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Analysis of Mechanical Properties in Micro and Nano Composites: A Comparative Study

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Abstract

Machining A development in microstructure within the Al-7075/Al_2O_3 (Alumina) combination was exhibited in this instance by altering its granular sizes for reinforcements throughout its substrate using the technique of powder metallurgy. Attention was placed on altering various reinforcing sizes of particles, including analyzing individual micro-structural architectures and potential consequences for overall nano-composite mechanical characteristics. Powder metallurgy was used to create nanocomposites of 9 vol.% Al_2O_3 (average size - 40 nm) strengthened within an aluminum matrix. A further additional set of exhibits with a comparable constitution (average size 20 m) was created to contrast both the mechanical and physical characteristics of the micro-composites and nanocomposites. Those nano- and micro-composites were characterized through a combination of X-ray diffraction (XRD), microscopy, and a scanning electron microscope (SEM), including density, microhardness, compressive strength, resistance to wear, and corrosion resistance tests. When compared against the Al_2O_3 micro-particles, the Al_2O_3 nanoparticles displayed contact with substantial physical closeness within the aluminum matrix. Because the operating temperature gets relatively inadequate, aggregates get minimized, and no new phases are generated when using the powder metallurgy approach.

Keywords

Stir casting, Material removal rate, Surface roughness, Flank wear, Orthogonal array

Introduction

Because of inherent diverse qualities, aluminum along with alloys of aluminum have become appealing alternatives during use in the aerospace, military, and automotive sectors. These kinds of applications need a high strength-to-density ratio. Heat treatment, thermomechanical processing, alloying addition, severe plastic deformation, and other methods can be used toward enhance its potency with aluminum and aluminum alloys. However, each of these procedures has its own set of downsides. The creation with metal matrix composites (MMCs) be a novel approach in support of increasing its potency with aluminum and aluminum alloys. Aluminum metal matrix composites (AMMCs) have gained special interest in automotives and also space sectors while promising superior structural resources throughout the past 30 years.

The liquid-state approach was used to create Al-7075/Al_2O_3&SiC at (2, 4, 6, and 8 wt.%). To efficiently produce aluminum matrices compound of Al-

7075/Al_2O_3&SiC, a typical cost-effective stir casting approach is adopted. combined resources constructed of Al-7075/Al_2O_3&SiC have a greater stiffness than non-reinforced Al-7075 [1]. Using Al-7075 with grey cast iron also ash dust metal matrix compound, a classic, economically viable stirring casting technique has been effectively performed. If compared with non-reinforced Al-7075 with ash dust also grey cast iron compound materials, Al-7075 with ash dust along with grey cast iron compound materials had a higher rigidity number [2]. Studied this consequence with machining process variables on top of the exterior irregularity during machine cutting with hardened mild steel [3]. Surveyed about the aspect distressing on specimen external irregularity are noted [4]. Also studied these causes affecting surface parameter [5]. It seems that there has been an excellent deal of research conducted regarding microparticles strengthened metal substrate compounds. Fortunately, there are relatively limited publications regarding nanoparticles strengthened AMMCs, despite the reality that nanoparticle composites with reinforcement have been supposed to possess outstanding characteristics [6].

However, it is worth noting that limited attention has been given to other aspects beyond mechanical performance. While the mechanical properties are crucial, future research should also consider exploring other potential benefits of these composites. These may include electrical conductivity, thermal stability, corrosion resistance, and biocompatibility. By broadening the scope of research, a more comprehensive understanding of the nano and micro-strengthened AMMCs can be achieved, leading to diverse applications in fields like automotives, aviation, electronic devices, and healthcare engineering. Therefore, it can be essential to encourage investigations into the non-mechanical properties of these materials to unlock their full potential [7]. Mechanical milling was suggested as a potential method to achieve uniform dispersion of nanosized Al_2O_3 particles within aluminum powder.

