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Experimental investigation on the mechanical properties of Al2024 doped with green synthesized quantum dots

Pushpa Raj Berlin Push[1], Balac Retnam Bavanish[1]

[1]Noorul Islam Centre for Higher Education, Department of Mechanical Engineering. 629180, Kumaracoil, Tamilnadu, India.
e-mail: berlinpush12@gmail.com, dr.bbavanish@gmail.com

ABSTRACT

This work used a novel technique known as powder metallurgy to create Aluminium (Al) 2024 matrix composites using Al 2024 reinforced with graphene quantum dots at concentrations ranging from 0.25 to 1 wt.%. Here, Al alloy 2024 is presented as a metal matrix composite reinforced with graphene quantum dots. Graphene quantum dots (GQDs) are fragments of graphene that are smaller than 100 nm in size. Graphene quantum dots are added to Al 2024 in proportions of 0.25%, 0.5%, 0.75%, and 1% to create composites. Atomic force microscopy, X-ray diffraction analysis, Fourier transform infrared, TG/DTA, transmission electron microscopy, and scanning electron microscopy experiments have been carried out to determine the characteristics of the synthesized GQD nanoparticles doped with Al 2024. This powder metallurgy process in Al 2024 offers a number of advantages. Shape and material flexibility, application variety, and cost-effectiveness are all made possible by these characteristics. The results showed that powder metallurgy is a suitable method for incorporating and dispersing nanoparticles into Al 2024.

Keywords: Powdermetallurgy; Aluminium 2024; Graphene Quantum Dots; Aluminum Metal Matrix Composite.

1. INTRODUCTION

Scientific research has been driven toward the creation of creative approaches and environmentally friendly means in order to utilize sustainable materials, not just for the creation of new, reducing materials and platform molecules for the modern chemical industry but also for the production of energy. There is an increasing decline in fossil resource availability, coupled with an obvious energy crisis, and the escalating environmental damage as a result of their usage. Because carbon nanomaterials, like graphene quantum dots (GQDs), have unique chemical and physical properties, researchers have been looking for new ways to use them in a wide range of applications, such as solar cells, biosensors, optical sensors, rechargeable batteries, and electrochemical devices. As a result, a study concentrates on new findings about the production of GQDs using simple, affordable, and eco-friendly synthetic techniques from biomass waste.

The effects of graphenequantum dots reinforcement in the Al matrix are based on important factors such as yield strength, ductility, micro-hardness, and tensile strength [1]. Various primary and secondary Al-graphenequantum dots processing methods have also been investigated. The Hall-Petch connection is also used in this study [2] to explain the mechanism of grain strengthening and to demonstrate the impact of post-processing on grain size and, consequently, grain characteristics. The essential aspects of the stir casting process, including the furnace design, the characteristics of the composites, the difficulties in producing composites, and possible research prospects [3], concentrated on the effects of aluminum particles employed as reinforcement in composite materials on conductivity [4] and electrochemical energy storage, and clarified the interaction of polyaniline with aluminum particles by maintaining a consistent monomer-oxidant ratio and HCl acid dopant. Many inhibitors intercalated into LDH coatings might offer long-lasting corrosion protection. They provide an illustration of LDH inhibitor release kinetics and corrosion prevention techniques [5].

Periodic changes in production technology of Functionally Graded Materials (FGM) as well as the impact of heat treatment on a material's structural, physical, and manufacturing features [6], which are critically reviewed in this research. The self-lubricating tribological behavior was tested using nano-scratch testing. X-ray diffraction, optical, and scanning electron microscopy were used to examine how the G-content affected the crystallite size variation and the lattice strain for the ball-milled powders compared to the hot extruded rods [7]. The functional group and its placement on the phenyl molecule, as well as how well it protects modified graphene

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layers against corrosion [8]. By utilizing aromatic molecules to change the surface of graphene-coated carbon steel (CS/G), the effectiveness of graphene's corrosion resistance was increased. A critical review and summary of the most recent advancements in graphene-enhanced water-based elastomer composites (G-WBEC), such as the production methods, characterization methods, characteristics, and potential commercial applications of graphene and composites [9]. An eco-friendly and simple method for chemically converting grapheme nanosheets (GNS) using minimizing sugars like fructose, sucrose, and glucose as a precursor and exfoliated graphite oxide (GO) [10].

2. PROPOSED WORK

Surface roughness always made it harder for ice to stick to the tested materials, which included metallic surfaces and polymeric coatings with different levels of surface wetness [11]. The synergistic effects of the anodizing process and the cerium-based conversion deposit (CeEC) on the corrosion behavior of a substrate made of the aluminum alloy 2024-T4 [12] When concentrated on the conductivity and electrochemical energy storage effects of aluminum particles utilized as reinforcement in composite materials and clarified the interaction of polyaniline with aluminum particles by maintaining a constant concentration of HCl acid dopant and monomer-oxidant ratio [13]. The mechanical, tribological, and other difficulties involved in creating nanocomposites In addition to reviewing graphene's manufacture, strengthening process, and applications, it also discusses the knowledge gap regarding graphene metal matrix nanocomposite (GMMNC) [14]. The MMCs are also hardened materials that retain their original qualities even in harsh situations. It's interesting that MMC processing techniques can be changed to provide them with new features for broader uses [15].

Weight loss, surface characterizations, and electrochemical tests, and investigate the inhibitory character of N and S-CDs of 5052 aluminum alloy in HCl solution [16]. The results show which N- and S-CDs may successfully protect aluminum, with inhibitory efficiency reaching 85% even at 5 mg L^{-1}. The mutual riveting effect, and the composite coating's thickness significantly increased when compared to that of silane coating [17]. The adhesion force was significantly increased by the covalent metallic-siloxane linkages (AlOSi). The procedure of phosphoric acid anodizing (PAA) used in this review to treat aluminum alloy sheets under various conditions A change in perceived surface energy and surface roughness was influenced by the formation of homogeneous pits as well as pores at the nanometer scale [18]. Explains Conversely, graphene oxide (GO), which has functional groups containing oxygen on its surface, may be widely diffused in water but has only fair barrier qualities because of its flaw, which makes it difficult to successfully resist the permeability of corrosive ions [19]. Describe and discuss the corrosion protection that two-dimensional graphene offers. A brief introduction to corrosion is followed by information on how graphene is used in the creation of coatings and films [20]. First, the problems with galvanic corrosion are highlighted by reviewing reduced graphene oxide (rGO) and graphene layers that resemble metallic materials.

