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Comparative Analysis of Mechanical Properties in Al7068 Alloy Reinforced with Micro and Nano Al_2O_3 Particles

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Abstract

This research, the focus was on developing a modified microstructure in the Al-7068/Al_2O_3 (Aluminum oxide) combination using powder metallurgy techniques. The goal was to vary the sizes of reinforcement particles within the substrate to investigate their effects taking place this total nano-composite mechanical property. Specifically, nanocomposites among 9 vol.% alumina 40 nm were fabricated in an aluminum matrix, and a separate set of micro-composites with a similar composition (average size of 20 μm) was created for comparison. The characterization of these composites involved X ray diffraction (XRD) and scanning electron microscopy (SEM), along with tests for density, microhardness, strength that squeeze, resilience wearable, along with deterioration confrontation. This result showed that the alumina nanoparticles exhibited strong physical bonding with the aluminum matrix, leading to reduced aggregation and no new phases being formed during the powder metallurgy process, even at relatively low operating temperatures.

Keywords

Powder metallurgy, X-ray diffraction, Scanning electron microscope, Density, Wear, Corrosion resistance tests

Introduction

Aluminum with these alloys include achieve widespread appeal here aerospace, military, with automotive manufacturing due to their diverse and desirable properties, particularly their high strength-to-density ratio. To enhance their strength, various methods like heat treatment, thermo mechanical processing, alloying addition, and severe plastic deformation have been utilized, but each comes with its own limitations.

A promising solution for boosting the strength of aluminum and its alloys lies in the development of metal matrix composites. The aluminum metal matrix composites have emerged as a novel approach, attracting significant concentration during the automotive and also space manufacturing sectors while sophisticated materials for construction during over continue for thirty years. The unique properties and performance of aluminum metal matrix composites (AMMCs) make them a compelling choice for addressing the demanding requirements of modern engineering applications.

The purpose of this research was to examine the effects of adding silicon carbide (SiC) and Al_2O_3 to an Al-7068 alloy in order to improve its mechanical and tribological characteristics. Al-7068 is used as the matrix material, while SiC also Al_2O_3 serve as the reinforcing agents. Different weight percentages of these reinforcements were employed to analyze their impact on the properties of the aluminum. The samples consist of four variants: the 1st sample contains Al_2O_3 8% and SiC 2%, the 2nd sample consists of 4% SiC and 6% Al_2O_3, the third sample has Al_2O_3 4% also 6% SiC, and the fourth sample contains 8% SiC and 2% Al_2O_3. The fabrication of the composite materials was carried out using the swirl transmit procedure, and obtained resulting testing samples are prepared in accordance with standards of ASTM. This main objective was examined with motorized also tribological characteristics with the Al-7068/SiC/Al_2O_3 composites, which were prepared using the stir casting method with varying weight fractions [1, 2]. The liquid-state approach was used to create Al-7075/ Al_2O_3&SiC at (2, 4, 6, and 8% wt). To efficiently produce an Al-7075/Al_2O_3&SiC alloy, a typical cost-effective stir casting approach is adopted. It contains Al-7075/Al_2O_3&SiC contains greater rigidity than non-reinforced Al-7075 [3].

Using Al-7075 with grey cast iron and 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 [4]. Studied this consequence with machining process variables on top of the exterior irregularity during machine cutting with hardened mild steel [5]. Surveyed about the aspect distressing on specimen external irregularity are noted [6]. Also studied these causes affecting surface parameter [7]. It seems that there has been an excellent deal of research conducted regarding micro particles 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 [8]. 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 that are automotive, aerospace, electronics, and also biomedical engineering. Therefore, it's essential to encourage investigations into the non-mechanical properties of these materials to unlock their full potential [9].

