Investigation of physical properties of Al_2O_3 using waste eggshell-reinforced composite material

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Abstract

Eggshell is a highly polluting by-product (a substance created as a by-product of another product). However, making use of this trash can help lessen environmental damage. This study tried to create a composite material using eggshells and alumina (Al_2O_3) as reinforcing material. Ball milling carbonized eggshell and Al_2O_3 ceramic particles for up to 100 hours produced reinforcement particles with a consistent size distribution. After being ball-milled, the combination of Al_2O_3 and eggshell in creating an aluminum-based composite material dramatically increased mechanical qualities. A composite of heat-treated Al, 5% carbonized eggshell, and 5% Al_2O_3 showed a 46.55% improvement in tensile strength. Independent of heat treatment, it was discovered that adding fivewt.% eggshells or Al_2O_3 alone increased the hardness of composite materials by roughly 50.84 and 60.16 percent, respectively, compared to the primary material. The material is less robust and malleable, though. The heat treatment method further enhanced the composite material's mechanical qualities. The impact of eggshell and Al_2O_3 addition on thermal expansion and corrosion behaviour during the creation of an aluminum-based composite material was also studied.

Keywords: Eggshell, Alumina, Aluminum matrix composites (AMCs), Heat Treatment Copper.

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1. Introduction

Scientists and engineers all over the globe are actively focusing on aluminum matrix composites (AMCs) because of their many benefits over monolithic alloys. The mechanical and physical properties of AMCs include toughness, flexibility, exceptional strength, high specific stiffness, weathering loss, low density, etc. [1]., which contribute to their widespread use. The cost is a consideration while making material selections. Utilizing cheap reinforcement, like scraps, can help you save money. Using recycled materials as reinforcement particles also helps decrease the price of composites [2]. Consumption of ES from chicken eggs has been connected to environmental damage (a secondary product obtained from a production process). The dust on an egg's shell could contain bacteria on the egg or in the air inside the body [3]. It's just as harmful to inhale dust that has settled on one's hands, furniture, belongings, etc [31]. A worsening of Eggers' asthma or emphysema symptoms; recurrent infections of the eyes and eyelids; sinusitis; lung difficulties; congestion that lasts for days; frequent, persistent, or chronic coughs or colds; and so on are all causes for concern[4-6]. Eggshells are widely used as a sustainable material due to their cheap cost, abundance, and low weight. ES weighs less than calcium carbonate. But after curing, the composite material made of eggshell and other ceramic particles like SiC displayed numerous defects owing to mismatch density [7-9].

Aluminum-based composites, alumina (Al_2O_3), the most complex ceramic particle, are often employed [10]. In most cases, adding alumina to a composite material will increase both the material's hardness and tensile strength. Compared to aluminum alloy, alumina has consistently superior wettability and interfacial reaction layer properties [11]. When the aluminum-based composite material solidified, however, porosity frequently resulted from the combination of small particle size and a high weight percent of alumina.

The use of various ceramic reinforcing materials in creating aluminum-based composites is a current trend in materials science and engineering [12]. In many cases, aluminum has replaced other materials because of its strength and hardness. As the composite material was being developed following the solidification process, the mismatch in particle densities from the reinforcement posed some significant difficulties. In addition, several scientists are working on metal matrix composites based on aluminum that has a variety of reinforcing materials and enhanced mechanical characteristics [13-15].

An examination of the existing literature reveals that only a select few scientists have used eggshells and alumina to reinforce aluminum-based composite materials. However, accumulating reinforcing particles owing to mismatch densities has proven to be a significant obstacle in developing composite materials [16]. More so, voids were eliminated, and particle clumping was avoided by squeezing pressure.

From the previous works about the usage of eggshells and alumina to develop the aluminium-based composite materials, it is found that apart from the aspect of durability and toughness of the composite material which is not up to the mark the cost of the fabrication is also very high comparatively. Various previous researchers have tried to go through various replaceable options to find out the best combination and application of the eggshells with the alumina to find out the best extraction as a composite material [37]. After the extraction of the final product lower ductility and toughness was still an issue to be resolved. However, with the lower ductility and toughness, the extraction process was still very high in cost for fabrication in order to achieve high-performance MMCs.

Hence the current study needs to find out a solution about making the processes of extraction cheaper along with introducing cheaper materials in the experiment process. The cheaper materials are like new fibres with better all-purpose design properties like the inclusion of higher strength, higher temperature and lower cost. Environmental behaviour, fractural behaviour, and non-destructive evolution are also needed to be considered. All these aspects are not Still found to be the best version achieved by various researchers.

