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

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Abstract. The current investigation indicated that the microstructure of the Al-7075/RHA/Al_2O_3 combination is altered by the utilization of the powder metallurgy method. This is accomplished by altering the granular sizes of reinforcements that are distributed across the substrate. Altering the various particle sizes made use of for reinforcing is the primary focus of attention. To do this, it is necessary to investigate the microstructural architectures of individual particles, in addition to determining the potential effects on the nanocomposite's overall mechanical properties. Nano powder metallurgy is utilized in order to produce nanocomposites that are strengthened within an aluminum matrix. These nanocomposites are composed of 9 % RHA/Al_2O_3 and have an average size of 40 nanometers respectively. contrast me with to compare and contrast the mechanical and physical qualities of the nanocomposites and the micro composites, generated an additional set of displays that had a composition that is comparable to the previously mentioned ones. twenty meters in length. To determine the characteristics of these nano- and micro-composites, a combination of X-ray diffraction, microscopy, and a scanning electron microscope is considered. Density, micro-hardness, compressive strength, resistance to wear, and corrosion resistance are among the tests that examine the material's properties. When examining the nanoparticles of RHA/Al_2O_3 in comparison to the microparticles of RHA/Al_2O_3, notice that the nanoparticles of alumina are far more closely packed together within the matrix of aluminium. The utilization of the powder metallurgy approach leads to the absence of the formation of any new phases and a decrease in the quantity of aggregates that are accomplished.

Keywords: Stir Casting, Tensile, Wear, Impact,

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1. Introduction

Aluminium and aluminium alloys have emerged as viable alternatives in the aerospace, military, and automotive industries due to their intrinsically diversified properties. The strength-to-density ratio must be high for these types of uses. Improving its effectiveness with aluminium and Al alloys can be achieved through a variety of means, including heat treatment, thermo mechanical processing, alloying addition, and severe plastic deformation. These surgeries have different drawbacks, however. Making it with MMCs is an innovative way to boost its strength when combined with Al and aluminum alloys. Due to their promise of improved structural resources, aluminum metal matrix composites (AMMCs) have garnered significant interest in the automotive and space sectors during the last three decades.

A mixture of Al-7075 and Al2O3 with SiC added at 2, 4, 6, and 8% weight percent is prepared using the liquid-state method. We use a standard, cost-effective stir casting method to effectively create aluminum matrices compounds of Al-7075/Al_2O_3&SiC. In comparison to non-reinforced Al-7075, combined resources made of Al-7075/Al_2O_3&SiC are more rigid [1]. successfully executed a traditional, economically feasible stirring casting process using Al7075 with grey cast iron and ash dust metal matrix composition. The combination of ash dust and grey cast iron compound increased the stiffness number of Al-7075 relative to non-reinforced Al-7075 [2]. Investigated this outcome by controlling the machining process factors in addition to the surface irregularity while cutting hardened mild steel by machine [3]. Noted are the aspects about the aspect that are upsetting on the specimen's outward irregularity [4]. Also looked at the effects of these factors on the surface parameter [5]. It would seem that micro particle reinforced metal substrate composites have been the subject of a great lot of study. Thankfully, there is a dearth of literature on nano-particle reinforced aluminum matrix composites, even though these materials are widely believed to have exceptional properties to begin with [6]. Not much thought has gone into factors other than mechanical performance, however. Future studies should think about investigating other possible advantages of these composites, even if the mechanical qualities are critical. Some examples of these characteristics include biocompatibility, resistance to corrosion, thermal stability, and electrical conductivity. More study into nano and micro-strengthened AMMCs will lead to a better understanding of these materials and their many potential uses in industries as varied as transportation, electronics, medicine, and the aerospace industry. For this reason, it may be crucial to promote research into these materials' non-mechanical characteristics in order to release their maximum potential[7]. One possible approach to create a homogeneous distribution of nano-sized Al_2O_3 particles in Al powder is to use mechanical milling. Agglomerates, which usually measure around 1 micron in size, are limited because the milling procedure helped to evenly distribute the second phase. In addition, flexural properties with an Al- Al_2O_3 nano-mixture showed a considerable increase in hardness, around five times greater than those of unmilled, pure aluminium [8]. Using a mix of milling and mixing techniques, this research examined the compressibility of a nano composite made of aluminium and alumina.

