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Investigation of Physical and Thermal Properties of Aluminum with Carbon Nano Tubes

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***Abstract*— Aluminum is found wide application for rail coaches, aircraft industry, bearing materials, piston material, transmission lines etc. But due to their low melting point and low hardness they will wear and deformed easily. The metal Aluminum cannot meet all the required properties suitable for various engineering applications. So it is necessary to develop the Aluminum based materials that could have all combinational properties satisfying all our engineering requirements. Carbon nano tubes can be considered as ideal reinforcements, due to their high strength, high aspect ratio and thermo-mechanic properties. However, until now, the main obstacle is to obtain a homogenous dispersion of the CNTs in the desired matrix. Quite a few methods have studied to help improving the dispersion of CNTs in a polymer matrix. The objective of this work is to reinforce light Aluminum with CNT by melt stirring method. Different wt% of CNTs was added to Aluminum [1100] separately to make Aluminum composites and its mechanical, physical and thermal properties have been investigated using test like tensile, hardness and coefficient of thermal expansion. The improvement of mechanical, physical and thermal properties for both the cases has been compared with pure Aluminum [1100].**

***Index Terms* — Carbon Nano Tubes, Aluminum, Rockwell Hardness**

1. INTRODUCTION

The issue of CO_2 emission has become more and more critical during the last decades. One of the main sources of CO_2 emission is transportation. One liter of petrol consumption induces 2.34 kg CO_2 and the petrol consumption is directly connected to the average weight of a car. European Commission has proposed to reduce the average CO_2 emission from new cars to 130 g/km by 2012. To fulfill this regulation, one of the solutions is to reduce the weight of a car. An average weight for a car of less than 800 kg is required. Therefore the use of light metals is becoming important. Currently lightweight metal alloys are used in relatively small quantities in automotive applications due to their relatively low strength which limits their potential applications. To overcome the limitations, much research has been done on producing light metal matrix composites to improve the mechanical properties by adding different reinforcements (Qianqian Li, 2010).

Metal matrix composite (MMC) is engineered combination of the metal (Matrix) and hard particle/ceramic (Reinforcement) to get tailored properties. MMC's are either in use or Prototyping for the space shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs, and a variety of other applications.

Like all composites, aluminum-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, reinforcement material, volume and shape of the reinforcement, location of the reinforcement and fabrication method can all be varied to achieve required properties. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. Metals have a useful combination of properties such as high strength, ductility and high temperature resistance, but sometimes have low stiffness, whereas ceramics are stiff and strong, though brittle. For example, Aluminum and silicon carbide have very good mechanical properties: Young's module of70 and 400 GPa, coefficients of thermal expansion of 24×10^{-6} and 4×10^{-6}/°C, and yield strengths of 35 and 600 MPa, respectively. By combining these materials, e.g. A6061/SiC/17p (T6 condition), an MMC with a Young's modulus of 96.6 GPa and a yield strength of 510 MPa can be produced (S.Skolianos, 1990). By carefully controlling the relative amount and distribution of the ingredients of a composite as well as the processing conditions, these properties can be further improved. The correlation between tensile strength and indentation behavior in particle reinforced MMCs manufactured by powder metallurgy technique (Williams, 2001). The microstructure of SiC reinforced aluminum alloys produced by molten metal method. It was shown that stability of SiC in the variety of manufacturing processes available for melt was found to be dependent on the matrix alloy involved (Morris, 1989).

1.1 CARBON NANOTUBES

Carbon nano tubes (CNTs; also known as buckytubes) are allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1(Wang, 2009), which is significantly larger than any other material. These cylindrical carbon molecules have novel properties which make them potentially useful in many applications in nanotechnology, electronics, optics, and other fields of materials science, as well as potential uses in architectural fields. They may also have applications in the construction of body armor. They exhibit extraordinary strength and unique electrical properties, and are efficient thermal conductors.

Nanotubes are members of the fullerene structural family, which also includes the spherical buckyballs. The ends of a nanotube may be capped with a hemisphere of the buckyball structure. Their name is derived from their size, since the diameter of a nanotube is on the order of a few nanometers (approximately 1/50,000th of the width of a human hair), while they can be up to 18 centimeters in length (Wang, 2009). Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs).