In this study, eggshells and alumina (Al2O3) were used as reinforcement to make a composite material. Carbonized eggshell and Al2O3 ceramic particles were subjected to a 100-hour ball milling process to create reinforcement particles with a uniform size distribution. The combination of Al2O3 and eggshell in an aluminum-based composite material significantly improved mechanical properties after being ball-milled. The tensile strength of a composite made of heat-treated aluminium, 5% carbonised eggshell, and 5% aluminium oxide increased by 46.55%. It was shown that adding five weight percent eggshells or Al2O3 alone increased the hardness of composite materials by around 50.84 and 60.16 percent in comparison to the main material, respectively, without requiring heat treatment. Yet, it is less durable and malleable. The mechanical properties of the composite material were further improved by the heat treatment process.

2. Materials and methods

2.1 Matrix material

The matrix material used in this study was aluminum alloy (with primary components of Al 99.8%, Cu 0.40 %, and Mg 0.80 %). Due to the low density, high specific strength, and little corrosion loss, aluminum has become the best material for the automotive and aerospace sectors. Various Structural components including pistons for internal combustion engines, brake and rotor hubs are all fabricated using aluminum alloys [17-19].

2.2 Primary reinforcement material

This study explored ceramic particles made of Al_2O_3 (alumina) as a significant reinforcing material. The particles of alumina are the fourth-hardest of all ceramics. Diamond, boron carbide, and silicon carbide each have a Knoop hardness of 7,000, 2,800, and 2,500 respectively. Alumina (Al_2O_3) has a hardness of 2100 Knoop on the hardness scale. Alumina's high hardness increases the material's tensile strength and hardness. [20, 21].

2.3 Secondary reinforcement material

From the grocery shop, collection of the eggshells that had been discarded. It was cleaned in water and allowed to air dry for around 25 hours. Dry eggshell was processed using a ball mill. After being converted to the eggshell in powder form by ball-milling, the eggshell particle was carbonized at 500^o C for 24 hours [22-23].

2.4 Reinforcement particles change by Ball-milling process

The ball-milling procedure is depicted in Figure 1 (Mechanical alloying) where (a) is ball milling and (b) is regular mixing processes. Ball milling combines the two reinforcing particles into one uniform material. A ball mill is used to mechanically alloy particles of carbonized eggshell (mean particle size: 55 m) with particles of Al_2O_3 ceramic. One hundred hours of ball-milling recorded to successfully combine alumina powder with carbonized eggshell particles aluminum [25]. Firstly, the eggshell is purchased from the food industry and alumina (Al_2O_3) from the shop. After crushing in the ball mill, the eggshell is washed with water to remove the dust and ligament particles. It has been taken out from the ball mill, pre-heat all the reinforcement and mixing in the stir casting technique and put in the prepared pattern. Alumina and carbonized eggshell powder are shown in their combined state in Figure 2 after being ball-milled to create reinforcement particles from leftover eggshells.

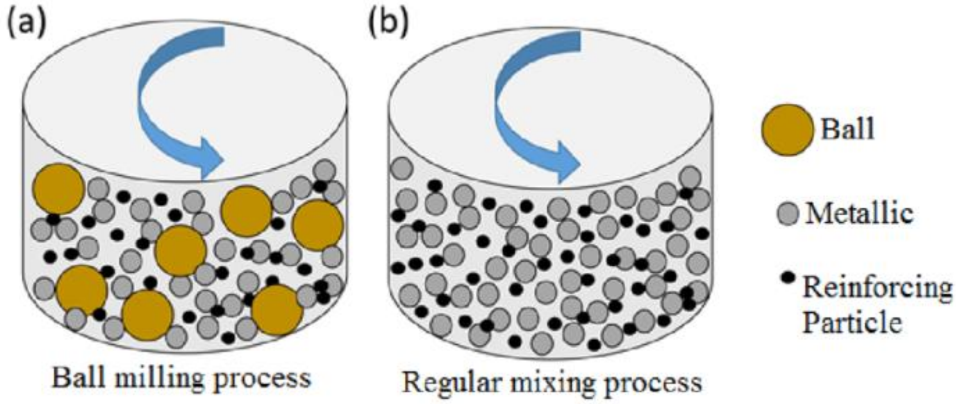

Figure 1: Usage of Ball mill to mechanically alloy particles of carbonized eggshell

