ZIBELINE INTERNATIONAL PUBLISHING
ISSN: 1024-1752 (Print)
CODEN: JERDFO

Journal of Mechanical Engineering Research & Developments (JMERD)

DOI : http://doi.org/10.26480/jmerd.01.2019.89.93

CrossMark

RESEARCH ARTICLE

INFLUENCE OF SIZE AND WEIGHT FRACTION OF CARBON NANOTUBE ON COEFFICIENT OF THERMAL EXPANSION OF Al-CNT METAL MATRIX

Pothamsetty Kasi V Rao[1]*, B. Raghu Kumar[2]

[1]Research Scholar, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Andhra Pradesh, India.
[2]Professor, Department of Mechanical Engineering, Prasad V. Potluri Siddhartha Institute of Technology, Andhra Pradesh, India
**Corresponding Author email: kasi.special@gmail.com*

ARTICLE DETAILS

Article History:

Received 24 November 2018
Accepted 05 January 2019
Available online 11 February 2019

ABSTRACT

Metal matrix composites are grabbing more attention by researchers due to their outstanding properties which meets the requirements of a specific application. The work presented in the current paper investigates the influence of size of carbon nanotube in Al-CNT metal matrix composite. The metal matrix composites were fabricated using powder metallurgy process. The influence of size (Type1, Type2 and Type3) and content (0.5, 1.0 and 1.5wt %) of multi walled carbon nanotube in matrix on thermal properties (CTE) were experimentally investigated. Scanning Electron Microscope (SEM) was used to observe the microstructure of fabricated metal matrix and to examine the uniform dispersion of CNT without any agglomerations in the matrix and was found to be satisfactory. The results of thermal test showed that if the CNT particle content increases considerably the Coefficient of thermal expansion decreases markedly upon the increase in CNT content and Type 1 Al-CNT matrix shows a maximum decrement of 15.36% in CTE when compared to Type 2 and Type 3 Al-CNT matrix.

KEYWORDS

Carbon Nanotube (CNT), Powder Metallurgy, Scanning Electron Microscope (SEM), Aluminium Matrix, Coefficient of Thermal expansion(CTE).

1. INTRODUCTION

Nanotechnology makes it possible to create new materials and devices with a vast range of applications in the field of medical science, electronics, biomaterials, energy production, aviation departments and automotive sectors. Researchers are showing great interest in reinforcing carbon nanotubes (CNT) in metals over the past few years. Especially they have been concentrating on the enhancement of mechanical and thermal properties of metal matrix due to reinforcement. Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure which exhibit many remarkable mechanical, electrical and thermal properties. Due to their excellent physical properties and outstanding ability to suit for practical applications many researchers are showing interests in them.

Most of the research works are done on reinforcement of Multi walled carbon nanotubes (MWCNT) instead of Single-walled carbon nanotubes (SWNT) which have a very high Young's modulus of about 5 TPa compared to MWCNT(Young's modulus of 1.5TPa) [1, 2]. It is due to the fact that MWCNT is more chemically stable. Low cost mass production makes them to use widely in many applications and especially in metal matrix composites [3, 4]. There are many routes available for fabricating the metal matrix composites. Out of which Powder metallurgy technique was selected as it has many potential advantages. Metal matrix composites (MMCs) have been used for many applications due to their outstanding properties like high strength to weight ratio, creep resistance, high coefficient of thermal expansion, good wear resistance etc [5, 6]. Carbon nanotubes being one of the reinforcement elements in metal matrix nano-composites also possess good electrical and thermal conductivity properties apart from good mechanical properties, thus offering opportunities for the development of new nano-composites [7].

Aluminium is one of the best choices for replacing many metals in the field of automobiles due to its corrosion resistance capability and good formability. Hence aluminium alloys are being fabricated with addition of various elements like carbon nanotubes and other nano sized particles so as to enhance the properties of metal matrix to meet the specific applications [8]. One of the major applications is automobile sector where in the engine piston should be designed with materials of high strength and low thermal expansion to withstand the high combustion pressure and temperature [9-11]. The sequence of operations involved in powder metallurgy technique to fabricate metal matrix composite were represented in Figure 1.

Cite The Article: Pothamsetty Kasi V Rao, B. Raghu Kumar (2019). Influence Of Size And Weight Fraction Of Carbon Nanotube On Coefficient Of Thermal Expansion Of Al-Cnt Metal Matrix. *Journal of Mechanical Engineering Research & Developments*, 42(1):89-93.

