ABSTRACT

Strong, tough, protective and impact resistant materials which are cost effective and easily workable are required for several engineering applications in daily life, industries and defense. In order to address this problem, present work has been undertaken which was inspired and motivated by the sudden availability of new and novel materials in the form of carbon nanotubes, whose mechanical properties are extremely interesting. These materials have been exploited by making composites with other materials like polycarbonates, as well as by coating them over glass to enhance their dynamic and static strength by adding protective layer over glass.

This research work reports fabrication methods adopted by us to produce light weight materials and propose their utility for various mechanical engineering applications by characterizing them for impact mechanical strength, hardness and modulus.

We fabricated two types of materials- one as a composite material and the other as a coated specimen. In both cases, we used as synthesized- Multi Wall Carbon Nanotubes (MWCNTs) as a filler to be used as minor component. MWCNTs possess excellent mechanical properties. For fabricating the composite, we chose the base matrix polycarbonate (PC) which is a polymer containing carbonate group and is of great commercial interest because PC being soft and light weight, can be easily worked upon, molded and thermoformed. So our main goal was to modify PC by embedding MWCNTs in them. Similarly, glass based specimen were also modified by coating them with different amounts of MWCNTs layers. These coatings could serve as excellent materials to resist impact loads and protect the glass surfaces. We used simple chemical methods to fabricate composites and coated samples. We also used certain characterization techniques to validate the composition of these composites. The properties of the composite and coated materials were extensively studied by methods commonly employed for mechanical characterization.
Composites of PC with varying concentrations of MWCNTs as well as layered coats of MWCNTs over glass surface and studied for i) their dynamic load testing using Split Hopkinson Pressure Bar (SHPB) giving dynamic load response of the specimen in the form of stress-strain diagrams, and ii) their static load response by using Nano-indentation technique. These experiments indicated on how the composition of MWCNTs affects the modulus and hardness of the composite specimen. In addition, as an analysis, generalized expressions were also generated to relate dynamic and static properties with MWCNTs' compositions in PC by using least square fittings to express all the experimental results in terms of polynomials.

Finally, a model for pure PC and MWCNT-PC composite was suggested to realize how the mechanical properties were affected by concentration variation. This model used a simple Lennard Jones interacting potential between different PC-PC and PC-MWCNT molecules through atom-atom interactions. This gave us a numerical estimate of total cohesive energy of pure and varying concentration of composites as a function of intermolecular separation. Various static properties like equilibrium densities, cohesive energies, bulk and elastic modulus were obtainable which broadly interpret observed behavior.

In the following, we present a summary of each of the Chapters for a quick overview.

After giving an Introduction in Chapter-1, in Chapter-2, we cover the methodology behind MWCNT-PC fabrication. For composite preparation, we took the base material as PC. A simple technique of solution blending was adopted for preparing composites of MWCNTs and PC. We obtained compositions of 0.1, 0.5, 0.75, 1.0, 2.0, 5.0 and 10.0 wt % of MWCNTs in PC. These solutions of different compositions were then stirred to form a uniform dispersed solution which were then poured in separate glass petri dishes for drying. After drying, we obtained thin films of nearly 0.2mm thickness and each film was molded into a disc shaped specimen of diameter 10mm and height 5mm by pressing the films in a compression moulding machine. This fabrication technique can be used to obtain compositions of various other compositions and shapes.
In Chapter-3, we present the high strain rate loading procedure adopted on composite samples fabricated by us. Before testing composites for impact and static load testing, these were characterized using Raman spectroscopy and Scanning Electron Microscopy (SEM). These were then subjected to high strain loading using SHPB. Such type of loading is generally encountered during explosions. After analyzing the data for all the composites comprising different MWCNTs composition we found out that for a strain rate of nearly 2500/s, the stress resistance for composites comprising 0.1wt% to 2wt% MWCNTs enhanced consistently in comparison to pure PC. For a composition of 0.5wt% and 1wt% this enhancement was about 20% higher in comparison to the resistance offered by pure PC specimen for minor (10% to 20%) deformations. Similarly, specimen comprising of functionalized-MWCNTs as reinforcement in MWCNT-PC composites were also tested and the resistance offered by these composites was compared with composites comprising of as synthesized-MWCNTs. It was observed and suggested, that although functionalized MWCNT fillers have stronger bonding with PC but they did not enhance the stress resistance under impact loads because of their shorter length and most of the impact load is taken up along the lengths of MWCNTs.