Examine all the essential aspects of the stir casting process, including the characteristics of the composites, the furnace design, the difficulties in producing composites, and possible research prospects [21]. The various ways to synthesize PANI, with an emphasis on oxidative polymerization and the deposition of thin films using physical and chemical processes [22], Investigations were done on the tribological and mechanical behavior as well as the structural evolution of composites made of AA2124-3 and 5-wt.% graphene (G) that were produced by combining ball milling with hot extrusion [23]. The results of X-ray diffraction (XRD), Fourier transformed infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), Raman spectroscopy, atomic force microscopy, and transmission electron microscopy (TEM) confirmed that reactive PUA molecules covalently modified with graphene oxide (GO) can increase their interaction with the polymer matrix and dispersibility (AFM) [24]. That graphene can significantly improve the anticorrosion performance of an EP coating when used as a filler in epoxy resin (EP) [25]. In large-scale manufacturing of graphene, the novel option is provided by hydrothermal exfoliation on NaF and F127 solutions.

3. TREATMENT METHODS FOR AL-MMCS

Effective dispersion of the reinforcing particles into the parent alloy is the common objective of all processing methods. 2024 Aluminum Alloy is an alloy of aluminum, with copper serving as the main alloying component. It is utilized in applications where strong fatigue resistance [26] and a high strength-to-weight ratio [27] are necessary. 2024 aluminum alloy is extensively used in aerospace and aircraft because of its fatigue resistance and high strength, particularly in tensioned wing and fuselage structures. A broad range of processes for creating materials or powders from metal powders are referred to as powder metallurgy. It is an advanced and trustworthy technique for producing ferrous and non-ferrous parts. Treatment methods for Al-MMCS are discussed below.

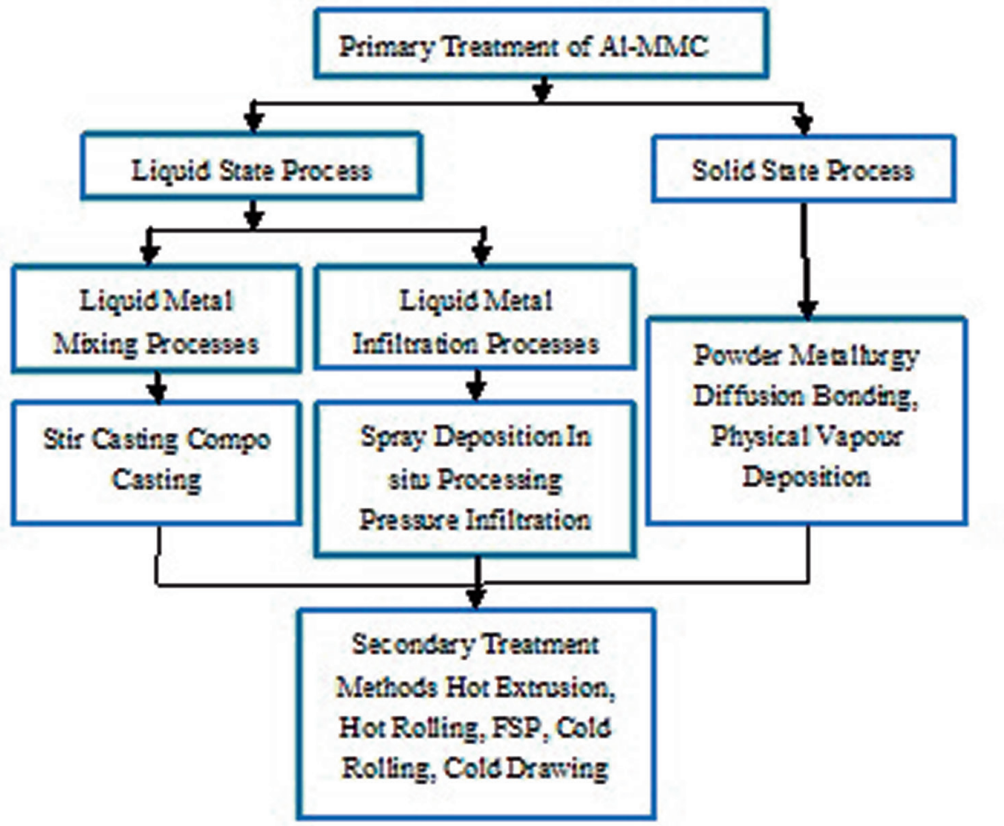

Figure 1: Primary and secondary treatment method of Al-MMC.

3.1. Primary treatment methods

In liquid-state methods, molten metal is used to perform the dispersion of reinforcement. Al-MMCs are produced via a variety of liquid-state methods, such as in situ processing, spray deposition, stir casting, and compo casting. Solid-state processing, as compared to liquid processing, is done in metal that is solid or semi-solid. Al-MMCs were synthesized using a variety of solid-state methods, including powder metallurgy. In powder metallurgy, composites are developed by processing the fine powder in a number of processes.

3.2. Secondary treatment methods

Most often, MMCs are subjected to secondary treatment methods in order to mold them into desired configurations for required goods. The interfacial adhesion of the Al matrix was improved throughout the extrusion process, which is essential for enhancing the mechanical characteristics of MMCs. Hot rolling made sure that, during processing, graphene was evenly dispersed and exfoliated. Figure 1 depicts the Primary and secondary treatment methods of Al-MMC. In powder metallurgy, composites are created by processing the fine powder in a number of processes.

4. PERFORMANCE ANALYSIS OF MMCS MADE OF AL-GRAPHENE

MMCs may be a viable alternative to satisfy these sectors' expectations Al-based MMCs are the most effective and popular MMCs because of their exceptional qualities, including their good wear resistance, light weight, and low thermal coefficient of expansion. A two-dimensional film of graphite, a single atom thick, is called graphene. It is a hexagonal-shaped sheet of carbon atoms with a honeycomb crystal structure. In an investigation of reinforcements in Al-MMCs, graphene and other carbon nanofillers are favored because of their advantageous properties. Additionally, these nanofillers have specific mechanical, thermal, and electrical characteristics. Additionally, graphene was investigated as a reinforcement for the Al matrix while using the semi-powder metallurgy process to create MMCs.

5. GREEN SYNTHESES OF GRAPHENE QUANTUM DOTS (PYROLYSIS METHOD)

20 ml of leaf extract was mixed in equal volume of sterile distilled H_2O and was filtered using whatmann filter paper with a diameter of 110 mm. 25 ml of the filtrate was heated to 100°C in a mantle for 90 minutes until the citric acid in the extract gets altered to form an orange liquid. This liquid was then centrifuged at 10,000 rpm for 30 min, filtered and the resultant product is used a GQDs and is refrigerated for further studies.

6. EXPERIMENTAL INVESTIGATIONS

6.1. Materials

MMC with aluminum reinforcement is created using powder metallurgical techniques. Al-2024 was employed as a metal matrix composite in this investigation for varying weight percentages of graphene. Al 2024 weighs 18 grams, and the amount of graphene quantum dots needed to make composites is 0.25, 0.50, 0.725, and 1% by weight. Due to their lightweight construction, tribological, thermal, and electrical properties, and superior mechanical properties, aluminum (Al) matrix dopped with graphene-based nanomaterial composites have gained attention as prospective candidates for a variety of applications. Zero-dimensional materials called graphene quantum dots (GQDs) show characteristics related to both graphene and quantum dots. GQDs are created by simply mixing GQD nanoparticles for 24 hours. Table 1 illustrates the properties of the matrix material Al 2024.