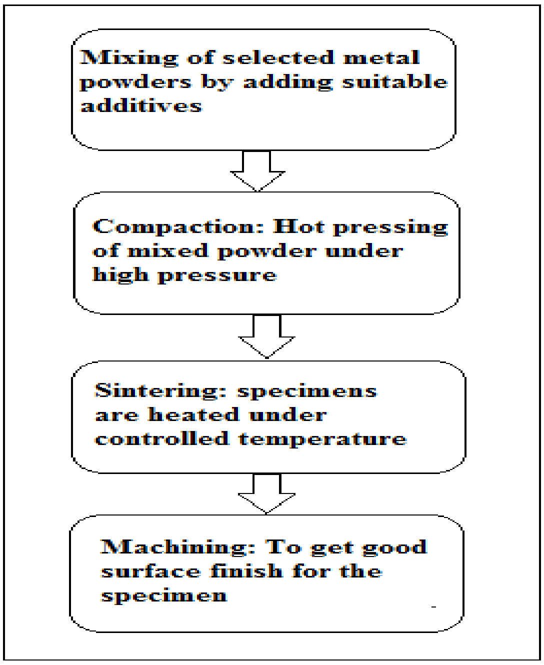

Figure 1: Sequence of steps involved in powder metallurgy technique for fabricating MMCs

2. OBJECTIVE

The main objective of present work is to investigate the influence of size of multi walled carbon nanotubes on coefficient of thermal expansion of Al-CNT matrix. Pham Van Trinh investigated the effect of CNT on coefficient of thermal expansion for Al-CNT matrix [12]. The results revealed that coefficient of thermal expansion (CTE) decreases markedly upon the increase in carbon content, maximum of 30% decrease was observed in 2 wt% of CNT compared to the pure Aluminium. His results were used to validate the present work and also further concentrating on the effect of size of MWCNT by selecting three different types (Type 1, Type 2 and Type 3).

3. EXPERIMENTATION

The procured aluminium powder is 99% pure with a mesh size of minimum 90 % (passing through 200 meshes) and three types of multi-walled carbon nanotubes were selected with the specifications as mentioned in Table 1.

Table 1: Specifications of selected MWCNT

S.No	Specifications	Type-1	Type-2	Type-3
1	Range of Length (μm)	10-30	10-30	10-30
2	Range of Outer Diameter (nm)	<8	10-20	30-50
3	Purity (%)	95	95	95

3.1 Ball Milling

The different compositions of Al-CNT powders selected were subjected to ball milling process in order to achieve uniform mixing of carbon nanotubes in aluminium powder and to maintain rigid bonding between the two powders. The equipment contains a jar with three balls made of alumina which are added based on ball to weight ratio. The machine was operated at a speed of 250 r.p.m for a time period of 30 minutes.

3.2 Compaction

After achieving the nano size the next process is to compact by pressing under a high pressure. Compaction is done to make the bonding of powders and get adhered to each other. All the atoms will be closely packed and will be formed as a solid material. The shape of the solid material is achieved by various dies according to requirement. The base plate is kept on the stand so that it can hold the die. A plunger from top comes downward and applies pressure of 80bars on to the die. The holding time was 10 seconds. After that, the plunger moves upward, and the required solid shape is achieved as shown in Figure 2.

Figure 2: Hydraulic press equipment

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3.3 Sintering Process

After the compaction process the specimens are subjected to sintering process in which the specimens are allowed to heat in a controlled atmosphere furnace. In this process the compacted powder was transformed into solid form upon heating at temperatures below the melting point of the selected aluminium powder. For Al-CNT metal matrix composite, the sintering temperature is maintained at 500 °C. As a result, the compact powder becomes denser and the porosity can be minimized to maintain good mechanical strength for the sintered metal matrix. The specimens are placed on Cumic-32 brick plate which acts as an insulator as shown in Figure 3. The working temperature of the machine is 1400 °C. These specimens are kept in the furnace for nearly 2 hours and dwell time of 2 hours is maintained for all specimens. The temperature and voltage are set in the digital indicators. The specimens are cooled to room temperature and then taken out from the furnace. After sintering the specimens are subjected to machining process in order to achieve good finishing.

Figure 3: Sintering equipment

3.4 Dilatometer Test

Dilatometry is a technique which measures the dimensional change of a substance as a function of temperature. The coefficient of thermal expansion is one of the thermal properties that can be obtained from Dilatometer test. CTE is used to examine the behaviour of the specimen towards change in its dimensions when subjected to change in temperature. In specific it is used to measure the fractional change in size of the substance per degree change in temperature at a constant pressure. For Metal matrix composite the coefficient of linear expansion was found as for solid substance the change along length is required. Change in area and volume due to thermal expansion can also be determined from this dilatometer test as per the specific applications. It was known fact that the expansion or contraction of substance takes place due to the temperature difference. Temperature controls the kinetic energy of the molecules which increases with temperature. Thus, the molecules try to vibrate or move and usually maintain a greater average separation leading to change in dimensions of the substance.

