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Thermal Expansion Behaviour of PMMA/MWCNT Composites

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Abstract

This paper is aimed at analysing the thermal expansion behaviour of Poly (methylacrylate) (PMMA)/multi walled carbon nanotubes (MWCNTs) composites under different temperature conditions in a range between 15^{0}C to 65^{0}C for different compositions of MWCNTs. Composites of PMMA/MWCNTs with 2.5wt% and 5.0wt% MWCNTs in PMMA were fabricated using a simple solution mixing technique. These composites were moulded in the form of a disc with diameter 10mm and thickness 5mm. Dilatometer was used to study the thermal expansion behaviour of these composites. The coefficient of thermal expansion for these composites was evaluated and compared to the pure PMMA specimen. It was observed that the coefficient of thermal expansion (CTE) for 2.5wt% and 5.0wt% MWCNT/PMMA composite specimen was higher by nearly 40% and 50% respectively in comparison to that of pure PC. This study is very important from the aspect of applications where composite materials are used under unpredictable temperatures variations. Composites with higher coefficient of expansion get expanded when subjected to higher temperatures which can cause interference with other devices installed in the vicinity. Therefore, this study can assist as a guideline to select the composition of materials to be used for different temperature conditions.

Keywords

Composites, MWCNTs, Dilatometer, Thermal Expansion

I. Introduction

Thermal expansion [1-2] is of significant importance among materials especially due to the wide variety of applications in the modern day world is of significant importance among materials especially due to the wide variety of applications in the modern day world. Applications related to aerospace engineering, under water studies and various extreme temperature conditions require the equipments to be fabricated out of various combinations of materials. Therefore, the usage of composite materials becomes very important. Whenever any composite material is fabricated by using any of the established methodology, it becomes very critical to understand the effect of the filler and the base matrix on the overall behaviour of the composite. CTE is one such important parameter which has been widely analysed for composite materials over the past decade. Xi et al [3] fabricated composites of virgin polytetrafluoroethylene (V-PTFE)/glass fibre (GF) and recyclate polytetrafluoroethylene (R-PTFE)/glass fibre (GF) using two separate sintering approaches(with pressure-SWP and without pressure-SWOP) and evaluated the effect of content of GF on the CTE of the composites for a temperature range between 30^{0}C and 120^{0}C. The specimens were in the shape of a cuboid and CTE was measured both along X direction and Y direction of the specimen. GF has a CTE of 5.4ppmwhile CTE of PTFE is nearly 150ppm. This meant that the presence of GF in the composite would cause an overall decrease in CTE of the composite. So, with increase in GF content in the composite specimen, an overall decrease in CTE was observed for both virgin and recyclate composites when sintered using SWP approach along X and Y directions. However, for composites which were sintered using SWOP approach, a usual behaviour was observed in which, an increase in CTE was observed till 15vol% of GF in the composite when measured along Y direction. Beyond this composition again the usual decrease of CTE followed. This behaviour was observed for both virgin and recyclate PTFE composites. It was suggested that the entrapment of air inside the structure lead to increase in porosity and upon heating these air bubbles tend to expand much more causing the GF to expand more in the Y direction.

Alamusi et al [4] used numerical, theoretical and experimental techniques to study thermal expansion behaviour for CNT/epoxy composites for a temperature range of 30^{0}C to 120^{0}C. Since CTE of CNTs is negative, thermal contraction for the composites was observed in a temperature range of 30^{0}C to 62^{0}C with increase in CNT composition, however the composites exhibited thermal expansion behaviour during the temperature range of 62^{0}C to 120^{0}C. The CTE behaviour for the composites with temperature increased linearly and this behaviour was observed for composites comprising both uni-directional and multi-directional CNTs inside the composite. However, it was suggested that the thermal contraction behaviour of CNT based composites is largely dependent upon fabrication method of the composites and agglomeration of CNTs inside the matrix may weaken this thermal contraction effect.

