Fabrication and Characterization of Neat and Nanophased Polyurethane Foam

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Abstract

In this study, 1wt% carbon nanofiber (CNF) and TiO_2 nanoparticles have been infused in part A of polyurethane (PUR) foam by ultrasound sonication, then mixed with part B of PUR foam by mechanical stirrer. Tensile, flexural and compression tests were performed to evaluate mechanical performance of neat and nanophased PUR foams. Experimental results show that CNF reinforced PUR foam exhibit the highest tensile strength, flexural strength and compression strength as compared with other PUR Foams.

Introduction

Polymer foams, due to their low densities, high specific stiffness, and high energy absorbing capabilities, good mechanical, thermal and fire resistant properties, have been given an increasing amount of attention. This combination of properties makes polymer foams an attractive choice for structural applications like structural sandwich cores, sound damping panels and energy absorbing packaging. Their low density also permits the design of light, stiff components such as aircraft-interior panels, structural shapes in fiber-reinforced plastic (FRP) boat building, impact-limiters and crash-pads, composite foam cores[1-2].

Polyurethane (PU) foam consists of closed cellular structures embedded in a continuous matrix. This kind of closed cell geometry is attractive for mechanical and insulating properties. Polyurethane foam is widely used as a core material for sandwich structures which are mostly used in aircraft, marine and automobile body structures. The incorporation of nanosized inorganic fillers has been proved to be an effective way of improving the mechanical properties, and in particular the strength, of polyurethane foam. For example, Benedicte et al reported the study of Poly (ε-caprolactone)/clay nanocomposites prepared by melt intercalation [3]. In their study, they reported that stiffness and thermal stability were increased with clay loading up to 5%. Xia Cao [4] et al used the organoclay to modify the polyurethane and found increase in thermal and mechanical properties like glass transition temperature, compressive strength and moduli. They also concluded that the presence of clay results in increase in cell density and a deduction of cell size compared to pure PU foam. Polyurethane with higher molecular weight polyol showed improved mechanical properties when 5% organically treated clay was added. On the other hand, opposite effects were observed in nanocomposite foams with highly cross linked structure. Uddin et al [5] infused titanium dioxide nanoparticles to modify rigid

polyurethane foams and studied their static and high strain rate properties. They reported significant improvement in the failure strength and energy absorption in nanophased PU foams.