The milling process facilitated the even distribution of the second phase, resulting in minimal agglomeration, with agglomerates typically measuring around 1 micron in size. Furthermore, flexural characteristics with Al/Al_2O_3 nano-mixture exhibited a significant improvement in hardness, measuring approximately five times higher than that of pure, non-milled aluminum [8]. In this study, the compressibility of an Al/Al_2O_3 nanocomposite was investigated using a combination of methods of milling and mixing. The ability to squeeze behavior observed in aluminum and Al_2O_3 nanoparticles that have been ground and mixed together show similarities to the typical compaction process of metal powders. The consolidation process during compaction is primarily governed by particles rearranging themselves causing deforming into plastic [9]. This study examined the fabrication of AMMCs enhanced with nanoscale Al_2O_3 particles and micro-scale aluminum particles by means of stir casting. Micro-structural analysis indicated a relatively homogeneous dispersion from nanoparticles of Al_2O_3 within its aluminum compound, leading to grain structure refinement in the cast materials [10]. This research focused on synthesizing and characterizing plasma spark sintering for the production of micro and nano-scale Al/Al_2O_3 composites. Through the spark plasma sintering method, Al/Al_2O_3 nanocomposites with different volumes of Al_2O_3 nanoparticles (0.5, 1, 3, 5, and 7%) in addition to millimeters range compound among varying Al_2O_3 micron size particle contents (1, 5, and 20 vol.%) were successfully fabricated [6]. The investigation focused on strips of powder metallurgy and heat rolling produced Al/Al_2O_3 composites with metal matrix. The acquaintance superiority among the aluminum also Al_2O_3 constituent parts was found to be good [11].

The study investigated the impact of its constituent parts route dimension also reinforcement quantity scheduled the physical characteristics with microscopic substructure with aluminum mold composites fabricated through fine particles metallurgy. It was observed that reducing the size of Al_2O_3 particles lead en route for an enhance its hardness. Moreover, as the amount of Al_2O_3 in this compound decreased, the grain size decreased while the distribution homogeneity of Al_2O_3 particles increased [9].

This work quantifies the mechanical characteristics of Al_2O_3 nanoparticle and microparticle-reinforced AMMCs. Additionally, the study aims to assess the degradation and deterioration effectiveness of these AMMCs. Composites are produced using powdered metal metallurgy and conventional processing methods. Through this research, a comprehensive understanding of the mechanical behavior and durability of AMMCs with different reinforcement sizes will be obtained. The results will contribute to the optimization and selection of appropriate reinforcement strategies for AMMCs, leading to improved material performance and increased applicability in various industries.

Experimentation

This investigation focuses on the enhancement of commercially pure aluminum by introducing micro- and nano-Al_2O_3 particles as reinforcement. The objective is to assess how these particles influence the properties of the aluminum matrix. Through a comprehensive analysis of the mechanical and physical characteristics of the composite, valuable insights can be gained, shedding light on the potential advantages and applications of incorporating micro- and nano-Al_2O_3 reinforcement into commercially pure aluminum.

The investigation holds the potential to unlock new opportunities for utilizing micro- and nano-Al_2O_3 reinforcement, offering insights into how to optimize the properties of aluminum-based materials and expand their range of applications in various industries. Table 1 displays each of the compounds' terminology and combined utilize.

In this experiment, commercially available aluminum also Al_2O_3 fine particles with micro/nano scales be utilized. A total of 20 g of each powder were mixed to achieve a consistent volume fraction of 9% Al_2O_3 inside together the micro/nano size mixtures. Six samples—three per scale—were produced.

Table 1: List of composites with their respective chemical composition and names.

S. No.	Composition used	Nomenclature used
1	Al-7075 + 9% Nano Al_2O_3	Al-7075 + NA
2	Al-7075 + 9% Micro Al_2O_3	Al-7075 + MA

To ensure thorough blending, the samples were properly mixed using an abrasion tester, allowing for two revolutions to achieve uniformity. To facilitate the uniform distribution of alumina particles within the aluminum matrix, these fine particles are placed in addition to several balls of steel in a plastic container. This setup ensured proper blending and dispersion of nanoparticles made up of Al_2O_3. Subsequently cool compaction was used for the mixed specimens. using a die with a diameter of 12 mm. A load of 600 MPa be pertain throughout it compaction procedure. To aid in this easy removal of the compacted cylindrical samples, a lubricant, specifically zinc-stearate, was employed. By following this methodology, the aim was to create a well-blended compound through a consistent allocation with Al_2O_3 elements within aluminum mold. This experimental approach ensures the accurate evaluation of the subsequent nanocomposite's structural as well as physical characteristics.

