Study on mechanical properties of CNT reinforced LM20 Alloy Nanocomposite

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Abstract:

The main aim of this paper was to determine the amount of CNT reinforcement that results into best combination of mechanical properties. Nanocomposites is being prepared with Al-Si alloy (LM 20) as matrix and multi walled carbon nanotube (MWNT) of 0.25, 0.5 and 0.75 wt% as reinforcement through powder metallurgy (PM) by using die setup designed according to ASTM standard B925 the compacted green samples are tested for density and hardness and compared after sintering which reveals that the density and hardness is optimumat 0.5 Wt% of CNT reinforcements is added into Al-Si alloy(LM20) matrix.

Keywords:

Glass fibre, CNT, Nanocomposites, LM20, powder metallurgy

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Introduction

The need for lightweight, high strength materials has been recognised since the invention of the airplane. As the strength and stiffness of a material increases, the dimensions, and consequently, the mass, of the material required for a certain load bearing application is reduced. This leads to several advantages in the case of aircraft and automobiles such as increase in payload and improvement of the fuel efficiency. With global oil resources on a decline, increase in the fuel efficiency of engines has become highly desirable. The inadequacy of metals and alloys in providing both strength and stiffness to a structure has led to the development of metal matrix composites (MMCs), whereupon the strength and ductility is provided by the metal matrix and the strength and/or stiffness is provided by the reinforcement that is either a ceramic or high stiffness metal based particulate or fibre. Metal matrix composites can be designed to possess qualities such as low coefficient of thermal expansion and high thermal conductivity which make them suitable for use in electronic packaging applications. Metal matrix composites today are extensively used in automobile and aerospace applications[1].

Composite materials are combination of different constituent materials which can lead to the desired combination of low weight, stiffness and strength. At present, knowledge has advanced to a level that materials can be modified to exhibit certain required properties. At the same time, the fact that these materials are composed of different constituents makes their mechanical behavior complex. Moreover, density and homogeneity of composites are very important factors in engineering applications because in homogeneity and residual pores are harmful to mechanical and physical properties. Great interest has recently been developed in the area of nanostructures carbon materials and it is becoming of considerable commercial importance. Besides, with much interest growing rapidly over the decade, the discovery of carbon nanotubes (CNTs) at the beginning of the last decade has been the focus of the growing attention of scientific communities, due to their vast interesting properties as well as their large potential for practical applications. Consequently, based on their unique size and structural diversities, CNTs have attractive properties with their tensile strength to be at least 10 times higher, and their weight is less than half that of conventional carbon fibers. The Young's modulus of a single-wall nanotube was theoretically estimated between 1.8 and 5 TPa. Powder metallurgy (PM) is an established technique for developing state of component. The process of PM starts with homogenous mixing of reinforcement with powder matrix. The mixing is followed by compaction and compacted samples which are sintered in selected environments for densification of components. However, when using the conventional PM route,the interfacial bonding of matrix alloy and reinforcements proves to be weak due to their mutual insolubility and/or non-wetability, which results in low density, high porosity content, and segregation of reinforcements. Several alternative processing techniques have been researched to develop composites through hot isostatic pressing and liquid phase sintering. Despite these techniques could overcome the problem of low density, they failed to solve the problem of in homogeneity[2]. This research focused on developing the carbon nanotubes with reinforced Aluminium alloy (LM20) via powder metallurgy technique.

Carbon nanotube reinforced metal matrix (MM-CNT) composites are prepared through a variety of processing techniques. Fig.1shows the various processes that have been adopted for synthesis of CNT-reinforced MMCs. Powder metallurgy is the most popular and widely applied technique for preparing MM-CNT composites [1].

