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Dynamic Compressive Response of Polymeric Nanocomposites

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Summary

Polymeric nanocomposite materials present potentials in applications with high-rate loading. In the experiments to determine the dynamic response of such nanocomposites, we used pulse shaping techniques on a split Hopkinson pressure bar (SHPB) for constant-strain-rate deformation under dynamically equilibrated stresses in specimens such that accurate stress-strain curves at various dynamic strain rates were obtained. Corresponding quasi-static stress-strain was also obtained to study the rate effects over a wide range. In this paper, the dynamic and quasi-static compression experimental results are presented and discussed on two types of polymeric nanocompositres: a polycarbonate (PC)/clay nano-composite and a set of epoxidized soybean oil (ESO)/clay nanocomposites with various nanoclay weights. Strain-rate and nanoclay weight effects on the compressive properties of the nanocomposites were experimentally determined.

Introduction

Polymeric nanocomposites have been increasingly used in impact related applications. For example, a polymer coating with ceramic and metal particles has been used to protect light vehicles from destructions by blast and fragment impact [1]. Since these polymer systems are subjected to such impact environment, it is important to thoroughly understand their intrinsic material response characteristics at high loading rates. When polymers nanocomposites are used as transparent armors, it is important to maximize the strength and stiffness of the transparent materials within strict limitations in clarity, dimensions, and weight. Nano-particle reinforcement is considered a viable approach to enhance the material properties without significantly affecting transparency. The mechanical response of such materials at high rates certainly needs to be determined and understood.

Systematic investigations into the mechanical behavior of nano-composites probably started when a Toyota group developed the nylon 6-clay hybrid [2-4]. One of the most promising composite systems was determined to be organic polymers reinforced by inorganic clay minerals. Clay is an inexpensive natural mineral that has been used as filler for rubber and plastic for many years as conventional micro-composites. It was recently found that the reinforcing ability of clay could be improved through chemical modification to make the clay complexes compatible with organic monomers and polymers.

In the experiments summarized in this paper, we added clay (weight percentages of 0, 2.5 and 5) to a polycarbonate material [5] and 0, 5, and 8% to a poly-

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merized soy-bean oil [6]. A split Hopkinson pressure bar (SHPB) was modified to conduct the dynamic compressive experiments. As an efficient dynamic experimental technique, SHPB has been widely employed to obtain stress-strain curves of engineering materials in the strain rate range of $10^2 - 10^3$ s^{-1} [7].

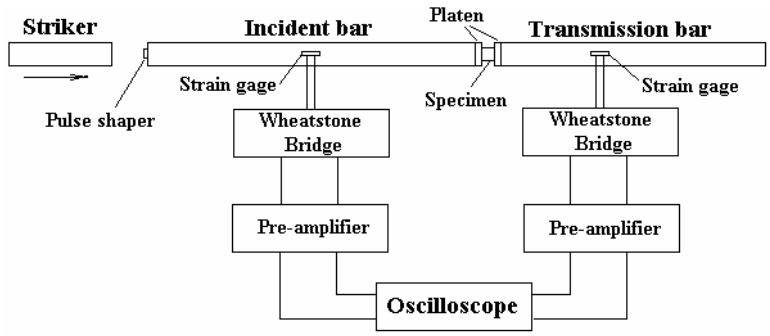


Figure 1: A Schematic of a split Hopkinson pressure bar with pulse shaping.

When the SHPB is used to test soft materials such as polymers, the applicability needs to be carefully examined because it is difficult to ensure that the specimen deforms at a nearly constant strain rate under dynamically equilibrated stresses in a conventional SHPB experiment that is required to obtain valid stress-strain data [8]. Therefore, modifications on the SHPB technique for testing soft material are necessary to obtain valid and accurate dynamic results for soft materials at high strain rates [8]. A schematic of the modified SHPB setup is shown in Fig. 1. Copper tubes were used as pulse shapers to ensure that the specimens deformed at nearly constant strain rates under dynamically equilibrated stresses [9]. Quasi-static compressive stress-strain curves were also obtained to extensively examine the strain-rate effects in a wide strain-rate range. The effects of nanoclay weight on the compressive properties were also investigated.

Experimental Results on the Soy-bean Oil Nanocomposites

Figure 2 shows a typical set of the compressive stress-strain curves of the polymerized soy-bean oil nanocomposites over a wide range of strain rates. The strain rates effects can be clearly observed from the figure. As a general trend, the material behaves stiffer and stronger at higher strain rates.