Sintering

These compacted pellets obtained from the previous step underwent a thermal treatment procedure in a tubular furnace under an inert atmosphere of 99.99% pure argon gas. The pellets were heated to 600 °C and kept there for 2 h. The powder samples were compressed, and then subjected to heat treatment to assure densification of materials for further study and characterization, the density within the sintering specimens is evaluated and then published.

Quantifying concentration

This hypothetical, immature, also compacted densities for selected specimens are determined with its mixture rule, enabling calculations based on the composition and characteristics of the materials used in the samples.

Concentration in theory

$$D_c = D_m \text{ x } V_m + D_f \text{ x } V_f \tag{1}$$

Where, D_c, D_m, and D_f - concentrations among the combination, matrices, as well as reinforcement stage. V_m and V_f - matrices volumetric percent as well as reinforcement stage, correspondingly.

Green concentration

$$D_{gc} = \text{Mass}/\text{Volume of compressed concrete} = \pi d^2 h/4$$

Where, d = Diameter of the compact and h = height of the compact.

XRD analysis

XRD analysis was conducted on all the composites using a PANalytical X- ray Diffractometer. The measurement involved varying the 2θ angle from 10° to 90°, while the scanning rate was set at 2° per minute. XRD is a powerful technique used to determine the crystallographic structure and phase composition of materials. By analyzing the diffraction patterns produced when X-rays interact with the sample, valuable information regarding the crystalline phases present in the composites can be obtained. The 2θ angle variation allows for the identification of specific crystal planes and their corresponding diffraction peaks. This XRD analysis enables the characterization and identification of the crystallographic phases present in the composites. It helps in determining the degree of crystallinity, phase composition, and potential phase transformations that may have occurred during the fabrication process.

SEM analysis

Microstructural characterization of the entire combinations, both within their following durability examination plus as-sintered, was performed using SEM. Prior to examination, the Al-7075/Al_2O_3 samples underwent mechanical polishing using standard metallographic techniques to ensure optimal surface preparation. SEM analysis allows for the observation of the composite's microstructure at high magnification, providing insights into features such as grain size, distribution of reinforcement particles, and any structural changes caused by the wear test. By examining the microstructure, valuable information about the composite's mechanical properties, wear resistance, and overall performance can be obtained.

Results and Discussion

Permeability

Permeability = (Hypothetical concreteness − Investigational concreteness).

Hypothetical concentration

Tiny nanoparticle-augmented specimens with reinforcing stage volume fractions are V_f = 8% and D_m (Al) = 2.7 g/cc and D_f (Al_2O_3(m)) = 3.95 g/cc.

Now D_c = 2.7 x 0.92 + 3.95 x 0.08, D_c = 2.8 g/cc.

D_m (Al) = 2.7 g/cc, D_f(Al_2O_3(n)) = 3.97 g/cc, and V_f(reinforcement) = 8% for a nanoparticle reinforced sample.

Now D_c = 2.7 x 0.92 + 3.97 x 0.08, D_c = 2.8016 g/cc.

Green concentration

Specimen enhanced with microparticles, the higher porosity observed in the nanocomposite suggests that the particles in this composite may not have achieved optimal bonding or densification during processing (Table 2 and table 3). The smaller particle size in the nanocomposite could contribute to this outcome, as it can result in less effective particle rearrangement and compaction during the manufacturing process. Understanding the presence of porosity is crucial as it can impact nanocomposites' physical attributes and effectiveness. Steps be able to optimize the processing parameters and densification in future production to minimize porosity and improve the overall quality of the composites. Table 4 presents Al-7075 +

Table 2: Green densities of the microparticle reinforced samples (Al-7075 + MA).

Sample No.	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm³)	Density (g/cc)
1	5.8067	14.174	13.1287	2.0786	2.8065
2	5.7576	14.167	13.1174	2.0675	2.7854
3	5.8054	14.165	13.1285	2.0685	2.8064

MA microparticle enhanced sample sinter densities. Table 5 presents Al-7075 + NA nanoparticle enhanced sample sinter concentrations.

Table 3: Green concentrations of nanoparticle strengthened materials (Al-7075 + NA).