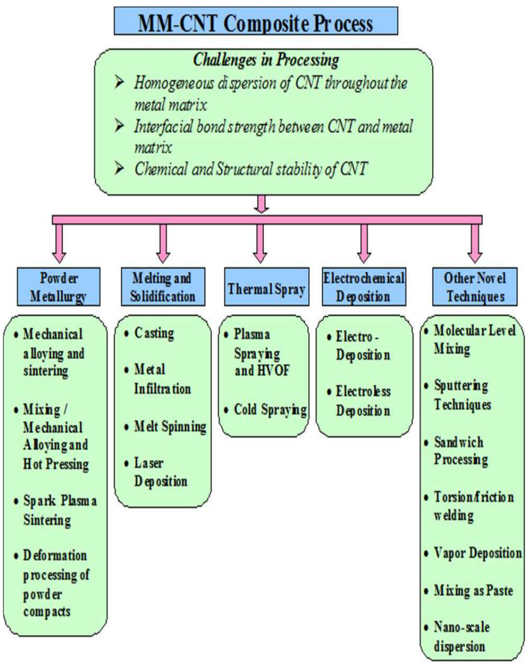

Fig.1:Shows various routes by which MM-CNT composites can be processed

Materials and Methods

2.1 Carbon nanotubes (CNTs)

2.1.1 Structure

The structure of a single wall carbon nanotube is described by rolling one graphene sheet to form a hollow tube which is closed at the two tips by half fullerenes or more complex structures including pentagons. When the axis of the CNTs is normal to a threefold axis of the half-fullerene, this structure is called zigzag or armchair respectively. Besides these two simple structures, more complex ones, which present helicity, are called chiral structures. The smallest inner diameter achieved is that of the fullerene C60 (about 0.7 nm) and lengths often reach several micrometers and sometimes some tens of micrometers, giving very high aspect ratios (1000 ± 10,000). Multiwalled nanotubes (MWNTs) are composed of concentrically rolled graphene sheets. The measured interlayer distance (0.34 nm) is very close to that measured between graphene sheets in graphite and no particular correlation appears between the chirality of concentric layers. Very often, SWNTs or MWNTs are found together in bundles where the intertube interaction may be strong [3].

2.1.2 Properties

Theoretical and experimental studies have shown that CNTs have excellent mechanical properties: the Young's modulus of MWNTs has been calculated to be up to 1.4 times that of graphite whiskers and values derived from thermal vibrations experiments performed on several MWNTs in a transmission electron microscope are in the 0.4±3.7 TPa range. Moreover, the CNTs are extraordinarily exible under large strains and resist failure under repeated bending. Both theoretical and experimental works on electronic properties have shown a metallic or semi-conducting behaviour of the SWNTs and MWNTs. Scanning tunneling microscopy and spectroscopy have recently evidenced that these properties do indeed depend on diameter and helicity[4].

2.2 Al-Si alloy(LM 20)

Aluminium alloy composites (AACs) are becoming potential engineering materials offering excellent combination of properties such as high specific strength, high specific stiffness, electrical and thermal conductivities, low coefficient of thermal expansion and wear resistance. Because of their excellent combination of properties, AACs are being used in varieties of applications in automobile, mining and mineral, aerospace, defence and other related sectors. In the automobile sector, Al composites are used for making various components such as brake drum, cylinder liners, cylinder blocks, drive shaft etc. In aerospace industries, Al composites are used essentially in structural applications such as helicopter parts, rotor vanes in compressors and in aero-engines.Lightweight body armour plate, track shoes of vehicles are also tried out for defense sectors. In general, Al composites are classified into two major groups depending upon the aspect ratio of the reinforcements. In the first category, the aspect ratio (l/d, l : length, d : diameter) is varied in the range of 100 – 10,000 in which, fibres are reinforced in metal matrix to achieve properties required for structural applications [5].

Al-Si (BS: LM20) alloy was used as the matrix material. The alloy contains 12.00 wt.% Si, 0.1 wt.% Mg, 0.1 wt.% Cu, 0.80 wt.% Fe, 0.50 wt.% Mn and balance was Al. LM20– 0.25,0.5,0.75 wt.% CNT composite was prepared by dispersing fine particles in aluminium alloy matrix using powder metallurgy technique. The steps involved in preparing the composite were blending of powder, mixing of aluminium alloy powder with carbon nanotube using high speed ball milling and compaction.

2.3 Methods

2.3.1 Powder and carbon nanotubes

A fine aluminium alloy powder produced by ball milling (powders of 200 mesh size) and MWNTs (size 7-15nm outer and 3-6nm inner diameter with length of 0.5-200micro meter and 90% purity synthesized using Chemical Vapour Deposition (CVD) method as reinforcement is being used. The properties of the aluminium alloy powder (LM20) and carbon nanotubes are given in Table 1and Table 2 respectively. The MWNT was rinsed in concentrated Nitric acid, then filtered, washed with de-ionized water and dried at 1200C to remove the surface impurities [6].