Mechanical milling was suggested as a potential method to achieve uniform dispersion of nano sized 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, Al/Al_2O_3 nanocomposite mechanical properties exhibited a significant improvement in hardness, measuring approximately five times higher than that of pure, non-milled aluminum [10]. In this study, the compressibility of an aluminum/alumina nanocomposite was investigated using a combination of joining together with automatic granulate techniques. This compressibility behavior observed in that mix together also pulverized mixture of Al/Al_2O_3 nanoscale elements reveals similarities to its typical compaction process of metal powders. The consolidation process during compaction is primarily governed through 2 occurrences: elements reorganization also synthetic buckle [11]. This study examined the fabrication of Al/Al_2O_3 nanosized compound through swirl transmits, utilizing a combination with nano and micro Al_2O_3 reinforcements. Micro-structural analysis indicated that relatively homogeneous dispersion with nano Al_2O_3 within its aluminum, leading to grain structure refinement in the cast materials [12]. This research focused on synthesizing and characterizing Al/Al_2O_3 using sintering that is plasma spark. Through the spark plasma sintering method, Al-Al_2O_3 nanocomposites with different volumes of alumina nanoparticles (0.5, 1, 3 - 7 vol.%) also micro compound among varying alumina micron size particle contents (1, 5, and 20 vol.%) were successfully fabricated [8].

Investigation focused on Al/Al_2O_3 MMCs specimens manufactured through fine particles semi-solid method also fusion rolling methods. The joining excellence among the aluminum with alumina elements was found to be good [13]. Study investigated the impact with elements route dimension also reinforcement quantity taking place the micro-structure also motorized characteristics with aluminum mold composites fabricated through powder metallurgy. It was observed that reducing the size of alumina elements pilot headed for enhance into hardness. Moreover, the quantity of alumina in its composite decreased, its grain size decreased while the distribution homogeneity of alumina particles increased [11].

Main objectives for this investigation with evaluate its quantitative motorized characteristics with AMMCs. Al_2O_3 nano-micro elements reinforcements. 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 the numerous composite formulations and their respective names.

Table 1: Composition and nomenclature used for the composites.

S. No.	Composition used	Nomenclature used
1	Al-7068 + 9% nano Al_2O_3	Al-7068 + NA
2	Al-7068 + 9% micro Al_2O_3	Al-7068 + MA

In this experiment, commercially available aluminum with Al_2O_3 fine particles with nano and micro scales is utilized. A total of 20 g of each powder were mixed to achieve a consistent volume fraction of 9% Al_2O_3 within micro and nano level mixtures. 3 specimens at every measurement level totaled six. To ensure thorough blending, the samples were properly mixed using an abrasion tester, allowing for two revolutions to achieve uniformity. Entire granules and several metallic pellets became stored under a container made of plastic to ensure that the alumina particles were evenly dispersed throughout the aluminum matrix. This setup ensured proper blending and dispersion with the Al_2O_3 elements. Subsequently, its combine model is crushed using the die with a diameter of 12 mm. This compression operation included applying a force of 600 MPa. To aid in its easy removal of the compacted cylindrical samples, a lubricant, specifically zinc-stearate, was employed. By following this methodology, the aim was to create well-blended composites with a consistent allocation with Al_2O_3 elements within aluminum alloy. This experimental approach ensures the accurate evaluation of the subsequent motorized structural characteristics of the composites.

Sinetiring

The compacted pellets obtained from the previous step were subjected to a heat treatment process in a tubular furnace under an inert atmosphere of 99.99% pure argon gas. Those granules subsequently preheated above 600 °C along with kept there approximately 2 h. This heat treatment process ensured its density of the specimen is compacted. Its compactness with this compacted specimen was carefully measured and also with recorded for further analysis and characterization.

Quantifying densities

This imaginary, emerald, compact densities for tester specimen was determined by means of the regulation with blends, enabling calculations based on the composition and characteristics of the materials used in the samples.

Calculated the density

$$D_c = D_m * V_m + D_f * V_f \quad (1)$$

Where, D_c is densities of the composite; Dm is matrix; and D_f is reinforced phase, respectively. V_m is volume fraction of the matrix and V_f is reinforced phase, respectively.

Green density

$$D_{gc} = \frac{\text{Mass of the compacted composite } (m)}{\text{Volume of the compacted composite } (V)}$$

$$V = \frac{\pi d^2 h}{4}$$

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

Investigation via XRD

XRD investigation was conducted on every specimen by means of a PANalytical X-ray Diffractometer. This measurement involved varying 10° to 90° of 2θ angle, while it scrutinizes time exist set at 2° per minute. XRD is a powerful technique utilized for determining 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 crystalline, phase composition, and potential phase transformations that may have occurred during the fabrication process.