Sample No.	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm^3)	Density (g/cc)
1	5.785	14.166	13.135	2.066	2.7950
2	5.811	14.176	13.145	2.075	2.7955
3	4.852	14.175	11.125	1.754	2.7691

Table 4: Al-7075 + MA microparticle enhanced sample sinter densities.

Sample No.	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm^3)	Density (g/cc)
1	5.802	14.17	13.142	2.071	2.795
2	5.750	14.165	13.125	2.067	2.765
3	5.791	14.654	13.13	2.068	2.79

Table 5: Al-7075 + NA nanoparticle enhanced sample sinter concentrations.

Sample No.	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm^3)	Density (g/cc)
1	5.754	14.179	13.145	2.074	2.77
2	5.804	14.175	13.165	2.075	2.76
3	4.841	14.175	11.102	1.751	2.74

Microstructure

Microstructure analysis with these micro-composites, moreover nanocomposites exist conducted with a SEM. This analysis involved capturing both secondary electron images and backscattered electron (BSE) images. The SEM images provide information about the surface topography and morphology of the composites, while the BSE images offer insights into the compositional variations and atomic number contrasts within the materials. By examining both types of images, a comprehensive understanding of the microstructural features, such as the distribution and arrangement of reinforcement particles, grain structure, and possible defects, can be obtained. This microstructural analysis aids in evaluating the quality of the composites, understanding the influence of processing parameters on the microstructure, and assessing the potential impact on the material's mechanical and physical properties.

It is clear from looking at figure 1, figure 2, figure 3, and figure 4 that the composites exhibit an advantageous interface bonding between the particles and the aluminum matrix. This may be deduced from the data shown in those figures. In addition, the nano and micro reinforcement particles that are included in the aluminum matrix are distributed in an even manner throughout the material. It is essential to note that the micrographs do not display any indications of aggregation of the nanoparticles. This lack of agglomeration is noteworthy, as the liquid metallurgy route often leads to such clustering of nanoparticles. However, the powder metallurgy technique employed in this investigation resulted in minimal agglomeration. Furthermore, Minimal outcomes of reaction are observed at the particle-matrix contact.

Examining figure 1, figure 2, figure 3, and figure 4, it is ev-

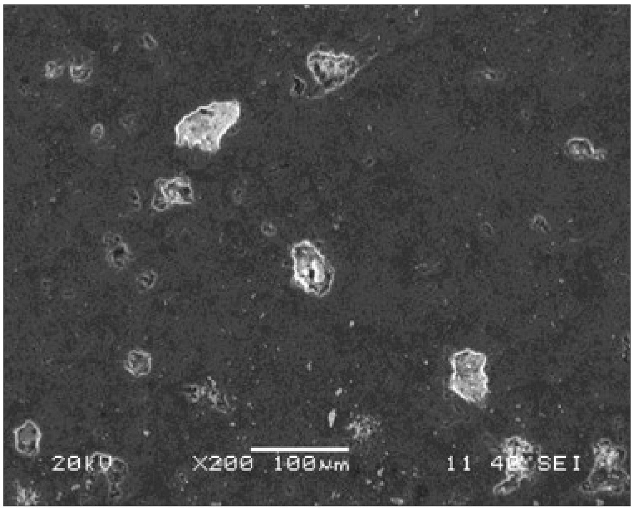

Figure 1: SEM of Al-7075 + MA.

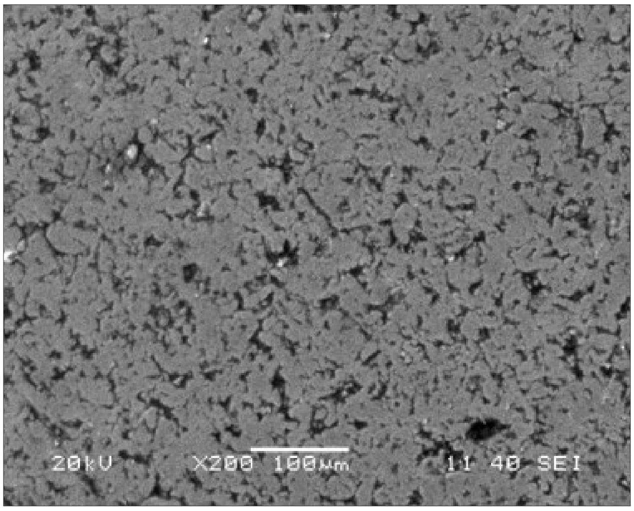

Figure 2: SEM of Al-7075 + NA.

