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Physical and Mechanical Characterization of Multiwall Carbon Nanotube Reinforced LM13 Alloy Composite

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Abstract:

Aluminium (Al)/Aluminium alloy composites are emerging as very promising materials, especially in the fields of aerospace and automotive for their various attractive and technically demanding properties. Powder metallurgy technique is used to fabricate the MWCNT reinforced LM13 alloy composites. The Al and MWCNT-LM13 composite are compacted with different compaction loads. The density and hardness of the 99.9% pure Aluminium and MWCNT-LM13 composites are calculated before and after sintering. After particular compaction load density of both the materials are become constant. The hardness and youngs modulus of the pure Aluminium is increased with increase in compaction load. The hardness and youngs modulus of the MWCNT-LM13 composites is shows enhanced value in 0.5% of MWCNT reinforcements.

Keywords:

Aluminium alloy, LM13, Multiwall Carbon Nanotube, Powder metallurgy, Young's Modulus

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Introduction

In aviation, automobile and other structural applications, the demand for materials possessing superior properties like higher strength to weight ratio, high modulus and high temperature stability along with good damping ability is continuously increases. However, it is difficult to achieve all these properties in a single material. This is one of the driving force for the development of composite materials [1].

Aluminium (Al) and its alloys have emerged as one of the most governing metal matrix materials in the 21st century [2]. This is because of their attractive mechanical properties [3, 4]. Among the Al alloys, Aluminium-Silicon (Al-Si) alloys in particular have been utilized considerably for engineering applications due to their better mechanical and physical properties. They also possess good manufacturing ability and lower density than Al [5]. This reduces weight and results in energy savings in automotive and aerospace applications.

Aluminum matrix composites (AMCs) are the competent material in the industrial world. Due to its excellent mechanical properties, AMCs is broadly used in aerospace, automobiles, marine etc [6 - 8]. Researchers, particularly in the defense application, are continuously striving hard to find the materials that suit their specific requirements.

MMCs are generally fabricated through processes such as casting, extrusion and powder metallurgy (P/M). Out of these, P/M process is regarded as one of the important processing techniques on account of homogeneity in composition and microstructure, minimum scrap, consistent porosity and close dimensional tolerances. P/M process also gives ample scope to produce wide variety of alloying systems and metal matrix composites [9 - 12]. With this insight it has been reported that, Al based particle reinforced composites produced by P/M process exhibit attractive mechanical properties such as increased stiffness, low density and good specific strength [13 - 16].

Research in the field of carbon was revolutionized by the discovery of carbon nanotubes (CNTs) by Iijima6 in 1991. Although CNTs might have been synthesized in 1960 by Bacon, it took the genius of Iijima to realise that they are tubes made by rolling a graphene sheet onto itself. A multiwalled carbon nanotube (MWCNT) is made up of many single walled carbon nanotubes (SWCNT) arranged in a concentric manner. Unless otherwise specified, CNT in this work refers to MWCNTs. Experiments and simulations showed that CNTs have extraordinary mechanical properties over carbon fibres, e.g. stiffness up to 1000 GPa, strength of the order of 100 GPa and thermal conductivity of up to 6000 W m-1 K-1. These investigations showed that CNTs were the strongest fibres known to mankind that possess exceptional properties. Since the last decade, a number of investigations have been carried out using CNT as reinforcement in different materials, namely polymer, ceramic and metals [17].

Major works have been carried out on polymer and ceramic based CNT reinforced composites [18]. From the literature survey it is noticed that many researchers are made an attempt to reinforcement of CNT to Aluminium alloy composites [17]. Many researchers have also produced and characterized the Carbon nanotube based Aluminium metal matrix composites by powder metallurgy process and it has been reported that Powder metallurgy process is one of the better processing techniques for these kinds of metal matrix composites [19 - 21].

Present study is carried out on physical and mechanical characterization of multiwall carbon nanotubes reinforced LM13 alloy composites and pure Aluminium to know the density, hardness and Young's modulus of the prepared materials.