Aluminium and alumina nanoparticles that have been crushed and combined exhibit squeezing behaviour that is comparable to the usual compaction of metal powders. The main mechanism by which particles reorganize and undergo plastic deformation during compaction is the consolidation process [9]. This research looked at the process of stir casting aluminum matrix composites with nano- and micro-scale Al_2O_3 and Al particles added to it. The micro-structural investigation of the cast materials revealed that the aluminum compound had a very uniform distribution of nano-particles of aluminum oxide, which resulted in a refined grain structure [10]. Plasma spark sintering, a process for creating micro and nano-scale aluminum-alumina composites, is the subject of this research's synthesis and characterization. Alumina nanoparticles in varied quantities (0.5, 1, 3, 5, 7%), millimeter-range compounds, and alumina micron size particle contents (1, 5, 20 vol.%) are all effectively produced using the spark plasma sintering process to create Al- Al_2O_3 nano composites [11]. examination centered on metal matrix Al/ Al_2O_3 composite strips made by powder metallurgy and heat rolling. There is a considerable degree of familiarity and superiority among the aluminum and alumina component portions [12]. This research looked at the effects of microstructure on the physical properties of aluminum mould composites made using fine particles metallurgy, as well as the route size and reinforcement amount. Researchers found that increasing the hardness of alumina is possible by decreasing its particle size. In addition, the compound's grain size dropped and the distribution homogeneity of alumina particles rose as the quantity of alumina decreased [13].

Al_2O_3 nanoparticle and microparticle reinforced aluminum metal matrix composites (AMMCs) have their mechanical properties quantified in this study. The research also intends to evaluate how well these AMMCs degrade and deteriorate. We use powdered metal metallurgy and standard processing techniques to make the composites. This study will help us understand the mechanical behaviour and durability of AMMCs with various reinforcement sizes. Improving material performance and increasing application in many sectors, the findings will help optimize and choose suitable reinforcing schemes for AMMCs.

2. Experimental Procedure

Adding micro and nano alumina particles as reinforcement to commercially pure aluminium is the main focus of this work. Finding out what effect these particles have on the aluminium matrix's characteristics is the main goal. The possible benefits and uses of adding micro and nano alumina reinforcement to commercially pure aluminium may be better understood by conducting a thorough investigation of the composite's mechanical and physical properties.

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

S.No.	Preferred Composition	Notation
1	Al-7075+ 9% Nano Al_2O_3/RHA	Al-7075+NA
2	Al-7075+ 9% Micro Al_2O_3/RHA	Al-7075+MA

This study has the makings of a game-changer in terms of micro and nano alumina reinforcement, which might lead to better aluminum-based material characteristics and more uses across a variety of sectors. Table 1 shows the combined uses and nomenclature of each component.

This experiment will use fine particles of aluminium dioxide (Al_2O_3) with sizes ranging from micro to nano and rice husk ash. For the micro/nano size mixes, a constant volume fraction of 9% alumina is achieved by mixing 20 grammes of each particle. Each scale yielded three samples for a total of six. By waiting two rotations to attain consistency, the samples are thoroughly mixed using an abrasion tester. To ensure that the alumina particles are evenly distributed throughout the aluminium matrix, it is recommended to put these tiny particles in a plastic container together with many steel balls. This arrangement guaranteed that the aluminium oxide nanoparticles would be mixed and dispersed correctly. The combined specimens are then compacted using chilled air. by use of a 12-millimetre-diameter die. At all times during compaction, a force of 600 MPa must be constant. With the help of a lubricant, namely Zinc-Stearate, the compressed cylindrical samples are quickly and easily removed. In order to get a well-blended compound, the goal is to use this approach to consistently allocate alumina components inside an aluminium mould. The precise assessment of the physical and structural properties of the resulting nano-composite is guaranteed by this testing method.

3 Results and Discussions

3.1 Sintering

The compressed pellets that are made in the previous phase are heated in a tube furnace with an inert gas environment consisting of 99.99% pure argon. After being heated to 600^0C for two hours, the pellets are removed. Densification of materials is ensured by compressing and then heating the powder samples. Next, we provide the results of our evaluation of the density inside the sintering specimens for further research and characterization.

3.2 Quantifying concentration

Its mixing rule allows calculations based on the composition and properties of the materials employed in the samples to calculate these hypothetical, immature, and also compressed densities for chosen specimens.

3.2.1 Concentration in Theory:

$$Dc = Dm*Vm + Df*Vf$$

Where Dc, Dm, Df - concentrations among the combination, matrices, as well as reinforcement stage. Vm,Vf- matrices volumetric percent as well as reinforcement stage, correspondingly.

