Mechanical Characterization of Varying Deposits of MWCNTs on Glass Surfaces under High Strain Rate Loading

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Abstract- Disc shaped glass specimen with 10mm diameter and 5mm thickness were coated with variable deposits of Multi-Walled Carbon Nanotubes (MWCNTs) and characterized for dynamic mechanical strength using Split Hopkinson Pressure Bar(SHPB) under high strain rate loading of 2500/s. The experimental stress- strain results for these specimens were correlated with polynomial and Gaussian fit expressions using Least Square Fit techniques. These equations were based on the experimental results which varied with change in coating thickness and deposits of MWCNTs on the glass surfaces. Cubic polynomial equations using least square fitting were reasonably close to the experimental results for stress- strain variations for different MWCNT deposits. Experimental results for maximum stress variation with MWCNT deposits also matched well with Gaussian fit. In this way, simple generalized expressions were generated which could be used to predict stress strain behavior of various deposits of MWCNTs on glass surfaces under dynamic impact loading with strain rates of nearly 2500/s. As these equations, correlated well with the experimental results therefore, these can be used for coated specimen which are yet to be conducted for dynamic loading experiments under similar conditions and hence save on the experimental cost.

Index Terms- Glass coatings; Polynomial; Gaussian; Least Square Fit; Mechanical properties.

1. INTRODUCTION

Ever since the synthesis of carbon nanotubes (CNTs) [1] and study that followed exploring mechanical and structural properties of CNTs [2]–[4] there has been wide ranging interests in scientific and engineering communities to exploit these for varying applications[5], [6]. These CNTs are often used as filler materials in composites and coated materials. Due to the exceptional mechanical properties of CNTs, the mechanical characterization of the composites and coated materials comprising them have been of significant interest among scientists over the past few decades. Considering that experimental procedures for evaluating static and dynamic mechanical strength of composites and coated materials are very costly and time consuming, various simulation and modelling techniques using Molecular Dynamics(MD) computations and Finite Element Modelling(FEM) have been widely used over the years [7], [8]. MD is limited to nanoscale and is costly in terms of computational inputs, which has promoted the development and usage of alternate approaches for characterizing CNT reinforced composites at microscale. Similarly, FEM [9], [10] is used to validate the data on CNT reinforced composites. Simple least square fitting techniques and generating polynomial expressions to fit the experimental results for mechanical strength evaluation have also been studied for various compositions of CNT based composite materials and provided very useful results[11].

In our recently published work[12], we observed the enhancement in stress absorption capacity of glass specimen which were coated with various deposits of MWCNTs. It was observed that a variation in the coated amount of MWCNTs of 0.1mg and 0.2mg on clear glass surface enhanced the dynamic stress by 50% to 70% in comparison to the pure/uncoated glass specimen. However, deposits of MWCNTs beyond this amount showed considerable decrease in dynamic strength. Estimated coating thickness equivalent to 0.1mg and 0.2mg MWCNTs coatings was nearly 12µm and 25µm respectively.

This experimental work required lot of sample preparation procedures and the mechanical characterization was performed using SHPB. For every test run, nearly 8 to 10 samples were prepared and therefore it involved lot of time and experimental cost consumption. Hence, we worked on formulating some simple mathematical expressions which could help us in saving time and experimental cost and at the same time assist us in evaluation of mechanical properties for different deposits of coatings of MWCNTs on plain glass surfaces.

2. ANALYSING DYNAMIC STRESS-STRAIN DATA

The stress-strain data using SHPB was obtained for a wide range of strain rates (500/s to 3300/s) for all samples but we compared the samples which were limited to a strain rate of 2300/s to 3000/s. This strain rate is a useful range in normal shock conditions, encountered during aviation and defense requirements.

A cubic polynomial expression was generated for the stress strain variation for different coated specimen as given in equation (1) which matched with the experimental stress strain behavior of various MWCNT coated deposits on glass surfaces as shown in Fig.1

$$y = Ax^3 + Bx^2 + Cx + D \quad (1)$$

Here, y is the stress (MPa), x is the strain(%) and A,B,C and D are constants depending upon coated deposit of MWCNTs. Table-1 relates these constants for the cubic polynomial expressions of equation (1) with various MWCNTs deposits and the stress-strain variation for various compositions have been plotted in Fig.1 accordingly.

