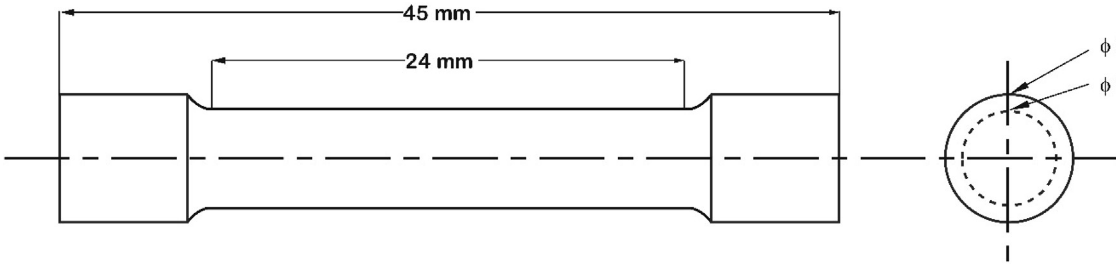

Fig. 1. Tensile test sample dimensions.

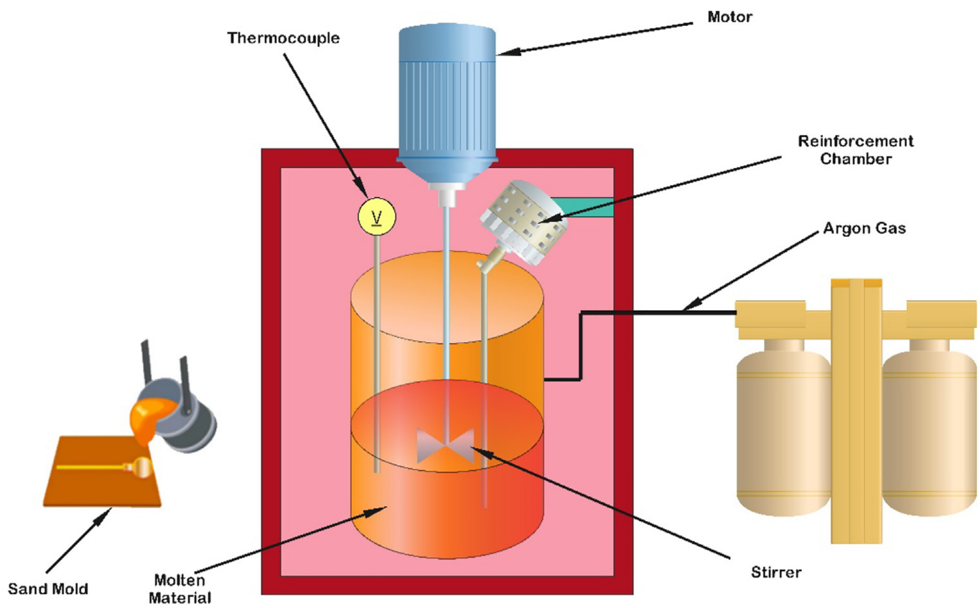

Fig. 2. Schematic view of Stir casting technique.

poor zone is generated, preventing the production of CNT precipitates. AA2219 intermetallic complexes that are unique from Al2CuMg now encircle the interdimeric zones following homogenization treatment. These intermetallic compounds, because to their high melting points, might be diffused into the framework. These secondary aluminium particles have been reported by other researchers in the field. Sample S-0′s as-cast and homogenised microstructures contain these particles. The homogenization treatment has had no effect on their morphology, as can be shown.

Adding nickel and conducting homogenization treatment can be found to have a positive effect. Nickel and aluminium compounds were the starting point for this intermetallic compound. The interdimeric areas of sample S-1.5 have generated CNT, nickel, and AA2219 compounds after homogenization treatment. According to previous studies, incorporation of these compounds in the microstructure can increase thermal stability at high temperatures, especially with the CNT compound. Sample S-0 also displays a dry area. Raising Ni from 0% to 1.5% wt% increased the width of the precipitation-free area by 1.2 μm. An increasing precipitate-free zone has been analysed in the interdimeric regions because of the high copper adsorption capacity of the Al-Ni intermetallic and CNT intermetallic, as well as their tendency to grow. Note that eutectic volume in nickel-containing samples has reduced, and the unreacted Ni AA2219 and CNT intermetallic compounds have been generated in the interdimeric areas of aluminium particles.