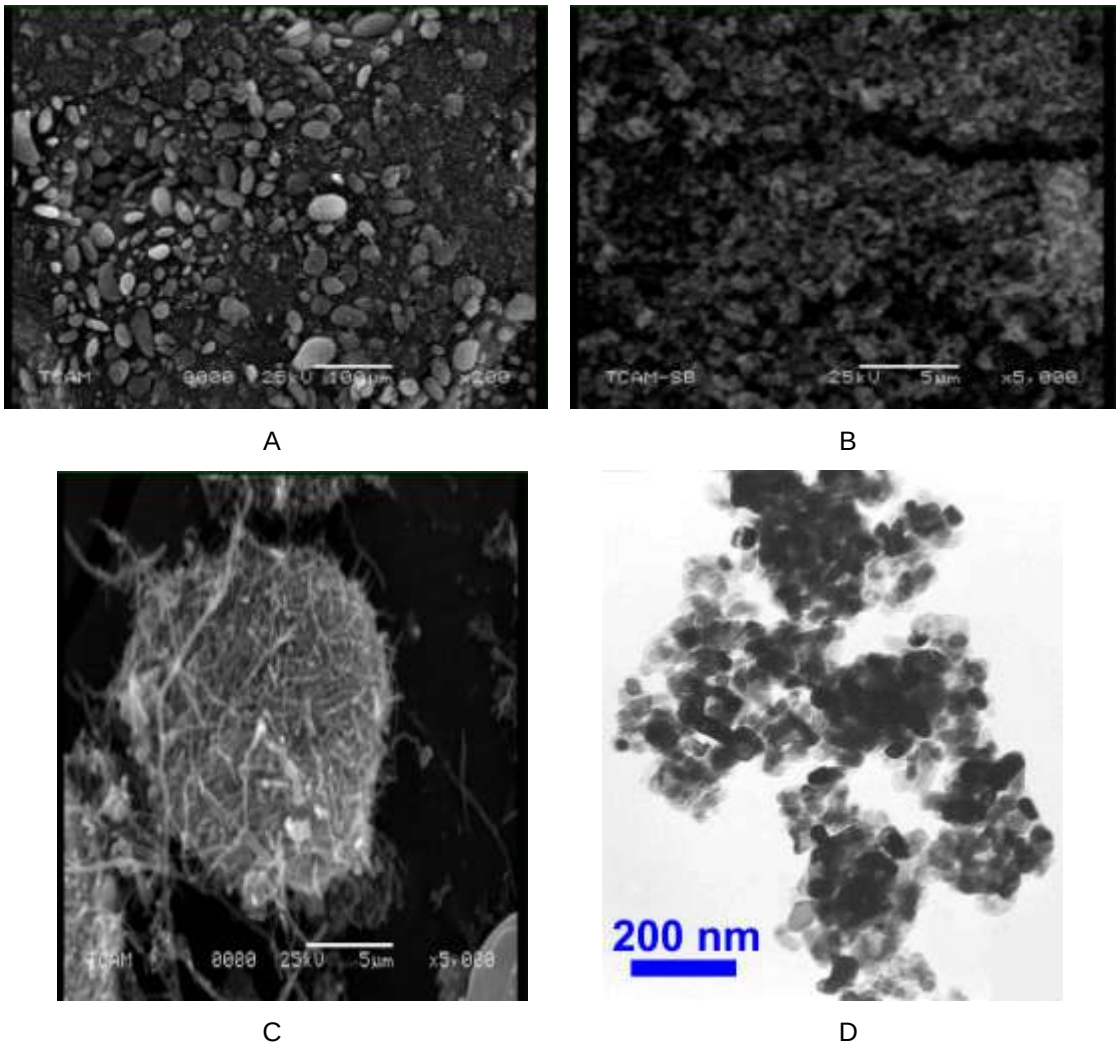
In the current study, nanoparticle and carbon nanofiber reinforced polyurethane foam were prepared with sonication mixing method. Quasi-static tensile, flexural and compressive tests were performed on the nanophased foams and neat polyurethane foam.

EXPERIMENTAL

Materials and Synthesis

Two types of nanophased fillers were used: CNF and TiO_2. The PR-24 carbon nanofibers were obtained from Applied Science, Inc. In PR-24, the fiber diameter ranges from 60 to 200 nm, and the fiber length ranges from 30 to$100\mu m$. TiO2 nanoparticles were obtained from Nanostructured and Amorphous Materials, Inc. with diameter of 30 nm.

Figure 1A to 1D show the picture of as received carbon nanofibers and particles at different magnifications. High specific surface area and cotton-like entanglement cause the formation of agglomerates. Agglomerates of CNFs and particles are difficult to separate and infiltrate with matrix. For polymer matrix nanocomposites, the high power dispersion methods, such as ultrasound and high speed shearing, are the simplest and most convenient to improve the dispersion of CNFs in a polymer matrix.



A B

C D

Figure 1 Picture of as received carbon nanofiber (A and C) and nanoparticles (B and D)

In this study, dispersion of nanosized fillers was performed by ultrasonic method. In processing, the application of alternating acoustic pressure above the cavitation threshold creates numerous cavities in the liquid. Some of these cavities oscillate at a frequency of the applied field (usually 20 kHz) whereas the gas content inside these cavities remains constant. However, some other cavities grow intensely under tensile stresses whereas yet another portion of these cavities that are not completely filled with gas start to collapse under the compression stresses of the sound wave. In the latter case, the collapsing cavity generates tiny particles of debris and the energy of the collapsed one is transformed into pressure pulses. It is noteworthy that the formation of the debris further facilitates the development of cavitation. It is assumed that acoustic cavitation in liquids develops according to a chain reaction. Therefore, individual cavities on real nuclei develop so rapidly that within a few microseconds an active cavitation region is created close to the source of the ultrasound probe.