1.2 MULTI-WALLED CARBON NANOTUBES

Multi-walled nanotubes (MWNT) consist of multiple rolled layers (concentric tubes) of graphite. There are two models which can be used to describe the structures of multi-walled nanotubes. In the Russian Doll model, sheets of graphite are arranged in concentric cylinders, e.g. a (0,8) single-walled nanotube (SWNT) within a larger (0,17) single-walled nanotube. In the Parchment model, a single sheet of graphite is rolled in around itself, resembling a scroll of parchment or a rolled newspaper. The interlayer distance in multi-walled nanotubes is close to the distance between graphene layers in graphite, approximately 3.4 Å.

The special place of double-walled carbon nanotubes (DWNT) must be emphasized here because their morphology and properties are similar to SWNT but their resistance to chemicals is significantly improved. This is especially important when functionalization is required (this means grafting of chemical functions at the surface of the nanotubes) to add new properties to the CNT. In the case of SWNT, covalent functionalization will break some C=C double bonds, leaving "holes" in the structure on the nanotube and thus modifying both its mechanical and electrical properties. In the case of DWNT, only the outer wall is modified. DWNT synthesis on the gram-scale was first proposed in 2003 (Laurent, 2003) by the CCVD technique, from the selective reduction of oxide solutions in methane and hydrogen.

The Literature reveals that most of the studies that has proposed in their journal of improved processing of carbon nanotubes/magnesium alloy composites. In this study, a two-step process was applied. In first stage, a block copolymer was used as a dispersion agent to pre-disperse multiwall carbon nanotubes (MWNTs) on Mg alloy chip. Then the chip with the well dispersed MWNTs on their surface were melted and at the same time vigorously stirred[1].

C.S.Goh Wei, et al., (2008) has proposed in their journal of Development of novel carbon nanotubes reinforced magnesium nano composites using powder metallurgy technique.Carbon nanotubes (CNTs) reinforced magnesium nanocomposites were synthesized using the powder metallurgy technique followed by hot extrusion. Up to 0.3 wt% of CNTs were added as reinforcements [2].

The research work reveals Investigation of carbon nanotube reinforced aluminum matrix composite material. In this journal the tensile strength without compromising the elongation of aluminum (Al)–carbon nanotube (CNT) composite by a combination of spark plasma sintering followed by hot-extrusion processes. From the micro structural viewpoint, the average thickness of the boundary layer with relatively low CNT incorporation has been observed by optical, field-emission scanning electron and higher solution transmission electron microscopes[3].

E. Carreño-Morelli,et al., (2004)has proposed in their journal of Carbon nanotube/magnesium composites.The Resonant measurements showed an improvement of about 9% inthe Young’s modulus of Mg–2wt%CNTs (38.6 ± 0.7 Gap) compared with unreinforced sintered Mg (35.3 ± 0.8 Gap) [4].

It studies the Effect of carbon nanotube (CNT) content on the mechanical properties of CNT-reinforced aluminium composites. In this study, dispersion of MWCNTs within an aluminium matrix was achieved using high energy ball milling for 30 min at 400 rpm. Such conditions were found to be generally effective in dispersing the CNTs while limiting strain hardening of the aluminium powder. Mechanical properties were found to improve significantly with the increase in CNT content and either exceeded or were close to predicted values based on composite theory except at 5 wt. % when the mechanical properties fell short of predicted values[5].

Esawi,et al., (2006) has proposed in their journal of Dispersion of carbon nanotubes (CNTs) in aluminium powder. One of the key issues in the development of CNT/metal matrix composites is controlling the agglomeration of the nanotubes. This has been a major impediment facing the development of these new materials. The results presented in this paper demonstrate that mechanical alloying is a promising technique to overcome this problem. The SEM results showed that the usual CNT clustering often observed when using Tubular mixing was eliminated; moreover, individual nanotubes were observed embedded in the aluminium matrix after 48 h of milling which did not appear to be damaged by the selected milling intensity (200 rpm) and ball-to-powder ratio (10:1) [6].

2. MATERIALS AND METHODS

2.1. MATERIAL USED

The metals identified for the present study are

- Aluminum [1100] (Al).
- Carbon nanotubes (MWNTs).

2.2. EXPERIMENTAL PROCEDURE

The components present over in melt stirring machine are Furnace, heating element, sample crucible, mechanical stirrer, argon inlet, argon outlet.