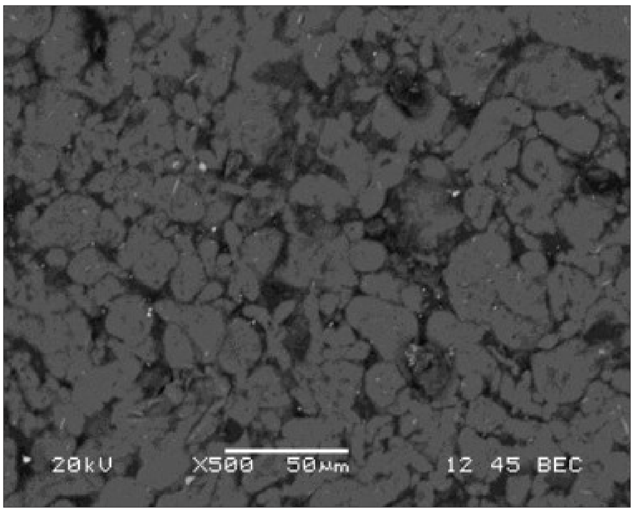

Figure 3: BSE Al-7075 + MA.

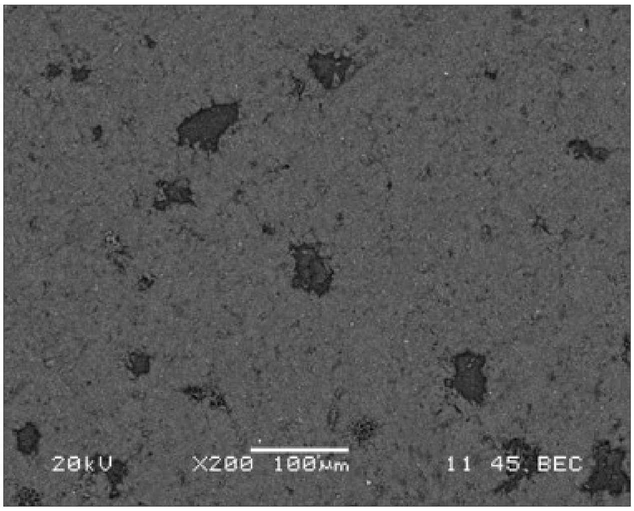

Figure 4: BSE Al-7075 + NA.

ident with the intention of granule modification have occurred in the composites. This indicates that the microstructure of the material has been modified, resulting in smaller and more refined grains compared to the matrix without reinforcement. Grain refinement is an advantageous characteristic as it can improve its structural and physical characteristics for its composite, like potency also hardness. Table 6 presents a comparison of micro- and nano-composite porosity.

Table 6: Comparing micro- and nano-composite porosity.

Sample	Investigational density	Theoretical density	% Porosity
Al-7075 + MA	2.7981	2.8	0.14
Al-7075 + NA	2.783	2.802	1.3

XRD analysis

This XRD psychoanalysis reveals distinct crest matching near pure Al/Al_2O_3, indicating the presence of these phases in the samples (Figure 5). No additional phases or impurities are observed, suggesting that the fabrication process successfully retained the integrity of the aluminum and Al_2O_3 components without the formation of undesired compounds. This finding indicates the high purity and composition stability of the composite materials, which is essential for their intended applications. The absence of additional phases confirms the suitability of the chosen fabrication method and supports the desired characteristics and properties of the composite samples.

