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Carbon Nanotube Reinforced Metal Matrix Composites by Powder Metallurgy: A Review

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Abstract

This Review paper mainly focuses on the processing technique of carbon nanotube reinforced materials with light material matrix composites of the powder metallurgy route. Different mixing/alloying conditions are used for carbon nanotube dispersion (CNT) in the Aluminium matrix using a ball milling process with ball milling time, milling speed, Ball to powder (BPR) ratio, and Process control agent (PCA). Processing parameters are discussed, such as sintering temperature, sintering time, pressure, and heat treatment condition. Mechanical and microstructural properties are discussed.

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Introduction

Materials always play an essential role in human history by providing suitable viability in different applications starting from the Stone Age, Bronze Age, or silicon age.[1] Aircraft and aerospace industries enhanced with alloys with low weight and high strength lead to less fuel consumption with high efficiency.[2–4] Metallic alloys, particularly aluminum alloys, magnesium, and copper alloys, play an essential role in enhancing materials' properties.[5–7] With the advent of Nano-materials such as multi-wall carbon nanotubes, graphene leads to improved ownership of stuff.[8,9] But with these Nano-materials, there is a problem of aggregation in composite tends to deficiency in properties of materials.[8] To avoid an accumulation of Nano-materials within the composite and achieve uniform distribution, ball milling with suitable parameters followed by powder metallurgy plays an important role.[10–12] Constituent materials concentration employing the powder metallurgy route is possible.[3] A day Aerospace materials require thermal stress relieving materials such as functionally graded materials, also fabricated by powder metallurgy.[13] Powder metallurgy helps in

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the synthesis of functionally graded materials in layers.[14,15]

Thermal mismatch in chromium coating on the piston rings due to the thermal expansion coefficient's difference avoids utilizing powder metallurgy if the particular material fabricates in layers.[16,17]

The review paper broadly discusses processing technique, mechanical properties, tribological properties of powder metallurgy for the metal matrix, Nano-matrix composites.

Areas Covered

This Review paper broadly discusses the powder metallurgical route for the fabrication of Nano-composites. Processing technique with the layout of powder metallurgy. Processing powder metallurgy parameters, such as sintering temperature, sintering time, pressure, and heat treatment conditions. The effect of ball milling with suitable parameters helps in controlling the agglomeration effect of nano-materials. The powder metallurgy routes will be applicable for advanced materials for Aerospace, such as functionally graded materials.

Expert Opinion

powder metallurgy is an effective process of controlling the constituents in the composites. Dispersion of nano-particles such as multi-wall carbon nanotubes, graphene, etc. leads to agglomeration problems in metal matrix composites. Agglomeration tends to Isotropic property of the composite affected to crack and damage the composites; this problem can overcome by powder metallurgy. Powder metallurgy helps in controlling the matrix and reinforcement dispersion ratio. More excellent load transfer from matrix to reinforcement can occur. Agglomeration avoids ball milling with suitable controllable parameters such as ball milling time, ball milling speed, BPR, and PCA. Ultra-Sonication followed to disperse the MWCNTs in materials. Wear property increases with CNT addition, yield strength, and hardness values increase with increasing carbon nanotube concentration. The thermal analysis helps in determining the reaction of Aluminium and CNTs by DSC-differential scanning calorimeter. XRD help in identifying the presence of phases such as the Al4C3 phase and the Al2Cu phase. Morphological changes in SEM during the sintering process. The effect of ECAP on consolidation validate during high energy ball milling. Crystallite size and lattice strain determine by Williamson-Hall peak broadening analysis in high energy ball milling process.

Powder Metallurgy Processing Technique

Powder metallurgy is a technique wherein matrix and reinforcement mixed in pre-determined quantity in a powder form using the various jar, ball milling methods, etc. After mixing, compaction is done in a pre-determined shaped die to give green strength and a particular shape, followed by sintering to get the required blend in a stable or porous media utilizing heating without liquefaction.[17]

The flowchart is indicating the powder metallurgy process shown in Fig.1.

Processing parameters play a significant role in the properties of the composite. Table.1 indicates the processing parameters considered during powder metallurgy. Powder metallurgy has advantages over other processing techniques because material wastage is minimal; agglomeration of nano-materials reduced to achieve uniform distribution, and machining cost is significantly less.

Investigated effect of the ball milling on the Al-CNT composite. Mechanical properties by varying milling time from 2-12 hours. Uniform dispersion of CNTs achieved in 6 hour milling and 8-12 hour ball milling results in severe damage to CNT structure. Upon increasing the ball milling time to 6hours tensile and yield strength increases and then decreased with increased ball milling time. The yield strength increased by 42.3% compared to the matrix after 6 hour milling.[19] Fabricated CNT reinforced Al composite by powder metallurgy route. Wear test carried out with 1ms-1 sliding speed, 30N load, and varied sliding distance of 500-2500m. The weight loss was significantly less for Al-0.5wt% CNT composites.[20] Excessive plastic deformation and increased local scrap observed for 1wt%CNT in worn surface images indicate a weaker bond between Al and CNT. Initially, hardness value increased for Al-1wt%CNT and gradually decremented in hardness due to the agglomeration of CNTs.

