Chapter 2
Fabrication of Composites and Coatings

Among the thermoplastic group of polymers, polycarbonates (PC) have attracted a great deal of attention due to their ability to be easily worked upon and moldability. Figure 2.1 gives the general structure of PC. Their capability to resist temperature and impact makes them a common application material in housewares, laboratories, and industries. Therefore, any modification in their properties to suite specific requirements becomes interesting.

Polycarbonates are lightweight and smooth materials. Their softness and low scratch resistance makes them vulnerable for certain load-related applications. Some of their mechanical properties have been given in Table 2.1. Polycarbonate has a glass transition temperature of about 150 °C. When heated beyond this point, it softens gradually and begins to flow above 300 °C. PC undergoes large plastic deformations and does not break easily, which is a suitable property for any engineering application.

Other polymers like polymethyl acrylate (PMMA) are brittle and suddenly break even at room temperature. Lot of enclosures, bottles, glass cases, lenses, etc., are fabricated using PC. Polypropylene (PP) does not shrink uniformly so it is difficult to achieve accurate fabrication.

Just like polymers, glass has been widely used over the years for many applications. Window panes are one of the commonest applications of glass. Major component of glass is silica. Glass is of various types like soda lime, borosilicate, optical glass, etc. Their Young's modulus varies between 40 and 75 GPa, and Vickers hardness number is about 700 Vickers. Despite its various uses, it has some limitations. Glass is very brittle and susceptible to heavy loading. An attempt to modify its brittle behavior and increase its load-bearing capacity needs to be explored either by embedding strong fibers inside or by coating it. Borosilicate is a type of glass that is widely used for laboratory glassware. Some properties of borosilicate glass are given in Table 2.2. Borosilicate glass has excellent thermal properties with its low coefficient of expansion and high softening point.

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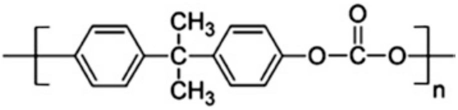

Fig. 2.1 General structure of a PC molecule

Table 2.1 Properties of polycarbonates

Property	Value
Young's modulus	2.0–2.4 GPa
Tensile strength	55–75 MPa
Poisson's ratio	0.37
Thermal conductivity at 23 °C	0.19–0.22 W/mK
Density	1,200 kg/m^3

Table 2.2 Properties of borosilicate glass

Property	Value
Density	22.3 kg/m^3
Specific heat (20 °C)	750 J/kg °C
Thermal conductivity (20 °C)	1.14 W/m °C
Poisson's ratio (25–400 °C)	0.2
Young's modulus (25 °C)	64 GPa

Resistance to acid, solvents, and other solutions is also high although some acids can cause rapid corrosion also. In several defense vehicles, glass window panes are used. Toughened glass is one of the strong materials, but it is very heavy in weight. So, for protecting man power inside the vehicle, the glass itself can be made strong enough to resist the impact or it can be coated with some material which can resist the impact and in turn save the glass from breakage. Coatings on glass can cause loss in transparency of the glass to some extent, but depending upon the overall application and extent of transparency required, the choice of coating materials can be explored.

Therefore, both borosilicate glass and PC have been used as base materials to explore their mechanical properties with MWCNTs as coat and fillers.

2.1 Composite Fabrication with PC and MWCNT

Composite materials of PC and MWCNTs were fabricated to study the role of MWCNTs in enhancing the mechanical properties of PC-based composites. As-synthesized MWCNTs (a-MWCNT) with diameter about 10–30 nm and length 1–10 μm were used as filler material, and PC was used as base matrix. Figure 2.2 shows Raman spectra of the pure MWCNTs which indicates signature peaks as D (1,338/cm), G (1,563/cm), and G′ (2,678/s).

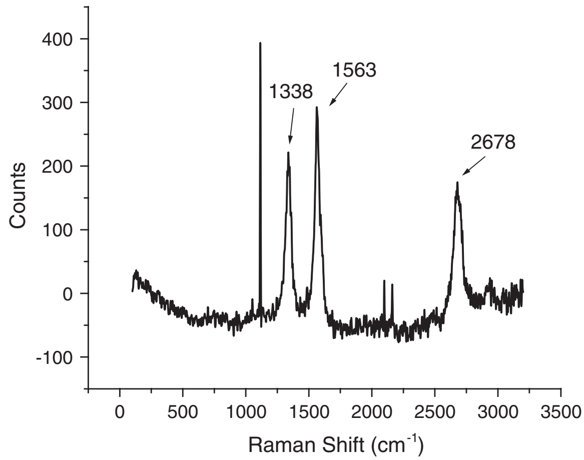

Fig. 2.2 Raman spectra for MWCNTs with D (1,338/cm) peak, G (1,563/cm), and G′ (2,678/s) peaks

After characterization of the MWCNTs as mentioned above for the fabrication of MWCNT-PC composites [1], MWCNTs were first ultrasonically dispersed in chloroform to obtain a stable suspension of carbon nanotubes. Clear solutions of PC were also formed in chloroform by stirring. Chloroform was used the solvent in a quantity about 10 times MWCNTs and PC. The suspensions were then mixed with solutions of PC in chloroform to obtain a series of mixtures of MWCNT/PC containing different weight percent of MWCNT with compositions 0.5, 0.75, 2.0, 5.0, and 10.0 wt% in PC to relate the effect of amount of MWCNTs on mechanical strength. The mixtures were then stirred to obtain uniform dispersions of MWCNTs in PC. Thin polymer films were cast from this solution by pouring the solution into glass petri dish and allowing the solvent to evaporate. The resulting films had a thickness of about 0.2 mm. These films were then broken into smaller pieces and inserted in the die of a compression molding machine.