Following the homogenization procedure, the Vickers hardness of several materials is displayed in Fig. 3 When considered as the basic casting, sample S-4.5 has risen following homogenization treatment. In the as-cast stage, the composite becomes harder due to the inclusion of additional nickel. Intermetallic compounds

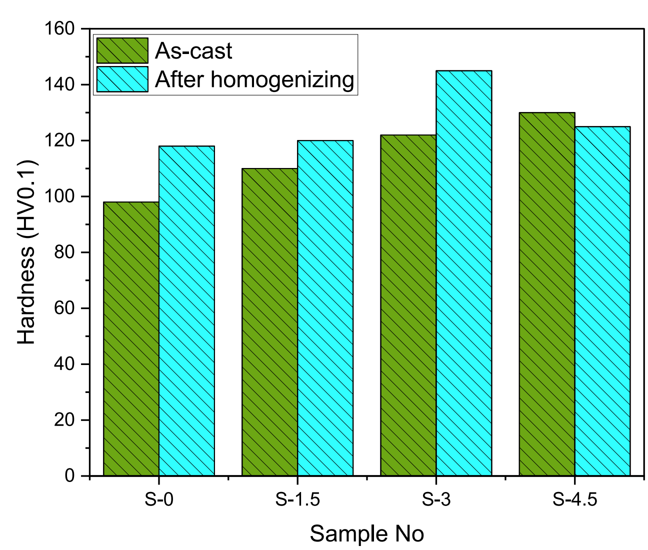

Fig. 3. Using Vickers hardness (As-cast" implies the specimen has not yet been exposed to homogenization heat treatment, and "After homogenising" means that homogenization heat treatment was conducted at 500 °C for 24 h).

with high hardness such as Al-Ni alloys are projected to play a major role in enhancing composite hardness by adding nickel. The hardness of aluminium alloy can be increased by the use of AlNi-based intermetallic compounds (AA2219, CNT). Sample S-0 has a slightly greater hardness following homogenization treatment (116.09 ± 6.2 Vickers Hardness) than sample S-1.5 (116.47 ± 4.4 Vickers Hardness), as can be seen from a comparison of S-0 and S-1.5. As an example, sample S-1 has a greater porosity (2.8 ± 0.4 percent) and decreased precipitation of aluminium precipitate when nickel is added to the melt, resulting in a loss of the strengthening action of Al-Ni intermetallic compounds. Inspite of the homogenization process, there is no noticeable increase in hardness. Increased hardness (144.05 ± 7.4 VHN) has been achieved by raising the nickel content to 3 wt%. Nickel can help to minimise precipitation of AA2219 in this sample, Despite the fact that nickel-rich intermetallic compounds developed after homogenization have increased in hardness significantly.

The hardness was reduced to 118.54 ± 4.6 VHN with a nickel content of 4.5 wt% after homogenization treatment (sample S-4.5). The as-cast condition hardness of the composite rises with the addition of additional nickel. Intermetallic compounds with high hardness (Al-Ni) are believed by adding nickel to composite materials, hardness can be greatly improved. AlNi-based intermetallic compounds (Al, CNT) have also been shown to increase the toughness of aluminium alloys.

In comparison to sample S-1.5 (115.37 ± 4.4% Vickers Hardness), sample S-0 (116.09 ± 6.2 Vickers Hardness) has considerably increased hardness subsequently standardization treatment. Al-Ni intermetallic specimens in sample S-1.5 can be reduced by increasing porosity (2.8 ± 0.4 percent) and decreasing the formation of precipitate (AA2219) by adding nickel to the melt.