Apart from this, another important aspect was studied, which indicated that maximum and elastic deformation of the composites increased with increase in strain rate. This pattern was analyzed for samples of pure PC and with 0.1wt%, 0.5wt% and 1wt% MWCNT-PC compositions. All these samples indicated same behavior of increase in both elastic and maximum strain. This information provides important information in the context that for specific strain rate, the maximum deformation that the specimen undergoes can also be estimated. Our SHPB experiments on composites revealed that minor compositions (0.5wt% to 2wt%) of MWCNTs in PC enhanced the strength so that PC can be used high strain rates specifically for defence and aviation related applications.

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Apart from composites, we also fabricated coated samples. This sample preparation process has been discussed in Chapter-4. We took the base material as boro-silicate glass of the same disc shape as 10mm diameter and 5mm thickness. After properly cleaning the glass surface, different amounts of dispersed MWCNTs were poured over their surface and dried. This resulted in forming a coat of variable thickness on the glass surface. We obtained different samples, with MWCNTs coating thickness in the range of 12 μm to 95 μm. This method can be used to fabricate coated samples of variable thickness and layers that comprise of random orientation of MWCNTs.

In Chapter-5, we discuss the high strain rate loading on coated glass samples. These impact tests were similar to the ones performed on composites earlier. The results obtained from the impact studies revealed that for a strain rate of nearly 2500/s, minor coatings (0.1mg to 0.2mg) of MWCNTs enhanced the maximum stress resistance in comparison to pure glass surfaces, exhibiting 50% to 70% increased stress resistance. However, for thicker coatings this resistance reduced and remained nearly constant in comparison to 0.2mg of coatings. This stress resistance was still 30% higher in comparison to the stress resistance offered by pure glass surface.

Chapter-6 elaborates the static strength testing on composites. For static strength, we used a Hysitron T1 950 TribolIndentor which evaluates elastic modulus and hardness of the specimen. Using a Berkovich tip which is a standard three sided pyramidal probe, the area and height of the indent caused resulted in a measure of hardness and elastic modulus directly. We observed that for minor compositions of MWCNT-PC composites there was improved elastic modulus and hardness by nearly 50% in comparison to pure PC. Hardness increased consistently till 5wt% MWCNTs composition but beyond that it began to saturate and remained almost constant till 10wt% MWCNT composition.

Chapter-7 has been devoted to analyzing the results obtained in earlier chapters by understanding general trends and making statistical polynomial fits to various data relating to dynamic stress-strain at various concentrations of MWCNTs by the method of least square fitting.
Most results have been wonderfully expressed in terms of expressions. The chapter then reports the results of a theoretical model for composites. Our proposed simple model is based on the assumption of a potential between constituent PC-PC or PC-MWCNT or MWCNT-MWCNT molecules interacting via their constituent atoms. We obtained an expression for total energy of the composite at various inter-particle separation distances and accordingly a minimum energy configuration was also obtained. The minimum energy configuration gave us shape of the potential function whose second derivative with respect to inter-particle distance gave us Young’s modulus. Thus we were able to model density, Young’s modulus and the energy of the composites with respect to their configuration. It was noted that this model was able to qualitatively interpret the properties of bulk PC and its composites reasonably well.

Our aim was to understand in a simple way if the strength of the composite material gets modified in the manner the experimental observations were made. As an initial step this calculation provides enough insight into the problem. The proposed model and procedure can be further refined to optimize the observed static and dynamic loading results for various mechanical applications.

The thesis findings have been summarized in Chapter-8 and concluded with the hope that all the experimental work reported here will motivate applications for using the suggested low cost and simple to produce composites for applications in various fields. It is also hoped that more theoretical work will be generated in the future to provide insight into the dynamic strength enhancement effects and lead to successful development of a pressure sensing and energy absorbing device.