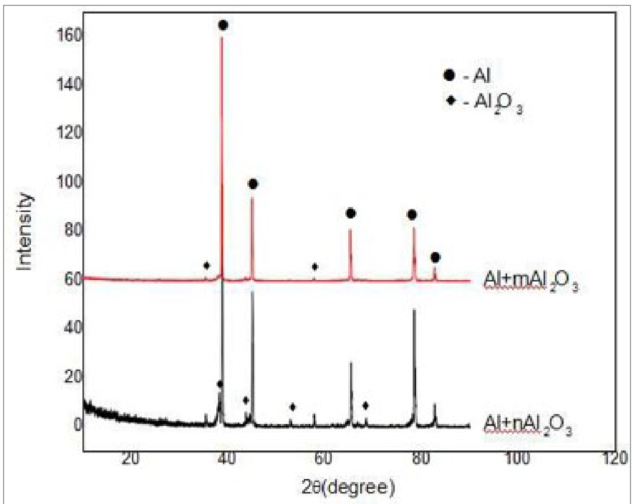

Figure 5: XRD of Al-7075 + MA and Al-7075 + NA.

Hardness measurement

Based on figure 6 and table 7, it is evident so as to the microhardness for the nanocomposite is superior to that of the micro-composite. The difference in microhardness can be attributed in the direction of overall escalation method furthermore granule sophistication. Its overall escalation mechanism is a result of the hindrance caused by the dispersed reinforcement particles on dislocation movement, leading to increased strength and hardness. Additionally, grain refinement, as observed in the microstructure, can contribute to enhanced mechanical properties. These combined effects likely contribute to the higher microhardness observed in the nano composite compared to the micro composite.

The Hall–Petch equation is a useful tool for understanding the grain refining process.

$$\sigma_y = \sigma_i + kD^{-1/2} \quad (2)$$

Where, σ_y = Yield stress, σ_i = Friction stress, K = Locking parameter (constant), and D = Grain diameter.

Endurance under compression

It is essential to take into account the fact that the ten-

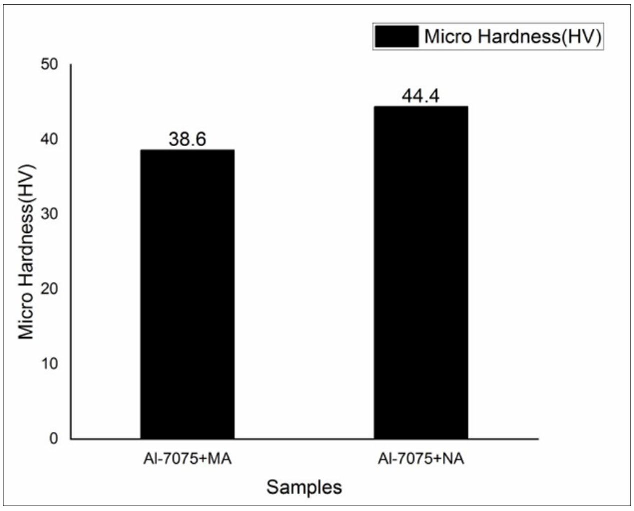

Figure 6: Plot comparing the microhardness of micro- and nano-composite.

Table 7: Microhardness values for both micro- and nano-composite.

Sample	1	2	3	4	5	6	7	8	9	Average hardness
Al-7075 + mAl_2O_3	39.1	38.7	39.6	34.1	36.9	37.0	37.6	37.0	37.0	38 ± 2.38
Al-705 + nAl_2O_3	41.0	44.6	38.9	44.8	41.0	42.2	44.7	42.9	40.4	44.4 ± 1.82

sion values obtained represent the stress at which the material reaches a 50% reduction in height, rather than the ultimate compressive stress (Figure 7). An examination of the graph indicates that the stress value for the nano composite at the point when it has been reduced by 50% is greater than that of the micro-composite at the same point. It is probable that the overall strengthening process and the observed grain refinement in the nanocomposites are to blame for this variation in stress.

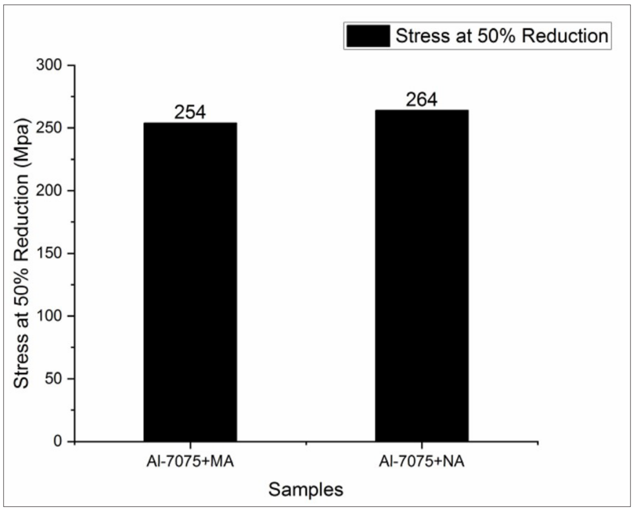

Figure 7: Plot of micro- and nano-composite stress at 50% decrease.

