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Static Load Measurement Using Multi Walled Carbon Nanotubes

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Abstract

Multi-walled carbon nanotubes (MWCNTS) possess extremely attractive mechanical and electrical properties. When any external load is applied on the carbon nanotubes, then the electrical resistance tends to vary through the nanotubes. This change in electrical resistance upon load application is dependent upon the alignment of the nanotubes. In present paper, authors have studied the change in electrical resistance upon static load applications. The measurements indicate that with increase in static load on the nanotubes, the electrical resistance tends to decrease. Considering that the inner structure of these nanotubes is hollow from inside, the vacant spaces allow larger flow of current through them. The experiment has been conducted using a small setup in which nearly 2 to 3mg of MWCNTs was used and static load varied from 0.5kg to 3kg. It has been observed that when the external load increased from 0 to nearly 5MPa, the electrical resistance fell by nearly 67% from 2.5Ω to nearly 1.5Ω. The results obtained during present study are also very useful in estimating the unknown external static loads by calibrating them with change in electrical resistance or current.

Keywords: Static load, nanotubes, electrical resistance.

Introduction

Measurement of unknown external loads has always been a challenge to the scientists. External loads can be both static and dynamic. The load calibrating or measuring devices need to have a proper response time as per the type of load which they have to measure. External load measurements are calibrated by using different types of strain gauges and sensors. The primary aim of such sensing devices is always to pick up the effect of external load by a change in dimension. This dimensional change can further be calibrated in the form current, capacitance, resistance etc. Over the years, many devices have been used for such calibrations [1]. Scientists have used different types of materials [2] due to their electrical conducting properties with change in load for such calibrations.

Ever since the discovery of carbon nanotubes [3], scientists have shown great interest in exploiting their extremely attractive mechanical and electrical properties [4]. The unusually high mechanical strength of the carbon nanotubes, revealing them as about 100 times stronger than steel, motivates us to fabricate and modify other useful materials(polymers, ceramics and metal) which are cheaply available in bulk form by embedding carbon nanotubes in them. For mechanical engineering applications, both static [5] mechanical properties like hardness, tensile and compressive strength etc. and dynamical [6] properties like impact strength that are of great significance. As far as their use for electrical properties is concerned, they exhibit the property of change in band gap [7] with change in applied pressure. This leads to a change in their electrical resistance and hence the load variations can be suitably calibrated. The hollow structure of carbon nanotubes also contributes to the change in electrical resistance [8, 9] with variation of applied load. MWCNTs have been used in different forms to measure external loads and pressures. They can be combined with other surfaces as strain gauge materials or even used in direct form to calibrate pressure variations. It was observed that electrical resistance fell significantly by more than 50% when external pressure was increased from 0GPa to nearly 4GPa.

In this paper, the authors aim is to measure the known static load/pressures by using a small setup in which small portions of MWCNTs are used. The known external loads are used to compress the MWCNTs and the electrical resistance is measured across the MWCNTs through an applied voltage. This variation in electrical resistance depends upon the change in external static load.

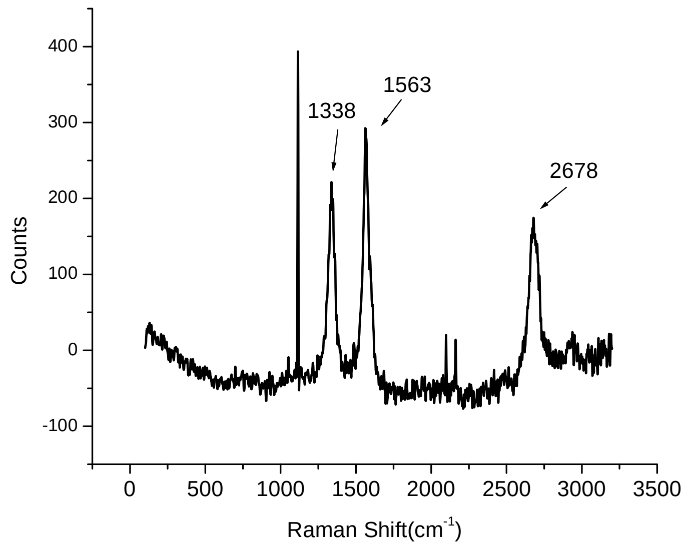

Fig. 1 Raman spectra for MWCNTs with D (1338/cm) peak, G (1563/cm) and G' (2678/s) peaks

Calibration setup

MWCNTs with size 10-30nm diameter and length 1-10μm were taken up in small proportions (2mg to 3mg) to be used in the calibration setup. These were characterized using Raman spectroscopy. Fig. 1 indicates Raman spectra which was used to validate the purity of MWCNTs and the presence of D, G and G' peaks confirm and validate the MWCNTs. The setup used by the authors for current study has been shown schematically in Fig. 2. There is a cylindrical cavity with diameter 6mm. MWCNTs are placed inside this cavity which are pressed by a copper metal road. The known static load is placed on this rod which ultimately presses the MWCNTs. The depth of the cavity is adjustable up to 10mm which was fixed to 6mm for this experiment. The pressing of MWCNTs by the static load causes a change in electrical resistance across the two copper metal rods as depicted in Fig. 2.

