REVIEW ON CNT REINFORCED A356 NANOCOMPOSITES

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Abstract:

A356 aluminum alloy, with its excellent balance of mechanical properties, low weight, and corrosion resistance, is widely utilized in the automotive and aerospace sectors. Nonetheless, the ongoing search for stronger and lighter materials has prompted research into A356 nanocomposites reinforced with carbon nanotubes (CNTs). The remarkable characteristics of carbon nanotubes (CNTs) and their combined action with the A356 matrix contribute to the notable improvements in tensile strength, hardness, and wear resistance that these nanocomposites display. This review offers a thorough analysis of the characteristics of A356 nanocomposites reinforced with carbon nanotubes (CNTs), looking at the effects of different processing methods and CNT content, such as squeeze casting, compocasting, friction stir processing, powder metallurgy, stir casting, and ultrasonic cavitation. The paper also emphasizes the difficulties in manufacture, namely getting consistent CNT dispersion and robust interfacial bonding, and talks about current studies being done to solve these problems and improve processing parameters. The results highlighted the potential of CNT-reinforced A356 nanocomposites for a variety of applications that need materials that are strong, lightweight, and thermally conductive.

Key words: A356 alloy, Carbon nanotubes, Metal matrix composites, Mechanical properties, Nanocomposites.

1. INTRODUCTION:

The continuous demand for lightweight materials with superior mechanical properties in industries like aerospace, automotive, and electronics has driven the development of metal matrix composites (MMCs). Among MMCs, aluminum matrix composites (AMCs), particularly those utilizing A356 aluminum alloy, have gained significant attention due to their potential to reduce weight while enhancing performance [1]. A356, known for its excellent castability, weldability, and corrosion resistance, is further improved by reinforcing it with carbon nanotubes (CNTs) [2].

CNTs possess exceptional mechanical properties, including high tensile strength and stiffness, attributed to the strong sp2 bonding between carbon atoms in their structure [3]. These properties, along with their low density and high aspect ratio, make CNTs ideal reinforcements for enhancing the mechanical properties of A356 aluminum alloy [4]. This review aims to provide a comprehensive overview of the mechanical behavior of CNT-reinforced A356 nanocomposites, examining various fabrication methods, the influence of CNT content on mechanical properties, and potential applications while addressing the challenges associated with these materials.

2. A356 ALUMINUM ALLOY AND CNTS: A SYNERGISTIC COMBINATION:

1.1. **A356 Aluminum Alloy**: A356 is a hypoeutectic aluminum-silicon alloy widely used in structural applications, particularly in the automotive and aerospace industries [5]. Its popularity stems from its excellent castability, low density, good mechanical properties, and corrosion resistance. The alloy's microstructure consists of aluminum dendrites and a silicon eutectic phase, which can be modified through heat treatment or alloying additions to further enhance its properties [1].

1.2. **Carbon Nanotubes [CNTs]**: CNTs are allotropes of carbon with a cylindrical nanostructure. They exhibit exceptional mechanical properties, including high tensile strength and stiffness, due to the strong covalent bonds between carbon atoms [3]. CNTs also possess excellent electrical and thermal conductivity, making them attractive reinforcements for various applications.

The combination of A356 aluminum alloy and CNTs offers a synergistic approach to materials design, leveraging the strengths of both components. A356 provides a lightweight and corrosion-resistant matrix, while CNTs act as reinforcements to enhance its strength, stiffness, and wear resistance

3. PROCESSING TECHNIQUES:

The fabrication of CNT-reinforced A356 nanocomposites presents challenges, primarily in achieving uniform dispersion of CNTs in the aluminum matrix and ensuring strong interfacial bonding between the CNTs and the matrix [6,7]. Various processing techniques have been developed and refined to address these challenges, each with its own set of advantages and limitations.

Stir Casting: This widely used method involves mechanically stirring CNTs into molten A356 alloy [8,9,10]. It is favored for its simplicity and cost-effectiveness, making it suitable for both research and industrial production. However, achieving uniform dispersion and preventing CNT agglomeration can be challenging.

Compocasting: A semi-solid processing technique that offers better control over CNT distribution and porosity reduction compared to stir casting [8]. This method involves stirring CNTs into a semi-solid A356 slurry, potentially leading to improved dispersion and reduced agglomeration compared to fully liquid stir casting.

Powder Metallurgy: This method involves mixing A356 powder with CNTs, followed by compaction and sintering [11,12]. Powder metallurgy offers superior control over the microstructure and enables a more homogeneous distribution of CNTs compared to liquid-based methods. However, it can be more expensive and time-consuming.

Friction Stir Processing [FSP]: A solid-state technique that utilizes frictional heat and plastic deformation to disperse CNTs and refine the microstructure [13]. FSP can achieve excellent dispersion and interfacial bonding but is limited to surface modification and may not be suitable for complex shapes.

Squeeze Casting: This technique involves solidifying the molten A356-CNT mixture under high pressure, which helps to improve the densification and reduce porosity in the composite [14]. Squeeze casting can also enhance the interfacial bonding between CNTs and the matrix, leading to improved mechanical properties.