2.5 Development of composite material

Firstly, Food store's discarded eggshells were gathered. The collected eggshells were ground into a powder using a ball mill. Carbonizing eggshells at 500 degrees for 24 hours yields a fine powder. Carbonized eggshells and alumina nanoparticles (Al_2O_3) were scrums for as long as 100 hours to produce reinforcement particles with uniform particle size [26]. Ball milling the reinforcement particles after heating them (to as high as 400 degrees Celsius) increased their wettability. The aluminum alloy has been blended with various reinforcing particles, each with its unique chemical makeup [27]. When compressed in the mushy zone (the porous layers of dendritic crystals that typically form during the solidification of multi-component melts), eggshells and alumina transform into the carbonized form (Figure 3). The compression resulted in a shrinking of the pores and an increase in porosity in the composite (bubble-shaped cavities).

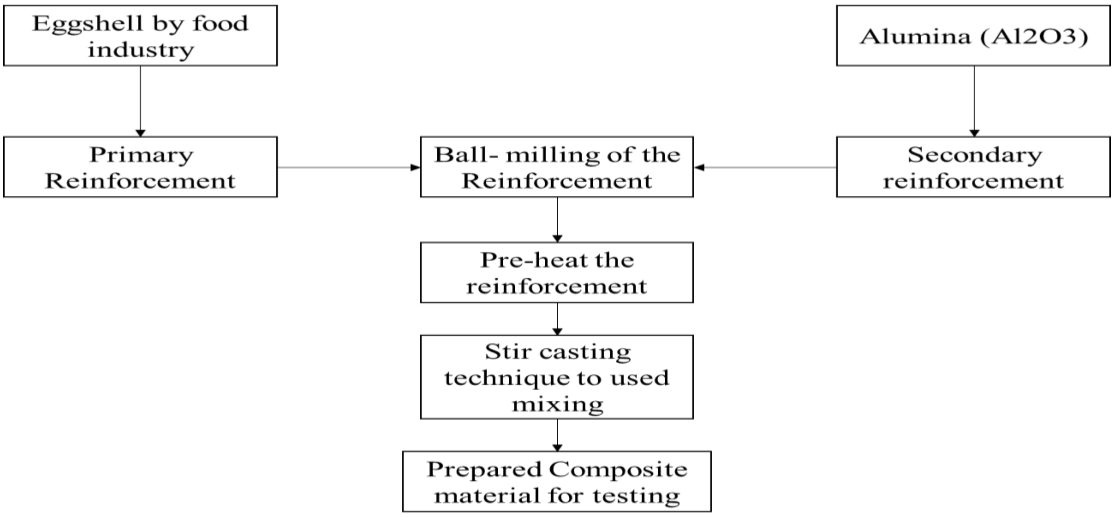

Figure 2: Steps to produce the composite material

Figure 3: Eggshell and alumina converted into the carbonized form

2.6. Methods for measuring tensile strength and Ductility.

2.6.1. Tensile Strength

The ASTM D3039 is one of the most used measuring scales to measure the required force to break a polymer composite specimen and the actual extent to of the polymer can be stretched. Even it can also measure the highest stability of the polymer to the breaking point. Tensile tests are mainly developed to produce a diagram of stress and strain which is effectively used to find out different tensile modules [36]. The available data is frequently used to specify a material so that the designing of the parts to apply force and the result can be checked as a quality control check of materials. In the current study, the composite material and its tensile strength are also measured by the same process. As the physical properties of different materials can be different at ambient temperature sometimes it is proper to test the materials at different temperatures.

2.6.2. Ductility

Ductility can be measured with the amount of permanent deformation directed by the stress-strain curve. There are major three methods that have been reported to measure ductility. These are the elongation of percentages after the fracture, the decrease in the area of the region of fracture and finally the cold bend test. The current study of the green test was very helpful to provide a visual indication related to the composite material. The print test is required of the different specimens that needed to be loaded at the reach centre point with a plunger by providing support at the ends. Then it gets rest to the final point till the specimen of the composite material gets been to a pre. determined angle or fractured.