Wear characteristics shown by dry sliding

According to the findings of the dry sliding wear test, the wear rate of the nanocomposite is much greater than that of the micro-composites. The increased hardness values of the Al-7075 + NA composites are likely responsible for the improvement in wear resistance shown by these materials. This higher hardness provides enhanced resistance to deformation and material removal during the sliding wear process, leading to reduced wear rates. Therefore, the improved wear resistance observed in the Al-7075 + NA composites can be directly linked to their higher hardness, emphasizing the significance of hardness in determining the wear performance of these materials (Figure 8).

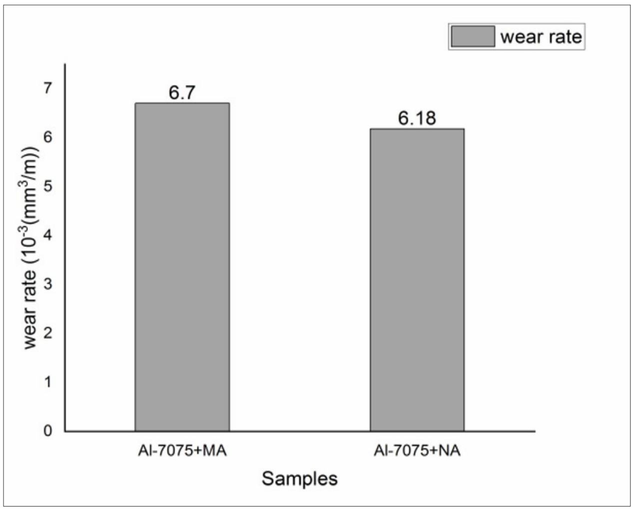

Figure 8: Plot comparing the wear rate between micro- and nano-composite.

Following the completion of the wear tests, the worn surfaces were examined using SEM to gain insights into the wear mechanisms involved. Representative micrographs obtained from the SEM analysis are presented in figure 9 for the micro-composite and figure 10 for the nanocomposites. These micrographs allow for visual examination of the worn surfaces, aiding in the identification and understanding of wear mechanisms such as abrasive wear, adhesive wear, or any other surface damage. By analyzing micrographs, valuable information can be obtained regarding the nature and extent of wear, providing important insights into the wear behavior and performance of both the micro-composites and nanocomposites.

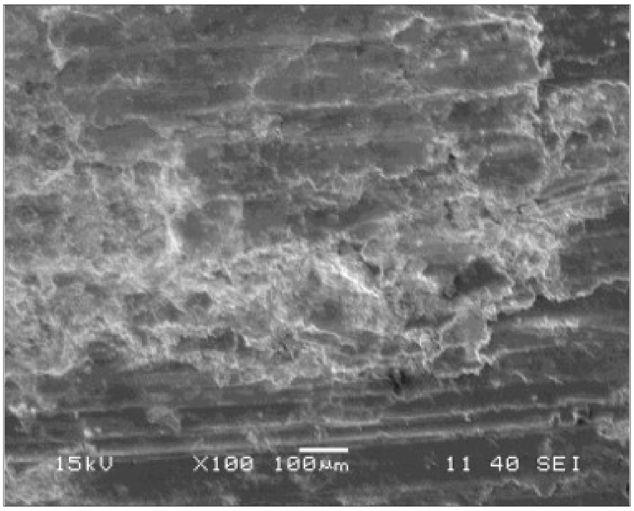

Figure 9: SEM showing the surface of micro-composite.