6.2. Compaction, sintering and testing

The aluminum powder used to create the metal matrix composites.18 grams of Al 2024 and varying proportion of GQD are added, and the mixture is processed on an ultrasonic liquidizer for roughly 30 minutes. On a magnetic stirrer, the resulting solution is then left undisturbed for approximately 3 hours to ensure adequate particle distribution. The stirring process was conducted by the magnetic stirrer.

To obtain a dry mixture of Al2024 and graphene, the mixture is held in a hot air oven for around 24 hours and this makes it as a semi-solid. The powder is taken after 24 hours and preheated to roughly 300°C. After heating, the powder is placed in a die, and is compressed using an universal testing machine at 20-ton weight. The sample is taken out of the die, and the specimen is made.

The ability of the composites to resist tensile and flexural strength increases with aluminum particle content. The abrasive quality of the aluminum particle, which increased to the optimal level, is what caused the composite's flexural strength to increase. Aluminum's chemical makeup can be altered to improve certain desired material properties. The increase in hardness may be the result of the matrix's filler having a larger surface area. However, as the hardness test indicates, the addition of 25% aluminum particles systematically changes the matrix's elastic behavior. The tensile and flexural strengths decrease as the aluminum particle concentration rises because the matrix is better able to absorb hardness.

7. RESULTS AND DISCUSSION

7.1. UV analysis of Aluminum 2024 metal matrix composites

In order to conduct a close analysis, a material was examined using visible and UV light with a wavelength of 300–800 nm. Its extract has been centrifuged for approximately 10 minutes at 3000 rpm to prepare it for UV-VIS spectrophotometer examination before filtering it through Whatman No. 1 filter paper. Using the same solvent, 1:10 is the sample's dilution rate. Aluminum 2024 metal matrix composites' UV absorption spectra have an absorption peak at 471.9 nm in the visible ranges, as shown in Figure 2. This graph illustrates the significant absorption peak of the silver nanoparticles in the Aluminum 2024 metal matrix composites.

7.2. XRD analysis of Aluminum 2024 metal matrix composites

The produced Aluminum 2024 metal matrix composites' structure and crystalline size were analyzed by XRD. The Al 2024 metal matrix combinations were centrifuged for 15 minutes at 10,000 rpm before the pellets were redispersed in sterile double-distilled water and centrifuged for 10 minutes at that speed. A 50°C oven was used to dry the purified pellets before they were subjected to X-ray Diffraction Unit (XRD) analysis. Aluminum 2024

Table 1: Properties of the matrix material Al 2024.

ELEMENT	Fe	Si	Mn	Cu	Cr	Mg	Ti	Zn	Al
%	0.5	0.5	0.4	4.0	0.1	1.5	0.15	0.25	Bal.

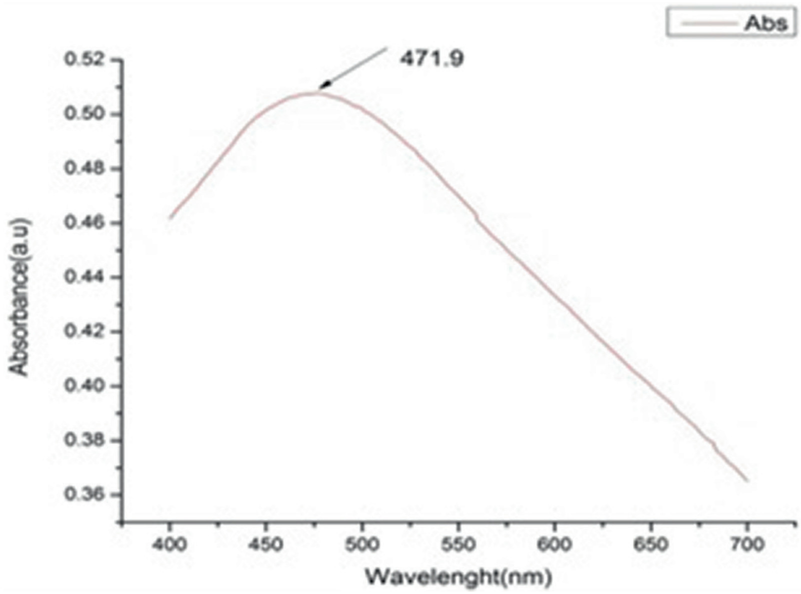

Figure 2: UV absorption spectra of Aluminum 2024 metal matrix.

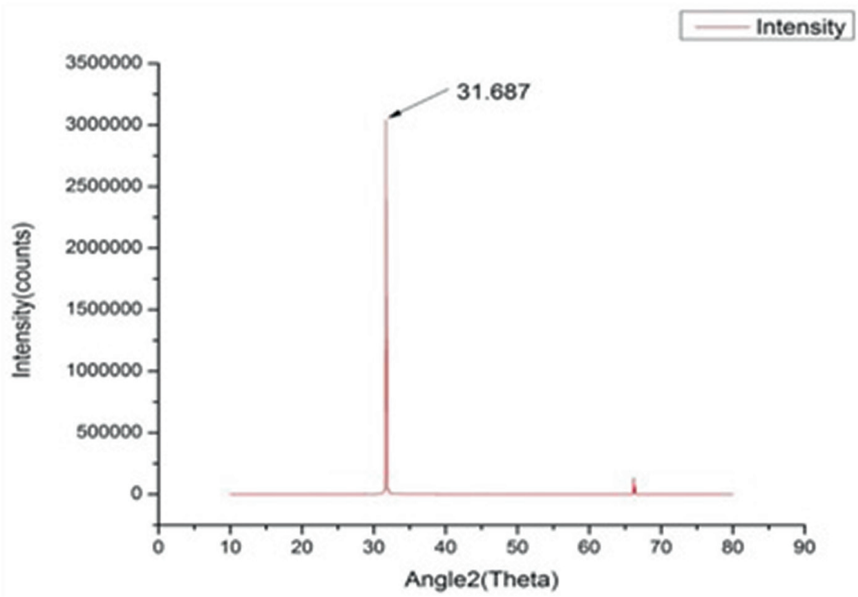

Figure 3: XRD analysis of Aluminum 2024 metal matrix.

metal matrix composites that were manufactured from them displayed diffraction peaks at $2\theta = 31.687°$ respectively, in the XRD study and are shown in Figure 3 The acquired XRD spectrum, when compared to the reference, demonstrated that the synthesized Al2024 metal matrix composites were crystalline and in nanocrystal form. The planes (121), (114), (200), (221), and (313) of the aluminum crystal, respectively, could be attributed to the peaks. The active Al 2024 metal matrix composites also had indexing, as indicated by the high peaks in the XRD examination.

