International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN : 0974-4290
Vol.6, No.3, pp 2057-2059, May-June 2014

ICMCT-2014 [10th – 12th March 2014]
International Conference on Materials and Characterization Techniques

Electrical Conductivity and Thermal Expansion Measurement of Nanocrystalline Aluminum Reinforced with Functionalized Multiwall Carbon Nanotubes

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Abstract: The nanocomposites of carbon nanotube (CNT) reinforced nanocrystalline aluminium (nano Al) was synthesized by the physical mixing method. The structure of the nanocomposites and dispersion of carbon nanotubes (CNTs) in the nano Al matrix was investigated using X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and high resolution transmission electron microscopy techniques (HRTEM). The results of the structural studies showed that the CNTs get homogeneously dispersed throughout the Al matrix. A strong interface created between the CNTs and Al particles was also observed. The coefficient of thermal expansion (CTE) of the nanocomposites with CNT content (0, 0.5 wt %) was measured in the temperature range 25-250 ^{o}C. From which it was found that the CTE decreases with the addition of CNT and reduce to about 80% to that of pure nano Al. The four probe technique was used to measure the electrical conductivity of the nanocomposites at room temperature. The prepared nanocomposite has importance for thermal management applications and aerospace industry.
Keywords: Nanocomposite; Electrical conductivity; Thermal expansion.

Introduction:

Nano Al is an attractive material due to its resistance to corrosion, lightweight, good electrical and thermal conductivities. Al and its composites are used in transmission lines, electronic packaging, mechanical components and thermal management applications. These applications of metal matrix composites require low thermal expansion characteristics. So a low coefficient of thermal expansion (CTE) and high electrical, thermal conductivity material is demanded for packaging and space structures. CNTs are considered as attractive reinforcement for metal matrix composites due to its unique properties (very low CTE ≈0 and high thermal & electrical conductivities) [1, 2].

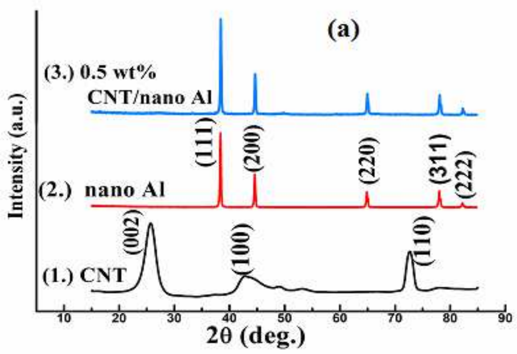
The reports on thermal behaviors of CNT reinforced nano Al composites were limited. Tang et al. [3] reported 65 % decrease in the CTE of single walled carbon nanotube (SWCNT) reinforced nano Al composite. Deng et al. [4] have observed that CTE of 2024 Al matrix decreases by about 12% with the addition of 1 wt% CNT and Adhithan et al. [5] reported 50 % reduction in CTE of 4 wt% CNT reinforced Al composite, indicating that CNTs with an appropriate content can significantly decrease the CTE of metal matrix composites. The present work reports the synthesis, study of microstructure, electrical conductivity and the thermal expansion behavior of nano Al matrix composite reinforced with functionalized multiwall carbon nanotubes (FMWNTs).

Experimental Procedure:

FMWNTs (MWCNT-COOH, Nanoshel, purity 80-90 Vol %) of diameter 20-30 nm and length 5-15 µm and nano Al (Nanoshel, purity 99%) of average particle size 100 nm have been used for synthesis. CNT (0, 0.5 wt %) /nano Al composites have been fabricated by the physical mixing method and followed by cold pressing. The XRD patterns of the powdered samples were recorded with a Panalytical 3050/60 Xpert-PRO using Cu K_α radiation. The microstructure and EDS characteristic profile of the samples was studied using SEM FEI Quanta FEG 450 and TEM JEOL JEM 2100F. Electronic dilatometer NETZSCH DIL 402 PC was used to measure CTE of consolidated samples (Ø 8 x 3 mm pellets) in the temperature range from 25 to 250 ^{o}C at heating rate of 5 ^{o}C /min. The electrical conductivity of the consolidated samples (Ø 13 x 1 mm) at room temperature was measured by four probes and Keithley 6221 source meter.

Results and Discussion:

The XRD scans of the CNT, nano Al and the CNT reinforced composite are shown in fig. 1a. All the characteristic peaks of the fcc crystalline structure of Al are intact in the graph. The (002) graphene peak of CNT is absent in the nanocomposite due to their dispersion in the metal matrix and the very small amount of CNT reinforcement.



(b)

Material	Crystallite Size (nm)	Electrical Conductivity (σ x 10^5 S/m)
Nano Al	45.61	2.01
0.5 wt% CNT/nano Al composite	48.12	2.1

Fig. 1: (a) XRD pattern of the CNT, nano Al and CNT/nano Al composite and (b) Table showing crystallite size and electrical conductivity of nano Al & CNT reinforced composite.