2.7. Method of Corrosion test

Among the three general methods of corrosive testing service history, field performance and accelerated corrosion test, the service history method is one of the most reliable and available methods of corrosion testing over a long period of time. However, the data from testing may not be reflected the certain conditions attached to the material which is exposed currently. In the current study, the service history method is effectively used to find out the corrosion capability of the composite material that is supposed to be developed by the project with the usage of eggshells [35]. The best part of the corrosion test is it makes the composite material go under heat treatment to find out if the resistance of the material gets increased or not. In the current material, the final grain structure that got extracted from the heat treatment had a huge contribution to the enhanced resistance of the composite material.

Accurate knowledge about the corrosion capability of the composite material is very important because those types of materials develop via several experiments only because of understanding the actual behaviour of the material so that can tolerate every situation and every atmosphere. Oxidation is very common in any material and sometimes is not healthy the longevity of that material, so it is very important to get actual durability capacity in terms of corrosion for the composite material.

2.8. Method of Thermal expansion

Similarly, like that corrosion test the thermal expansion test is also done by three main techniques. These are dilatometry, interferometry and thermal mechanical analysis. In the case of extreme temperature optical thermal imaging can also be introduced in the thermal expansion determination method. In order to identify certain changes x-ray diffraction can be used to study those changes in a lattice parameter. The current study is also finding the same method and applying it in measuring the thermal expansion of the composite material to find out the highest temperature durability of the material before it gets expanded [34]. It is very crucial for any composite material or any other material because any type of material is important based on its application, the applicability temperature is very necessary to be measured before applying it because having proper knowledge about its capacity of bearing temperature might cause severe accidents due to breakage of the composite material.

2.9. Preparation of composites

The global market for composites is expected to reach $130.83 billion by 2024. Glass fibre is the main reinforcing material used in the United States. It had a $2.1 billion growth value in 2017. Materials that are strong, resilient, and lightweight are becoming more and more in demand. To discover reinforcements of a certain design, several sectors are turning to composites. They are trying to find solutions to the problems that fibre-reinforced polymers have. The composite fabrication process produced these reinforcements [33]. In the business, there are numerous composite fabrication techniques. Your choice will depend on the composite's composition, design, and intended use.

The preparation method of the composite materials is hand lay-up, open moulding, Resin infusion methods, Resin transfer moulding, reaction injection moulding, Vaccuam-assisted transfer moulding, Ball Milling etc. Among all the above mention processes the ball milling process is effectively used in the preparation of the composite of the study. The ball milling process is very effective because it is very cheap compared to other composite preparation methods and provides the same quality comparatively. Hence the diagram and the details regarding the ball milling process and preparation of the composite are discussed in a descriptive manner. And as earlier mention, the global market for composite material is going rapidly the chances for the development of composite preparing methods might also be the main focus of radius researchers who are working on the development of composite material.

3. Results and discussion

3.1 Tensile strength analysis

The tensile strength of the foundational material was measured (Al 99.8%, Cu 0.4%, and Mg 0.8% were the primary constituents). After several tests, the value was settled at 132 MPa. The highest tensile strength, measured without applying heat, of a ball-milled reinforcing composite material (egg particles and alumina) with a ratio of Al/5% carbonized eggshell/5% Al_2O_3 was determined to be 182.25 MPa. In Figure 4, we can see the microstructure of a ball-milled composite material made of Al, 5% carbonized eggshell, and 5% Al_2O_3(a). The tensile strength of the composite was improved by the equal distribution of reinforcing particles throughout the aluminum alloy. Additions of tough Al_2O_3 inorganic nanoparticles and charcoal eggshell particles made the composite more durable, which increased its tensile strength. $CaCO_3$ (about 96%), S (roughly 2%), Mg (approximately 0.4%), and P (about 0.5%) are all components of eggshells that contribute to the composite material's higher tensile strength. In addition, the composite's tensile strength was boosted by the even distribution of single-entity reinforcing particles (made of Al_2O_3 and eggshell) throughout the matrix. The improved microstructure after heat treatment led to an additional boost in tensile strength for the composite material[29].They used the stir casting method to create a composite out of eggshell-reinforced Al-Cu-Mg alloy, and they found that the percentage of eggshell in the alloy affected the alloy's properties. The tensile strength of the aluminum alloy was improved by around 14.28% when 12 wt.% carbonized eggshell was added to it. The results of the present investigation showed that the tensile strength of aluminum alloy could be improved by around 38.06% by adding ball-milled Al_2O_3 and carbonized eggshell particles. Compared to its base material (main compositions are Al about 99.8%, Cu approximately 0.40%, and Mg about 0.8%), tensile strength in a composite containing heat-treated Al/5% carbonized eggshell/5% Al_2O_3 increased by around 46.55%.