The effects of clay loading are more complicated. Figure 3 summarizes the results of the clay-load effects on the compressive strength of the nanocomposites, as represented by the stress at 40% of strain. Figure 3 (a) displays the results obtained under quasi-static loading conditions with the associated strain rates varying from 0.001/s to 0.1/s, whereas Fig. 3 (b) shows the results obtained at higher rates with strain rates varying from 1/s to 3,500/s. The results shown in Fig. 3 (a) indicate that the compressive strength of nanocomposites increases with increasing clay

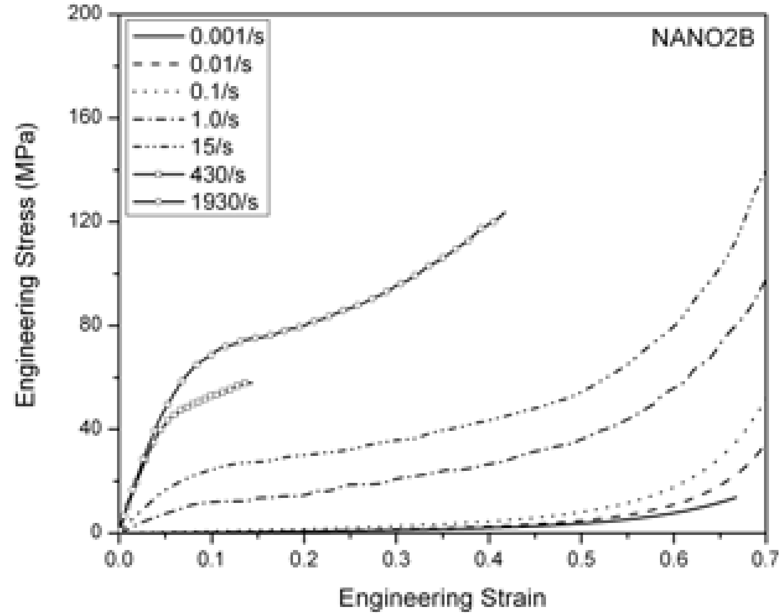
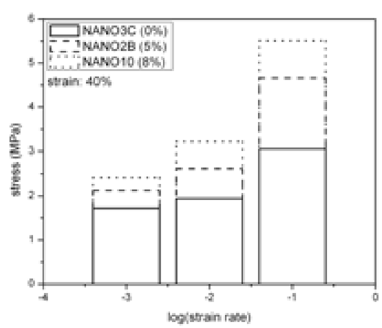
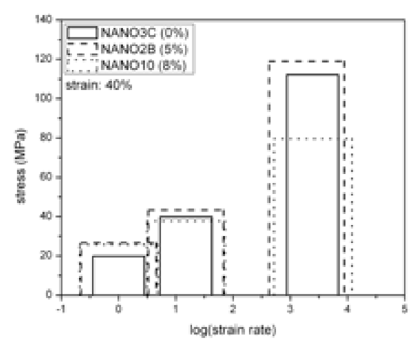


Figure 2: A typical set of stress-strain curves for soy-bean oil nanocomposites.

loads and strain rates under quasi-static loading conditions. The results displayed in Fig. 3 (b) show that the compressive strength also increases with increasing strain rates at higher loading rates. However, the clay-load effects on the compressive strength are complicated. With 5% clay, the high-rate compressive strength increases slightly from base matrix material. When the clay is increased to 8% in weight, the compressive strength is severely decreased.



(a) Quasi-static behavior



(b) Dynamic behavior

Figure 3: Effects of nanoclay on the strength of the oil/clay nanocomposite.

Experimental Results on the PC/clay Nanocomposites

Figure 4 summarizes the results of the effects of strain rate and clay-load on the compressive yield strength of a polycarbonate (PC). It is also observed that the compressive yield strength of this PC nanocomposite also increases with increasing strain rate over a range from quasi-static to 8,000/s. Increasing clay load increases the yield strength up to the strain rate of about 1,000/s. At the highest strain rate, the increase in clay load (up to 5%) does not have apparent strengthening effects anymore.