The development of cavitation processes in the ultrasonically processed melt creates favorable conditions for the intensification of various physicochemical processes. Acoustic cavitation accelerates heat and mass transfer processes such as diffusion, wetting, dissolution, dispersion, and emulsification.

The fabrication of nanophased polyurethane foam was carried out in two steps; the first was the doping of liquid polyurethane with nanoparticles and the second, casting of the foam. The density of the liquid foam (Utah Foam Products) used in this investigation, as specified by the supplier is 240 kg/m^3. It has two parts, Part A and Part B. Part A was selected for infusion of nanoparticles since it is less reactive. Nanosized fillers were first carefully measured along with Part A to have a specific percentage of loading by weight. The mixing was carried out by irradiation with a high intensity ultrasonic horn (Ti-horn, 20 kHz, and 100 W/cm_2) in open air for 30 min at room temperature. In order to avoid temperature rise during sonication, external cooling was employed by submerging the mixing beaker in a cooling bath maintained at 5 °C. After infusion, the modified Part A was mixed with Part B by using a mechanical stirrer at about 2500 rpm. The mixture was then cast in a steel rectangular mold. The mold was heated to about 40 °C prior to pouring into the mold. After about 4–5 hours the cast foam was demolded. The process was repeated to prepare a number of plates. All the plates so prepared were measured and weighed. Density of the plates was consistently found out to be about 250 kg/m^3. The processing method and confining the foam within the mold could be the reason to obtain different density as compared to that specified by the supplier. Samples were extracted from the plates for various tests.

Structure of Neat and Nanophased Foams

Figure 2a-d show SEM picture of neat and carbon nanofiber reinforced PU foams. The cell size and shape are fairly uniform. At the same density, infusing of CNF increased cell diameter and cell face thickness. Similar results were found in particles reinforced foams.