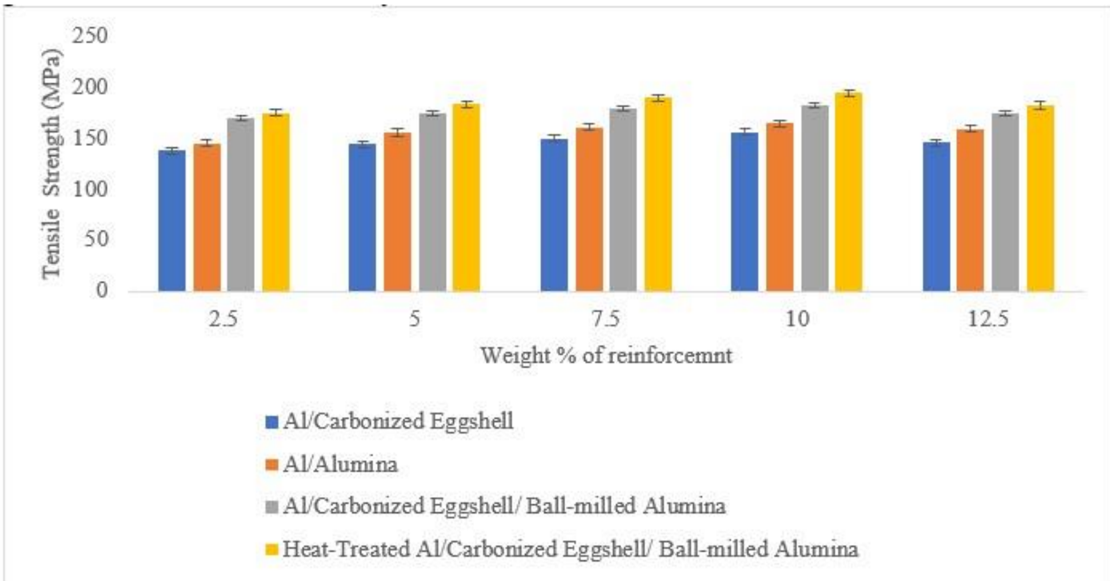

Figure 4: Tensile strength investigation of composites

From figure 4, From the grocery store, leftover eggshell was gathered. The Eggshell that had been collected was ground into powder using a ball mill. At a temperature of 500C, eggshell powder has been carbonized for 24 hours. To create homogenous reinforcement particles with a consistent size, carbonized eggshell powder and alumina particles (Al2O3) were further ball-milled for 100 hours. To improve wet ability, warmed reinforcement particles from ball milling (up to 400°C) were used [32]. Aluminum alloy has been combined with reinforcement particles that have varied compositions. Using a UTM (universal testing machine) for squeezing pressure testing, a produced composite material in the mushy zone (Mushy zone is porous layers of dendrite crystals that frequently form during solidification of multi-component melts) was transferred.

3.2 Hardness test analysis

Scrum-reinforced composites (like the one seen in Figure 5) are very durable. Three locations on each sample were tested for hardness. All models were graded based on an average of three separate hardness tests. The testing revealed that the base material had a hardness of 59 BHN. The maximum Brinell hardness of an eggshell, aluminum, and aluminum oxide composite material was 89 before heat treatment (BHN). The microstructure is shown in Figure 4; it exhibits the anticipated intermetallics layer between the matrix and reinforcing elements. A composite's permeability and blow holes are reduced following solidification if an intermetallic compound layer is formed between the matrices and supporting material.

In contrast, there is no indication of porosity in the microstructure picture of the Al/5% Al_2O_3/5% carbonized eggshell composite materials with prepared ball-milled reinforcing particles. The composite, therefore, achieved a more rigid surface than any other material. The inclusion of challenging phases [27,29] as $CaCO_3$ [29] in activated carbons eggshell and Al_2O_3 [30] in alumina improved the composite's hardness. The heat treatment only strengthened the composite material's already impressive hardness. Heat treatment improved the material's hardness by refining its grain structure. It has been proven that adding carbonized eggshell particles to an aluminum-based composite makes it more resistant to abrasion [27]. Their research showed that using Al-Cu-Mg/12 wt% enhanced the hardness of eggshell by around 25.4% when compared to the original materials. 5 wt% eggshell and five wt% Al_2O_3 in single entity were found to boost the hardness of composite materials by about 50.84% and 60.16%, respectively, relative to the base material, regardless of whether the composites were heat-treated.