Investigations of CTE in carbon/epoxy laminated composite plates by Nawab et al [5] showed that orientation of the fibre inside the composite also effects CTE behaviour with temperature. Composites were fabricated in the shape of a parallelepiped. It was observed that CTE was minimum for the composites in which fibres were aligned along the direction of thermal expansion while CTE was maximum for composites in which fibres were along perpendicular direction of thermal expansion. For a temperature range of 20^{0}C to nearly 150^{0}C, the thermal strain increased linearly with increase in temperature for composite specimen which were cut along Z direction (001) and along diagonal in XY plane (111). The thermal strain for the (001) specimen increased from 50% to nearly 100% in comparison to the (111) specimen with increase in temperature from 60^{0}C to 140^{0}C. Therefore, these studies indicated that the thermal expansion behaviour of composites is dependent on many factors related to composite fabrication, dispersion and alignment of filler material, direction of thermal expansion, porosity etc.

Considering that composites fabricated with MWCNTs possess high dynamic [6] and static [7] mechanical strength due to strong structural [8] and mechanical properties [9-10] of MWCNTs, therefore their thermal expansion behaviour also becomes very important for enhancing their utility under variable loading and temperature conditions. We fabricated composites with the base matrix of PMMA as it is a soft and easily mouldable material with variety of engineering applications like light weight plates, jackets, shields etc. and filler constituent as MWCNTs which could provide sufficient strength to the PMMA composites [11].

II. Sample Fabrication

Composites of PMMA/MWCNTs with 2.5wt% and 5.0wt% MWCNTs in PMMA were fabricated using a simple solution mixing technique [12]. Chloroform was used as solvent for dissolving both PMMA beads and MWCNTs. Random dispersions were done using Ultra-sonicator and the dried thin films were moulded into small discs with diameter 10mm and thickness 5mm. These samples were fabricated without any external pressure, therefore the alignment of MWCNTs was considered random.

III. Thermal Expansion Measurements

NETZSCH DIL 402 PC dilatometer was used for evaluating the thermal expansion behaviour of samples for a temperature range of 15^{0}C to 65^{0}C. Fig. 1 shows the basic principle on which the dilatometer works. This instrument is used to capture the dimensional change in the materials when exposed to high temperatures. Therefore, we can relate the thermal expansion coefficients of materials using the equation below.

$$\alpha = \frac{\Delta L}{L \Delta T}$$

α is the CTE, ΔL is the change in dimension of the specimen along which the thermal measurement is done, L is the original dimension of the specimen and ΔT is the temperature change for the experiment.

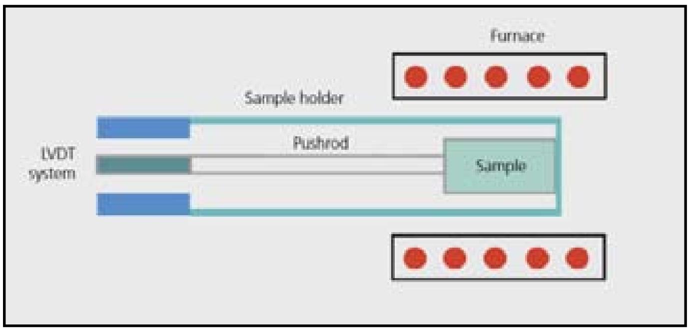

Fig. 1: Schematics of NETZSCH DIL 402 PC Dilatometer

The composite samples were placed in the sample holder and heated from 15^{0}C to 65^{0}C through the furnace at a heating rate of 5K/min. As the specimen got heated, there was dimensional change in it which was picked up by the transducer LVDT system through an intermediate push rod.

IV. Results and Discussion

Figure 2 indicates the thermal expansion behaviour of three types of composite samples within the given temperature range. Interestingly, the strain for composites with 2.5wt% and 5.0wt% MWCNTs in PC shows almost a linear variation.