7.3. FTIR analysis of Aluminum 2024 metal matrix composites

According to FTIR analysis, it is frequently possible to determine a molecule's structure from its absorption spectra. Dry potassium bromide was combined with a tiny quantity of Al 2024 metal matrix composites (KBr). A mixture was really well combined on the mortar before being compressed at 6 bars for 2 minutes to create a thin disc of KBr. Next, a very low-reflectance accessory cup is used to hold the disc.

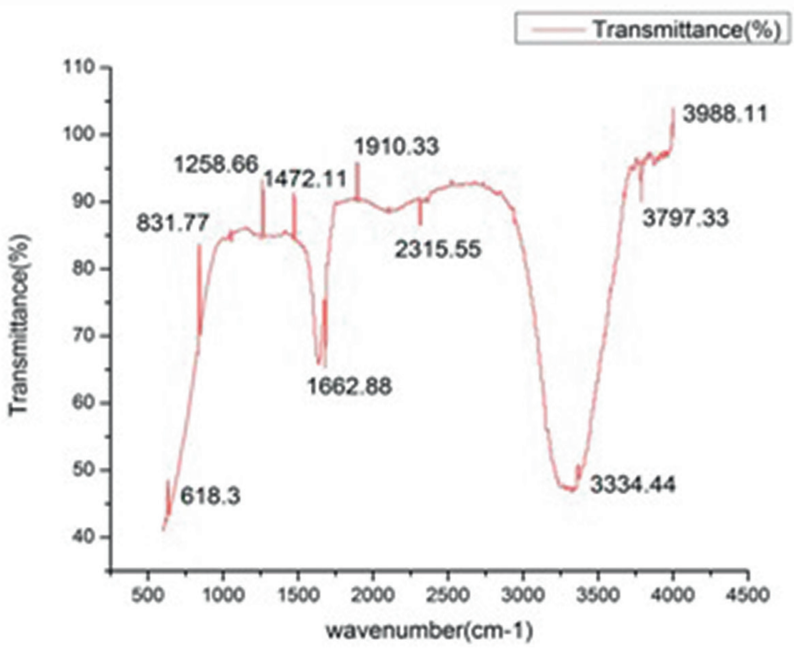

Figure 4: FTIR signals of Aluminum 2024 metal matrix composites.

The wave number ranges of 500–4500 cm^{-1} were used during the FTIR investigation of Aluminum 2024 metal matrix composites. Figure 4 shows the existence of several chemical groups and FTIR signals, including Aluminum 2024 metal matrix composites derived from C=O vibrations of oxygen (618.3 $cm^{-1)}$, C=C stretching of alkenes (831.77 0 cm^{-1}), then (1258.66 cm^{-1}) C=C stretching of alkenes, (1472.11 cm^{-1}) N-H stretching of nitrogen groups, (1662.88 cm^{-1}) N-H stretching of aliphatic groups, (1910.33 cm^{-1}) C=O Carbonyl group, (2315.55 cm^{-1}) O-H Hydroxyl group, (3334.44 cm^{-1}) Hydroxyl group, (3797.33 cm^{-1}) C=O Carbonyl group, (3988.11 cm^{-1}) C=C Alkenes group. This group hypothesizes the existence of composites made of aluminum 2024 metal.

7.4. TG/DTA analysis of Aluminum 2024 metal matrix composites

The thermal properties were studied using TGA/DTA analyzer (Perkin Elmer STA 6000) with air flowing at 20 mL/min. Ground rice husk biochar powder was mixed with aluminium oxide (1:1, v/v) before analysis to avoid artefacts in data due to shrinkage of samples during combustion. The temperature was raised from 30°C to 100°C at 10°C/min then kept at 100°C for about 10 mins. Then the temperature was increased from 100°C to 1000°C at a 10°C/min heating rate while DTA and TGA data were recorded.

The thermal degradation of green synthesized graphite quantum dots was studied using thermogravimetric techniques as indicated in Figure 5. The thermogram was recorded in the temperature ranges of 100–800°C with the heating rate of 10 degree per minute. The DTA graph (Figure 1) represents the carbon combustion temperature which was distinctly marked in terms of the temperature of maximum mass change rate (T_{max}). Graphene quantum dots show the combustion rate of (T_{max} 550 – 600).

7.5. SEM analysis of Al2024 metal matrix composites

The SEM seems to be a tool that creates a picture using electrons instead of light, producing a greatly enlarged image. An electron beam is created by electron cannon at the top of the microscope. The electron beam passes through the microscope in a vertical direction while it is kept in a vacuum. A scanning electron microscope (SEM) has been used for examine shape and size of graphene quantum dots. From SEM images, it can be seen that nano-composites made using electromagnetic stir casting and stir casting was stir casting have higher porosity percentages over nano-composites made using hybrid stir casting.

Cube-shaped Aluminum 2024 metal matrix composites, as seen in Figure 6 and some SEM pictures, The metal matrix is depicted in (a) and (b) of the SEM picture as a collective cauliflower. Shaped-cubic structures with good regularity are visible in the SEM pictures in (c) and (d).