Therefore, the hardness of sample S-1 after homogenization does not differ from sample S-0. Increases in the nickel content of sample S-1.5 resulted in an increase in hardness (144.05 ± 7.4 VHN) During homogenization, the hardness of mixtures containing nickel-rich intermetallic compounds has increased, despite this sample's low nickel content. The hardness was reduced to 118.54 ± 4.6 VHN with a nickel content of 4.5 wt% after amalgamation treatment (sample S-4.5). Despite the creation of more nickel-rich aluminium alloys, precipitates in the aluminium matrix increase porosity by up to 4.6 0.3 percent, resulting in a drop in hardness. Reduced formation of S-aluminum precipitates reduces AA2219 precipitation in Al-Cu-Ni alloys. Because of these two conditions, the hardness of sample S-4.5 decreases.

A variation in elastic modulus can be followed by additional strengthening processes when intermetallic compounds are formed. Because of its dependence on lattice shear modulus, dislocation energy may be represented as a function. The dislocation energy fluctuates when dislocations move from one phase to another with a changing shear modulus. Increased tensile strength is the result Fig. 4 shows the Tensile Test Curves. CNT intermetallic compounds are the primary variation between samples, although other chemicals are not significantly different. Al and AA2219 have elastic moduli of 70 and 185 GPa, respectively [30]. It follows that a high elastic modulus is associated with high shear modulus, as the two are directly related.

As shown in Fig. 5a,b,c several materials were tested for strength, elongation, toughness. In both as-cast and homogenised samples, strength, elongation, and toughness improve when the nickel content is increased to 3 wt%. However, nickel's growth to 4.5 wt% has significantly weakened its mechanical characteristics. The development of Al-Ni intermetallic compounds, notwithstanding the increase in porosity, is the most important factor in improving mechanical characteristics. These intermetallics can hold dislocations in place because of their high strength and strong binding to the aluminium matrix. It is also possible to boost the elongation of nickel-containing composites by lowering precipitation of AA2219 precipitates. Porous structure and dispersion have increased in AA2219, leading in worse mechanical characteristics, as has the number of Al-Ni composite.

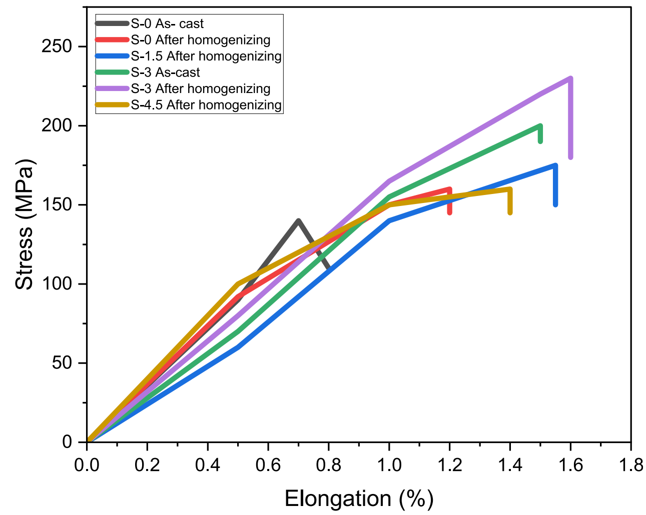

Fig. 4. Tensile Test Curves.

Increases in CNT intermetallic compounds in the aluminium matrix are expected to improve strength through modulus strengthening. Up to 4.5 percent nickel can be added, modulus strengthening boosts the composite's strength. Absorption and dense solution bolstering procedures have been found to be negatively affected by nickel concentrations in excess of 3 wt%, although modulus strengthening has an influence up to this point.

Following solid solution process at 515 °C for 2 h at 200 °C, the furnace was used to heat the S-0 and S-3 samples and the hardness was determined at different intervals to explore how CNT affects the thermal stability of AA2219-CNT composites. Due to over-aging, hardness of sample S-0 (Fig. 6) diminishes quickly after the maximum hardness is reached (after 2 h). S-3′s maximum hardness is greater and the average decrease rate is lower than that of S-0′s, although taking longer to reach its maximum. Sample S-3 has a stronger thermal stability and lower hardness degradation rate due to CNT intermetallic compounds, notwithstanding the over-aging phenomena that occurs in this sample. The hardness of sample S-0 begins to decline rapidly after over-aging because this sample's principal reinforcement comes from aluminium precipitates.