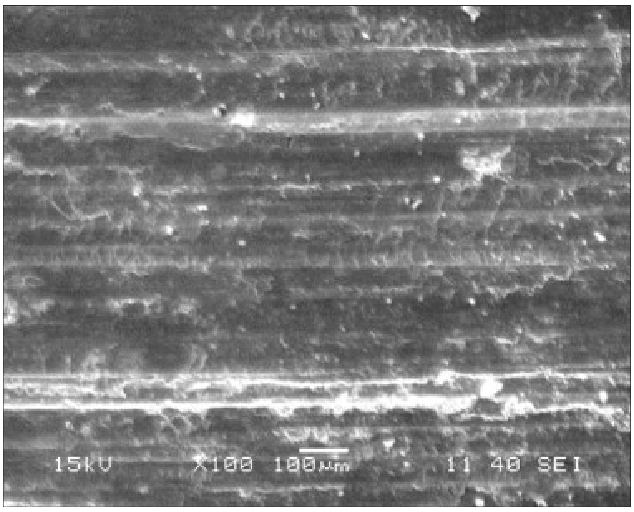

Figure 10: SEM showing the surface of nanocomposite.

Corrosion test

Figure 11 shows how the nanoscale combination outperformed the smaller compounds in terms of resistance to corrosion. The detected improvement in grain shape in the nanocomposites is responsible for their improved durability against

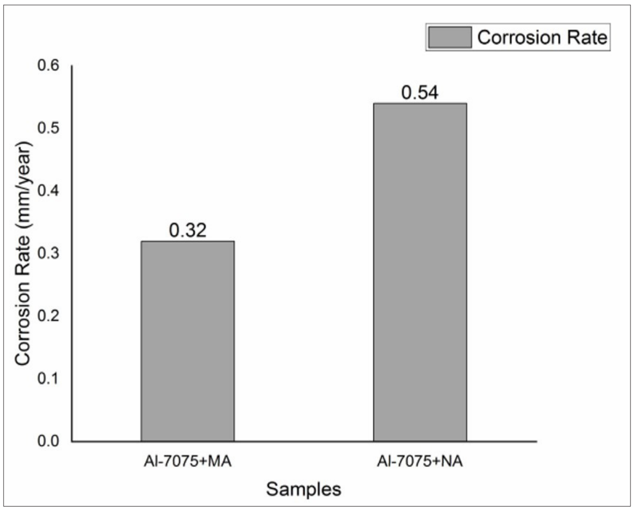

Figure 11: Plot comparing the corrosion rate between micro- and nano-composite.

corrosion. The refined grain structure hinders the propagation of corrosion, thereby reducing the susceptibility of the material to corrosive attack.

Conclusions

In the current study, we conducted an investigation into these physical characterizations, wear behavior, also aluminum matrices compounds with high durability against oxidation reinforced among scale of micro also nano-element. These composites were fabricated using the powder metallurgy route. This incorporation for micro- and nano-particles as reinforcement in the aluminum matrix led to significant improvements in physical characterizations like stiffness, tensile strength, and compressive strength. This can be attributed to the overall escalation method and also granule sophistication pragmatic within composites. The nanocomposite outperformed the micro-composites in terms of wear resistance, as shown by the abrasion tests. This can be attributed to its higher hardness and the resulting ability to resist material removal and surface damage during sliding contact. Electrochemical corrosion tests indicated that the nanocomposites demonstrated better corrosion resistance than the micro-composites. The refined grain structure in the nanocomposites contributed to their improved corrosion resistance.

The powder metallurgy fabrication route provided successful dispersion of the reinforcement particles within the aluminum matrix, resulting in good interface bonding and uniform distribution. These conclusions provide valuable insights into the potential advantages and applications of micro- and nano-particle reinforcement in aluminum matrix composites. Further research can focus on optimizing the processing parameters and exploring additional properties and applications of these composites.

- The fabrication process was carried out successfully, and the resulting composites appear to be satisfactory with acceptable levels of porosity.
- The nanocomposite demonstrated superior properties compared to the micro-composites. The nanocomposite exhibited higher strength and hardness, which can be attributed with overall escalation system also the observed granule refinements with nanocomposite.
- The nanocomposite outperformed the micro-composites in terms of wear resistance, as shown by the abrasion tests.
- The nanocomposite outperforms the micro-composite in terms of corrosion resistance, and this improvement may be traced back to the nanocomposite's refined grains.

Acknowledgements

None.

Conflict of Interest

None.

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