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Modeling and Analysis of Strengthening Mechanism of MWCNT Reinforced Copper Matrix Nanocomposites by using Shear Lag Model

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***Abstract*---Young's modulus of carbon nanotubes is approximately 1 TPa. Hence an ideal reinforcement material for composites. In order to achieve better mechanical properties in CNTs reinforced metal matrix nanocomposites, understanding of strengthening mechanism is very important. One such model is shear lag model. The model explains load transfer mechanism between matrix and reinforcement. Here Shear lag model is analyzed along with experimental results.**

Keywords----Powder metallurgy route, MWCNT/Cu nanocomposite, Shear Lag model.

I. INTRODUCTION

Since the discovery of carbon nanotubes lot of research work has been carried out by researchers and scientists due to their best mechanical properties such as strength, stiffness, electrical conductivity and thermal conductivity. No material is available till today known to mankind, which can match these above mentioned mechanical properties for carbon nanotubes, for both experimental and theoretical results [1 - 6]. From literature Survey and scientist's experimental data it is evident that Young's modulus of single walled carbon nanotubes and multiwalled carbon nanotubes is in the range of 1 to 5 TPa. This is one of the major reason for using carbon nanotubes as reinforcement material in composites. Another reason is density. Density of multiwalled carbon nanotubes is nearly 1.8 g/cc which makes them lighter and stronger. But very less research work has been done in metal matrix nanocomposites when compared to polymer and ceramic matrix nanocomposites due to various reasons associated with metal matrix nanocomposites preparation. One among them is wettability of CNTs with metal matrix. To overcome this problem it is very much necessary to understand load transfer mechanism between reinforcement and matrix. Strengthening of metal matrix nanocomposites can be done by understanding load transfer mechanism between matrix and reinforcement, which is well explained by shear lag model. The present work addresses the processing of MWCNT/Cu nanocomposites, measurement of hardness of processed nanocomposites, providing an evidence of existence of wettability problem and explaining strengthening mechanism of nanocomposites by using shear lag model.

II. EXPERIMENTAL

A. Material Used

Multiwalled carbon nanotubes were procured from United Nanotech Laboratory Ltd.. Mechanical characterization XRD and SEM is done to check purity and quality of procured MWCNT. Average diameter of procured MWCNT is 5 - 20 nm and length is 10 microns.

Copper powder is procured and its purity is checked by using XRD characterization technique. Copper particle size is approximately in the range of 35 - 45 nm.

B. Fabrication Of MWCNT/Cu Nanocomposite

Powder metallurgy route technique is used to fabricate MWCNT/Cu nanocomposites. A mixture of MWCNT as reinforcement and copper powder as matrix were ball milled at 200rpm for 2 hrs consisting of 8 cycles each of 15 minutes with 5 minutes gap between each cycle. Along with mixture, few drops of ethanol is used for dispersion of MWCNT reinforcement in copper matrix and to avoid agglomeration of MWCNT. The milled powder was compacted in a circular die. And a 10 ton force is used to compact powder mixture. Then green compacted billet is sintered in an oven at 850 °C for 3 hours. No secondary operation is carried out. But turning and facing is done to remove oxide layer formed during sintering process and to get accurate required dimensions. Oxide layer is formed because sintering is carried out in an open air oven. EDX and SEM characterization technique provide proof for presence of MWCNT in sintered MWCNT/Cu nanocomposites.

III. RESULTS AND DISCUSSION

Quality and purity of procured MWCNT is validated by XRD and SEM given in figure 3.1 and 3.2 respectively. Copper quality is ensured by XRD given figure 3.3.

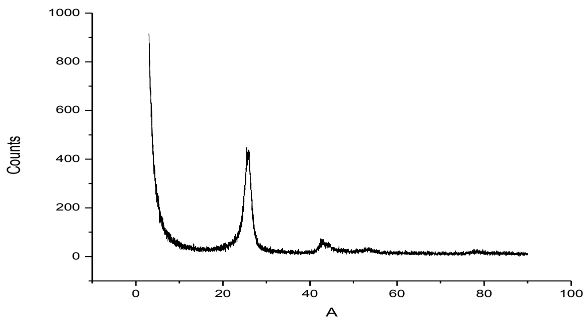


Figure 3.1 XRD of MWCNT
(Procured form United Nanotech Laboratory Ltd.)