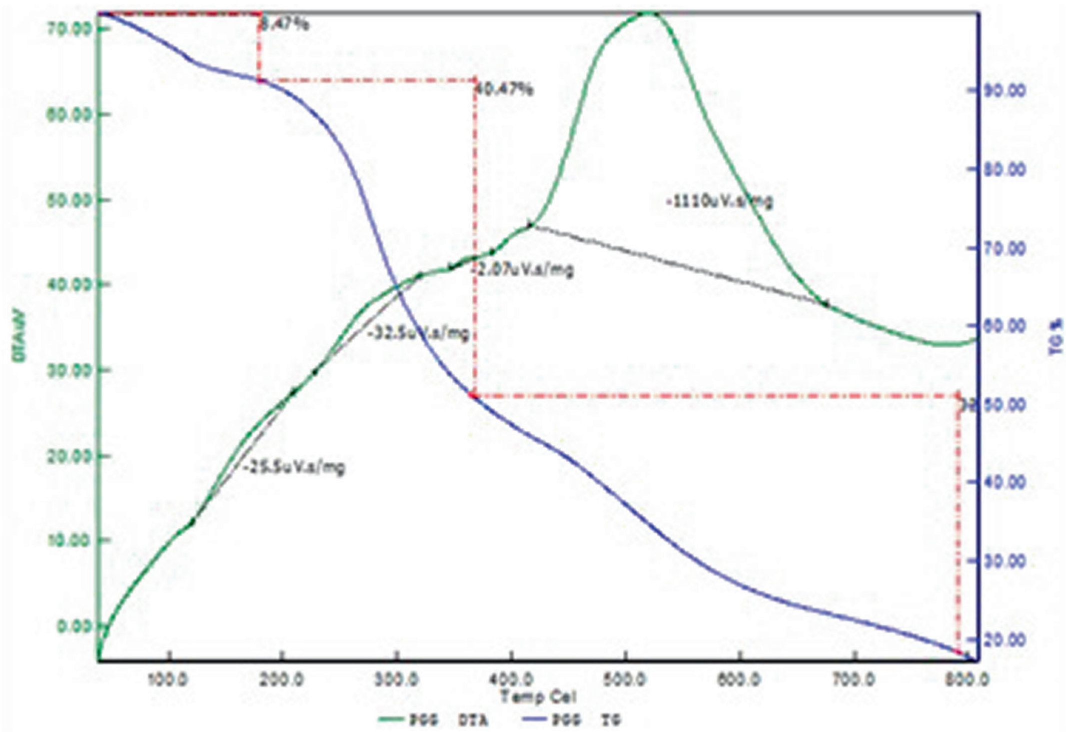

Figure 5: TG/DTA analysis of Al2024 metal matrix.

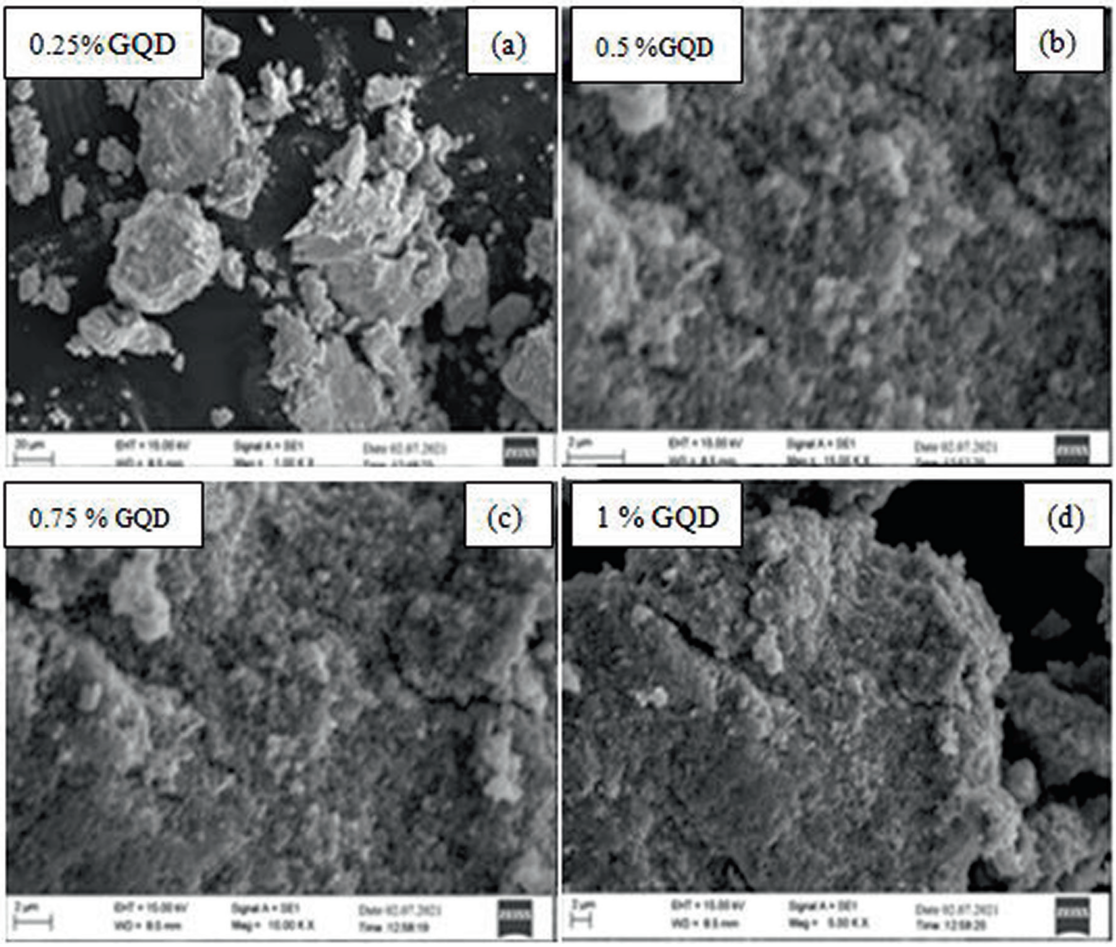

Figure 6: SEM images of cube shaped Aluminum 2024 metal matrix composites.

7.6. TEM analysis of Aluminum 2024 metal matrix composites

Figure 7 displays the TEM picture of the reinforcing particles. Due to the cold rolling method, the microstructure of the samples as they were created revealed elongated, non-recrystallized grains. In the as-rolled specimens, the intermetallic phases that had developed in the aluminum matrix were seen to be coarse and irregularly dispersed. The friction stir procedure has a considerable impact on the microstructure. Following the friction stirring procedure, distinct microstructure zones were created, including the stirred or nugget zone, the stirred or heat-affected zone, and the thermomechanical heat-affected zone. During the friction stirring process, severe deformation produced extra heat in the stirred zone, which led to a dynamic recrystallization. Selected TEM images of metal matrix composites made from synthetic aluminum 2024 Aluminum 2024 is seen in the (a) TEM image as having semi-spherical and spherical forms, some of which have agglomerated and others with well-dispersed regions. (b) The Aluminum 2024 metal matrix's nanoscale size was validated by a TEM picture.

7.7. AFM analysis of Aluminum 2024 metal matrix composites

All measurements were made using instruments from the market under ambient conditions (Park system,XE-70). Different n-doped aluminum cantilevers (Nanosensors TM) having resonance frequency of 190 kHz and 330 kHz and the spring constants of 48 N/m and 42 N/m, respectively, which were employed as force sensors for imaging. The head of Nanosurf scan were contained in a box (17 litresminicooler, Intertronic). The box's interior was lined with silica gel to help with humidity. The lab-view program was used to monitor the temperature and humidity. Imaging was carried out in a non-contact dynamic mode at an ambient temperatures and 30 to 40%