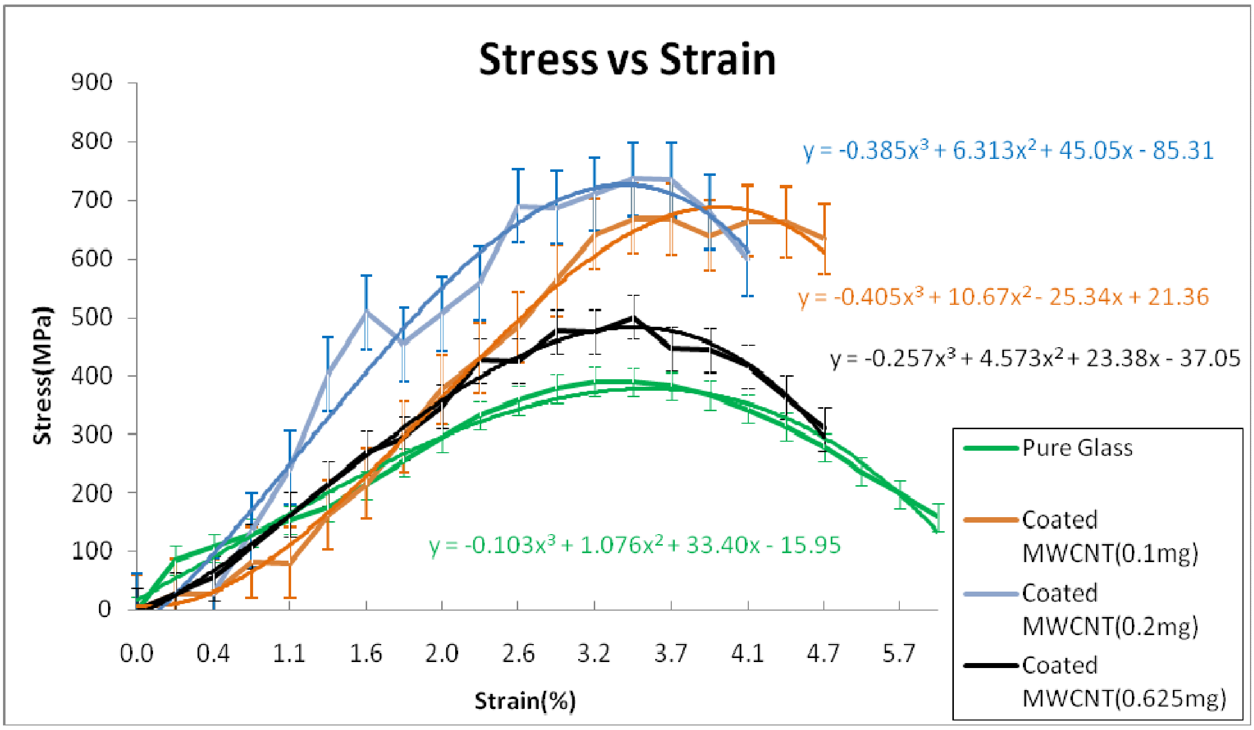

Fig.1 Variation of stress strain for different amounts of coated glass pieces with MWCNTs subjected to strain rates of nearly 2500/s obtained experimentally with standard error bars and continous curve variations indicate polynomial expressions for the same coated specimen.

In order to obtain the stress strain behavior for different coating deposits of MWCNTs on glass surface, values of A, B, C and D are required for each coated amount of MWCNTs. The variation of A, B, C and D with different deposits of MWCNTs was formulated using cubic polynomial expressions as given in equations (2),

$$y = \alpha x^3 + \beta x^2 + \gamma x + \delta \quad (2)$$

where y is the value of the respective constant(A, B , C and D) and x is the coated deposit of MWCNTs in milligrams. α, β, γ and δ are constants depending upon the respective values of A, B, C and D which are provided in Table-2.

Table-1: Values of constants A, B, C and D for various MWCNTs coated deposits on glass surface satisfying the polynomial expression $y = Ax^3 + Bx^2 + Cx + D$.

A	B	C	D	MWCNT coated deposit (mg)
-0.1038	1.076	33.402	-15.957	0
-0.405	10.678	-25.342	21.364	0.1
-0.385	6.313	45.054	85.316	0.2
-0.144	2.095	36.492	-16.78	0.385
-0.257	4.573	23.381	-37.053	0.625
0.033	-3.928	94.364	-123.55	0.75

Table-2: Values of constants α, β, γ and δ for various values of A, B, C and D satisfying the polynomial expression $y = \alpha x^3 + \beta x^2 + \gamma x + \delta$

α	β	γ	δ	Constant
-31.7	25.6	- 5.3	- 0.1	A
2003.9	- 1,299.5	205.9	1.1	B
23608.9	13,539.7	- 1705.3	33.4	C
14316.5	5,626.5	- 46.3	- 16.0	D

These values match fairly well for deposits upto 0.385mg (thickness 49µm) indicating that we can obtain the stress strain values for deposits of MWCNTs upto 0.385mg on glass surfaces. For larger coating deposits, some other expressions need to be formulated as these expressions do not fit well.