3.2.2 Green Concentration:

Dgc= Mass/volume of compressed concrete = $\pi d^2 h/4$, Where d = Diameter of the compact h, h= height of the compact.

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

Specimen	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

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

Specimen	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm3)	Density (g/cc)
1	5.785	14.166	13.135	2.066	2.7946
2	5.811	14.176	13.145	2.075	2.7955
3	4.852	14.175	11.125	1.754	2.7691

3.3 X-ray diffraction analysis

Using a PANalytical X-ray Diffractometer, we performed this X-ray diffraction (XRD) examination on each of the composites. The experiment involved changing the 2° angle from 10° to 90° and setting the scanning rate at 2° per minute. X-ray powder diffraction (XRD) is an effective method for studying material crystallography and phase composition.

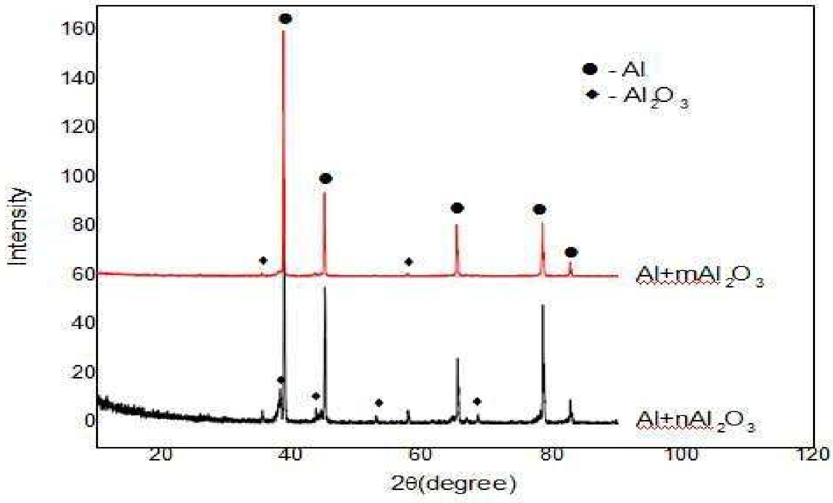


Fig. 1. AL+MA and Al-7075+NA X-ray diffraction patterns

It is possible to learn a lot about the composites' crystalline phases by studying the diffraction patterns produced when X-rays hit the sample. The 2θ angle fluctuation enables the detection of individual crystal planes and the diffraction peaks that correspond to them. By using XRD analysis, the composites' crystallographic phases may be characterized and identified. It is useful for finding out how crystalline is, what phases are present, and if any phase changes happened during production.

3.4 SEM analysis

Using scanning electron microscopy (SEM), the microstructurally characterized all of these combinations, both before and after their durability tests, and as-sintered. To make sure the surfaces of the Al-7075/Al_2O_3/RHA samples are perfectly prepared for analysis, they are mechanically polished using conventional metallographic procedures. Composite microstructure characteristics including grain size, reinforcement particle distribution, and wear-induced structural changes may be better understood with the use of scanning electron microscopy (SEM) analysis, which enables high-magnification imaging of the composite. You can learn a lot about the mechanical characteristics, wear resistance, and general performance of the composite by looking at its microstructure.

3.5 Conversation with outcomes

a. The permeability: Permeability = (hypothetical concreteness – investigational concreteness)

b. Hypothetical concentration: Tiny nanoparticle-augmented specimens with reinforcing stage volume fractions are Vf = 8% and Dm (Al) = 2.7 g/cc and Df (Al2O3(m)) = 3.95 g/cc.

Now Dc = 2.7*0.92 + 3.95*0.08, Dc = 2.8 g/cc

Dm (Al) = 2.7 g/cc, Df (Al2O3(n)) = 3.97 g/cc, and Vf (reinforcement) = 8% for a nanoparticle-reinforced sample.

Now Dc = 2.7*0.92 + 3.97*0.08, Dc = 2.8016 g/cc.

c. Green concentration: Even though the sample is microparticle-enhanced, the nanocomposite showed more porosity, which means the particles in it may not have bonded or densified as well as they might have. This might be because manufacturing processes using nanocomposites often include less effective particle rearrangement and compaction due to the smaller particle size. Because porosity may affect the physical properties and efficacy of nanocomposite, knowing its existence is critical. In order to reduce porosity and improve the composites' overall quality, it is possible to optimise the processing settings and increase densification during future manufacturing.