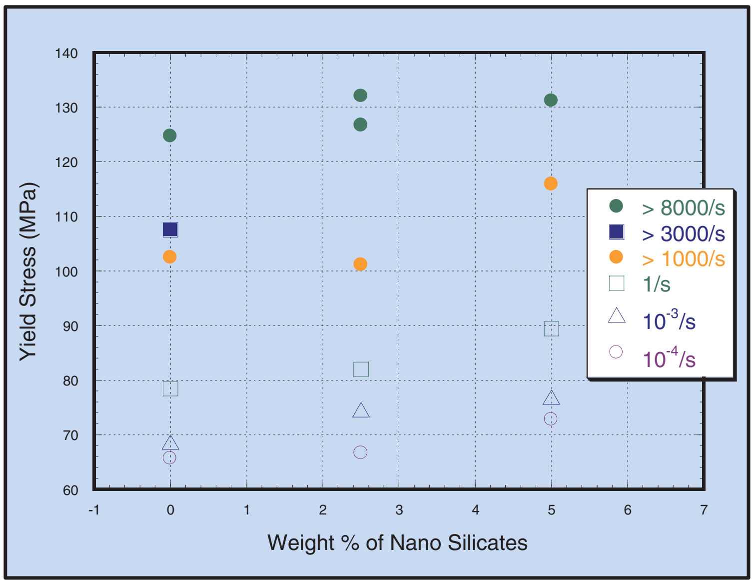


Figure 4: Yield strength increases with clay load in a PC/clay composite.

Conclusions

Quasi-static and dynamic compressive mechanical responses of two types of polymer nanocomposites at various strain rates have been experimentally determined. Nearly constant strain-rate deformation in specimen under dynamic stress equilibrium through pulse-shaping in the high strain-rate experiments yielded valid stress-strain curves at high strain rates. Both types of the nanocomposites exhibited strong rate sensitivities in their non-linear mechanical behaviors. The effects of nanoclay load on the material strength were mixed. The nanoclay is shown to have positive effects on the nanocomposites at lower strain rates. It has little or negative effects at high strain rates, especially when the clay load is high (8%).

References

1. DiMascio, J. (2006): "Military Researchers Study Spray-on Composite to Armor Vehicles," www.specialty-products.com.

2. Okada, A., Kawasumi, M., and Usuki, A., 1989, "Nylon 6-Clay Hybrid",

In: Polymer Based Molecular Composites (Editors: Schaefer, D. W., and Mark, J. E.), Materials Research Society Symposium Proceedings, Vol. 171, November 27-30, 1989, Boston, MA, pp. 45-50.

3. Kojima, Y., Usuki, A., Kawasumi, M., Okada, A., Fukushima, Y., Kurauchi, T., and Kamigaito, O., 1993, "Mechanical Properties of Nylon 6-Clay Hybrid," Journal of Materials Research, **8**, pp. 1185-1189.
4. Usuki, A., Koiwai, A., Kojima, Y., Kawasumi, M., Okada, A., Kurauchi, T., and Kamigaito, O., 1995, "Interaction of Nylon 6-Clay Surface and Mechanical Properties of Nylon 6-Clay Hybrid," Journal of Applied Polymer Science, **55**, pp. 119-123.
5. Weerasooriya, T., Moy, P., Hsieh, A. and Chen, W., 2004, "Effects of Weight Percentage of Nano-Silicate Filler on the Deformation of a Polycarbonate Nanocomposite under Different Strain Rates," Presentation at the 2004 SEM Annual Conference, June, 2004, Costa Mesa, CA.
6. Song, B., Chen, W., Liu, Z. and Erhan, S. Z., 2006, "Dynamic Compressive Mechanical Behavior of New Soybean Oil-Based Polymeric Nanocomposites," *International Journal of Plasticity*, vol. 22, issue 8, pp. 1393-1568.
7. Kolsky, H. (1949): "An Investigation of the Mechanical Properties of Materials at Very High Rates of Loading", *Proceedings of the Physical Society of London,* Vol. B62, pp. 676-700.
8. Chen, W., Lu, F., Frew, D. J., and Forrestal, M. J., 2002, "Dynamic Compression Testing of Soft Materials," *Transaction of the ASME, Journal of Applied Mechanics*, Vol. 69, No. 3, pp. 214-223.
9. Frew, D. J., Forrestal, M. J., and Chen, W. (2005): "Pulse Shaping Techniques for Testing Elastic-Plastic Materials with a Split Hopkinson Pressure Bar", *Experimental Mechanics*, Vol. 45, pp. 186-195.