The block copolymer disperbyk-2150 was first dissolved in ethanol in a small beaker. Then MWCNTs were added to the as-prepared solution. This mixture was put at room temperature into an ultrasonic bath for 15 min. Then it was stirred for 30 min at 250 rpm. After adding Al chip the suspension was further stirred at 250 rpm inside a fume cupboard to evaporate ethanol and homogenize the mixture.

After the mixture was dried, the MWCNT coated chips were placed in a cylinder sample crucible. This crucible was placed into an oven and heated up to 650 c under an inert gas atmosphere to avoid oxidation. When the Al chips were molten, the liquid was mechanically stirred at 370rpm for 30min to further disperse MWCNTs. After stirring, the molten MWCNT/Al composite was poured into a mould. The cooled sample was machined to cylinder shaped specimens for subsequent tests. Reference sample were made using exactly the same procedure but from pure Al.

2.3. ROCKWELL HARDNESS TESTINGEQUIPMENT

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F0 usually 10kgf. When equilibrium has been reached, an indicating device, which follows the movement of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. When the preliminary load is still applied an major load is applied with resulting increase in penetration. When equilibrium has again been reached, the additional major load is removed but the preliminary minor load is still remained. Removal of additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the RHN.

2.4. TENSILE TEST EQUIPMENT

The tensile properties of the Al (1100) and nanocomposite samples were determined in accordance with ASTM test method E8M-01 the specimen prepared to conduct tensile test for Al – CNT composites. Experiments have been conducted by varying Wt fraction of CNT (2% and 4%).Tensile test were recorded and tabulated. Tensile test has been conducted on each specimen using a Universal tensile testing machine (Model – UNITEK 94100). The corresponding values of Ultimate tensile strength and Yield strength were calculated from the standard formula.

2.5. COEFFICIENT OF THERMAL EXPANSION (CTE)

The coefficients of thermal expansion (CTE) test have been conducted by varying fraction of CNT (2%, 4%) and pure Al (1100) samples were determined by measuring the displacement of the samples as a function of temperature in the temperature range of 50°C to 450°C using an automated DILATOMETER.

3. RESULTS AND DISCUSSIONS

3.1. TENSILE TEST

Tensile test experiments have been conducted by varying Weight fraction of CNT (2% and 4%). Tensile test were recorded and tabulated. Tensile test has been conducted on each specimen using a Universal tensile testing machine (Model – UNITEK 94100). The corresponding values of Ultimate tensile strength and Yield strength were calculated from the standard formula.

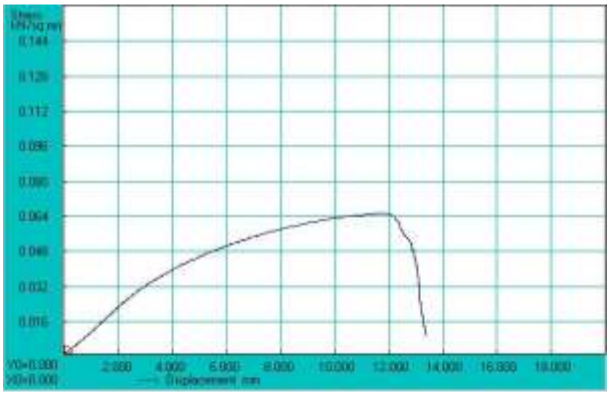


Figure.1 Stress Vs Displacement for Pure Al

From the Fig. 1, it could be observed that maximum Ultimate tensile strength (UTS) at 48 MPa for pure Al that results at maximum displacement 4.510 mm.

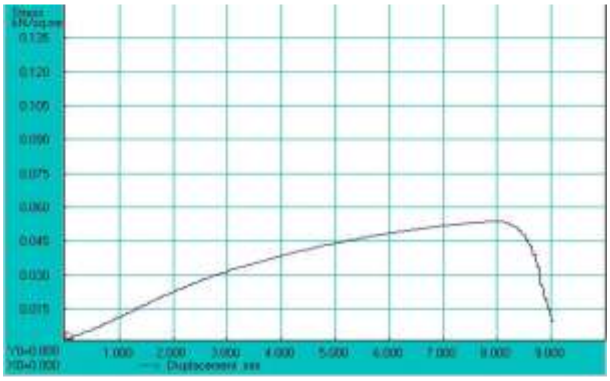


Figure.2 Stress Vs Displacement for Al – 2%CNT

From the Fig.2, it could be observed that maximum Ultimate tensile strength (UTS) at 54 MPa for Al – 2%CNT that results at maximum displacement 9.070 mm.