They were heated to temperatures of about 100 °C and then manually pressed in the compression molding machine to get disk-shaped samples of 10 mm diameter and 5 mm thickness. As per the specifications required for high-strain-rate loading, minor finishing processes were done on the sample surface to get smooth surface finish for load testing purposes. For characterization of the composites, Raman spectroscopy was done as shown in Fig. 2.3 which indicates the comparisons of D and G peaks (as discussed for Fig. 2.2) for composites consisting of 5 and 10 wt% MWCNT compositions.

It was observed that the intensity for D and G peaks is different for both composites. For 5 % MWCNT composition, the intensity for D (1,343/cm) peak is 12,139.6, while for G (1,562/cm) peak, it is 12,722.6. Similarly, for 10 % MWCNT composition, the intensity for D (1,361/cm) peak is 20,829.7, while for G (1,573/cm) peak, it is 22,392.6. So, it can be observed that the intensities of 10 % MWCNTs composite for both D and G peaks are almost twice that of 5 % MWCNTs composite which is in coherence with the composition of MWCNTs in the composite.

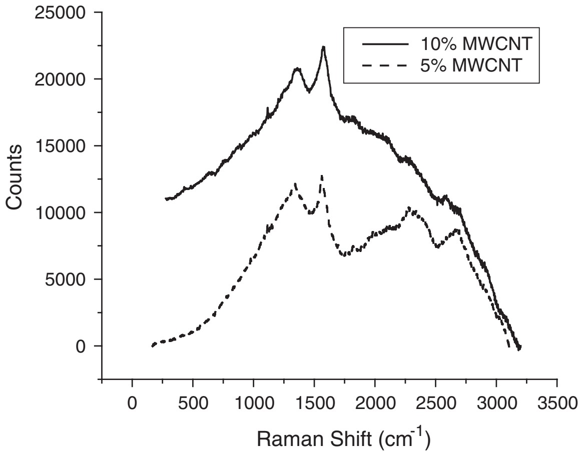

Fig. 2.3 Raman spectra for composite with 5 % MWCNT and 10 % MWCNT composition in PC

Therefore, 10 specimens were prepared for every composition to initiate the process of mechanical characterization of these composites.

2.2 Coating Glass with MWCNTs

Borosilicate glass pieces of disk shape having diameter 10 mm and thickness 5 mm were procured and used as the base material to be coated with MWCNTs. Their surfaces were cleaned with ethanol. MWCNTs of variable amounts were mixed with dimethylformamide (DMF) and ultrasonicated for a few hours to ensure reasonable dispersion. Measured quantities of different compositions of these MWCNT solutions were then spread over the surfaces glass pieces [2] to form uniform MWCNT coating on the glass surface. The different concentrations of these MWCNT solutions and amount spread over the glass pieces are given in Table 2.3. On evaporation of the solvent, coatings of varied thickness and quantity of MWCNTs distributed reasonably uniformly as solvent on the surface of glass samples of 79-mm^2 cross-sectional surface area corresponding to 10 mm diameter was obtained.

A simple estimate of a single layer of average thickness T of MWCNTs of bulk density ρ when spread over a surface area A of the glass disk will have mass as $m = \rho AT$. So, the thickness can be found by the equation

$$T = \frac{m}{\rho A}$$

The average bulk density of the procured MWNCTs was 100 mg/cm^3, average length = 5 μm. Glass surface area A = 0.79 cm^2 and mass of MWCNTs m = 0.1–0.8 mg deposited on the surface meant that the thickness for the samples varied from 10 to 100 μm.

Table 2.3 Samples of various concentrations of MWCNT solution on glass, volume of poured solution, thickness of coat, and rough estimate of number of layers

Sample no.	Concentration of coating on glass (mg/μL)	Quantity of solution poured (μL)	Coating thickness (μm)	Estimated no. of layers
1	10/1,000	10	12	3
2	18.6/930	10	25	5
3	20/520	10	49	10
4	25/400	10	80	16
5	15/200	10	95	19

It also meant that the samples were coated with 5–20 layers of MWCNTs. This way the MWCNT layers can be controlled to about 50 by varying the deposits of MWCNTs even if the MWCNTs are vertically aligned. The data of estimated number of layers are also presented in Table 2.3. It may be noted that the number of layers is based upon the assumption that MWCNTs are vertically aligned; however, in reality, MWCNTs can be a combination of various alignments. Hence, the number of layers given is a lower estimate.

In this way, 10 specimens of each coated composition specimen were prepared.

Hence, following simple fabrication procedures, PC composites with different MWCNT compositions and borosilicate glass specimen with variable coating thickness of MWCNTs were fabricated as per specifications of high-strain rate testing experimental setup.

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