The specimens were prepared, and experiment was performed as per ASTM E831 standards. Initially the specimen is loaded into the slot provided in the rod and is allowed to move into the heating coil furnace. The heating temperature is set as 600 °C and working temperature as 1400 °C with silicon carbide as the heating element. The initial temperature is set to room temperature 28 °C and the final temperature is set to 600 °C. The equipment as shown in Figure 4 has 1 °C accuracy at dwell temperature. Initially the displacement indicator is set to zero. It takes complete 3 hours for both heating and cooling of the specimen. The equipment is connected to computer which is programmed to plot graphs for the expansion at different temperatures.

Figure 4: Dilatometer equipment

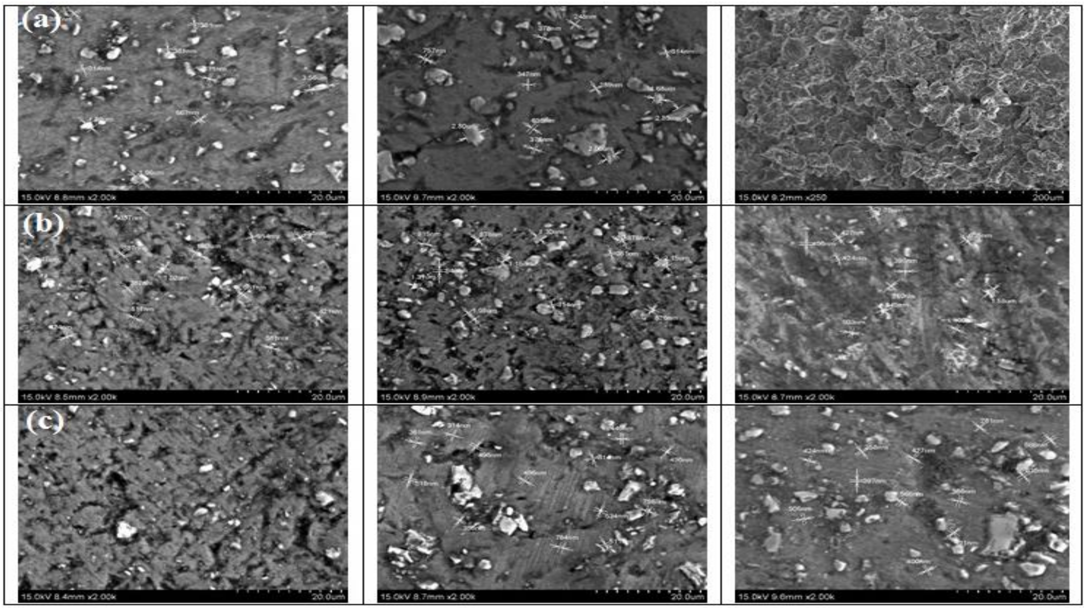

Figure 5: Microstructure of (a) 0.5, 1, 1.5 wt% type 1 CNT (b) 0.5, 1, 1.5 wt% type 2 CNT (c) 0.5, 1, 1.5 wt% type 3 CNT reinforced Aluminium matrix

4. RESULTS AND DISCUSSIONS

4.1 SEM Examination

The microstructure of the fabricated specimens were observed using Scanning Electron Microscope. The SEM analysis conducted on Hitachi S-3400N. The microstructure study reveals that the dispersion of carbon nanotubes in aluminium matrix was uniform and quite satisfactory. Some agglomerations were observed with minimum effect and hence the bonding between the reinforcements and matrix was satisfactory and acceptable. The detailed SEM images for all the specimens with different compositions of carbon nanotubes were shown in Figure 5.

4.2 Coefficient of Thermal Expansion (CTE):

The variation in CTE of the metal matrix in the temperature range 100 ^{0}C to 600 ^{0}C is shown in the Figure 6 to Figure 8 for different types of multi-walled carbon nanotubes. The trend shows that coefficient of thermal expansion increases gradually with increase in temperature irrespective of size of carbon nanotube, and less increment is observed in composites with more carbon content. The comparison of CTE for different weight percentages of CNT is shown in Figure 9. The recorded values of coefficient of thermal expansion obtained for all the specimens are shown in Table2. It was proved that coefficient of thermal expansion of Al-CNT metal matrix decreases as carbon nanotubes weight percentage increases in matrix. Also it is clear that Type 1 CNT showed a maximum decrement of 15.36% when compared with Type 2 and Type 3 CNT. Hence the size of CNT will definitely influence the coefficient of thermal expansion of Al-CNT metal matrix.