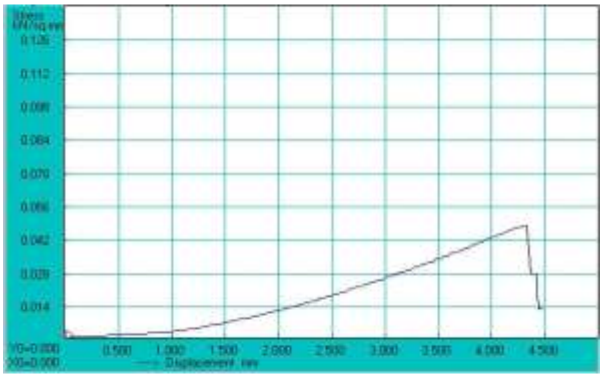


Figure.3 Stress Vs Displacement for Al – 4%CNT

From the Fig.3, shows that the maximum Ultimate tensile strength (UTS) at 65 MPa for Al – 4%CNT that results at maximum displacement 13.430 mm.

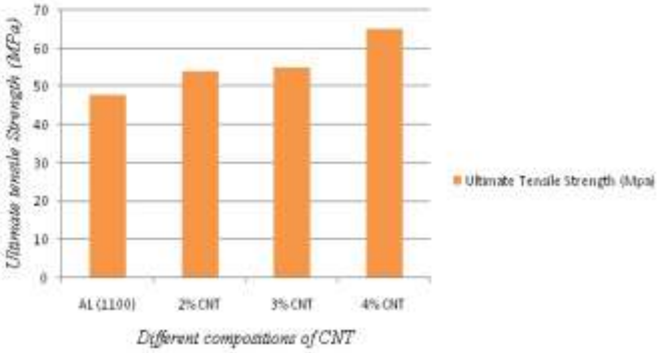


Figure.4 Comparative bar chart for UTS with Different Compositions of CNT

From the above Fig.4, illustrate that Ultimate tensile strength increases (UTS) up to 27% while adding 4% of CNT with Al (1100) at a peak load 8.672 kN and with increasing amount of CNT, the ductility gradually increase when compared to pure Al (1100). Breaking load result show that the maximum amount of energy required for breaking occurs when 4% of CNT have been incorporated.

3.2. ROCKWELL HARDNESS TEST

Hardness test experiments have been conducted by varying weight fraction of CNT (2% and 4%). Hardness test were recorded and tabulated. Hardness test has been conducted on each specimen using a load of 100Kgf and a steel ball of diameter 1.588mm as indenter.

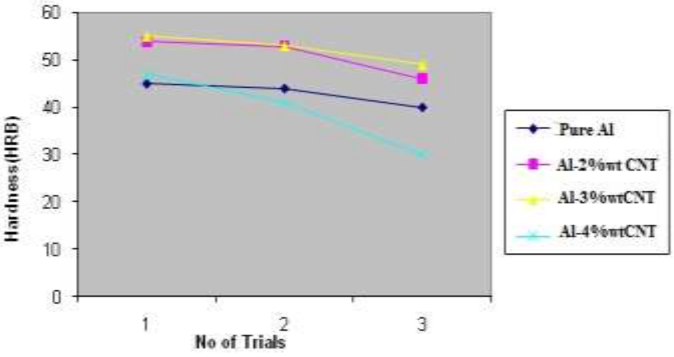
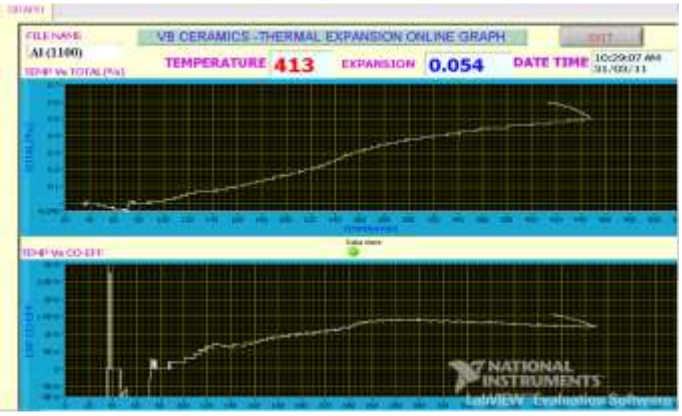