SEM analysis

Micro-structural characterization for all specimens, both within their sintered situation also later than its wear examination, be carry out by means of scanning electron microscopy. Prior to examination, the Al-7068/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

Conclusions while analysis

$$\text{Permeability} = (\text{Conceptual weight} - \text{Investigational weight})$$

Conceptual weight

For Al_2O_3 micro specimens, 2.7 g/cc for (Al)D_m also 3.95 g/cc $D_f(Al_2O_3(m))$, V_f = 8% in volume fraction of the reinforcement phase.

2.7 * 0.92 + 3.95 * 0.08 for Dc, 2.8 g/cc for D_c.

For Al_2O_3 micro specimens, 2.7 g/cc for (Al)D_m also 3.97 g/cc $D_f(Al_2O_3(nano))$, V_f = 8% in volume fraction of the reinforcement phase.

2.7 * 0.92 + 3.97 * 0.08 for D_c, D_c = 2.8016 g/cc.

Denseness in greens

Intended for Al_2O_3 micro specimens, The higher porosity observed in the nanocomposite suggests that the particles in this composite may not have achieved optimal bonding or densification during processing. The smaller particle size in the nano composite could contribute to this outcome, as it can result in less effective particle rearrangement and compaction during the manufacturing process. Understanding the pres-

Table 2: Green densities of the micro particle reinforced samples (Al-7068 + MA).

Sample No.	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm³)	Density (g/cc)
1	5.827	14.19	15.14	2.178	2.817
2	5.767	14.17	15.12	2.089	2.789
3	5.812	14.19	15.13	2.098	2.812

Table 3: Green densities of the nano particle reinforced samples (Al-7068 + NA).

Sample No.	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm³)	Density (g/cc)
1	5.786	14.167	13.137	2.07	2.7950
2	5.812	14.178	13.148	2.075	2.7999
3	4.851	14.17	11.128	1.754	2.7692

ence of porosity is crucial as it can impact these motorized characteristics and performance for compounds. Steps are taken to optimize its processing variables and enhance densification in future production to minimize porosity and improve the overall quality of the composites. Table 2 and table 3 presents green densities of the micro and nano particle reinforced samples.

Microstructure

Microstructure analysis for both micro along with nano composites exist conducted by means of 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 micro structural features, such as the distribution and arrangement of reinforcement particles, grain structure, and possible defects, can be obtained. This micro structural 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. Based on figure 1 it is evident to its compounds display a favorable boundaries acquaintance among its reinforcements and base materials.

Additionally, present be a homogeneous allocation for both micro and nano Al_2O_3 within its aluminum mold. Importantly, there are refusal signs for agglomeration of the Al_2O_3 nano elements within micrographs. 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, there are no visible reaction products next to its boundaries between the elements also the bond. Through examining figure 2, the composites clearly exhibit evidence of grain refining. 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

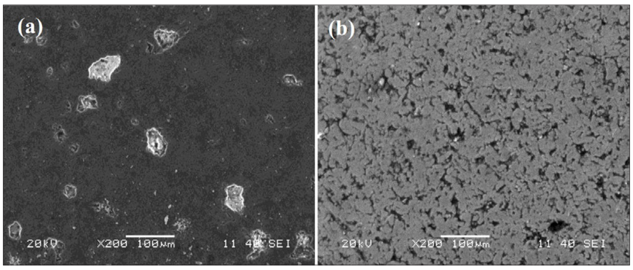

Figure 1: SEM image for **(a)** Al-7068 + MA and **(b)** Al-7068 + NA.

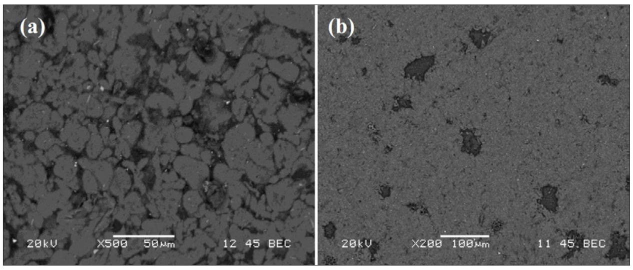

Figure 2: BSE image for **(a)** Al-7068 + MA and **(b)** Al-7068 + NA.

