Development of Aluminum–Copper–CNT Composites through a Tubular Metal Additive Extrusion Technique

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Abstract: Aluminum matrix composites (AMCs) reinforced with copper (Cu) and carbon nanotubes (CNTs) are emerging as high-performance materials for advanced engineering applications due to their superior thermal conductivity, strength, and wear resistance. However, conventional manufacturing methods face challenges in achieving uniform reinforcement distribution, defect-free structures, and complex geometries such as tubular components. This study proposes a novel Tubular Metal Additive Extrusion (TMAE) technique for the fabrication of Al–Cu–CNT composite tubes. CNTs were synthesized using the arc discharge method, followed by composite preparation via hot extrusion at 550°C and 8 MPa pressure. In the present work a review of the proposed study and synthesis of multiwalled carbon nanotubes is presented.

Keywords: Aluminum Matrix Composites, Carbon Nanotubes, Tubular Additive Manufacturing, Hot Extrusion, Microstructure, Mechanical Properties

Introduction

Additive manufacturing, is an innovative approach to production that involves creating objects layer by layer from digital models and scaling them accordingly. Unlike traditional manufacturing processes, which involve cutting of materials from a solid block, AM builds components by adding material, which allows for greater design flexibility and efficiency. This technology has gained significant impact across various industries, including aerospace, automotive, healthcare, and consumer goods, due to its ability to produce complex geometries that are often impossible to achieve with conventional methods. 3D printing is an example of additive manufacturing which is currently in trend and is known to all by its exclusive applications and potential. Additive manufacturing is classified into different methods like powder bed fusion, binder jetting, direct energy deposition, and material extrusion. From these hot extrusion is an essential process in manufacturing industry, high-performance metal parts by subjecting the material to heat and pressure to push the material through a die, and attaining defined geometries as well as better mechanical properties. In this we have used copper, carbon nanotubes layer by layer inside the cylindrical aluminium rod. And hot extrusion process at a fixed temperature and extruded at a specified load, passed through 10mm die and the sample is then carefully extracted and analysed. The general category of additive manufacturing (AM), which includes a variety of techniques for creating three-dimensional objects through the layer-by-layer addition of material, includes the specialized technique known as cylindrical additive manufacturing. Creating cylindrical forms or parts—which are commonly used in pipes, tubes, and other round structures—tends to be the main focus of this process.

Round geometries are typically best produced using the cylindrical additive manufacturing process. Reduced material waste, the ability to create intricate inner geometries, and the potential for lightweight yet structurally sound designs are the advantages of the process

Related work

Sinan Kose et al. (2024) It examines aluminum powder-filled cyclo-olefin copolymer (COC) composites, highlighting improvements in mechanical and tribological properties with aluminum reinforcement (15%-45%). Aluminum additions enhanced tensile strength (up to 10.6%), modulus of elasticity (up to 57.8%), and significantly reduced the coefficient of friction (up to 151.7% at 45% aluminum content). These advancements make the composites suitable for high performance applications, including aerospace equipment {1]

Xiaodong Wu et al. (2024) This highlights the characteristics and automotive applications of aluminum matrix composites (AMCs), valued for their lightweight, high strength, and corrosion resistance. AMCs are used in vehicle bodies, interiors, power systems, suspensions, and brakes, enhancing fuel efficiency and reducing emissions. Strengthening mechanisms involve grain refinement and dispersion. Challenges include high costs, recyclability issues, and environmental impacts. The study emphasizes optimizing AMC structures for applications in electric vehicle batteries and other energy-efficient technologies [2].

Chen Wang et al. (2022) The study examines copper/aluminum (Cu/Al) composite thin strips with a 75 µm copper layer and a 525 µm aluminum layer, annealed at 300°C, 400°C, and 500°C to analyze changes in microstructure and tensile properties. Annealing was performed in a vacuum furnace with argon gas protection. Key methods included SEM for microstructure, EDS for element diffusion, EBSD for grain texture, and tensile testing per ASTM standards[3]

Alexander Thewes et al. (2024) his study focuses on reducing adhesive wear during copper hot extrusion by applying surface modifications to extrusion tools made of DIN 1.2367 steel and alloy 718. Two methods were used: Ti–Si–B–C–N Nano composite coatings (via PECVD) and boriding (gas-phase boriding). The treatments improved tool hardness (1559 HV for coatings; 1623 HV for boarding) and oxidation resistance. Hot extrusion trials at 850°C, without lubrication, showed significant reductions in copper adhesion: from 36% to 5% for boride alloy 718 and from 82% to 6% for coated steel. These modifications improved durability, reduced interaction with copper, and extended tool life[4].

M. Anthony Xavior et al. (2017) The study developed AA 2024–Graphene Nanocomposites with 0.4 wt.% Graphene reinforcement. Fabrication involved ball milling, vacuum hot pressing at 500°C, and hot extrusion. Characterization via SEM, Raman spectroscopy, XRD, hardness, and tensile tests revealed uniform Graphene distribution, refined grain structure, and enhanced mechanical properties. Tensile strength increased from 235 MPa (pure AA 2024) to 352 MPa, with improved hardness and fracture surface characteristics indicating effective load transfer. The composites are promising for high-performance applications due to their superior strength and durability[5].