Each sample has a fracture surface that is similar, tiny and shallow dimples and intergranular separation of aluminium grains can be seen. Initial shrinkage porosity between aluminium grains may be seen in the intergranular separation. The presence of a eutectic melt causes shrinkage porosity. The intergranular spacing of aluminium grains decreases as nickel concentration increases, showing that the eutectic structure minimises shrinkage porosity. It is possible to lessen the risk of hot ripping by decreasing the shrinkage porosity. The fracture surface of nickel-containing composites contains intermetallic compounds rich in aluminium, nickel, and iron, according to the research. The lack of debonding at the nickel-rich particle-to-aluminium matrix contact indicates a very strong link between the two. Stress concentration and fracture nucleation are caused by the presence of iron-rich chemicals with strip. Small concentrations of iron-rich compounds can serve as fracture nucleation sites even after homogenization treatment. Sample S-3 has a fracture surface with cracks (in the as-cast state).

Since the loading step is responsible for causing the coefficient of friction to rise in a short distance, this may be explained, and

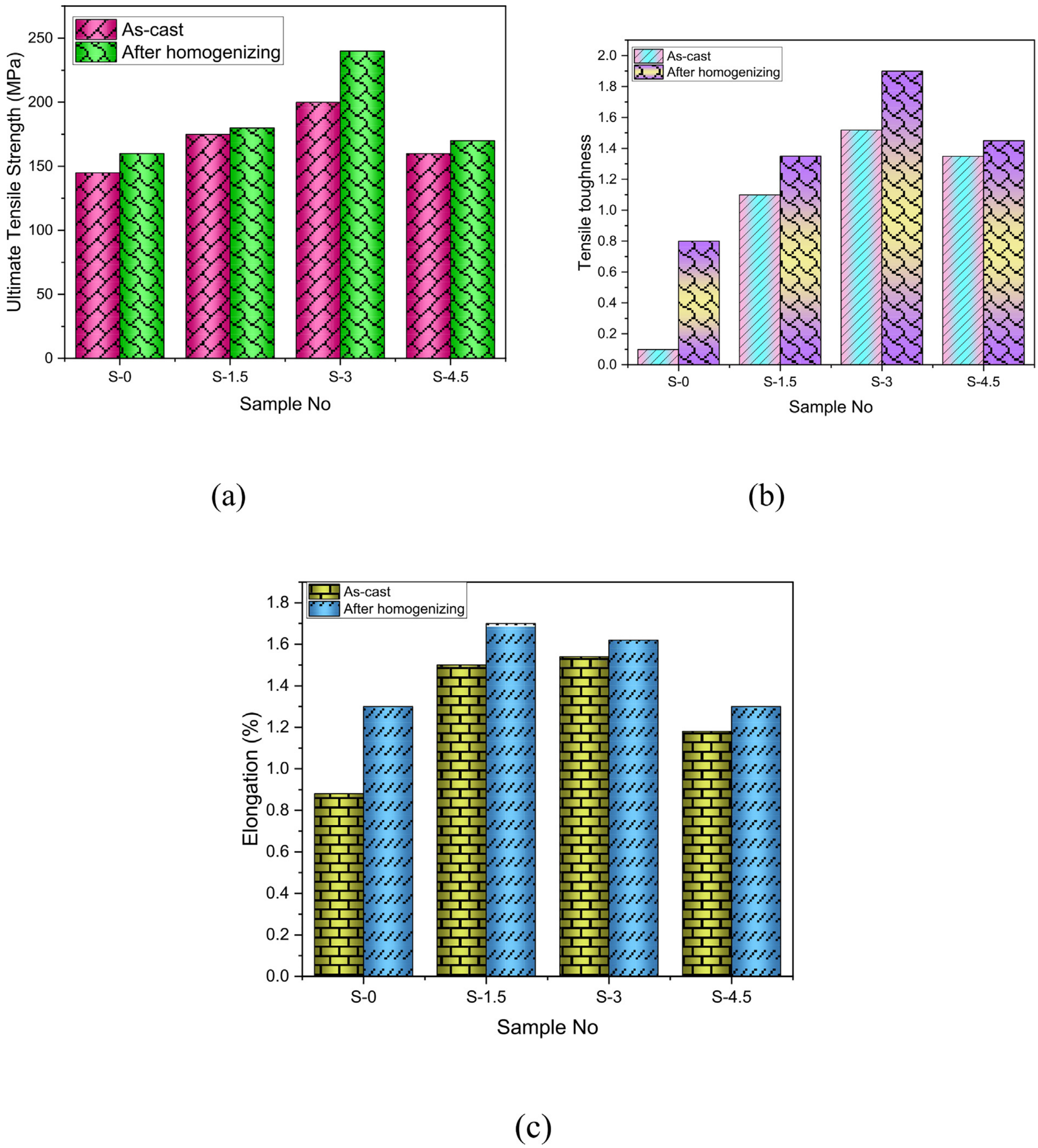

Fig. 5. a) tensile strength, b) elongation, and c) toughness of different samples.

subsequently oscillates within certain ranges at longer distances. As nickel content rises, so does the coefficient of friction. As a consequence of this study, it has been shown that by adding 3 wt% nickel to the composite, the coefficient of friction is lowered by almost 13 percent. The coefficient of friction has risen again with the addition of 4.5 wt% nickel. The coefficient of friction has a direct effect on the rate of wear. The friction coefficient and wear rate drop as shown in Fig. 7 as hardness increases, as can be seen by a comparison of the two. In the homogenised sample, this is most apparent. The wear rate and coefficient of friction have lowered as a result of the composite's increased hardness and homogenization treatment. From a variety of perspectives, it is possible to investigate variations in friction coefficient and wear rate. Friction is a physical