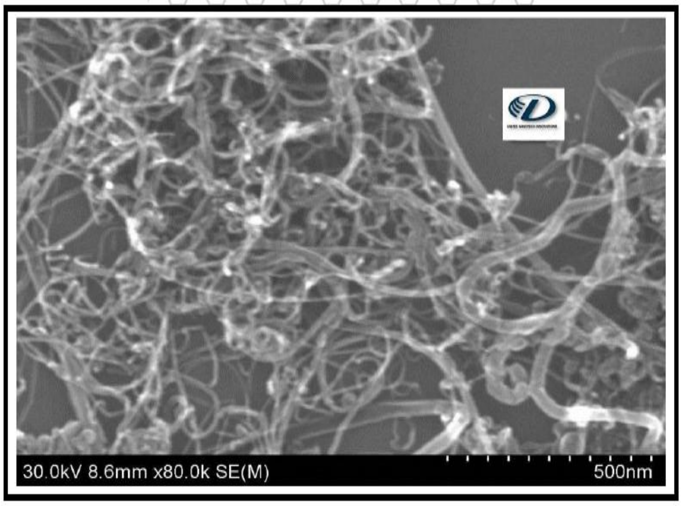


Figure 3.2 SEM of MWCNT
(Procured form United Nanotech Laboratory Ltd.)

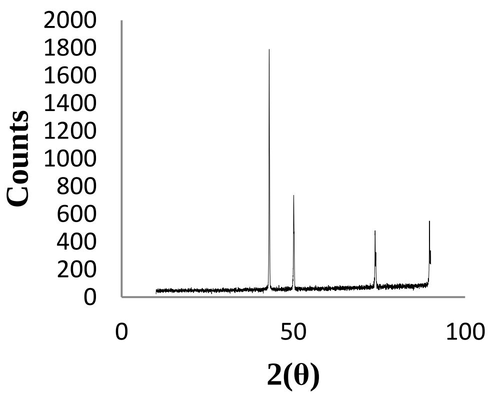
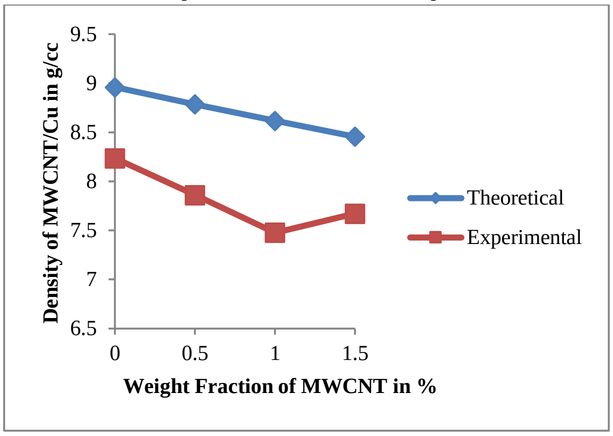


Figure 3.3 XRD of Procured Pure Copper

Density of prepared MWCNT/Cu nanocomposites samples were calculated by measuring weight and volume of the samples manually and from manually calculated density porosity of the samples calculated which given in Table 3.4 and respective graph is given in graph 3.5. Porosity is resulted because no secondary operation is carried out.

Weight fraction in %	Volume Fraction in %	Theoretically Calculated Density of MWCNT/Cu nanocomposite in g/cc	Experimentally Calculated Density of MWCNT/Cu nanocomposite in g/cc	Relative Density in %	Porosity in %
Pure	-	8.96	8.234836	91.906651	8.093348
0.5	2.391564	8.785271	7.86	89.467928	10.532071
1.0	4.691625	8.617226	7.476303	86.7599	13.375594
1.5	6.905337	8.455489	7.671666	90.730009	9.269990

Table 3.4 Showing Density of MWCNT/Cu nanocomposite and Porosity of Prepared MWCNT/Cu nanocomposite



Graph 3.5 Theoretical Density vs. Experimental Density

Shear Lag Model

This model explains the load transfer between matrix and reinforcement by interfacial shear stress as shown in figure 3.6. High aspect ratios are favored with this model but aspect ratio higher than 500, no significant effect on the strength of nanocomposites. Aspect ratio of MWCNT are in the range of ~100. From experimental results as sown in Table 3.7 and Graph 3.8 it is evident that the results were not up to the mark and not as expected by this model. And from the analysis of experimental results shown in Table 3.7 and Graph 3.8 it is evident that wetting of the MWCNT is the reason behind low experimental results of nanocomposites. From analysis it is evident that wetting is reason and it is found that the wettability problem is caused due to huge difference between surface tension of matrix and reinforcement. Surface tension for aluminum and copper is 600 and 750 mN/m.