Glass being a brittle material does not undergo large elastic strain, therefore rather than evaluating maximum deformation and stress for that deformation, we evaluate maximum elastic stress exhibited for different MWCNT coatings. Experimental results showed that maximum stress was achieved for a coated deposit of 0.2mg of

MWCNTs on glass surface. In order to predict the variation of maximum stress with coated deposit using mathematical expressions, a Gaussian fit was used as given in equation (3) which matched the experimental results fairly well as shown in Fig.2.

$$y = y_0 + \frac{A}{w\sqrt{\pi/2}} e^{-\frac{2(x-x_c)^2}{2w^2}} \quad (3)$$

where y is the maximum stress(MPa) , x is the deposit of MWCNT coating in milligrams, y_0 =472.86, w=0.19196, A=68.08 and x_c=0.21.

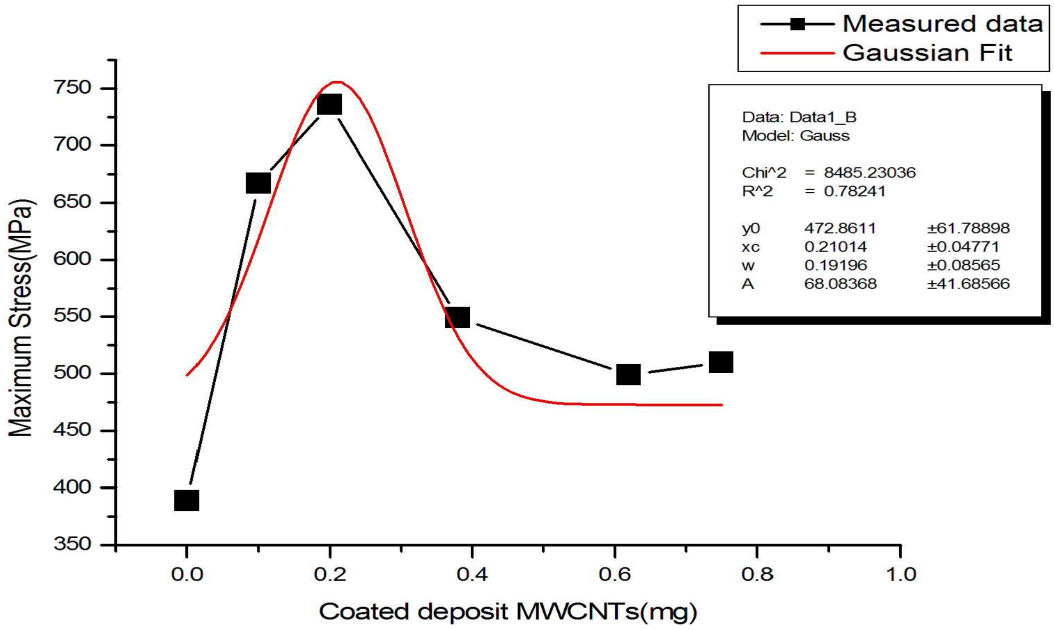

Fig.2 Maximum stress variation with different coated MWCNTs-glass samples subjected to strain rates of nearlty 2500/s both experimentally and Gaussian fit.

3. SUMMARY AND CONCLUSION

Dynamic mechanical strength of disc shaped glass pieces (10mm diameter and 5mm thickness) with variable deposits of MWCNTs on the glass surfaces was evaluated using SHPB at a strain rate of nearly 2500/s. It was observed that a coated deposit of 0.1mg (thickness 12µm) and 0.2mg (thickness 25µm) enhanced the impact strength of coated specimen by nearly 50% to 70% in comparison to pure glass surfaces. A reduction in strength was observed for deposits beyond this amount of MWCNTs. The suggested reasons for this reduction were slipping of MWCNTs layers among each other for large compositions[12]. The experimental results of these specimens were correlated with simplified cubic polynomial expressions and Gaussian fit expressions using Least Square techniques. These expressions matched fairly well with the experimental data and hence provided an easier method to evaluate stress strain behavior for a wide range MWCNTs coated deposits on glass surfaces. A polynomial expression in the form of $y = Ax^3 + Bx^2 + Cx + D$ matched with the stress strain behavior of various coated specimen under a high strain loading of 2500/s while a Gaussian fit $y = y_0 + \frac{A}{w\sqrt{\pi/2}} e^{-\frac{2(x-x_c)^2}{2w^2}}$ matched with experimental data of maximum stress variation with different coated deposits of MWCNTs. Thus, we obtain simple mathematical expressions to evaluate dynamic mechanical strength under high strain rate loading for an MWCNT coating range upto 0.385mg (thickness 49µm) on plane glass surfaces. For deposits beyond this coated amount these polynomial expressions do not fit well. So, further investigations and formulations are needed to generate expressions that fit the experimental data for MWCNT coated deposits more than 0.385mg on glass surfaces under high strain rate loading. However this study provides very useful and simplified expressions for evaluating dynamic mechanical strength of minor coating deposits of MWCNTs on glass surfaces which is significant as these compositions are sufficient to enhance the strength by more than 50% in comparison to pure glass surfaces. This study is significant for the future considering applications where base material surfaces need protection from external impacts by implementing very thin, light weight but strong coating materials.

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