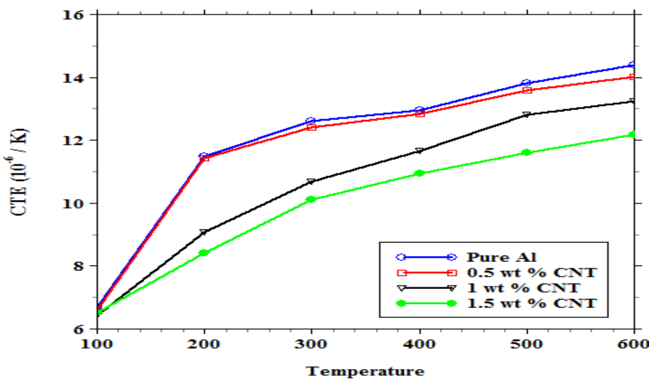

Figure 6: CTE of Type 1 Al-CNT matrix versus Temperature (0C)

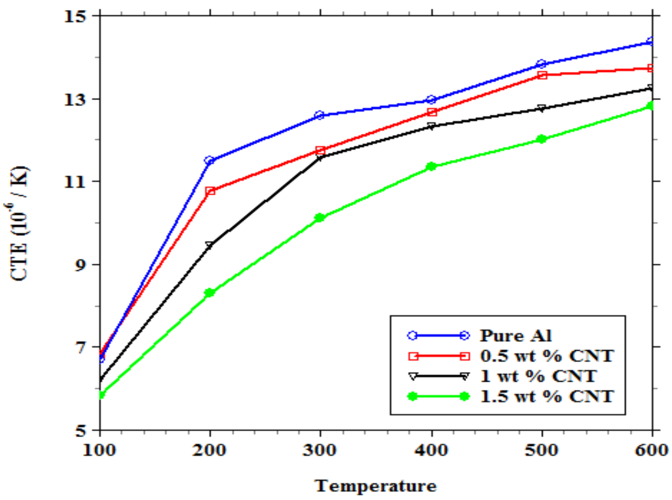

Figure 7: CTE of Type 2 Al-CNT matrix versus Temperature (0C)

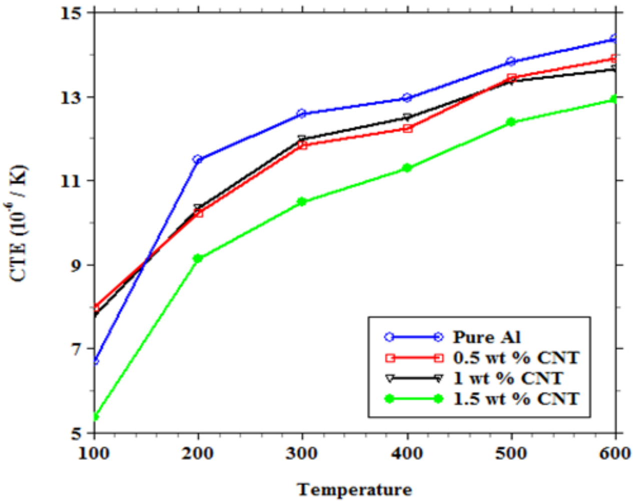

Figure 8: CTE of Type 3 Al-CNT matrix versus Temperature (0C)

Table 2: Coefficient of Thermal Expansion for different types of CNT reinforced Al matrix

Weight % of MWCNT in Matrix	Coefficient of Thermal Expansion (10^{-6} /K)		
	Type 1-CNT	Type 2-CNT	Type 3-CNT
0	14.38	14.38	14.38
0.5	14.02	13.74	13.92
1	13.25	13.25	13.65
1.5	12.17	12.82	12.94

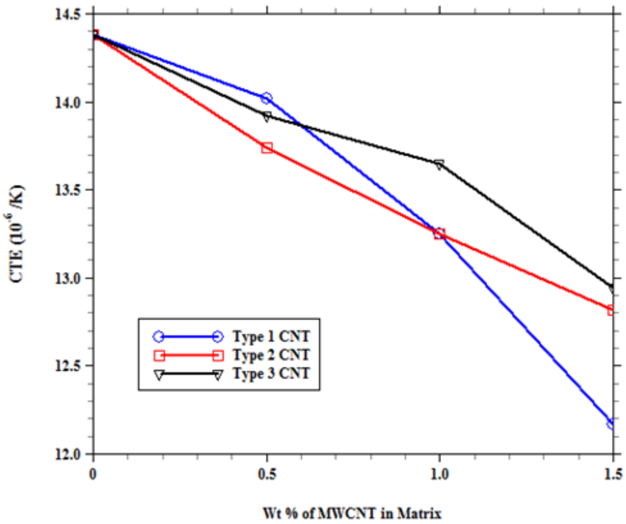

Figure 9: Comparison of CTE for different types of CNTs reinforced in Aluminium Matrix

5. CONCLUSION

The experimental results revealed that the coefficient of thermal expansion decreases markedly upon the increase in carbon nanotubes content and Type 1 Al-CNT matrix shows a maximum decrement of 15.36% in CTE when compared to Type 2 and Type 3 CNT/Al. Hence, we can conclude that the size of CNT will influence the coefficient of thermal expansion of Al-CNT metal matrix composite.

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