Table 4. Al-7075+MA micro particle enhanced sample sinter densities

Specimen	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm3)	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

Table 5. Al- 7075+NA nano particle enhanced sample sinter concentrations

Specimen	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm3)	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 6. Comparing micro and nano composite porosity

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

3.6 Microstructure

These micro- and nanocomposites have undergone scanning electron microscopy (SEM) to examine their microstructure. Images of the secondary electron (SE) and backscattered electron (BSE) are both taken for this investigation. Composite surface topography and morphology can be better understood with SE pictures, whereas compositional changes and atomic number differences can be better understood with BSE images. By learning everything about the microstructural details, such as the placement and distribution of reinforcing particles, grain structure, and potential flaws, by looking at the two kinds of pictures. This microstructural study can help us learn more about the quality of the composite, how the processing parameters affect the microstructure, and how that might affect the mechanical and physical properties.

Viewing figures 2-5 makes it very evident that the composites have a beneficial interface bonding between the particles and the aluminium matrix. The information in those numbers suggests this. Furthermore, the aluminium matrix evenly distributes the nano and micro reinforcing particles throughout the material. Keep in mind that there is absolutely no sign of nanoparticle aggregation in the micrographs. The absence of agglomeration is significant since nanoparticles commonly clump when processed by the liquid metallurgical method. There is very little agglomeration, however, since this study used a powder metallurgy approach. In addition, the particle-matrix interface shows little response consequences

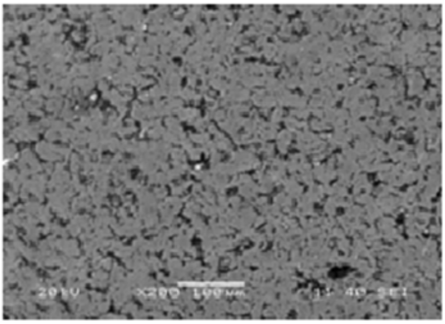


Fig. 2. SEM Al- 7075+MA

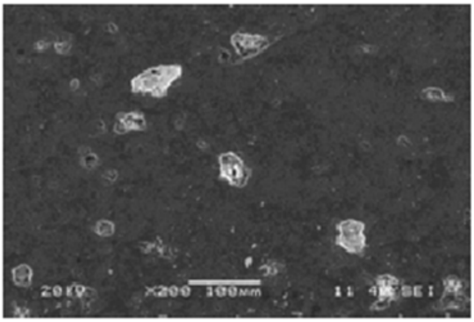


Fig. 3. SEM Al- 7075+NA

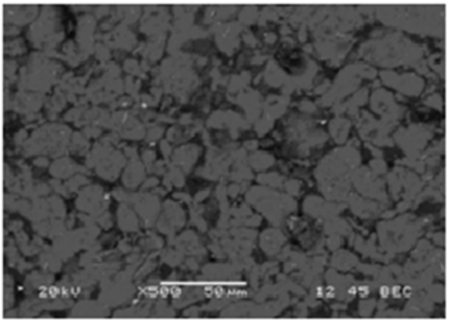


Fig. 4. BSE Al-7075+MA

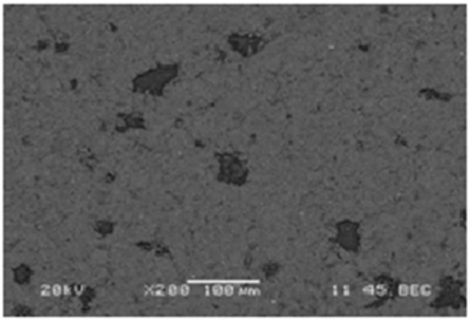


Fig. 5. BSE Al-7075+NA

It is clear that the composites have undergone granule alteration when looking at figures 2-5. This says that the material's microstructure has changed, leading to finer and smaller grains than in the unreinforced matrix. Grain refining is a desirable quality since it enhances the composite's structural and physical properties, such as hardness and potency.

3.7 X-ray diffraction analysis

It is evident from this XRD psychoanalysis that the samples contain pure aluminium or alumina, since there is clear crest matching. It seems that the manufacturing procedure is effective in preserving the aluminium and alumina components without forming any unwanted compounds, as no extra phases or contaminants are detected. Important for their planned uses, these results show that the composite materials are very pure and have a stable composition. Relying on the required traits and attributes of the composite samples, the lack of extra phases indicates the appropriateness of the selected manufacturing procedure.

3.8 Hardness measurement

The nano-composite clearly has better micro-hardness than the micro-composite, as shown in Figures 6 and 7 and Table 7.

