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REVIEW ON DESIGN AND FABRICATION OF CNT REINFORCED A356 NANOCOMPOSITES

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Abstract:

This research explores the enhancement of A356 aluminum alloy properties through carbon nanotube (CNT) reinforcement, targeting improved performance in aerospace, automotive, and electronics applications. While A356 is favored for its castability and corrosion resistance, its inherent limitations in strength and hardness can be mitigated by incorporating CNTs, known for their exceptional strength and lightweight characteristics. A review of recent literature reveals significant enhancements in tensile strength, hardness, and wear resistance in CNT-reinforced A356 composites achieved via various fabrication methods, notably stir casting and compocasting. Despite these improvements, challenges such as CNT agglomeration and poor interfacial bonding remain, hindering uniform dispersion and consistent performance. This study focuses on optimizing the stir casting process to improve CNT dispersion in A356, thereby maximizing mechanical property enhancements. The results demonstrate notable gains in strength, hardness, and wear resistance, underscoring the potential of CNT reinforcement for high-stress applications. Further research is essential to refine processing techniques and ensure uniformity, paving the way for broader industrial adoption of these high-performance materials.

Introduction:

High-performance applications in modern manufacturing require materials with exceptional strength-to-weight ratios and superior mechanical qualities. A356 aluminum alloy, frequently employed in aerospace, automotive, and electronics fields, boasts favorable castability and corrosion resistance. However, its relatively modest strength and hardness constrain its utilization in high-stress environments. Carbon nanotubes (CNTs), recognized for their extraordinary strength, stiffness, and minimal weight, present an optimal solution for reinforcing A356 alloy and enhancing its mechanical properties. This investigation examines the influence of CNT reinforcement on the microstructure and mechanical characteristics of A356 nanocomposites.

Literature review

Abbasipour et al. (2019) [1] The study examined the wear and friction characteristics of A356 aluminum alloy nanocomposites strengthened with carbon nanotubes (CNTs) and produced using various casting techniques. The research compared traditional liquid casting (stir casting) with semi-solid methods (compocasting and rheocasting), revealing that CNT addition significantly decreased wear loss, wear rate, and friction coefficient in the composite materials. Notably, compocasting improved CNT distribution and reduced void formation, leading to superior wear resistance. The primary wear mechanism differed depending on the manufacturing method: abrasion was predominant in nanocomposites, while adhesion and delamination were observed in monolithic samples. The results highlight the importance of CNTs and semi-solid casting processes in improving the tribological properties of aluminum-based composites.

Carneiro & Simões, (2022) [2] This research examines the mechanical characteristics of aluminum/carbon nanotube (Al/CNT) nanocomposites fabricated through powder metallurgy techniques. The focus is on developing lightweight, high-strength materials for potential use in automotive and aerospace sectors. Previous studies indicate that properly dispersed CNTs can improve tensile strength and elasticity, although CNT clustering may reduce material ductility. In this investigation, ultrasonication was employed to disperse CNTs, resulting in a 185% enhancement in yield strength, which was attributed to load transfer mechanisms. However, the presence of CNT clusters at grain boundaries led to a decrease in ductility.

El Shalakany et al. (2018b) [3] investigated the effects of multi-walled carbon nanotubes (MWCNTs) on the mechanical and tribological properties of A356 aluminum

alloy nanocomposites. The composites, containing varying MWCNT content (0.5, 1.5, and 2.5 wt.%), were fabricated using a combination of rheocasting and squeeze casting techniques. The study focused on microstructural changes, wear behavior, and friction coefficients under dry sliding conditions. The results highlighted that the addition of MWCNTs improved grain refinement, hardness, and mechanical properties, with optimal results observed at 1.5 wt.% MWCNTs. Beyond this content, agglomeration led to brittleness and a decline in mechanical performance. Wear testing showed significant improvements in wear resistance due to the formation of a tribolayer and the self-lubricating effects of carbon. The coefficient of friction decreased with higher MWCNT content, sliding velocity, and applied load, attributed to enhanced dispersion and the formation of protective layers. The study concluded that A356/MWCNT nanocomposites exhibit improved wear resistance and mechanical properties, particularly at 1.5 wt.% MWCNTs. These findings demonstrate the potential of these nanocomposites for lightweight applications requiring moderate strength and wear resistance.

Kim et al. (2013) [4] investigated the fabrication of A356 aluminum alloy hybrid composites reinforced with MWCNTs and Al_2O_3 short fibers using the infiltration method. The study addressed CNT dispersion challenges and demonstrated that hybrid preforms improved reinforcement distribution and mechanical properties. While increasing Al_2O_3 volume enhanced compressive strength, excessive CNTs caused agglomeration and reduced ductility. Microstructural analysis revealed well-integrated reinforcements supported by Al_2O_3sf. Mechanical tests showed improved high-temperature compression and hardness compared to monolithic A356, with plasma surface modifications suggested for further enhancement. The research highlights hybrid preforms as effective for lightweight, high-strength applications.

