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Study on Agglomeration Reduction Techniques and their Impact on Mechanical Properties of Al-8090/Graphene Composites

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ABSTRACT:

The present study focuses on the agglomeration reduction techniques and their influence on the mechanical properties of Al- 8090/graphene composites. Graphene, due to its exceptional strength, thermal conductivity, and stiffness, serves as an ideal reinforcement material for lightweight aluminum alloys. However, its tendency to agglomerate within the metal matrix limits uniform dispersion and degrades mechanical performance. In this work, various dispersion and agglomeration-reduction techniques such as ultrasonication, mechanical stirring, and the use of surfactants are investigated to enhance the homogeneity of graphene distribution in the Al- 8090 matrix. The fabricated composites are subjected to mechanical testing, including tensile, hardness, and impact strength evaluations, to determine the effect of improved dispersion. Microstructural characterization using optical microscopy and scanning electron microscopy (SEM) is also conducted to study particle distribution and interface bonding. The results indicate that optimized dispersion techniques significantly reduce graphene clustering and improve the overall mechanical properties of the composite. This research highlights the importance of effective agglomeration control in developing high-performance aluminum-graphene composites for advanced structural and aerospace applications.

1. INTRODUCTION:

The development of lightweight, high-strength materials has become a major focus in modern engineering, particularly in aerospace and automotive industries where weight reduction without compromising mechanical performance is essential. Aluminum-lithium alloys such as Al-8090 have gained significant attention due to their low density, high stiffness, and good corrosion resistance. At the same time, graphene, a two-dimensional nanomaterial composed of a single layer of carbon atoms, offers exceptional mechanical, thermal, and electrical properties, making it an ideal reinforcement for metal matrix composites. However, the full potential of Al-8090/graphene composites is often limited by the agglomeration of graphene particles during processing, which leads to non-uniform dispersion and weak interfacial bonding within the matrix. To address this challenge, various agglomeration reduction techniques such as ultrasonication, mechanical stirring, ball milling, and the use of surfactants have been developed to achieve better dispersion of graphene in the aluminum matrix. This study focuses on investigating these dispersion methods and analyzing their influence on the mechanical properties of Al-8090/graphene composites. By optimizing the dispersion of graphene, the research aims to enhance the strength, hardness, and overall performance of the composite, thereby contributing to the development of advanced lightweight materials for next-generation engineeringapplications.

2. EXPERIMENTAL DETAIL:

2.1 MATERIALS USED

2.1.1Aluminum Alloy (Al-8090)

High-strength Al-Li alloy used in aerospace applications
Supplied in powder/ingot form depending on process route
Chemical composition includes Al, Li, Cu, Mg, Zr, and trace elements.

Figure 2.1

2.1.2 Graphene Nanoplatelets (GNP)

High surface area 2D nanomaterial
Typical thickness: 3–10 nm
Added in varying weight percentages (0.1–1%)

4.2 PREPARATION OF GRAPHENE

Graphene dried at 80–100 °C to remove moisture
Sieved to break lumps
Pre-mixed in ethanol (for powder route) or added through vortex flow (for casting route)

Figure 2.2

2.3 EXPERIMENTAL ROUTES ADOPTED

2.3.1High-Energy Ball Milling (HEBM)

1. Al-8090 powder and graphene mixed for 1–4 hours
2. Ball-to-powder ratio (BPR): 10:1–20:1
3. Helps reduce graphene clustering and enhances bonding

Figure 2.3

4.3.2 Ultrasonic-Assisted Stir Casting

• Al-8090 melted at 720–750 °C
• Degassing using N_2 / Ar
• Graphene introduced into the slurry with mechanical stirring
• Ultrasonic horn used for 5–15 minutes to break agglomerates

Figure 2.4

4.3.2 Friction Stir Processing (FSP)

- Graphene packed in grooves on Al-8090 plate
- FSP tool: H13 steel
- Rotation speed: 80–120 rpm
- Traverse speed: 40–80 mm/min
- Intense plastic deformation disperses graphene uniformly