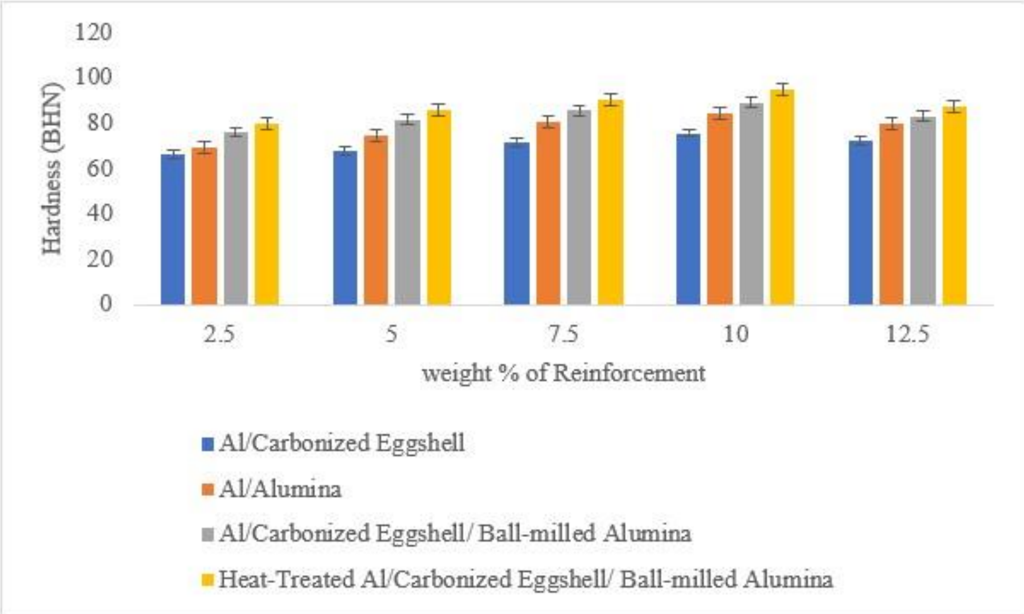

Figure 5: Hardness investigation of composites

3.3 Ductility

The per cent elongation (% EL) was calculated by measuring the flexibility of the composite. The adaptability of the foundation material was evaluated. The EL goal was met at 16.5%. Figure 6 shows how ball-milled reinforcing particles helped decrease the composite material's plasticity deformation behaviour. Activated charcoal, eggshell, and Al_2O_3 are some of the many hard particles that may be used in hybrids to boost mechanical properties at the expense of flexibility. Adding reinforcement particles to the aluminum alloy reduces the composite's flexibility, as seen in Figure 6. However, heat treatment resulted in improved flexibility of the hybrid metallic matrix composite.