Table1: Properties of LM20

Properties of LM20	Sand cast
Specific density	2.68 g/cm^3
0.2% Proof Stress	120
Modulus of Elasticity	71*103N/mm2
Coefficient of thermal expansion	0.000020
Tensile Strength	190-

	230N/mm2
Endurance limit(5*103cycles)N/mm2	80-100
Electrical Conductivity	37

Table2: Properties of CNT

Properties of CNT	
Specific density	1.3 – 2 g/cm³
Surface area	~1000 m2/g
Modulus of Elasticity	1TPa
Specific strength	48,462 kN·m/kg
Tensile Strength	10-60 GPa
Strain at Break	10 %
Thermal Conductivity	>3000 W/m.k
Temperature stability	2800o C in vacuum
Electrical Conductivity	106 – 107
Current density	1013 A/cm2

2.3.2 Pre-Blending

The test samples from aluminium alloy powder (LM20) as a matrix and carbon nanotubes as reinforcement are prepared accordingly by weighting them accurately mixed with matrix in ethanol solution by using ultrasonic shaker for 30 min. Then, the matrix and reinforcement blend was dried at 120°C in vacuum (less 10−2 Pa) and broken up by using Retsch PM100 high speed planetary ball mill for duration of 10 min at 200 rpm to ensure a uniform dispersion of carbon nanotubes in aluminium alloy powder (LM20). Weight fractions of 0.25% to 0.5% and 0.75% of carbon nanotubes were used.

2.3.3 Establishment of compaction load

The mixture of aluminium alloy powder (LM20) and carbon nanotubes was compacted in a circular die and punch set of 25.4 mm diameter to obtain specimen as per ASTM B-925is shown in Fig. 2. Zinc stearate was applied to die and punch to minimize friction during the compaction process to get cylindrical shape of solid green sample at room temperature. The dimension of the test sample was 25.4 mm in diameter and 30mm in length as shown in Fig. 3. In order to achieve the good density trial compaction was carried out for various mixture of reinforcement through a UTM machine of 40-Ton capacity. 30 grams of powder was taken for compaction. Specimens of size 25.4 mm diameter was produced by above said compaction technique. Density was determined in each trial.

Fig. 2: Punch and die set according to ASTM B-925

2.3.4 Sintering

After compaction the green specimen was subjected to sintering in nitrogen atmosphere for 1 hour at 4700c.

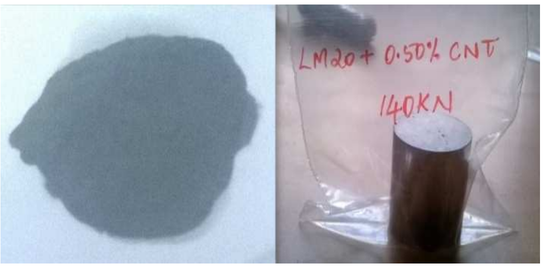

Fig.3: Uncompacted powder and compacted specimen

Fig.4: Setup of compaction

3. Results and discussion

3.1 Density

Density of LM20 matrix and MWNT reinforced nanocomposite specimens were computed in a Table 3 and plotted as shown in Fig.5,from the graph it is observed that density in LM20 reinforced composite before sintering and after sintering is found to be optimum for 0.5% CNT reinforcement.

Table3: Depicts the density variation with change in reinforcement wt.% before and after sintering

Specimen	Density(g/cm3)Before Sintering	Density(g/cm3) After Sintering

LM20	2.05	2.06
LM20+0.25% CNT	2.07	2.05
LM20+0.5%CNT	2.06	2.04
LM20+0.75% CNT	2.08	2.07

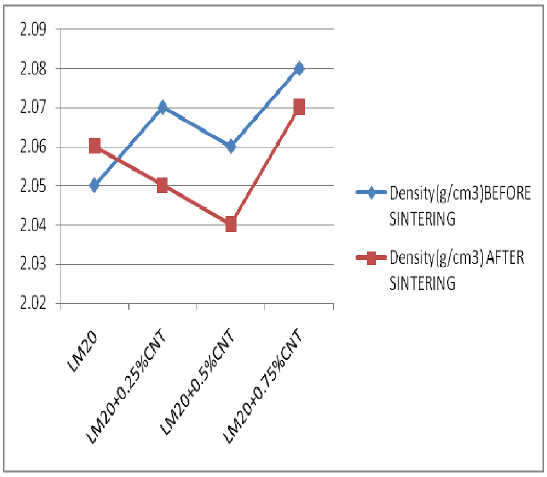

Fig.5: Shows the density variation in LM20 with change in reinforcement wt.% before and after sintering

3.2 Hardness

Hardness of LM20 matrix and MWNT reinforced nanocomposite specimens were computed in Table 4 and plotted as shown in Fig .6,from graph it is observed that hardness in LM20 reinforced composite before compaction is found optimum at 0.5% CNT reinforcement and after sintering its optimum at 0.75% CNT reinforcement. It is been seen that after sintering the bonding in 0.75% CNT reinforced has increased.