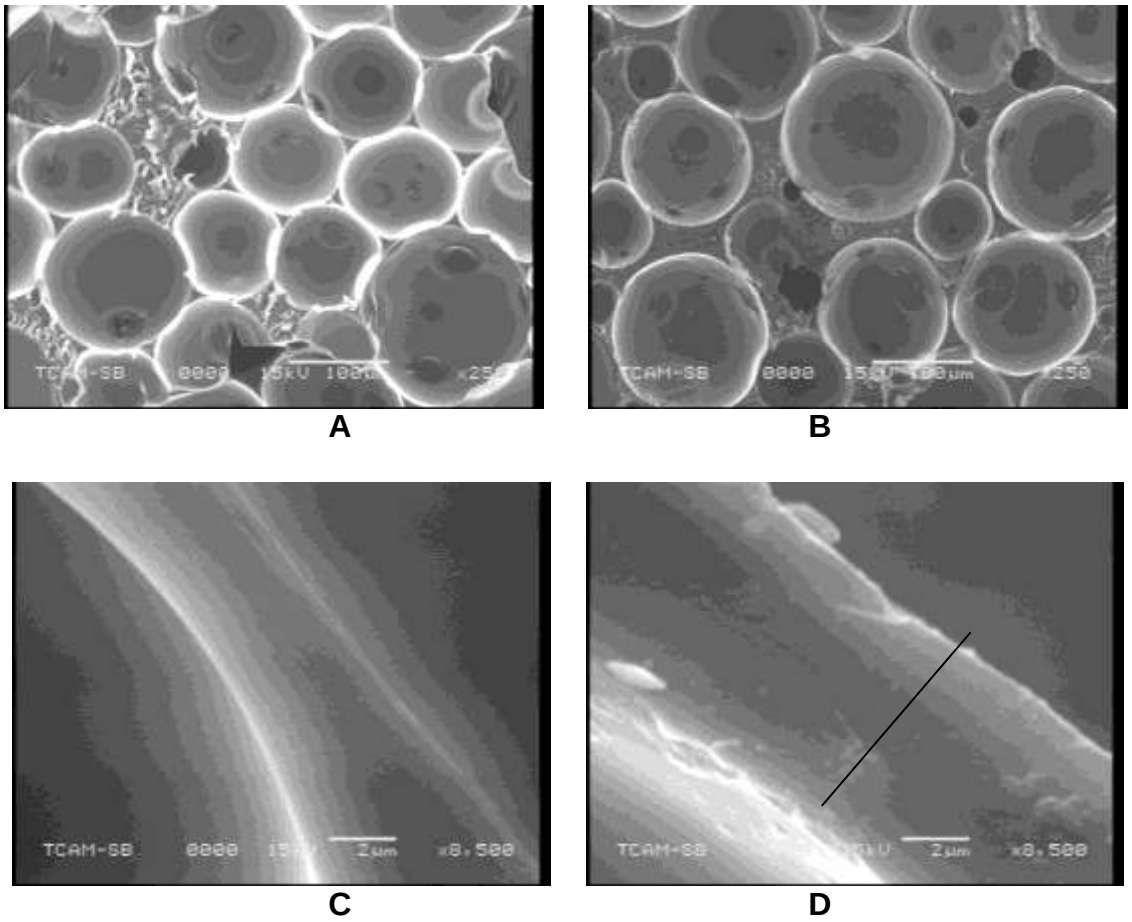


Figure 2 structure of neat (A and C) and nanophased (B and D) foams

Tensile Response

Tensile stress strain curves of neat and nanophased foamsQuasi static compression test was performed on MTS according to ASTM standard C-365-00. Samples were cut into square cross section of side 25.4 mm and a thickness of 12.7 mm. Samples were polished to ensure a smooth surface. Tensile stress-strain curve of neat and nanocomposite PUR foams are shown in fig 3. It can be observed that the stress-strain curves are linear up to about 75% of the ultimated tensile strength. The tensile modulus was calculated from the slope of the initial linear part of the stress-strain curve. It can be seen that tensile strength and modulus are higher for nanophased foam; CNFs infused PUR foam shows the highest values as compared with TiO_2 infused PUR foam and neat PUR foam. Addition of only 1-wt% of CNFs into the PUR foam increases its tensile modulus and strength about 86% and 35% respectively. The corresponding values for enhancement of PUR/TiO_2 systems are about 15% and 5%.