Figure.5 Comparative analysis of Hardness for Pure Al and different composition of CNT

The results of increasing trend of hardness with increase in Weight percentage of CNT up to 3% Weight fraction is illustrated in Fig.4. Beyond this Weight fraction the hardness trend started decreasing as CNT particles interact with each other leading to clustering of particles and consequently settling down. Eventually the density of CNT particles in the melt started decreasing thereby lowering the hardness. The best value of hardness comes out to be of sample containing 3% CNT i.e. 57 HRB (Hardness). By adding 3%wt of CNT with Al (1100) the hardness increases up to 22% when compared to pure Al (1100).

3.3. CO-EFFICIENT OF THERMAL EXPANSION

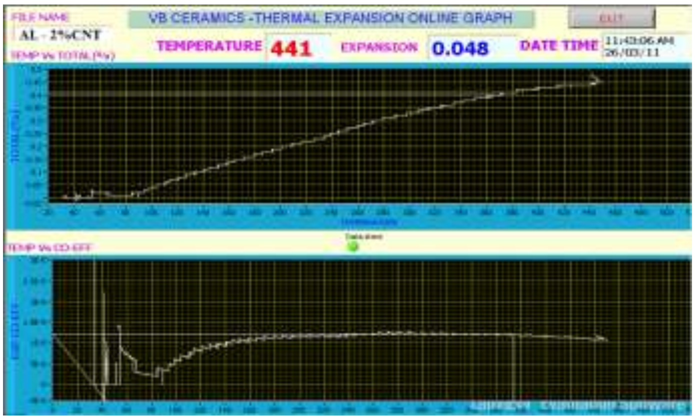
The coefficients of thermal expansion (CTE) test have been conducted by varying Weight fraction of CNT (2% and 4%) and pure Al (1100) samples were determined by measuring the displacement of the samples as a function of temperature in the temperature range of 50°C to 450°C using an automated DILATOMETER .



FILE NAME Al (1100)
VB CERAMICS -THERMAL EXPANSION ONLINE GRAPH
TEMPERATURE 413 EXPANSION 0.054 DATE TIME 10:29:07 AM 31/03/11

Figure. 6 Co-efficient of Thermal Expansion for Pure Al

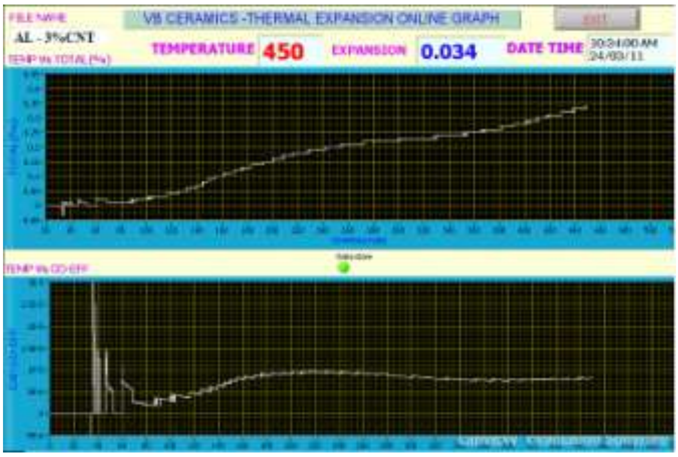
Figure.6 shows that The total percentage of thermal expansion gradually increases up to 0.054 µm/m-ºC for pure Al by increasing the temperature up to 413 ºC



FILE NAME AL - 2%CNT
VB CERAMICS -THERMAL EXPANSION ONLINE GRAPH
TEMPERATURE 441 EXPANSION 0.048 DATE TIME 11:42:06 AM 26/03/11

Figure. 7 Co-efficient of Thermal Expansion for Al- 2%CNT

Figure.7 shows that, the total percentage of thermal expansion gradually increases up to 0.048 µm/m-ºC for Al- 2% CNT by increasing the temperature up to 441 ºC.