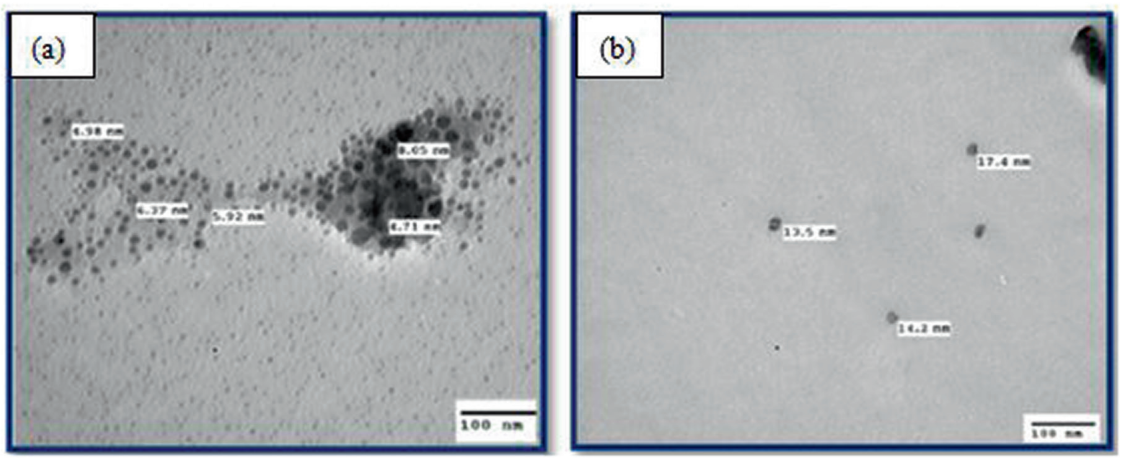

Figure 7: Aluminum 2024 in (a) TEM image with semi-spherical and spherical forms (b) Metal matrix's nanoscale size.

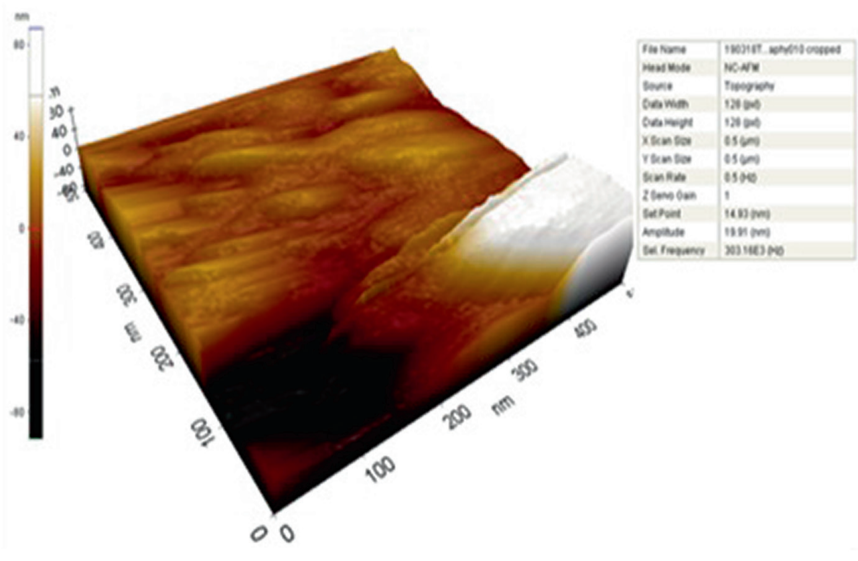

Figure 8: Three dimensions representations of generic particle.

relative humidity. Every photograph has undergone processing to improve quality. The topographic photos and their derivatives have been combined.

Images captured with an atomic force microscope (AFM) display the surface structure and size distribution of aluminum 2024 while it is dissolved. Reconstructed representations of the generic particle are shown in Figure 8 in three dimensions and Figure 9 in two dimensions. The size distribution and presence of the produced Al 2024 metal were assessed using AFM. The scanning area was 1 x 1 m, and the generated images in the figure are both two-dimensional (2D) and three-dimensional (3D). The illustration shows that the metal matrix composites for Al 2024 are distributed uniformly. The majority of the particles were sphere-shaped and between 40 and 80 nm in diameter.

7.8. Flexural properties

The load-displacement curve for the various ready samples is shown in Figure 10. According to the findings, adding 0.25% weight of graphene quantum dots boosted strength from 80 MPa to around 112 MPa (an increase in strength of 40%). But, the flexural strength would not be significantly increased by increasing the number of graphene quantum dots.

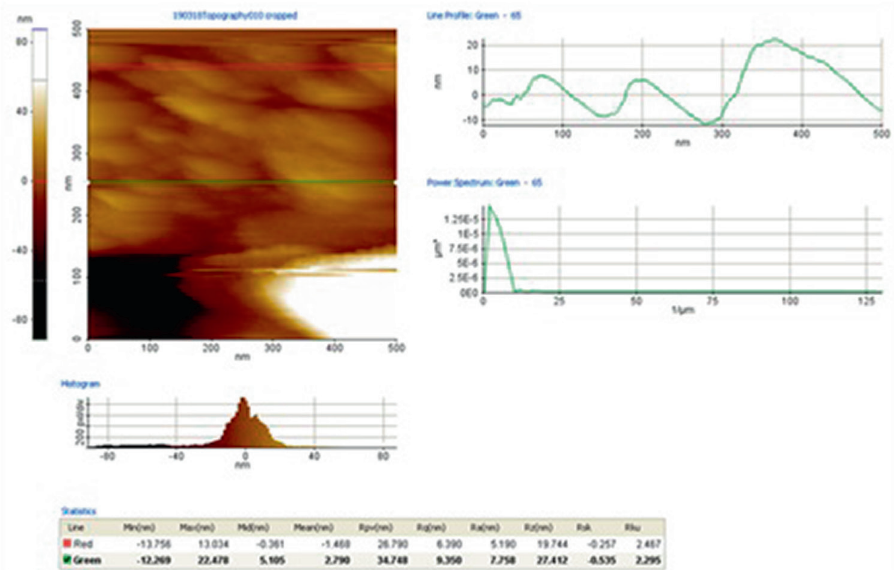

Figure 9: Two dimensions representations of generic particle.

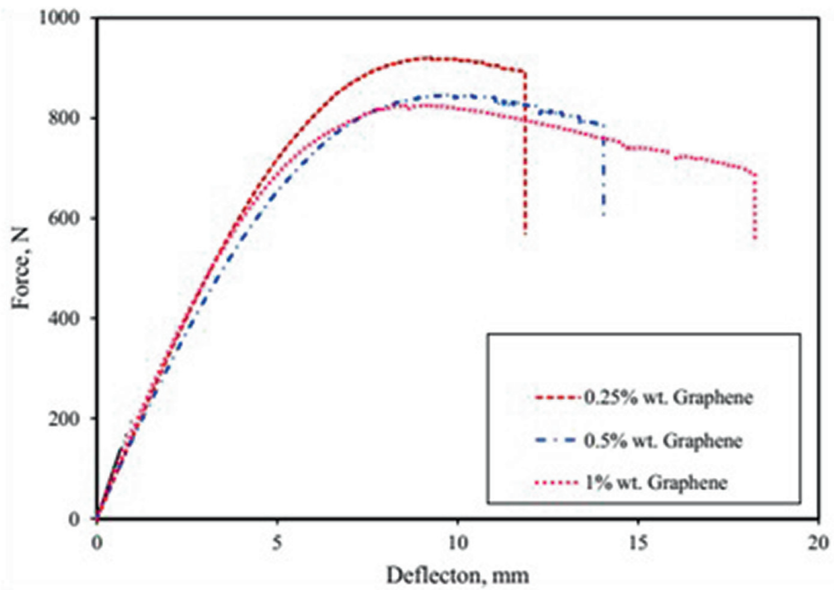

Figure 10: Load-displacement curve.