Figure 2.5

2.4 FABRICATION OF COMPOSITE SPECIMENS

Casting route: molten metal poured into molds

Powder metallurgy route: compacted under pressure (300–400 MPa) and sintered

FSP route: surface composite layer formed 27

2.5. MICROSTRUCTURAL CHARACTERIZATION 4.5.1 Scanning Electron Microscopy (SEM)

- Used to observe graphene distribution
- Identify agglomerates
- Study grain refinement in processed samples

2.5.2 Energy-Dispersive X-ray Spectroscopy (EDS)

- Confirms presence of carbon
- Checks elemental uniformity

2.5.3 X-Ray Diffraction (XRD)

• Detects phase formations

• Verifies whether Al_4C_3 formation occurred (unwanted brittle phase)

2.6 EXPERIMENTAL SETUP

1. **Raw Material Handling Station**

The experimental setup begins with the preparation of raw materials including Al-8090 alloy powder and graphene nanoparticles. A clean, moisture-free environment is maintained using a hot-air oven for drying powders, and sieves are used to obtain uniform particle size distribution.

2. **Graphene Dispersion Unit**

To reduce agglomeration, an ultrasonication bath and high-speed mechanical stirrer are used. The ultrasonicator breaks down graphene clusters, while the stirrer ensures proper mixing of surfactants and graphene for improved dispersion.

3. **Powder Blending and Milling Assembly**

A planetary ball mill or mechanical mixer is used for blending Al-8090 alloy powder with treated graphene. The unit consists of stainless steel vials, hardened steel balls, speed control, and timer to optimize milling parameters (speed, time, ball-to-powder ratio)

FIGURE2.6

3.TESTING

1. Hardness Testing

This test measures the resistance of the composite to indentation. It helps evaluate the effect of graphene addition and dispersion techniques on surface hardness and strengthening behavior.

2. Tensile Testing

Tensile testing determines the ultimate tensile strength (UTS), yield strength, and elongation of the composite. It reveals how graphene reinforcement and agglomeration reduction methods influence ductility and load-bearing capacity.

3. Compression Testing

Compression testing evaluates the material's ability to withstand compressive loads. It is useful for understanding the composite's structural stability and resistance to buckling or crushing.

4. Microstructure Analysis (SEM/EDS)

Scanning Electron Microscopy (SEM) is used to examine particle distribution, porosity, and agglomeration behavior. Energy-Dispersive Spectroscopy (EDS) confirms elemental composition and graphene dispersion quality.

5. Density and Porosity Measurement

These tests help determine the compactness of the sintered composite. Porosity affects the mechanical properties, so understanding it is crucial for evaluating composite quality.

6. X-Ray Diffraction (XRD)

XRD is used to identify the phases present in the composite, confirm graphene incorporation, and detect any unwanted intermetallic compounds formed during sintering.

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7. Wear Testing (if required)

Wear resistance testing measures material loss under sliding or abrasive conditions. Graphene addition often improves wear resistance due to its lubricating nature.

8. Raman Test (Raman Spectroscopy)

Raman Spectroscopy is a non-destructive characterization technique used to study the structural and molecular properties of materials by analyzing the inelastic scattering of monochromatic light, usually from a laser source. When the laser light interacts with the material's molecular vibrations, specific frequencies shift, creating a Raman spectrum that provides detailed information about the material's chemical structure, crystallinity, and defects. In the case of Al-8090/Graphene composites, Raman testing is particularly important because it can confirm the presence of graphene, identify its quality, and analyze its defect levels.

3. Conclusion

The study on agglomeration reduction techniques in Al-8090/graphene composites demonstrates that achieving uniform dispersion of graphene within the aluminum matrix is crucial for enhancing mechanical properties. Due to graphene's natural tendency to cluster, various techniques such as ultrasonication, mechanical stirring, ball milling, and hybrid processing methods are employed to minimize agglomeration and improve distribution. Effective dispersion enhances interfacial bonding, resulting in significant improvements in tensile strength, hardness, and wear resistance, while maintaining reasonable ductility. In contrast, poor dispersion leads to stress concentration points and reduced performance. Therefore, controlling agglomeration is essential to fully utilize graphene's reinforcing potential, and further research should focus on optimizing scalable fabrication methods for consistent and high-performance composite materials.

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