FILE NAME AL - 3%CNT
VB CERAMICS -THERMAL EXPANSION ONLINE GRAPH
TEMPERATURE 450 EXPANSION 0.034 DATE TIME 10:34:00 AM 24/03/11

Figure.8 Co-efficient of Thermal Expansion for Al- 4%CNT

From the Fig.8, the total percentage of thermal expansion gradually increases up to 0.034 µm/m-ºC for Al- 3%CNT by increasing the temperature up to 450 ºC

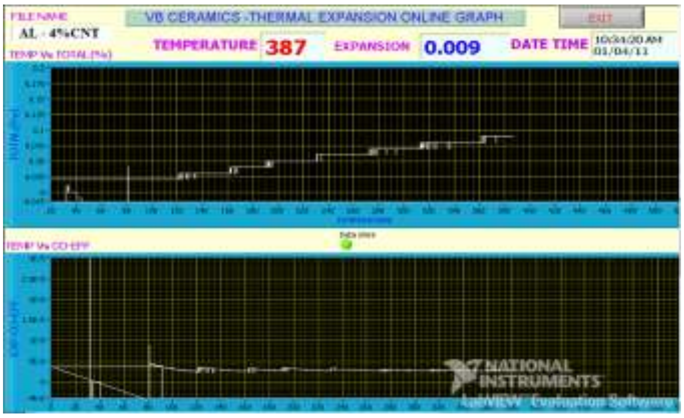


Figure.9 Co-efficient of Thermal Expansion for Al- 4%CNT

Figure.9 shows that, the total percentage of thermal expansion gradually increases up to 0.009 µm/m-ºC for Al- 4% CNT by increasing the temperature up to 387 ºC.

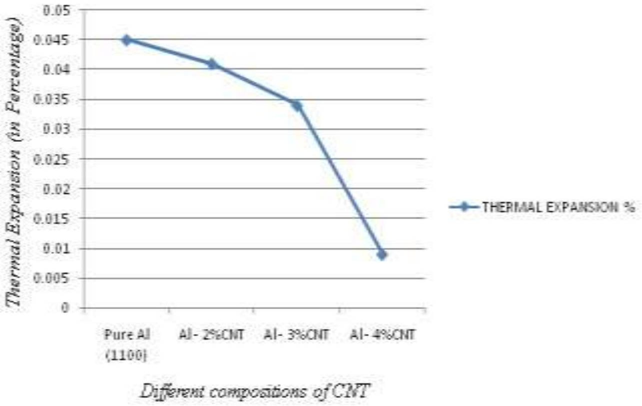


Figure.10 Comparative line chart for CTE with different compositions of CNT

S.NO	***MATERIAL COMPOSITION***	***CTE µm/m-ºC***
1	Al	0.045
2	Al + 2% CNT	0.040
3	Al + 3% CNT	0.034
4	Al + 4% CNT	0.009

Table.1 Comparison Table for CTE (Al – CNT)

Table .1 and Fig.10, illustrate that with addition of up to 4% of CNT with pure Al, The CTE of the Al-CNT composite decreases by approximately 80%. It has been shown by Ruoff (R.S.Ruoff, 1995), that the radialcoefficient of thermal expansion of CNT is essentially the same as the on-axis coefficient of thermal expansion. This desirable thermal property of CNT could result not only in more thermally stable Al-CNT composites, but also in composites that have isotropic thermal expansion.

In the present work reinforcement of CNT in light Aluminum using melt stirring method. Al with 2% and 4% CNT were prepared. The mechanical and thermal properties of composites were investigated. The Improvement of mechanical properties has-been compared with pure Al. The experimental study reveals following conclusions.

The result of study suggests that with increase in compositions of MWNTs, with Al shows increase in Mechanical properties has been observed.

4. CONCLUSION

In the present work reinforcement of CNT in light Aluminum using melt stirring method. The different compositions of specimens Al with 2%, 3% and 4% CNT were prepared. The mechanical and thermal properties of composites were investigated. The Improvement of mechanical properties has been compared with pure Al. The experimental study reveals following conclusions.
The result of study suggests that with increase in compositions of MWNTs, with Al shows increase in Mechanical properties has been observed.

4.1. Hardness Test

The improved result for hardness has been obtained at Al – 3%wt fraction MWNTs (57 HRB). When compared with pure Al, hardness value increases up to 22% respectively.

4.2. Tensile Test

The improved result for UTS has been obtained at Al – 4%wt fraction MWNTs (65Mpa). When compared with pure Al, UTS increases up to 27% respectively.

4.3. Co-Efficient Of Thermal Expansion

Co-efficient of thermal expansion result indicates that Al – MWNTs, nanocomposite are thermally more stable than pure Al (1100).

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