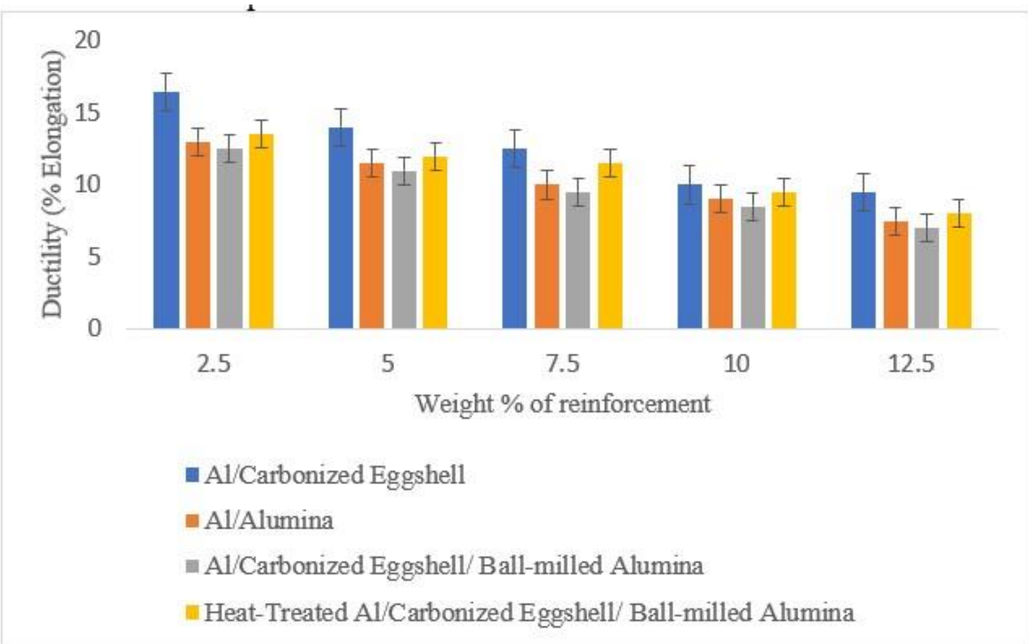

Figure 6: Ductility investigation of composites

3.4 Corrosion behaviour

After being submerged in 3.5% NaCl for 120 hours, the composite's corrosion behaviour was studied. Each specimen maintained a constant 9-gramme weight. The deterioration of the aluminum-based composite is shown in Figure 7. A chemical reaction occurs when metals meet one another, resulting in corrosion. When the composite material was left in the H2O and NaCl solution for too long, its surface characteristics deteriorated. For this purpose, carbonized eggshell and alumina nanoparticles were ball-milled to generate reinforcement particles, which boosted the composite material's resistance to corrosion [24, 25]. The composite material comprises Al, 1.25 wt% carbonized eggshell, and 1.25 wt. % Al_2O_3 lost just a little bit of weight after being heated. When the weight percent of reinforcing particles (eggshell and Al_2O_3) was increased, the corrosion resistance of the composite material decreased. It is possible that Al $(OH)_3$ develops on the surface of the composite in the presence of O_2 and OH^-, causing the observed reduction. After undergoing heat treatment, the corrosion resistance of the composite material significantly increased, according to the study. The finer grain structure that resulted from the heat treatment contributed to the composite material's enhanced corrosion resistance. Composite materials prevent top oxide, hydroxide, or supply from forming because of their refined grain structure. As a result, the composite lost less mass before and after being subjected to heat treatment. Corrosion-induced weight loss of the material is shown graphically.

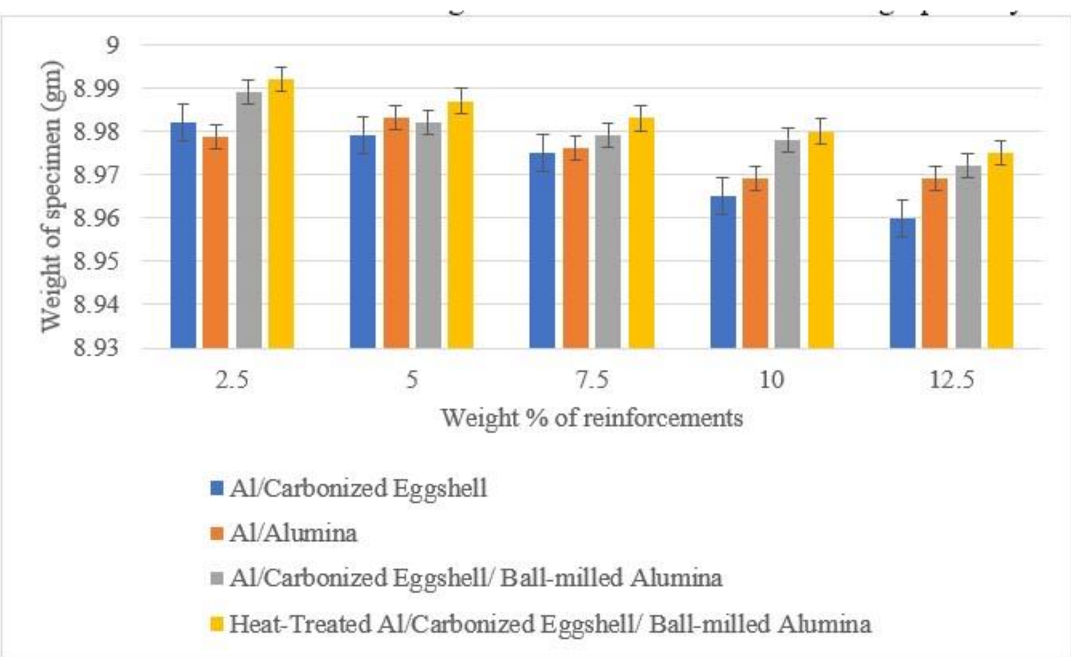

Figure 7: Corrosion weight loss of composites

3.5 Thermal expansion behavior

Studying their thermal expansion behaviour has evaluated composite materials' high-temperature stability. For reproducibility, we have kept the size of the thermal gradients test specimen at 25 mm 10 mm (2500 mm^3 volume). After 24 hours at 450 degrees Celsius, the muffle furnace was used to conduct a thermal expansion test. The samples were heated, and their books were recalculated. Sample volume variation for the Al/5% carbonized eggshell/5% Al_2O_3 composite material is shown in Figure 8. However, the heat treatment method significantly improved the material's durability.