view, reinforcing particles should not be used to raise or decrease its coefficient. As a rule of thumb, a lower coefficient of friction is associated with a smoother surface, and this is true in practise. The wear rate naturally decreases as the coefficient of friction decreases. The Archard equation is used to derive this result. An increase in surface roughness is correlated with an increase in abrasive penetration, which may be why increasing hardness appears to prevent abrasive penetration and an increase in coefficient of friction. Accumulation of fractures can be traced back to abrasion. It is possible to minimise wear by preventing fracture formation. In the preceding sections, it was stated that the substrate and the reinforcement have a strong connection, which means that these particles can help prevent fracture formation. In order to boost the wear resistance of a amalgamated surface, increasing its stiffness leads the wear process to heat up, resulting in the pro-

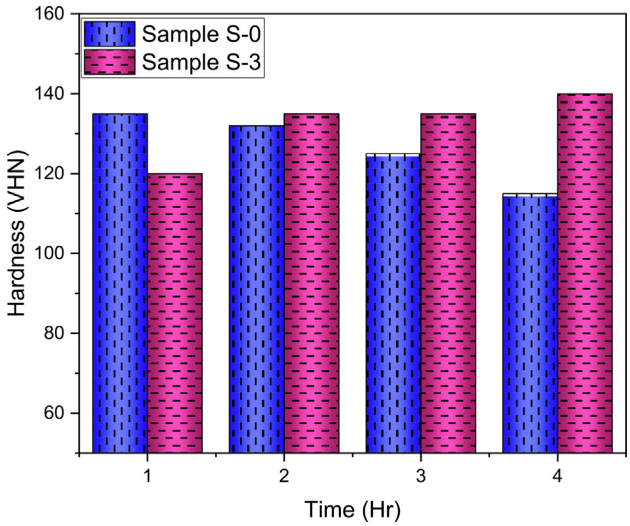

Fig. 6. The hardness of samples S-0 and S-3 with ageing time at 200 °C.

duction of new oxide layers that need an increase in temperature. An abrasive wear mechanism appears to be prevalent in the photos; modest levels of adhesive wear are visible on the variety of samples' aging facades. The worn surfaces have abrasion ridges caused by the counter face disc's surface piercing the pin. dimensions of the worn surface's grooving have decreased as a result of an increase in hardness. The most common form of abrasive wear found on the worn surface is two-body. As a result, there are aluminium oxide particles on the worn surface, which implies a complete breakdown of the three-body mechanism There are no aluminium oxide particles on the surface of homogenised sample S-3, which means that the three-body wear contribution diminishes with increasing hardness. Because of the enhanced hardness and higher heat production at the pin-counter-face disc contact in homogenised sample S-3, the adhesion wear mechanism was greatly decreased. Oxidation of the worn surface's split sections can reduce wear by allowing the oxide particles to slide into the grooves created by wear and therefore provide protection for the pin's surface.