Table 4: Sinter densities of the micro particle reinforced samples (Al-7068 + MA).

Sample No.	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm³)	Density (g/cc)
1	5.802	14.174	13.142	2.073	2.797
2	5.751	14.172	13.129	2.071	2.776
3	5.799	14.17	13.132	2.070	2.80

Table 5: Sinter densities of the nano particle reinforced samples (Al-7068 + NA).

Sample No.	Mass (g)	Diameter (mm)	Height (mm)	Volume (cm³)	Density (g/cc)
1	5.774	14.18	13.149	2.076	2.78
2	5.806	14.176	13.169	2.078	2.79
3	4.842	14.177	11.101	1.752	2.76

Table 6: Comparing the % porosity of micro and nano composite.

Sample	Experimental density	Theoretical density	% porosity
Al-7068 + MA	2.7986	2.806	0.14
Al-7068 + NA	2.788	2.804	1.29

characteristic as it can enhance its motorized characteristics of the composite, that are potency also hardness. Table 4 and table 5 presents sinter densities of the micro and nano particle reinforced samples. Table 6 presents the comparison of the % porosity of micro and nano composite.

XRD analysis

This XRD analysis reveals distinct greater matching in the direction of clean aluminum with Al_2O_3, indicating the presence of these phases in the samples (Figure 3). No additional phases or impurities are observed, suggesting that the

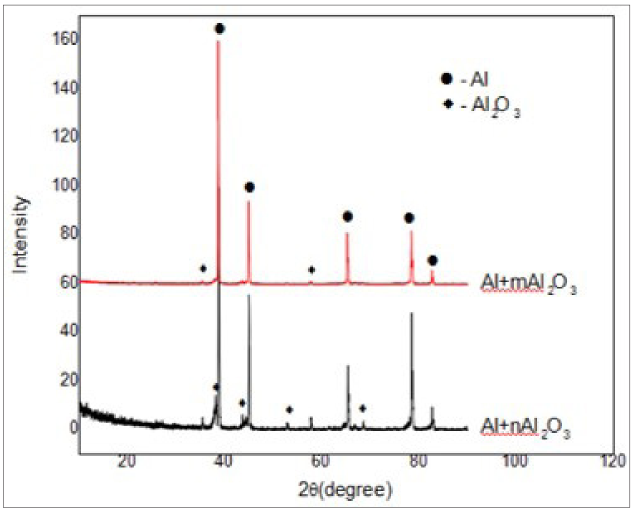

Figure 3: XRD pattern for Al-7068 + MA and Al-7068 + NA.

fabrication process successfully retained the integrity of the aluminum and alumina 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.

Hardness measurement

Based on figure 4 and table 7, it is evident that compared to the micro composite, the nano composite clearly has a greater microhardness. The difference in microhardness can be attributed toward this overall escalation methods and also granule enhancement. 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 accounts for grain refining.

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

Where, σ_y is Yield stress; σ_i is Friction stress; K is Locking parameter (constant); and D is Grain size.

Effectiveness under compression

It is important to note that the stress values obtained represent the stress at which the material reaches a 50% reduction in height, rather than the ultimate compressive stress. The plot analysis shows that the nano composite has a greater stress value for a 50% decrease compared to the micro composite. In its difference in stress can likely be attributed toward its escalation mechanism also the observed granule modification in this nanocomposite shown in figure 4b.

Characteristics of drying slide degradation

Characteristics of drying slide degradation test outcomes indicate so as to its degradation quantity are superior in its nano compound analyzed into the micro compound shown in figure 5. This enhances with resilience wearable of the Al7068 + NA compounds can be attributed into their elevated rigidity. 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 Al7068 + NA composites can be directly linked to their higher hardness, emphasizing the significance of hardness in determining the wear performance of these materials. 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 6a for the micro composites and figure 6b 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 and nano composites.