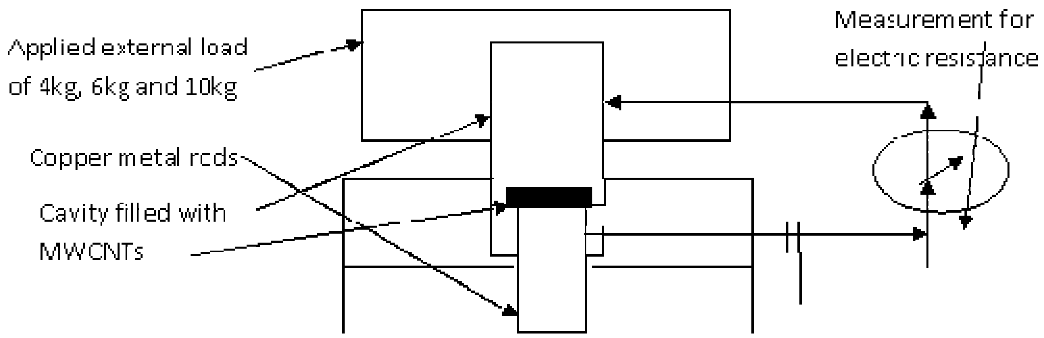

Fig. 2 Schematic diagram of the load-resistance calibration setup

Experimental procedure

Static load in steps of 4kg, 6kg and 10kg had been applied on the top end of the setup. The electrical resistance has been measured using a standard multi-meter across the metal rods. As these static loads have been applied on the top end of the upper rod, the same rod pressed the MWCNTs lying inside the cavity. As a result of this load change, a change in electrical resistance has been obtained in the multi-meter which has found to be reversible even when the load was decreased in steps. This indicated correctness in the experimental procedure and hence, the amount of MWCNTs inside the cavity was not changed. The response time for the reading in the multi-meter to stabilize has been observed nearly 1-2 seconds which was also sufficient for static load measurements.

Results

Fig. 3 indicates the variation of electrical resistance with change in external applied pressure. The results for electrical resistance remain within limits of 5% error bar for every value of applied external load/pressure. From this figure we can clearly observe a sharp fall by nearly 50% in the electrical resistance due to change in pressure from 0 to 6.5MPa. However, for further increase in external pressure from nearly 6.5MPa to

9.8MPa, the electrical resistance fell by only 15% indicating gradual saturation. However, a better scale with lower least count of the measuring multi-meter can be used to obtain better values. Similar reversible values were obtained when the loads were gradually reduced from 10kg towards 4kg.

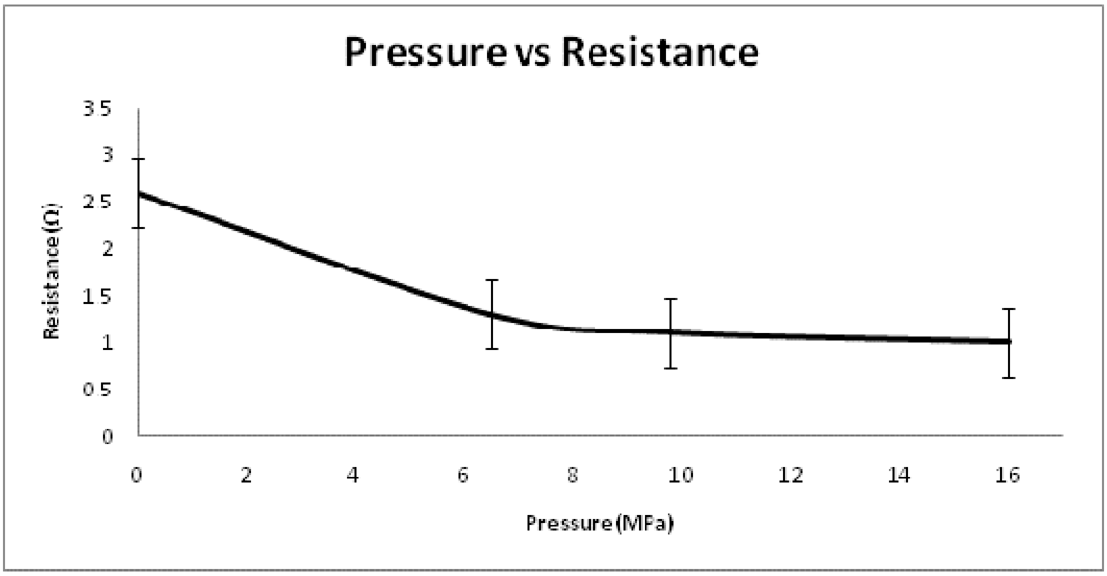

Fig. 3 Variation of electrical resistance with change in applied external pressure

Therefore, this experiment also validated the property of the carbon nanotubes that when load is increased, resistance decreases or current passed through the nanotubes [8].

Conclusions and Discussion

This experimental work has shown extremely interesting results related to the material properties of MWCNTs. The authors have observed that electrical resistance falls with increase in applied external load, which means that there is reduction of band gap among the carbon nanotubes. This reduction of band gap has also been established earlier by [7]. The results of current experiments show the reversibility for static loads of nearly 4 to 10kg by using minor amounts of MWCNTs. The suggested reason for the large initial fall in electric resistance is that compaction of the carbon nanotubes takes place when it is loaded for the first time, subsequently as load is increased the compacted nanotubes already possess a reduced band gap due to which the fall in electrical resistance is lesser. This work is significant considering that a small setup has been fabricated to present a prototype model based on which further investigations for very small and very large static load measurements can be done. MWCNTs can further be used in the form of polymer composites which will make them stiffer to pick up major changes in load only.

Overall, this experiment can be performed for larger variations of static as well as dynamic load. Large data base can assist this application for a wider application scope where unknown external loads need to calibrated with respect to change in electrical resistance and hence small and compact load sensors can be developed.

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