The SEM micrograph of the CNT reinforced composite is shown in fig 2a. Rod shaped CNT is clearly seen in the micrograph and is embedded between the spherical Al particles. The quantitative presence of the CNT (carbon) and Al in the nanocomposite powder is indicated by the EDS characteristics profile of CNT/nano Al composite (fig 2b). The peak at 1.5 keV corresponds to the electron binding energy of Al while a very small peak situated at approx. 0.2 keV corresponds to carbon, indicating the presence of the CNT in the Al matrix. There is another small peak at approx. 0.5 keV corresponding to the electron binding energy of oxygen and is due to the presence of a very thin layer of alumina over the Al particles. HRTEM image (fig 2c) of the nanocomposite shows the homogeneously and singly dispersed CNTs in the Al matrix. The CNTs are properly embedded between the Al particles and is well connected the matrix, leading to a strong interface between the CNTs and Al particles.The measured electrical conductivity values of nano Al and CNT reinforced nanocomposite at room temperature are listed in table (fig.1b). Conductivities of both materials are almost comparable, but are 1000 times less than reported by Xu et al. [6]. These values are less due to nanosized Al, the presence of a thin layer of alumina and surface scattering of electrons at the CNT/nano Al interface.

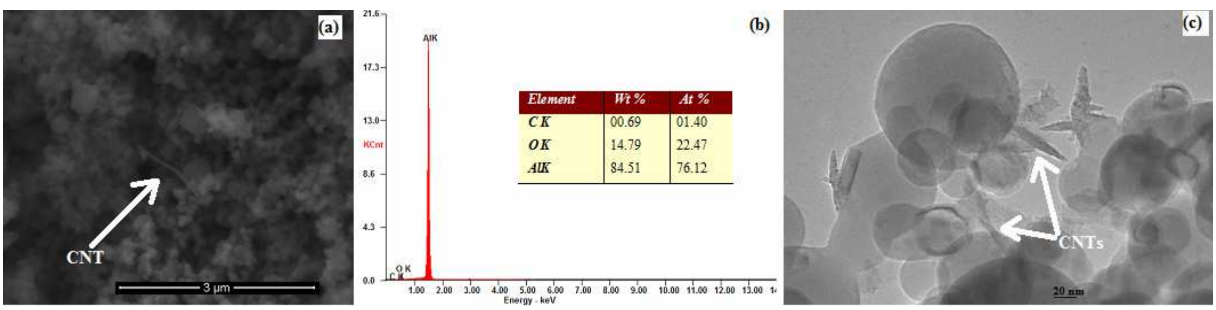


Fig. 2: (a) SEM image, (b) EDS characteristic profile, (c) HRTEM image of 0.5 wt% CNT/nano Al composite.

It can be seen from fig. 3a that TLC of both materials increases with increasing temperature, whereas the slope for nanocomposite curve is smaller than that of pure nano Al. It was found out that the TLC of CNT reinforced composite is 10.13 x 10^{-3} times less than that of pure nano Al.

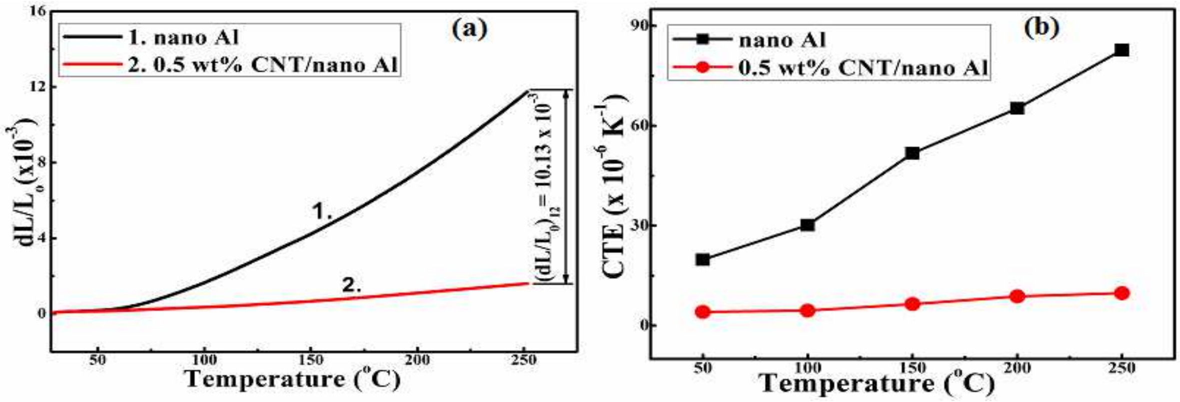


Fig. 3: (a) Thousandth linear change (TLC) vs. temperature plots and (b) CTE vs. temperature for nano Al and CNT/nano Al composite.

The CTE is calculated at an interval of 50 °C from the linear fitting of the TLC vs. temperature curve and is shown in fig. 3b. The CTE of nanocomposite decreases by about 75-85 % compared to that of nano Al in the measured temperature range. The reduction of CTE of the nanocomposite can be attributed to that fact that CNTs have very low intrinsic thermal expansion (CTE≈0). These results are in good agreement with the various theoretical models [7] that the CNT/metal interfaces effectively restrict the thermal expansion of metal matrix.

Conclusions:

Through the physical mixing method CNTs were well embedded, dispersed in the metal matrix and have strong interface with nano Al. CNT reinforcement has not shown a significant effect on the electrical conductivity of the nanocomposite but, has effectively reduced the CTE of the nano Al matrix and it reduces to about 75-85% of that of pure nano Al. This reduction is due to CNT/nano Al interface, which effectively restricts the CTE of the metal matrix.

Acknowledgements:

The authors would like to thank DRDO for the financial support to carry out this research work under the project grant [Project No.–ARMREB/CDSW/2011/135].

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