Table 7. Micro-hardness values for both micro and nano composite

Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Average hardness**
Al- 7075+m Al_2O_3/RHA	39.1	38.7	39.6	34.1	36.9	37.0	37.6	37.0	37.0	38±2.38
Al-7075+n Al_2O_3/RHA	41.0	44.6	38.9	44.8	41.0	42.2	44.7	42.9	40.4	44.4±1.82

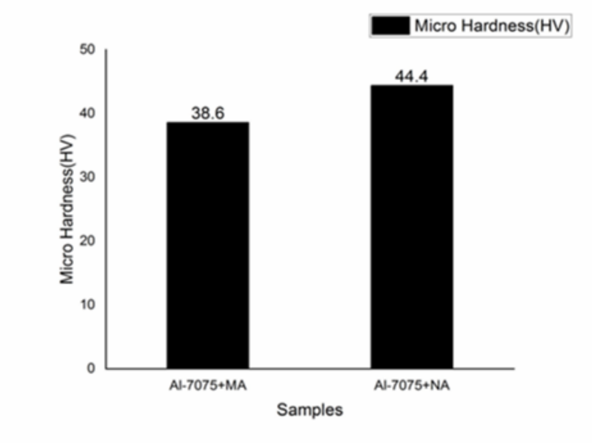


Fig. 6. Plot comparing the microhardness of micro and nano composite

The variation in microhardness is a result of both the overall escalation process and the complexity of the granules. The scattered reinforcing particles impede dislocation movement, which in turn increases strength and hardness, and thus serves as the mechanism for the overall escalation. Improvements in mechanical characteristics may also result from microstructure-observed grain refinement. The combined impact of these factors probably explains why the nano composite has a greater microhardness than the micro composite.

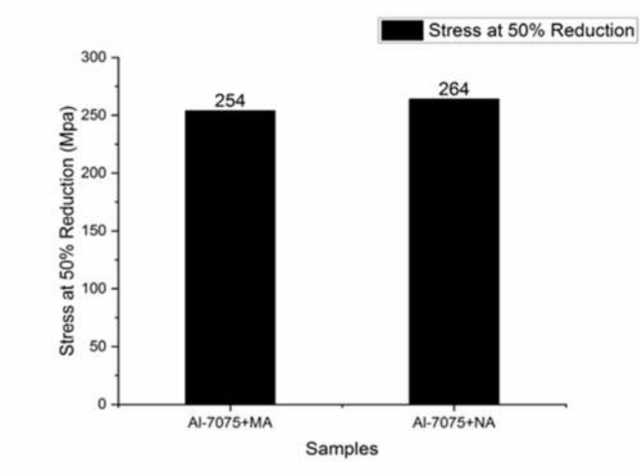


Fig. 7. Plot micro and nano composite stress at 50% decrease.

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

σy = σi+kD-1/2

somewhere, σy = Yield stress, σi = Friction stress, K = Locking parameter (constant) D = Grain diameter

3.9 Endurance under compression

Remember that the tension numbers you get do not reflect the final compressive stress, but rather the stress at which the material experiences a 50% drop in height. Looking at the graph, that at the 50% reduction mark, the nano composite has a higher stress value than the micro composite. The observed grain refinement in the nano composites and the overall strengthening process are likely to blame for this difference in stress.

3.10 Wear characteristics shown by dry sliding

Dry sliding wear test results show that nano composites wear at a much higher rate than micro composites. If 7075+NA composites have better wear resistance than other materials, it is probably because of their higher hardness values. The increase in hardness results in a decrease in wear rates because it increases resistance to distortion and material removal during sliding wear. It is clear that the 7075+NA composites' enhanced wear resistance is due to their increased hardness, highlighting the importance of hardness in defining wear performance.

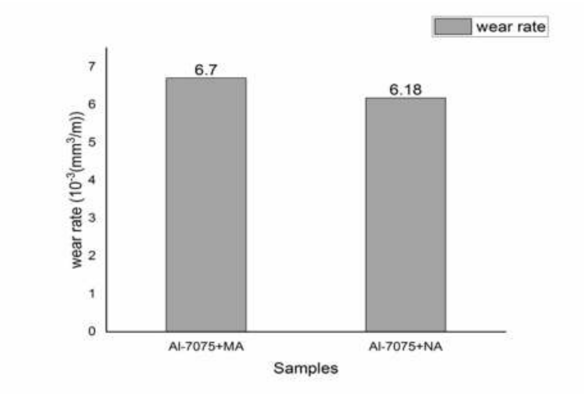
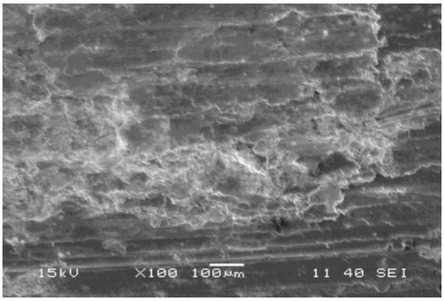