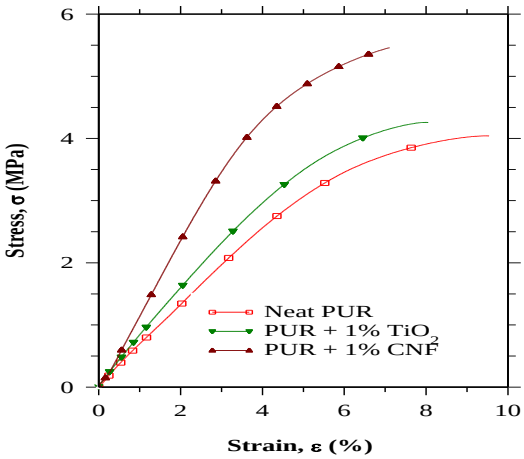


Figure 3 Tensile stress strain curves

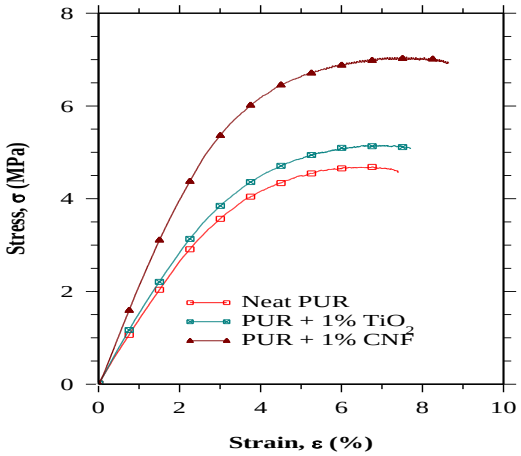


Figure 4 Flexural stress strain curves

Flexural Response

Flexural stress-strain curves of the neat and nanphased PUR foams are shown in fig. 4. In general, stress-strain curves are fairly non-linear. The initial slope of the flexural stress-strain curves is higher for all nanphased foam as compared to neat foam. PUR/CNFs shows the highest flexural modulus and flexural strength. Addition of 1-wt% of CNFs in the PUR foam increases its flexural modulus and strength about 45% and 40%, respectively. The corresponding values for the PUR/TiO_2 system are 11% and 8%. Failure of samples initiated on the tensile side of the specimen.

Compressive Response

Compressive stress-strain curves for the neat and nanophased PUR foams are shown in Fig.5. The curves show three stages of deformation; initial linear behavior, linear plateau region, and finally, densification. The initial slop is used to calculate the compressive modulus of foam and the intersection point between the initial slope and the plateau slope is used to calculate the compressive strength. It is observed that both the compressive modulus and strength are higher are higher for nanophased foam; PUR/CNF shows highest improvement. Addition of only 1-wt% of CNFs into the PUR foam increases its compressive modulus and strength about 40% and 57%, respecrtively. The corresponding values for the PUR/TiO_2 systems are about 12% and 16%. It should be noted that the slope of the linear plateau region is higher for nanophased foams. The plateau region depends on the type of cell collapse. In case of linear plateau, cell deformation occurs as combination of cell bending and collapse. Thus, it can be said that the post yield behavior of the PUR foam can be improved due to infusion of Nanosized fillers.

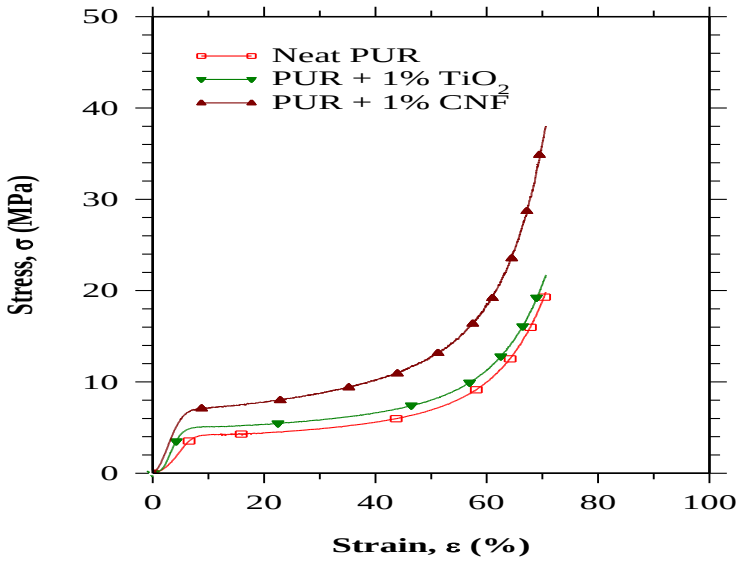


Figure 5 Compressive stress strain curves of neat and nanophased foams

Conclusions

1. Ultrasonic cavitation has been shown to be an efficient method of infusing nanosized filler into the polymer foam.
2. Tensile, Flexural and compression tests results show that mechanical properties of PUR foams have been significantly improved.

Acknowledgements

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