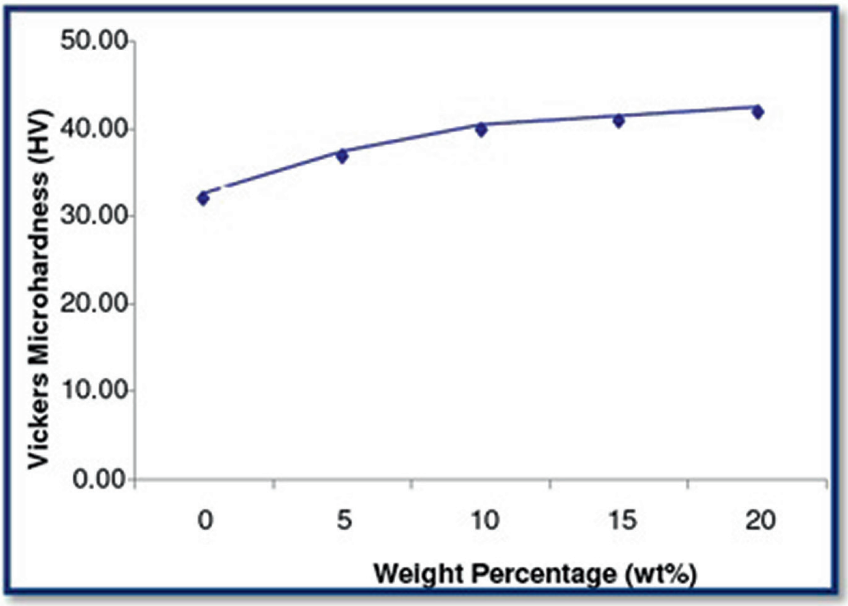

Figure 11: Vickers microhardness versus weight percentage.

7.9. Hardness properties

Vickers hardness values are plotted against rising supplement weight percentages in Figure 11. The weight proportion of alumina particles has a linear relationship with the microhardness value. The dislocation density is significantly higher, mostly in matrices, compared to the unreinforced alloys, and the availability of reinforcements favors the formation of incoherent precipitates due to the higher defect density. The grain size of the matrices was also smaller than that of unreinforced alloys. Thus, this explains why the Al matrix would become harder when there were tougher alumina particles present.

8. CONCLUSION

Additionally, numerous micromechanical systems for calculating the Aluminum matrix composites strength [28] with the help of various strengthening methods are explained. More significantly, depending on the observed features, promising and potential applications of Aluminum matrix composites have been suggested for a variety of industrial sectors, including the automotive, space, aerospace, electrical, energy, and electronics systems sectors. The current state of knowledge regarding Aluminum matrix composites is then clearly described. Moreover, several future study directions have been recommended in the area of Aluminum matrix composites. The test was conducted in accordance with ASTM guidelines. Graphene Quantum Dots and the received Al 2024 are examined using a scanning electron microscope (SEM).

It has been acknowledged that low-energy transmission electron microscopy (TEM) is a significant contribution to the family of electron microscopies because it may prevent knock-on damage and improve the contrast of weakly scattering objects. Utilizing a room-temperature 10-mm cell and a UV-visible spectrophotometer with just a slit diameter of 2 nm, a UV-visible spectrophotometric examination of the Aluminum 2024 metal matrix composites was performed. A molecule's structure can often be determined from its absorption spectra through the use of Fourier transform infrared (FTIR) analysis. Dry potassium bromide was combined with a tiny quantity of aluminum 2024 metal matrix composites (KBr). Measurements for atomic force microscopy analysis were made using commercial equipment in ambient settings. Using a PerkinElmer Diamond TG/DTA STA 6000 running between 0°C and 900°C at a rate of heating of 1°C/min and an O2 flow of 20 mL/min, TGDTA was performed. Silver nanoparticles made from the extracts of leaf and callus were measured by X-ray diffraction (XRD) utilizing a Cu-K radiation source with a scattering range of 20–80 on an apparatus running at 45 kV and 40 mA.

9. BIBLIOGRAPHY

[1] KHANNA, V., KUMAR, V., BANSAL, S.A., "Mechanical properties of aluminium-graphene/carbon nanotubes (CNTs) metal matrix composites: Advancement, opportunities and perspective", *Materials Research Bulletin*, v. 138, pp. 111224, 2021. doi: http://dx.doi.org/10.1016/j.materresbull.2021.111224

[2] KUSHWAHA, A.K., JOHN, M., MISRA, M., *et al*., "Nanocrystalline materials: synthesis, characterization, properties, and applications", *Crystals*, v. 11, n. 11, pp. 1317, 2021. doi: http://dx.doi.org/10.3390/cryst11111317

[3] POURHASHEM, S., GHASEMY, E., RASHIDI, A., *et al*., "A review on application of carbon nanostructures as nanofiller in corrosion-resistant organic coatings", *Journal of Coatings Technology and Research*, v. 17, n. 1, pp. 19–55, Nov. 2020. doi: http://dx.doi.org/10.1007/s11998-019-00275-6

[4] MA, Z., LI, Q., WEI, J., *et al*., "Effects of Al-based alloy powders on the mechanical behavior, corrosion resistance and infrared emissivity of polyurethane composite coatings", *Colloids and Surfaces. A, Physicochemical and Engineering Aspects*, v. 624, pp. 126782, 2021. doi: http://dx.doi.org/10.1016/j.colsurfa.2021.126782

[5] TABISH, M., YASIN, G., ANJUM, M.J., *et al*., "Reviewing the current status of layered double hydroxide-based smart nanocontainers for corrosion inhibiting applications", *Journal of Materials Research and Technology*, v. 10, pp. 390–421, 2021. doi: http://dx.doi.org/10.1016/j.jmrt.2020.12.025

[6] SAM, M., JOJITH, R., RADHIKA, N., "Progression in manufacturing of functionally graded materials and impact of thermal treatment: a critical review", *Journal of Manufacturing Processes*, v. 68, pp. 1339–1377, Aug. 2021. doi: http://dx.doi.org/10.1016/j.jmapro.2021.06.062

[7] L GHAZALY, A.H., "Effect of Graphene addition on the mechanical and tribological behavior of nanostructured AA2124 /Graphene self-lubricating metal matrix composite", *American Chemical Society*, vol. 95, pp. 325–336, April2017.