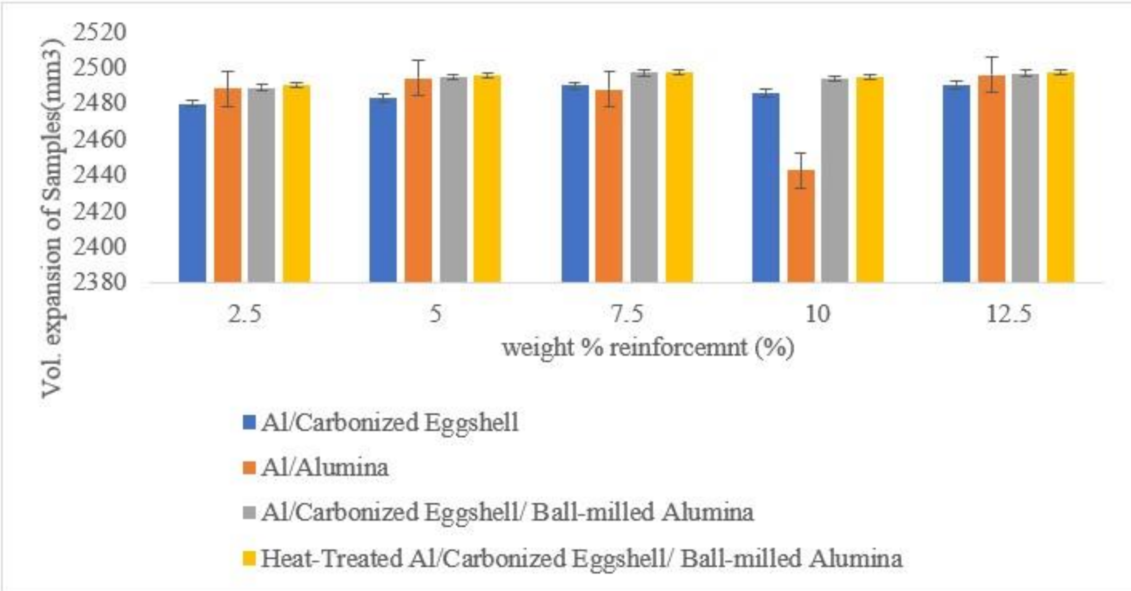

Figure 8: Thermal expansion behaviour of composites

4. Conclusion

It is possible to generate carbonized eggshell powder and Al_2O_3 ceramic particles by ball-milling them together. The tensile strength and hardness were increased by around 38.06 percent and 50.84 percent, respectively, when the reinforcement particles were ball-milled as a single entity. Toughness and flexibility were diminished, though. As a result of utilizing ball-milled reinforcing particles, composite material's resistance to corrosion and thermal sustainability were greatly enhanced. The composite exhibited enhanced mechanical behaviour, corrosion resistance, and thermal expansion following heat treatment.

After going through the neede tests the composite material is shown to be the growth of Tensile strength After several tests, the value was settled at 132 MPa. The growth of the tensile strength from the previous rate of the raw material had a growth in the ratio of Al/5% carbonized eggshell/5% Al_2O_3 was determined to be 182.25 MPa. Even the hardness also got a boost of composite materials by about 50.84% and 60.16% compared to the range of the raw materials.

If discussing the ductility The adaptability of the foundation material was evaluated with an EL goal that was finally met at 16.5%. The composite had loosened less mass due to going through the heat treatment. The entire Corrosion-induced weight loss of the material is shown graphically

In the Sample volume variation for the Al/5% carbonized eggshell/5% Al_2O_3 composite material. After the completion of all the related aspects of the composite material, it can be concluded that the results from the material are up to the mark and can be grown for future processing of the study.

The material has a wide range of applications, from short-term, one-time uses like packaging to longer-term, more permanent ones like the outside casing of home appliances, car components, piping, windows, and other building materials. Further synthesis, physical and characterization particles of the alumina and eggshell reinforcement composite and analysis of wear property of the composite material.

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