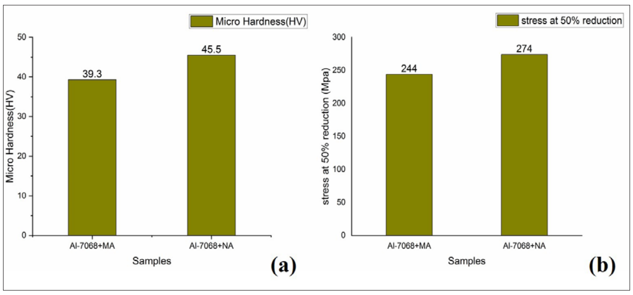

Figure 4: Plot comparing the **(a)** microhardness of micro and nano composite and **(b)** stress at 50% reduction between micro and nano composites.

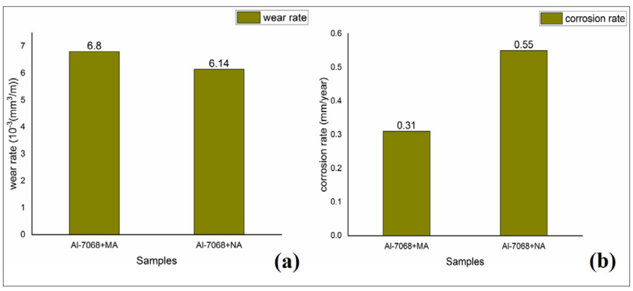

Figure 5: Plot comparing the **(a)** wear rate between micro and nano composites and **(b)** corrosion rate between micro and nano composite.

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

Sample	1	2	3	4	5	6	7	8	9	Average hardness
Al-7068 + mAl_2O_3	39.1	39.7	39.6	37.1	39.9	38.0	38.6	38.0	38.0	39 ± 2.38
Al-7068 + nAl_2O_3	43.0	45.6	39.9	45.8	43.0	43.2	44.7	43.9	41.4	45.4 ± 1.82

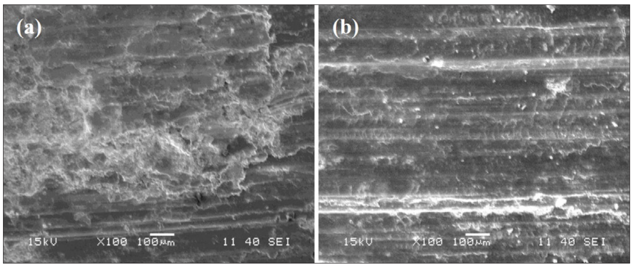

Figure 6: Micrograph showing the **(a)** surface of micro composite and **(b)** surface of nano composite.

Corrosion test

Figure 5 show demonstrated conventional nanoparticle composites have far better protection against corrosion than conventional tiny compounds. This enhanced durability against deterioration in Al_2O_3 nano compounds can be attributed to granule modification. 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 the mechanical properties, wear behavior, and corrosion resistance of AMMCs reinforced with micro and nano particles. These composites were fabricated using the powder metallurgy route. Based on our findings, the following conclusions can be drawn from this study:

- This incorporation of micro along with nano particles as reinforcement in the aluminum matrix led to significant improvements in mechanical properties such as hardness, tensile strength, and compressive strength. This can be attributed into an overall escalation mechanism with granule modification found into the composites.
- According to regular findings of its wearing examinations, the tiny compound appears more durable than its micro compounds. This can be attributed to its higher hardness and the resulting ability to resist material removal and surface damage during sliding contact.
- Comparable tiny compounds showed superior resistance to corrosion over micro compounds throughout electrochemical testing. This refined grain structure in the nano composites contributed to their improved corrosion resistance.
- The powder metallurgy fabrication route provided successful dispersion Al_2O_3 constituent part within its Al-7068, 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 AMMCs. 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 nano composite demonstrated superior properties compared to the micro composites. The nano composite exhibited higher strength and hardness, which can be attributed to its overall escalation mechanism also the observed granule modification in Al-7068/Al_2O_3.
- The resistance degradation of Al-7068/Al_2O_3 was superior, which can be attributed to its elevated hardness.
- Al-7068/Al_2O_3 displays improved decomposition confrontation contrast into micro-Al-7068/Al_2O_3 composite, which can be attributed into observed granule modification into Al-7068/Al_2O_3 nano composites.

Acknowledgements

None.

Conflict of Interest

None.

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