Synthesizes the Al-MWCNT nano-composites by pressure-less sintering technique. Relative density of the composite reduced by 1-5% compare to theoretical values. Archimedes method reveals best consolidation for Increased MWCNT content. Yield strength and Vickers hardness increases with increasing MWCNT content.[27]

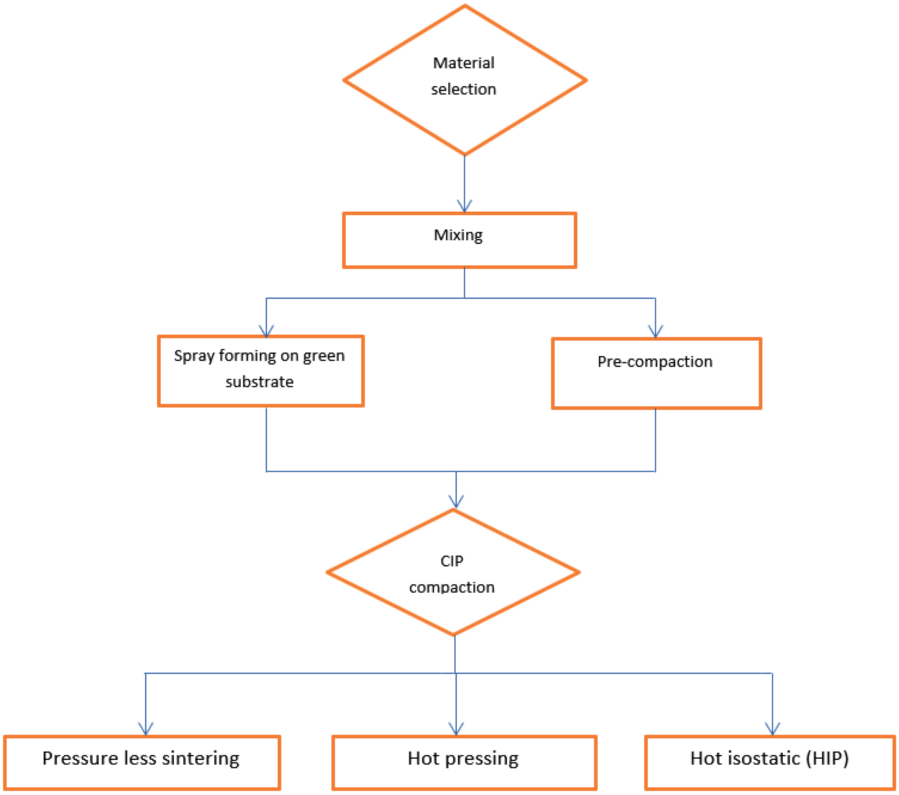

Fig. 1: Flowchart of powder metallurgy process

Table:1 process parameters considered during powder metallurgy process

Material System	Sintering temperature(⁰C)	Sintering time(min)	Pressure (Mpa)	Heat treatment condition	Literature
Al-CNT	500		475	Annealing for 2-12h	[20]
AD0/Al + C60/Al + CNT/Al + OLC/Al + graphite	270-290	Isothermal time of 7min	0.7Gpa		[21]
Al6061-MWCNT	600	45		solu-tionized at 555°C for 8 hours and quenched in three different media such as air, boiling water	[22]
CNTs-SiCp	630	60	30		[23]
Al-CNT	550	120			[24]
Al-CNT	450	5	300		[25]
Al-CNT	500	120			[26]

Evaluates the Ni-CNT disperse technique's effect on the mechanical properties of AlSi nano-composite. Ni-coated CNTs use to improve the bond between CNTs and matrix. The mixing process involves five different techniques. Process A is standard for comparison with other methods. Process B mixing in stainless steel jar for 6 days with low energy ball mill and milling atmosphere argon. Process C mixing in a ceramic pot for a 1minute using a high energy ball mill and milling atmosphere argon. Process D involves high energy ball in a steel jar with an ethanol milling atmosphere. Process E involves mixing by two techniques one is mechanical mixing for 30 minutes, and the second is ultrasonic mixing followed by high energy shaker mill for 1 minute. Process B indicates a better distribution of CNT with AlSi. Reactivity between CNTs and AlSi matrix evaluate by thermal analysis (DSC-differential scanning calorimeter). Low velocity results in less damage to CNTs after 48hours of mixing.[28]

A homogeneous mixture achievable with control of ball motion during milling, which reduces the grinding energy. UltraSonicator helps in the dispersion of multiwall carbon nanotubes. The formation of Al_4C^3 proves thermodynamic feasibility.[29] SEM and EDS analysis indicate the successful incorporation of multiwall carbon nanotubes in magnesium composites. Nano metric dimensional surface roughness and nano texture quantified by Atomic force microscopy.[30]

Conclusion

The review paper focuses on CNTs reinforced metal matrix composites by powder metallurgy route. Various ball milling processes for mixing and uniform dispersion of CNTs in light metal matrices discuss suitable ball milling parameters. Sintering temperature, sintering time, pressure, and heat treatment conditions are considering. Mechanical properties are discussed with each component of the composites.

Article Highlights

- Powder metallurgy helps in reducing material wastage cost, machining cost compared to the casting process.
- Powder metallurgy helps in controlling the accumulation by mixing process such as ball milling with suitable control parameters.
- Processing powder metallurgy parameters, such as sintering temperature, sintering time, pressure, and heat treatment conditions.
- Improvement in mechanical properties with the addition of CNTs.

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Conflict of Interest

Authors do not have any conflict of interest among themselves.

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