Table 1. Mechanical properties of LM13 alloy

Properties of LM13	Sand cast
Tensile Stress (N/mm2)	170 -200
0.2% Proof Stress (N/mm^2)	160-190
Elongation (%)	0.5
Brinell Hardness (BHN)	100-150
Vickers hardness (VHN)	130
Endurance Limit ($5x10^7$ cycles; N/mm^2)	85
Modulus of Elasticity ($x10^3$ N/mm^2)	73

Materials and Methods

The materials used in this work are pure Aluminium powder of 75 microns. LM13 alloy is used as a matrix material of 200 mesh size and MWCNT powder with different percentages (0.0, 0.25, 0.50 & 0.75 wt. %) based on the variation in weight as reinforcements. LM13 alloy ingot is supplied by Survell Industries Mangalore. Chips are produced in lathe from ingot and 200 mesh powder is manufactured in a ball mill. The chemical composition of the Al alloy (LM13) involves the following combination of metals (in wt %): Cu – 0.7-1.5, Zn - 0.5, Mg – 0.8-1.5, Si- 10.5-13, Ni – 1.5, Fe – 1.0, Mn – 0.5, Pb – 0.1, Sn – 0.1, Ti – 0.2 and Al – bal.. The mechanical properties of LM13 alloy is shown in table 1.

LM13 alloy is actually an eutectic alloy having the lowest melting point. The main composition of LM13 is about 85.95% of aluminum, 12% to 13% of silicon.

Multiwalled CNT was procured from M/s Sigma Aldrich, Bangalore. Impurities such as graphitic particle, amorphous carbons or any other present in the raw CNT powder were removed by immersing them in concentrated Nitric acid, then filtered and washed with de-ionized water and dried at 120^oC. The properties of as supplied MWCNTs are given in Table.2.

Table 2. Properties of MWCNT

Properties	Values
Purity	Carbon > 90% (trace metal basis)
OD × ID × L	10-15 nm × 2-6 nm × 0.1-10 µm

Total Impurities	Amorphous carbon, none detected by transmission electron microscope (TEM)
Melting Point	3652-3697 °C
Density	~2.1 g/ml at 25 °C

The LM13 alloy powder is mixed with CNTs in ethanol solution. These mixed powders were dispersed with mechanical stirring assisted with ultrasonic shaker for 30 minutes. Finally, the mixed powders were dried at 120^{o}C in vacuum (less than 10^{-2} Pa) and ball milled for 10 minutes in Retsch PM100 high energy ball mill. The mixed powders were compacted in compaction die made in EN31 steel at atmospheric temperature by using UTM shown in figure 1. The powders were compacted according to ASTM B-925 to form solid billets. The load applied to the aluminium powder are 40KN, 60KN, 80KN, 100KN, 120KN and 140KN. The load applied to the blended MWCNT-LM13 composite is 140KN. Sintering is done at 460^{o}C in vacuum atmosphere. Extrusion is carried out to improve the properties of the composite.

Figure 1. Compaction die set up kept in UTM.

Test Procedures

A. Density Test

Density test is carried out on the prepared pure Aluminium specimens and MWCNT-LM13 composites. Test specimens are prepared according to ASTM standard B-925. All these specimens are weighed in precision weighing machine and measure the dimensions so as to calculate the volume as well as density of the specimen. The test is carried out before and after sintering. The photograph of the density test specimens is shown in the Figure 2.