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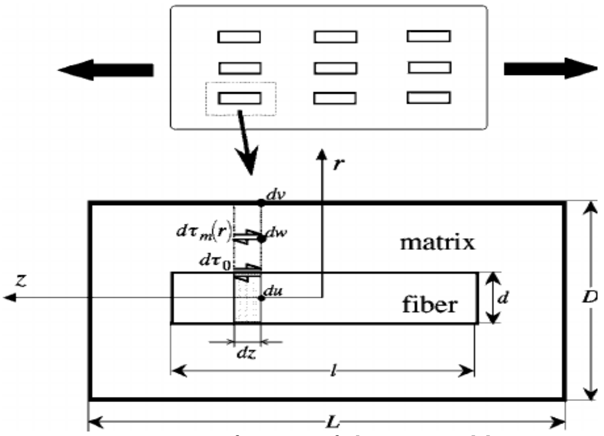


Figure 3.6 Configuration of Shear Lag Model

The Young's modulus of nanocomposites by Shear Lag Model is given by

$$E_c=V_f*E_f*(1 - (\tanh(n*s))/(n*s)) + (1 - V_f) * E_m$$

Where,

E_c - Young's modulus of nanocomposites in GPa

E_m - Young's modulus of matrix material in GPa

E_f - Young's modulus of reinforcement material in GPa

V_f - Reinforcement material volume fraction

S - Aspect ratio of reinforcement

n - Constant and is given by

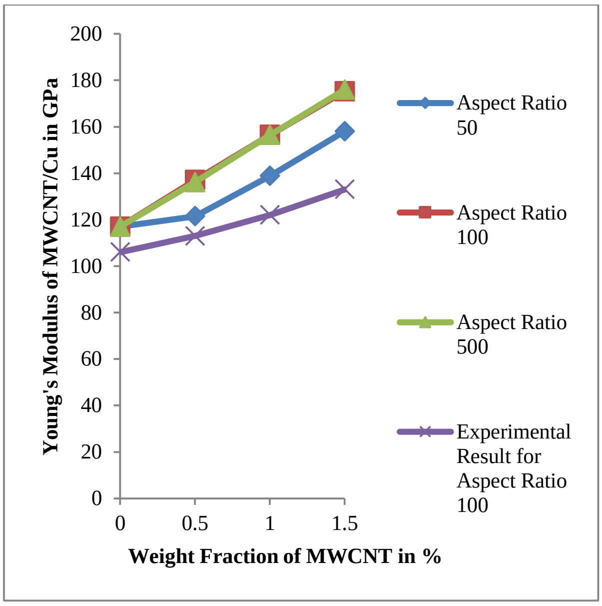
$$n = ((2*E_m)/(E_f*(1+v_m)*\ln(1/V_f)))^{1/2}$$

Calculation from the above theoretical model and experimental data are shown in below Table 3.7.

Commercial purity copper under the same processing and testing conditions shown lesser results than the MWCNT/Cu nanocomposites. Yield strength of nanocomposites is high than pure copper which is calculated from the measured hardness. 1% weight fraction reinforcement shown highest strength. From experimental results, Young's modulus of nanocomposites is less compared to theoretical values. This is mainly due to wetting problem of MWCNT.

Wt. Fraction of MWCNT in %	Measured Hardness in GPa	Predicted Yield Strength in GPa	Shear lag Young's modulus in GPa (For Aspect Ratio 50)	Shear Lag Young's Modulus in GPa (For Aspect Ratio 100)	Shear Lag Young's Modulus in GPa (for Aspect Ratio 500)	Experimental Young's modulus in GPa (For Aspect Ratio 100)
Pure	0.703075	0.234358	117	117	117	106
0.5	0.727642	0.242547	121.4701	137.0117	136.1174	113
1.0	0.729550	0.246516	138.7904	156.4633	156.4268	122
1.5	0.720967	0.177116	158.014	175.2725	175.9739	133

Table 3.7 Shear Lag and Experimental Young's Modulus of MWCNT/Cu nanocomposite



Graph 3.8 Shear Lag vs. Experimental Young's modulus

IV. CONCLUSION

In this chapter the conclusions are made by the result obtained by investigation of MWCNT/Cu nanocomposite. Investigations are carried out by hardness test, prediction of yield strength, Shear Lag model.

- From results it is evident that the experimental Young's modulus of nanocomposites did not met theoretical Young's modulus, calculated by using shear lag model.
- This is mainly due to inefficient transfer of load from matrix to reinforcement material. Mainly caused due to wettability problem of MWCNT. But strength of nanocomposites is increased as MWCNT reinforcement is increased. Strength is higher than pure copper and this can be used as light material in various applications.
- There is no significant effect on strength of MWCNT/Cu for higher aspect ratio
- Density of nanocomposites decreases as reinforcement increases because of density of MWCNT resulting decreased weight of nanocomposites.
- Agglomeration plays an important role in increasing strength of nanocomposites.
- Wettability problem can be improved by coating MWCNT with other materials which are having same crystal structure
- It is evident that aspect ratio higher than or equal to 500 is ineffective on the strength of the MWCNT/Cu nanocomposites.

Finally it is evident that strength of MWCNT/Cu was increased as the addition of MWCNT as reinforcement. But the experimental results were not up to the mark due to inefficient load transfer between matrix and reinforcement explained by Shear Lag model.

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