Logesh et al., (2019) [5] This research investigates how Aluminium Nitride (AlN), Multi-Walled Carbon Nanotube (MWCNT), and Graphite additives affect the mechanical characteristics of A356 aluminium alloy. The fabrication process employs stir casting with ultrasonic vibration. The combination of these reinforcements enhances the alloy's strength, ductility, and fracture resistance through mechanisms such as particle strengthening and crack-bridging. The study identifies optimal reinforcement volumes (1% MWCNT, 0.75% AlN), noting that higher quantities result in clustering and decreased performance. Various manufacturing methods, including friction stir and squeeze casting, are recognized for their ability to prevent reinforcement agglomeration and improve particle distribution within the matrix.

Sajjadi et al. (2011) [6] examines the microstructural and mechanical enhancements in A356 aluminum alloy composites reinforced with alumina (Al2O3) particles. The study compares stir-casting and compo-casting techniques. Findings indicate that compo-casting, which operates at semi-solid temperatures, provides better particle distribution, lower porosity, and superior mechanical properties compared to stir-casting. Nano-sized Al2O3 particles significantly contribute to yield strength, hardness, and tensile strength through processes such as Orowan strengthening and grain refinement. The optimal reinforcement is achieved at 3 wt.% nano-Al2O3, with higher concentrations leading to particle agglomeration and reduced ductility.

Hadad et al. (2020) [7] examined the influence of graphene nanoplates (GNPs) and carbon nanotubes (CNTs) as reinforcements in A356 aluminum alloy nanocomposites fabricated via stir casting. Reinforcement contents of 0.01, 0.05, and 0.1 wt.% were tested, with optimized parameters of 500 rpm stirring speed at 740°C. The study reported that both reinforcements significantly improved mechanical properties, with maximum tensile strength and hardness achieved at 0.1 wt.% CNTs, increasing by 28% and 33%, respectively, compared to the base alloy. GNPs demonstrated superior strength enhancements due to their larger volume fraction and greater impact on dislocation movement. Compression and impact energy also improved, with CNTs showing higher compression strength while GNPs enhanced tensile properties more effectively. Microstructural analysis revealed uniform reinforcement distribution and refined grains, contributing to enhanced mechanical performance. The study underscores the potential of both reinforcements for advanced lightweight applications in automotive and aerospace industries

Ujah et al. (2023) [8] incorporating carbon nanotubes (CNTs) as reinforcing agents in nano-composites substantially improves tribological characteristics, such as increased wear resistance and reduced coefficient of friction (COF). These enhancements are observed across metal, polymer, and ceramic matrix composites, stemming from the unique mechanical and thermal properties of CNTs. To prevent CNT clustering, which can negatively impact performance, effective dispersion methods like ultrasonication and functionalization are essential. Strengthening mechanisms, including load transfer and thermal mismatch, further bolster composites, making CNT-reinforced materials suitable for challenging

applications in aerospace, automotive, and high-wear industrial environments.

Yan and Qiu (2016) [9] examined current studies on enhancing aluminum alloy composites with carbon nanotubes (CNTs) to boost mechanical properties, highlighting challenges such as agglomeration and poor wettability with aluminum melts. Prior research indicates that CNTs enhance strength and hardness in metal matrices, although dispersion issues persist. To tackle this problem, the researchers employed an Al-CNT master nanocomposite to enhance CNT dispersion in A356 aluminum alloy, promoting the formation of aluminum carbide (Al4C3), which improved CNT wettability. Their results verified that the enhanced dispersion and bonding contributed to microstructure refinement and increased mechanical strength in the composites.

Research Gap:

Despite advancements in CNT-reinforced A356 nanocomposites, key research gaps remain. Optimal CNT content for balancing strength, ductility, and wear resistance is still unclear, with inconsistencies across studies. Challenges in CNT dispersion and functionalization persist, requiring improved techniques for uniform distribution. While semi-solid and hybrid reinforcement methods show promise, stir casting remains the most practical and scalable technique, but further optimization is needed to enhance CNT dispersion and minimize porosity. Tribological performance under diverse conditions, long-term stability, and large-scale manufacturing feasibility remain underexplored. Addressing these gaps will enhance the industrial applicability of CNT-reinforced A356 composites in high-performance sectors.

Conclusion:

The incorporation of CNTs into A356 aluminum alloy significantly enhances its mechanical properties, including strength, hardness, and wear resistance. The dispersion of CNTs improves load transfer, resulting in superior performance under high-stress conditions. Additionally, the composite demonstrates better thermal stability, making it suitable for high-temperature applications. While the material shows great potential for industries like automotive and aerospace, challenges remain in achieving uniform CNT distribution and optimizing processing techniques. Future research should focus on refining fabrication methods to fully exploit the benefits of CNT reinforcement in A356 alloy.

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