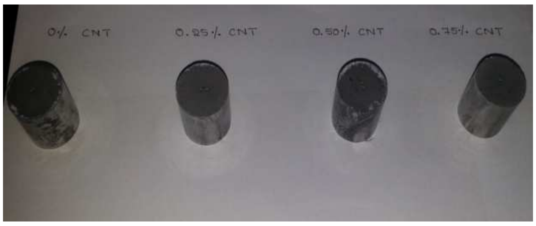

Figure 2. Density test specimens of composite

B. Hardness Test

Rockwell hardness test is done on the prepared pure Aluminium specimens and MWCNT-LM13 alloy composites according to ASTM standard B-925. Diamond cone indenter is used for Aluminium materials. The minor load applied is 10kgf and major load is 150kgf. Surface of the specimens are well cleaned before testing. After applying a major load wait for some dwell time of indentation and then release the load for equilibrium. Note the indicated readings from the dial. Figure 3 shows Rockwell hardness equipment with test specimen.

Figure 3. Rockwell hardness testing machine with test specimen

C. Tensile Test

Tensile test is carried out on the prepared pure Aluminium specimens and MWCNT-LM13 alloy composites. Test specimens are prepared according to ASTM standard E8. Tensile tests under constant rate and creep conditions were performed by an Instron 4502 universal testing machine on specimens. Constant rate experiments were conducted on dumbbell specimens. The tensile modulus was evaluated at a cross-head speed of 5mm/min by using an electrical clip gage extensometer with a gage length of 26 mm. Tensile load is applied to the specimen until it fractures. During the test, the load required to make a certain elongation on the material is recorded. A load elongation curve is plotted by an x-y recorder, so that the tensile behavior of the material can be obtained. Figure 4 shows the tensile testing machine with specimen.

Figure 4. Tensile testing machine jaws with test specimen

Result and Discussions

A. Density

Variation in density of the compacted 99.9% pure Aluminium for different values of compaction loads is shown in figure 5.

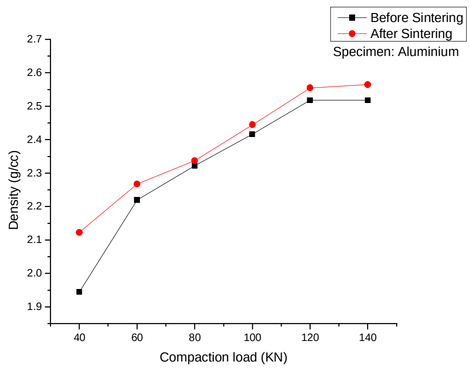

Figure 5. Variation in density with compaction load of pure aluminium before and after sintering

By observing the density curve for pure Aluminium with different values of compaction load, the density of the compacted material is gradually increased from 40KN to 120 KN load. The density curve is becomes flat after 120KN. So that density of the material is steady after 120KN.

Variation in density of LM13 composites for different wt.% of MWCNT reinforcements are shown in figure 6.

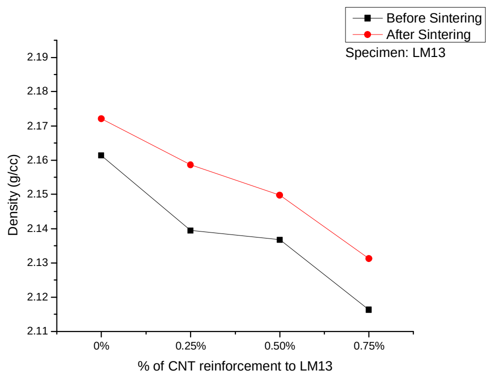

Figure 6. Variation in density with percentage of CNT reinforcement to LM13 before and after sintering

Density of the MWCNT-LM13 composite is decreases when increased reinforcement of CNT. It is increased after sintering due improved bonding of particles.

B. Hardness

Rockwell Hardness Number (RHN) of the pure Aluminium specimens for different compaction loads are shown in Figure 7.