Gap Identified

Based on literature survey,

- Aluminum is eco-friendly and can be a alternative for many applications if a correct mix composition is found out.
- Studies are limited regarding carbon nanotubes effects on aluminum matrix.
- Studies regarding mechanical properties of copper and CNT on Aluminum fabricated through hot extrusion are limited.
- Structural changes due to CNT additions into aluminum.

Method, Experiments and Results

Materials

- Aluminum rods (matrix material)
- Copper powder
- Aluminum powder
- Carbon Nanotubes (CNTs)

Method

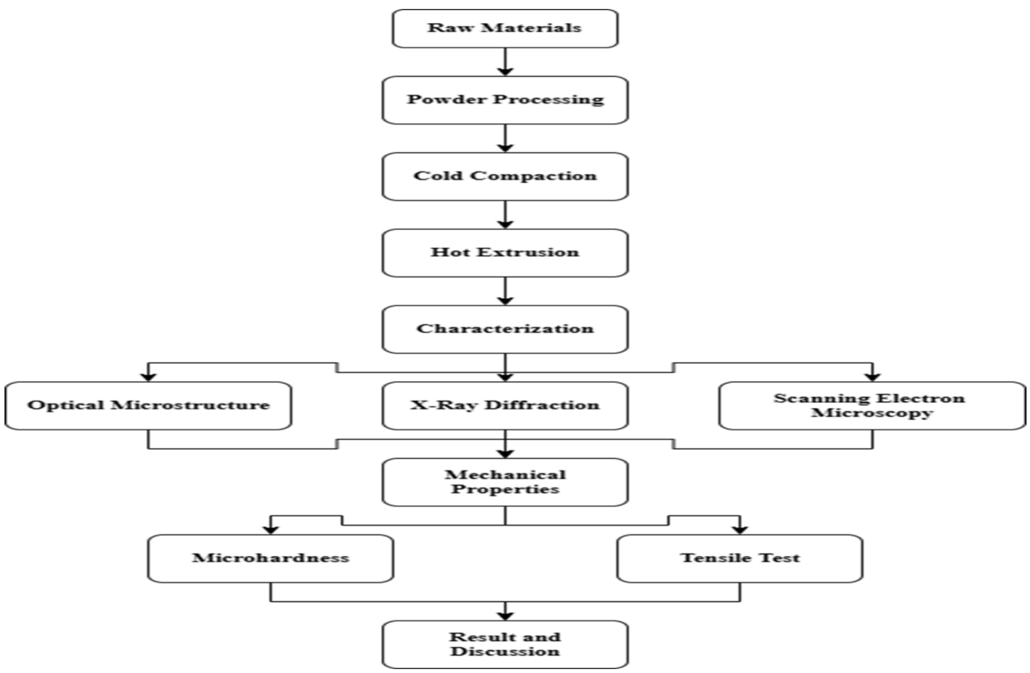

Figure 1. the schematic diagram of the process

EXPERIMENTAL SETUP

The experimental setup involved three primary stages: material preparation, extrusion process, and fabrication. These stages were carefully designed to ensure optimal composite formation using aluminum, carbon nanotubes (CNTs), and copper powders.

Material preparation was a crucial step in ensuring the uniform dispersion of the reinforcing materials within the aluminum matrix. The powder mixing technique was employed to blend aluminum powder with CNTs and copper in precise proportions as per the calculated data. Uniform dispersion of CNTs was particularly important, as CNTs tend to agglomerate due to their high surface energy. To overcome this, controlled mechanical mixing techniques such as ball milling and ultrasonic agitation were used to ensure proper integration of CNTs within the aluminum powder. The particle size distribution of each powder was carefully considered to achieve homogeneity, thereby enhancing the mechanical and thermal properties of the final composite material. The blending process was conducted under controlled environmental conditions to prevent oxidation and ensure purity.

TESTING AND CHARACTERIZATION

The structural, mechanical and physical properties of the extruded Pure Al, Al-Cu, Al-Cu-CNT composite samples were evaluated through testing and characterization. To analyze a complete evaluation of the properties variations, multiple tests were conducted. To measure the hardness and tensile strength of the fabricated samples, mechanical testing are to be performed. For hardness test grading, the Vickers hardness test at load 300g was selected basing on sample characteristics. This test indentations and it determines the materials ability to withstand indentations which is important in measuring overall wear resistance and durability of the sample. Subsequently, tensile strength testing was performed on a universal testing machine (UTM), which applied to the samples axial loads until they were no longer able to withstand such forces. Information about the yield strength, ultimate tensile strength, elongation and other relevant indicators of composite's robustness was measured and compared with CNT and copper reinforced models, thus either supporting or disputing the initial hypothesis. The aim of the study was to determine the extensiveness of mechanical strength improvement on account of alumina matrix reinforcement with CNT and copper.

Conclusions

A novel method for the fabrication of composite through additive manufacturing was successfully accomplished in our project. The method adopted for the fabrication was powder processing followed by hot extrusion technique. The metal particles are aligned together to form tubular additive manufacturing rods.

The conclusion of the research work is as follows

The processed Al-Cu can be used in Aerospace structural application as it shows layered alloy which is mainly used.

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