Table 4: Shows the hardness with % variation in reinforcements and before and after sintering

Specimen	RHN (Before Sintering)	RHN (After Sintering)
LM20	65.6	97
LM20+0.25%CNT	73.3	97
LM20+0.5%CNT	82.6	92.3
LM20+0.75%CNT	76	99.6

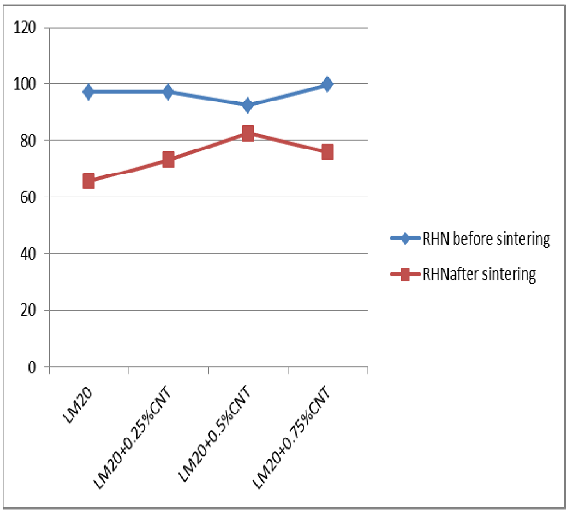

Fig.6: Shows the hardness with % variation in reinforcements and before and after sintering

3.3. Youngs modulus

The young's modulus of neat matrix and MWNT reinforced nanocomposite specimens were examined as per ASTM standard B925-03 by using computerized UTM It was observed that 0.5 wt % MWNT nanocomposites exhibits highest value (LM20- 68.3 GPa, LM20+0.25%CNT- 69.33 GPa,LM20 and LM25- 64.2 GPa). Further increase in MWNT in the nanocomposites was not beneficial. This reduction in young's modulus is also due to the agglomeration of MWNT in the matrix. At higher content agglomeration reduces interfacial bonding and weakens the material. Due to this the high concentration leads to stress concentration and reduces the fracture toughness. The young's modulus of nanocomposites mentioned as shown in

Table 5: shows the youngs modulus with change in variation of CNT

SPECIMEN	YOUNGS MODULUS
LM20	69
LM20+0.25%CNT	68.4
LM20+0.5%CNT	69.4
LM20+0.75%CNT	68

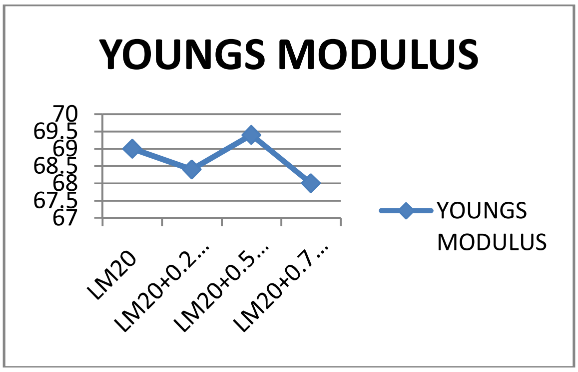

Fig 7: Shows the youngs modulus with % variation in reinforcements and before and after sintering

CONCLUSION

Carbon nanotubes reinforced LM20 matrix composites had been successfullydeveloped through powder metallurgy and characterized their mechanicalproperties. With about 140KN load which sufficient enough to produce near full density LM20 nanocomposite. By observing the density test result, it can be concluded that at 0.5wt% MWNT optimum density is obtained both before and after sintering.

By observing the hardness test results it can be concluded that hardness is optimum at 0.5wt% MWNT reinforcement before sintering and after sintering optimum hardness is obtained at 0.75wt% MWNT reinforcement.It can beconcluded that after sintering the bonding in 0.75% CNT reinforced has increased.

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