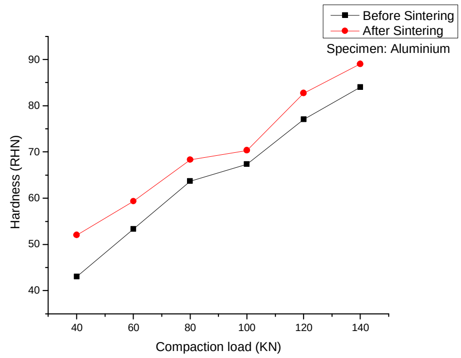

Figure 7. Variation in hardness with compaction loads for pure aluminium before and after sintering

The hardness of the compacted pure aluminium is increases with increase in compaction load. Hardness is still increased after sintering process due to improved bonding of particles.

Variation in hardness of MWCNT-LM13 composites for different values of reinforcements are shown in figure 8.

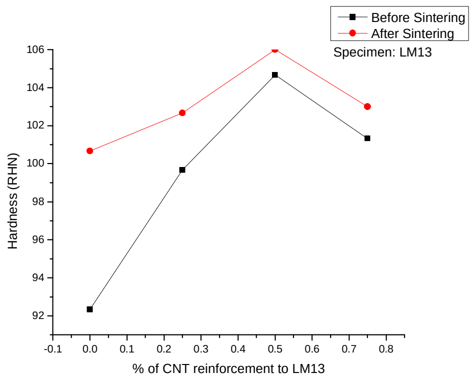

Figure 8. Variation in hardness with percentage of CNT reinforcement to LM13 before and after sintering

Hardness of the MWCNT-LM13 composite is increased with increase in wt.% of CNT reinforcements upto 0.5%. After that it is decreased due to poor bonding between the particles. It is further increases correspondingly after sintering process.

C. Young's Modulus

Variations in young's modulus of the pure Aluminium specimens for different compaction loads are shown in figure 9.

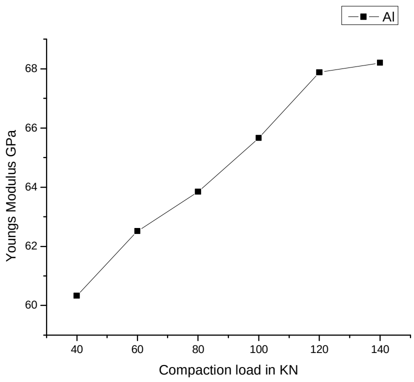

Figure 9. Variation in young's modulus with compaction load of pure aluminium specimens

It is showing that the young's modulus of the Aluminium specimen is increased gradually with increase in compaction loads. This is because of when compaction load increases the bonding between the particles is increases.

Variations in young's modulus of the of the MWCNT-LM13 composites are shown in figure 10.

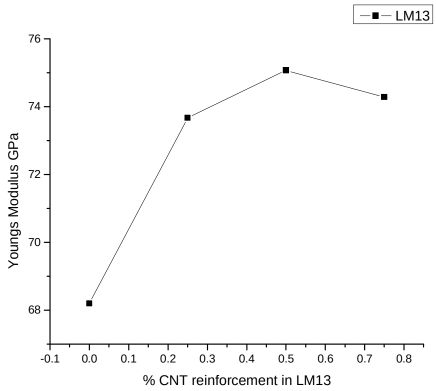

Figure 10. Variation in young's modulus with reinforcement of CNT

From the graph it is observed that the young's modulus of the composite is increased with increase in percentage of reinforcements. The curve is gradually increases up to 0.5% of CNT reinforcements and decreased afterwards. This is because of poor bonding between LM13 and MWCNT.

Conclusions

From this research work it is proved that CNTs can be efficiently reinforced into LM13 by powder metallurgy process.

By observing the density test result, it is conclude that the optimum compaction load for compaction of 99.9% pure Aluminium is 120KN and for MWCNT-LM13 composites is 140KN in powder metallurgy method.

Hardness and Young's modulus of the 99.9% pure Aluminium specimens is increased with increase in compaction load.

The hardness and Young's Modulus of the composite is increased while increase in reinforcements upto 0.5% MWCNT reinforcement. Hardness is increased in sintered specimens than the green sample.

So 0.5 wt.% can be treated as optimum quantity of reinforcement for LM13 composites.

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