[8] GHAHFAROKHI, Z.S., BAGHERZADEH, M., YAZDI, E.G., *et al*., "Surface modification of graphene-coated carbon steel using aromatic molecules for enhancing corrosion resistance, comparison between type of aryl substitution with different spatial situations", *Anti-Corrosion Methods and Materials*, v. 65, n. 3, pp. 249–262, 2018. doi: http://dx.doi.org/10.1108/ACMM-06-2017-1808

[9] NWOSU, C.N., ILIUT, M., VIJAYARAGHAVAN, A., "Graphene and water-based elastomer nanocomposites-a review", *Nanoscale*, v. 13, n. 21, pp. 9505–9540, 2021. doi: http://dx.doi.org/10.1039/D1NR01324F. PubMed PMID: 34037053.

[10] ZHU, C., GUO, S., FANG, Y., *et al*., "Reducing sugar: new functional molecules for the green synthesis of graphene nanosheets", *ACS Nano*, v. 4, n. 4, pp. 2429–2437, 2010. doi: http://dx.doi.org/10.1021/nn1002387. PubMed PMID: 20359169.

[11] MEMON, H., LIU, J., DE FOCATIIS, D.S., *et al*., "Intrinsic dependence of ice adhesion strength on surface roughness", *Surface and Coatings Technology*, v. 385, pp. 125382, 2020. doi: http://dx.doi.org/10.1016/j.surfcoat.2020.125382

[12] ZEGHAOUI, S., HANNICHE, Z., BOUYAKOUB, I., *et al*., "Intrinsic dependence of ice adhesion strength on surface roughness", *Chemistry Africa*, v. 1, pp. 1–9, Mar. 2022.

[13] DEMIR, F., "Effect of aluminum reinforcement on the structural, physicochemical, and electrochemical properties of polyaniline-derived polymer/aluminum composites by in situ polymerization", *Electrochimica Acta*, v. 385, pp. 138444, 2021. doi: http://dx.doi.org/10.1016/j.electacta.2021.138444

[14] RANJAN, R., BAJPAI, V., "Graphene-based metal matrix nanocomposites: recent development and challenges", *Journal of Composite Materials*, v. 55, n. 17, pp. 2369–2413, Jan. 2021. doi: http://dx.doi.org/10.1177/0021998320988566

[15] NTURANABO, F., MASU, L., KIRABIRA, J.B., "Novel applications of aluminium metal matrix composites", In: Cooke, K.O. (eds.), *Aluminium alloys and composites*, London, IntechOpen, 2019.

[16] CEN, H., ZHANG, X., ZHAO, L., *et al*., "Carbon dots as effective corrosion inhibitor for 5052 aluminium alloy in 0.1 M HCl solution", *Corrosion Science*, v. 161, pp. 108197, 2019. doi: http://dx.doi.org/10.1016/j.corsci.2019.108197

[17] DUN, Y., ZUO, Y., "Preparation and characterization of a GPTMS/graphene coating on AA-2024 alloy", *Applied Surface Science*, v. 416, pp. 492–502, Sep. 2017. doi: http://dx.doi.org/10.1016/j.apsusc.2017.04.116

[18] XU, Y., LI, H., SHEN, Y., *et al*., "Improvement of adhesion performance between aluminum alloy sheet and epoxy based on anodizing technique", *International Journal of Adhesion and Adhesives*, v. 70, pp. 74–80, Oct. 2016. doi: http://dx.doi.org/10.1016/j.ijadhadh.2016.05.007

[19] ZHONG, F., HE, Y., WANG, P., *et al*., "Self-assembled graphene oxide-graphene hybrids for enhancing the corrosion resistance of waterborne epoxy coating", *Applied Surface Science*, v. 488, pp. 801–812, Sep. 2019. doi: http://dx.doi.org/10.1016/j.apsusc.2019.05.321

[20] HEALY, B., YU, T., DA SILVA ALVES, D., *et al*., "Review of recent developments in the formulation of graphene-based coatings for the corrosion protection of metals and alloys", *Corrosion and Materials Degradation*, v. 1, n. 3, pp. 15, 2020. doi: http://dx.doi.org/10.3390/cmd1030015

[21] RAMANATHAN, A., KRISHNAN, P.K., MURALIRAJA, R., "A review on the production of metal matrix composites through stir casting-Furnace design, properties, challenges, and research opportunities", *Journal of Manufacturing Processes*, v. 42, pp. 213–245, Jun. 2019. doi: http://dx.doi.org/10.1016/j.jmapro.2019.04.017

[22] JANGID, N.K., JADOUN, S., KAUR, N., "A review on high-throughput synthesis, deposition of thin films and properties of polyaniline", *European Polymer Journal*, v. 125, pp. 109485, 2020. doi: http://dx.doi.org/10.1016/j.eurpolymj.2020.109485

[23] LU, T., ZHOU, M., REN, L., FAN, L., GUO, Y., QU, X., ZHANG, H., LU, X., QUAN, G., "Effect of Graphene Nanoplatelets Content on the Mechanical and Wear Properties of AZ31 Alloy", *Metals*, v. 10, pp. 1265, 2020. Doi: http://dx.doi.org/10.3390/met10091265

[24] MA, Y., YE, Y., WAN, H., *et al*., "Chemical modification of graphene oxide to reinforce the corrosion protection performance of UV-curable polyurethane acrylate coating", *Progress in Organic Coatings*, v. 141, pp. 105547, 2020. doi: http://dx.doi.org/10.1016/j.porgcoat.2020.105547

[25] YANG, S., ZHUO, K., ZHANG, Z., *et al*., "Sodium fluoride-assisted hydrothermal exfoliation of graphite into graphene as filler of epoxy resin coating to protect aluminum", *The Journal of Physical Chemistry C*, v. 123, n. 45, pp. 27969–27977, Oct. 2019. doi: http://dx.doi.org/10.1021/acs.jpcc.9b09081

[26] SHIN, S.E., BAE, D.H., "Fatigue behavior of Al2024 alloy-matrix nanocomposites reinforced with multi-walled carbon nanotubes", *Composites. Part B, Engineering*, v. 134, pp. 61–68, 2018. doi: http://dx.doi.org/10.1016/j.compositesb.2017.09.034

[27] DHARSHAN, K., RAJU, T., "Microstructure, tensile and impact behavior of Si3N4 particles reinforced Al2024 matrix composites", *Materials Today: Proceedings*, v. 152, pp. 1499–1503, Mar. 2022. doi: http://dx.doi.org/10.1016/j.matpr.2021.11.224

[28] SAFARI, M., SOUSA, R.A., SALAMAT-TALAB, M., *et al*., "Mechanical properties of green synthesized graphene nano-composite samples", *Applied Sciences (Basel, Switzerland)*, v. 11, n. 11, pp. 4846, 2021. doi: http://dx.doi.org/10.3390/app11114846