Rise in strain is an indicator of increase of CTE of the composite which is obtained by the slope of the behaviour and is presented in Table-1 for the three compositions. In the case of PC, the strain varies linearly till about 54^{0}C and beyond that it stagnates indicating breaking of internal bonds in the PC. The increase in strain for composites comprising of MWCNTs and pure PC remained almost the same for low values of temperatures (below 300C). But after about 300C, the increase in strain for both 2.5wt% and 5wt% MWCNT-PMMA composites kept rising till about 600C. The increase in strain for 2.5wt% MWCNT-PMMA composite was nearly 23% and 53% at 400C and 600C respectively in comparison to pure PMMA. Similarly, for 5wt% MWCNT-PMMA composite the strain increase was nearly 41% and 76% at 400C and 600C respectively in comparison to pure PMMA. This meant that the CTE also increased with increase in MWCNT content as the temperature increased as shown in Table-1. For composite with 2.5wt% MWCNTs in PC the increase in CTE was nearly 40% in comparison to the pure PMMA specimen and for 5wt% MWCNTs in PC specimen the CTE increased by nearly 50% in comparison to the pure PMMA specimen.

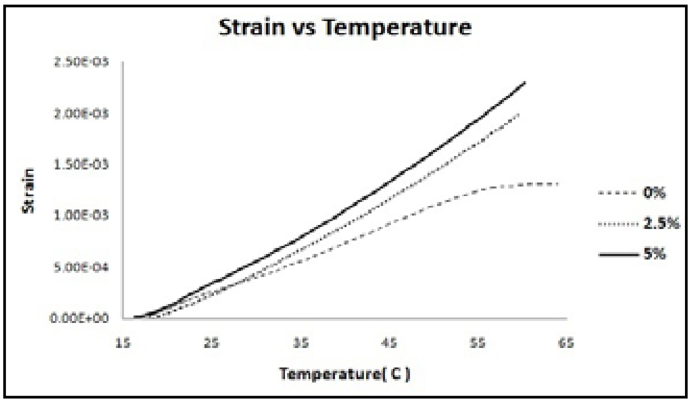

Fig. 2: Strain Variation With Temperature for Pure PMMA (0wt%), 2.5wt% MWCNT/PMMA and 5wt% PMMA/MWCNT Composite

Table 1: CTE variation with MWCNT composition in PMMA/MWCNT composite

Composition of MWCNTs(%) in PMMA/MWCNT composite	0	2.5	5.0
CTE(x10^{-5}) per ^{0}C	3.51	4.89	5.24

V. Conclusion

From Figure 2 and Table 1, we observed that as the composition of MWCNTs increased (2.5wt% and 5wt %) in PMMA-MWCNT composites, the strain also increased with rise in temperature from15^{0}C to 65^{0}C using a dilatometer. Both strain and CTE for MWCNT-PMMA composites increased with increase in MWCNT composition and temperature. The thermal expansion behaviour of these composites within this temperature range is significant for their applications where temperature variations are large. The fabrication method for these composites has been very simple and no modifications like applying pressure and alignments of MWCNTs in the composites were done. Previous literature studies have revealed that the thermal expansion behaviour for MWCNT based nano-composites varies with the temperature range, aggregation of MWCNTs, alignment of the filler, presence of air bubbles and direction of CTE measurements. However, in this work we suggest that if a simple solution mixing method for fabricating MWCNT-PMMA composites is used without any post fabrication refining techniques then CTE for MWCNT-PMMA composites comprising of 2.5wt% and 5wt% MWCNTs increases by nearly 40% and 50% respectively in comparison to pure PC. The suggested reasons behind this increase are that since we have not used any external pressure, therefore the air bubbles remain inside the specimen which allow more expansion with temperature. Apart from this, the MWCNTs are randomly arranged, which may cause random contraction of MWCNTs and expansion of PMMA with increase in temperature, so an average combined effect of the composite can be expansion as presence of MWCNTs inside the composite is very small.

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