Fig. 8. Plot comparing the wear rate between micro and nano composites



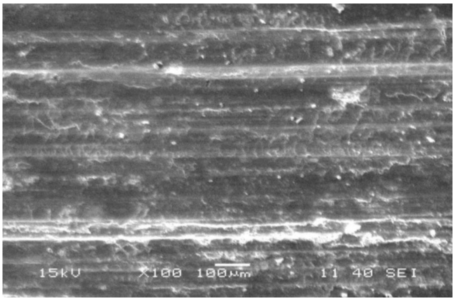


Fig. 9. Micrograph showing the surface of micro composite. **Fig. 10**. Micrograph showing the surface of nano composite

Scanning electron microscopy (SEM) is used to analyse the worn surfaces after the wear tests are finished in order to understand the wear processes. Figures 9 and 10 show representative micrographs of the micro composites and nano composites, respectively, acquired from the scanning electron microscopy examination. Surface damage, whether from abrasive or adhesive wear, or any other kind of wear, may be better understood with the help of these micrographs, which provide a visual inspection of the worn surfaces. Micrograph analysis reveals crucial details about the micro and nano composites' wear behaviour and performance by revealing the kind and amount of wear.

3.11 Corrosion test

When compared to the smaller components, the nano-scale combination demonstrated superior corrosion resistance (Figure 11). The enhanced resistance to corrosion in the nano-composites is due to the observed improvement in grain form. Corrosion may not spread as easily through materials with a refined grain structure, making them less vulnerable to attacks.

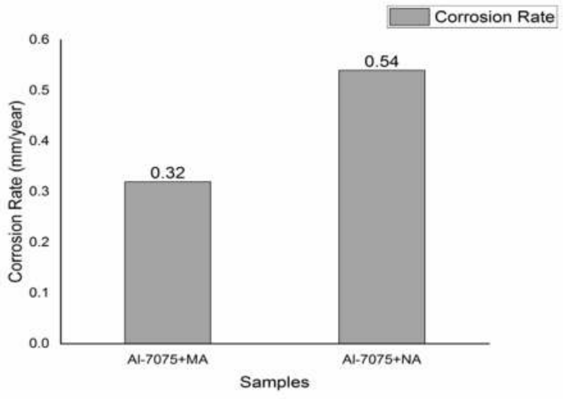


Fig. 11. Plot comparing the corrosion rate between micro and nano composite

4. Conclusions

The present research looked at the physical properties, wear behaviour, and micro- and nano-scale reinforcement of compounds with aluminium matrices that exhibit remarkable durability against oxidation. These composites are made by means of powder metallurgy. These are the inferences that can be made from our research:

Physical properties like as stiffness, tensile strength, and compressive strength are greatly enhanced by reinforcing the aluminium matrix with micro and nano particles. Everything from the general escalation mechanism to the pragmatic granule sophistication inside composites may be correlated with this.

- Abutment tests demonstrated that the nano composite has superior wear resistance compared to the micro composites. Its increased hardness is responsible for its resistance to material removal and surface damage caused by sliding contact.
- The results of the electrochemical corrosion experiments showed that nano composites are more resistant to corrosion than micro composites. The enhanced corrosion resistance of the nano composites is due, in part, to their finely ground grain content.
- With the powder metallurgy manufacturing approach, the reinforcement particles are evenly distributed and effectively dispersed throughout the aluminium matrix, leading to exceptional interface bonding. The benefits and uses of micro and nano particle reinforcement in aluminium matrix composites are illuminated by these findings. Better processing parameters and investigating other composite qualities and potential uses might be the subject of future studies.
- The composites that are made via the manufacturing procedure seem to have adequate levels of porosity and are carried out satisfactorily.
- When contrasted with micro composites, the nano composite performed better. Increases in hardness and strength are seen in the nano composite, which may be

explained by the overall escalation system and the noticeable improvements in granule refinement.

- The abrasion tests showed that the nano composite had better wear resistance than the micro composites.
- According to the results of the corrosion resistance testing, the nano composite has better performance than the micro composite. This could be because its grains have been polished.

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Disclosure of Interests.

NA

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