4. Conclusions

Mechanical and tribological effects of nickel aluminides on the composite were explored in this research using AA2219 aluminium alloy melt and stir casting. The following are the findings of the research:

1. A nickel content boost from 1.5 to 4.5 percent in the AA2219 aluminium alloy melt reduced the eutectic structure in as-cast samples.
2. Compounds formed between dendritic regions lost their integrated structure after the homogenization process and became distinct structures. In Intermetallic Compounds the quantity of nickel was shown to enhance the percentage of these intermetallic complexes.
3. Copper's propensity for the Al-Ni intermetallic compound to produce CNTs intermetallic precluded the production of aluminium precipitates in the interdimeric areas.
4. Nickel-rich intermetallic compounds, developed after homogenization, have increased in hardness and strength significantly despite nickel inclusions of up to 3 percent.
5. Precipitation of AA2219 was seen when nickel concentration was increased from 3 to 4.5 wt%, increasing porosity, and reducing hardness and strength in the aluminium matrix.
6. Reduced shrinkage porosity was caused by an increase in nickel in the eutectic structure.
7. Adhesion wear on worn composite surfaces was mostly caused by the abrasion wear process.

CRediT authorship contribution statement

J. Vairamuthu: Writing – original draft. **P. Sivakumar:** Methodology. **A. Senthil Kumar:** Validation. **G.D. Sivakumar:** Writing – review & editing. **S. Siva Sundar:** Formal analysis. **Ram Subbiah:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

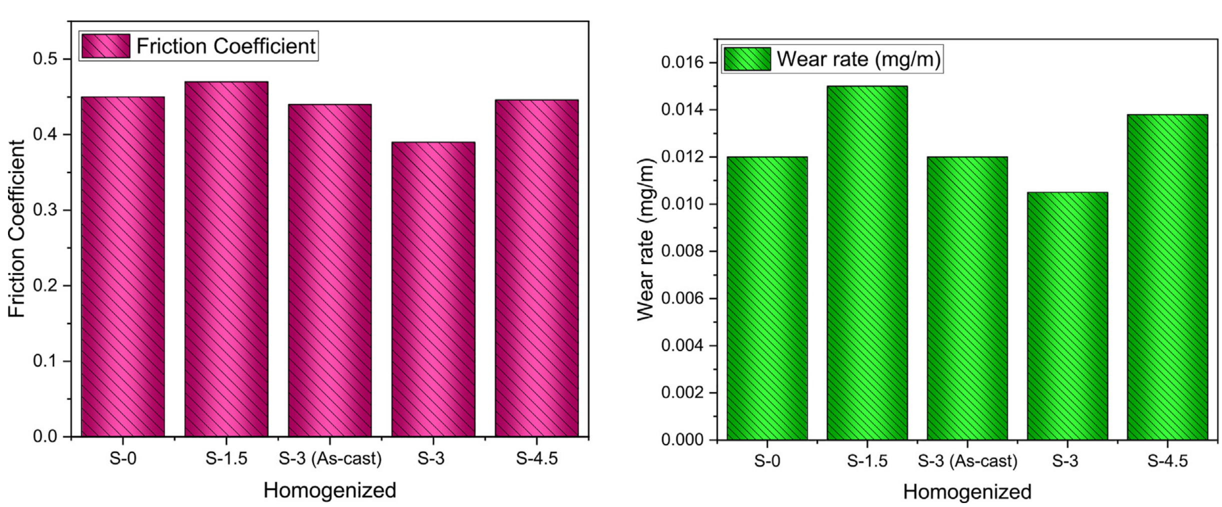

Fig. 7. Variation in friction coefficient and wear rate between samples.

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