Despite the challenges associated with uniform dispersion and interfacial bonding, ongoing research focuses on optimizing processing parameters, such as stirring speed, time, and temperature, to improve the quality of CNT-reinforced A356 nanocomposites produced via stir casting [8,9,10,15]. This continuous improvement makes stir casting a viable and competitive technique in the field of metal matrix nanocomposites

4. CHARACTERIZATION TECHNIQUES:

Microscopy Techniques: Optical microscopy, scanning electron microscopy (SEM), and transmission electron microscopy (TEM) are utilized to observe CNT dispersion, the microstructure of the matrix, and the interfacial bonding between CNTs and the matrix.

Mechanical Testing: Tensile testing, hardness testing, and wear testing are performed to evaluate the mechanical properties of the composite, with standardized methods ensuring reliability and comparability.

X-ray Diffraction (XRD): XRD is used to identify the crystalline phases present in the composite, providing information on the types of CNTs, the matrix material, and any reaction products formed during processing

5. MECHANICAL PROPERTIES:

The incorporation of CNTs into A356 has been shown to significantly enhance its mechanical properties [8,16,17,18]. This enhancement is attributed to the exceptional mechanical properties of CNTs themselves, including high tensile strength, stiffness, and the ability to impede dislocation motion. Key improvements observed in CNT-reinforced A356 nanocomposites include:

Tensile Strength and Yield Strength: CNTs act as reinforcements, effectively transferring load and increasing the strength of the composite [7,19]. Studies have demonstrated the potential of CNTs to enhance the tensile properties of A356 significantly. For example, Studies reported a 34% increase in ultimate tensile strength with the addition of 1.5 wt% MWCNTs using a semi-solid stir casting technique [20]. Similarly, studies observed a remarkable 50% improvement in ultimate tensile strength with 1.5 wt% MWCNTs using rheocasting and squeeze casting [14].

Hardness: The presence of CNTs increases the hardness of the composite due to their high intrinsic hardness and their ability to hinder dislocation movement [16,20]. Several studies have reported notable increases in hardness with the inclusion of CNTs in A356. For instance, [8] observed a significant increase in hardness with CNT reinforcement, with the highest hardness achieved in the compocast sample at 0.3 solid fraction. The increase in hardness is attributed to factors such as increased dislocation density, thermal mismatch between CNTs and the matrix, and the formation of harder interfacial phases like Al4C3 [9,10].

Wear Resistance: CNTs enhance the wear resistance of the composite by minimizing friction and protecting the matrix from wear and tear [9,21]. This enhancement is attributed to the self-lubricating properties of CNTs and their ability to form a protective layer on the composite's surface. The wear resistance of CNT-reinforced A356 composites is influenced by factors such as CNT content, dispersion, and the applied load and sliding speed during wear testing [22].

The extent of these property enhancements is influenced by factors such as CNT concentration, dispersion, aspect ratio, and the quality of interfacial bonding with the matrix. Studies suggest that optimal mechanical properties are often achieved at low CNT concentrations, beyond which agglomeration can adversely affect performance [23].

6. RESEARCH GAPS:

After extensive literature observed we found this gaps

1. It is very difficult to achieve uniform dispersion of CNT at higher concentration.
2. It is necessary to developing techniques to control CNT orientation during processing could enhance directional properties.
3. Many current fabrication methods are expensive or difficult to scale for mass production.
4. Developing cost-effective and scalable manufacturing processes is essential.

7. CONCLUSION

CNT-reinforced A356 nanocomposites offer a promising avenue for enhancing the mechanical properties of A356 aluminum alloy. The incorporation of CNTs can lead to significant improvements in tensile strength, hardness, and wear resistance, making these nanocomposites suitable for demanding applications in the automotive, aerospace, and other industries. While challenges remain in areas such as uniform dispersion, robust interfacial bonding, and cost-effective fabrication, ongoing research is addressing these issues. The future of CNT-reinforced A356 nanocomposites appears bright, with potential applications expanding into various fields that require lightweight, high-strength, and thermally conductive materials.

REFERENCES:

1. Sajjadi, S., Ezatpour, H., & Parizi, M. T. [2011]. Comparison of microstructure and mechanical properties of A356 aluminum alloy/Al2O3 composites fabricated by stir and compo-casting processes. *Materials & Design [1980-2015]*, *34*, 106–111.
2. Choi, H., Kwon, G., Lee, G., & Bae, D. [2008]. Reinforcement with carbon nanotubes in aluminum matrix composites. *Scripta Materialia*, *59*[3], 360–363.
3. Iijima, S. [1991]. Helical microtubules of graphitic carbon. *Nature*, *354*[6348], 56–58.
4. Singla, D., Amulya, K., & Murtaza, Q. [2015]. CNT Reinforced Aluminium Matrix Composite-A Review. *Materials Today Proceedings*, *2*[4–5], 2886–2895.
5. Dwivedi, S. P., Sharma, S., & Mishra, K. R. [2014b]. A356 Aluminum Alloy and applications- A Review. *International Journal of Advanced Materials Manufacturing and Characterization*, *4*[2], 81–86.
6. Elshalakany, A. B., Osman, T. A., Khattab, A., Azzam, B., & Zaki, M. [2014]. Microstructure and Mechanical Properties of MWCNTs Reinforced A356 Aluminum Alloys Cast Nanocomposites Fabricated by Using a Combination of Rheocasting and Squeeze Casting Techniques. *Journal of Nanomaterials*, *2014*, 1–14.
7. Jagannatham, M., Chandran, P., Sankaran, S., Haridoss, P., Nayan, N., & Bakshi, S. R. [2020]. Tensile properties of carbon nanotubes reinforced aluminum matrix composites: A review. *Carbon*, *160*, 14–44.
8. Abbasipour, B., Niroumand, B., & Vaghefi, S. M. [2010]. Compocasting of A356-CNT composite. *Transactions of Nonferrous Metals Society of China*, *20*[9], 1561–1566.
9. Abbasipour, B., Niroumand, B., Vaghefi, S. M. M., & Abedi, M. (2019). Tribological behavior of A356–CNT nanocomposites fabricated by various casting techniques. *Transactions of Nonferrous Metals Society of China*, *29*(10), 1993–2004.
10. Bakshi, S. R., Singh, V., Seal, S., & Agarwal, A. [2008]. Aluminum composite reinforced with multiwalled carbon nanotubes from plasma spraying of spray dried powders. *Surface and Coatings Technology*, *203*[10–11], 1544–1554.
11. Carneiro, Í., & Simões, S. [2022]. Investigation of Mechanical Properties of Al/CNT Nanocomposites Produced by Powder Metallurgy. *Applied Sciences*, *13*[1], 54.
12. Pan, J., Zou, L., Liao, Z., Lin, Z., & Chen, J. [2023]. Study on the Properties of Carbon Nanotube [CNTs] Reinforced AlSi10Mg Composites Fabricated by Powder Metallurgy. *Materials*, *16*[11], 3905.
13. Liu, Q., Ke, L., Liu, F., Huang, C., & Xing, L. [2013]. Microstructure and mechanical property of multi-walled carbon nanotubes reinforced aluminum matrix composites fabricated by friction stir processing. Materials & Design [1980-2015], 45, 343–348.
14. Elshalakany, A. B., Osman, T. A., Khattab, A., Azzam, B., & Zaki, M. [2014]. Microstructure and Mechanical Properties of MWCNTs Reinforced

A356 Aluminum Alloys Cast Nanocomposites Fabricated by Using a Combination of Rheocasting and Squeeze Casting Techniques. *Journal of Nanomaterials*, *2014*, 1–14.

15. Logesh, K., Hariharasakthisudhan, P., Moshi, A. a. M., Rajan, B. S., & K, S. (2019). Mechanical properties and microstructure of A356 alloy reinforced AlN/MWCNT/graphite/Al composites fabricated by stir casting. *Materials Research Express*, *7*(1), 015004.

16. Awate, P. P., & Barve, S. B. (2022). Microstructural observation and mechanical properties behavior of Al2O3/Al6061 nanocomposite fabricated by stir casting process. *Engineering Research Express*, *4*(1), 015023

17. Shan, L., Tan, C. Y., Shen, X., Ramesh, S., Kolahchi, R., Hajmohammad, M. H., & Rajak, D. K. [2022]. Creep Behavior of A356 Aluminum Alloy Reinforced with Multi-Walled Carbon Nanotubes by Stir Casting. *Materials*, *15*[24], 8959.

18. Velickovic, S., Stojanović, B., Djordjević, Z., Miladinović, S., & Blagojević, J. [2019]. Effect of reinforcement on mechanical characteristics of A356 alloy nanocomposites. *IOP Conference Series Materials Science and Engineering*, *659*[1], 012039.

19. Singla, D., Amulya, K., & Murtaza, Q. [2015]. CNT Reinforced Aluminium Matrix Composite-A Review. *Materials Today Proceedings*, *2*[4–5], 2886–2895.

20. Rashad, R., Awadallah, O., & Wifi, A. [2013]. Effect of MWCNTs content on the characteristics of A356 nanocomposite. *Journal of Achievements of Materials and Manufacturing Engineering*, *58*[2], 74–80.

21. Ujah, C. O., Von Kallon, D. V., & Aigbodion, V. S. [2023]. Tribological Properties of CNTs-Reinforced Nano Composite Materials. *Lubricants*, *11*[3], 95.

22. Evlen, H., & Akçaer, E. [2019]. Effects of wear load on mechanical and morphological properties of A356 matrix carbon nano tube composites. *Fullerenes Nanotubes and Carbon Nanostructures*, *27*[4], 351–357.

23. Thirugnanasambantham, K., Sankaramoorthy, T., Karthikeyan, R., & Kumar, K. S. [2020]. A comprehensive review: Influence of the concentration of carbon nanotubes [CNT] on mechanical characteristics of aluminium metal matrix composites: Part 1. *Materials Today Proceedings*, *45*, 2561–2566.