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AN INVESTIGATION OF THE DYNAMIC RESPONSE OF HMWPE/MMT NANOCOMPOSITES AT VERY HIGH RATES OF LOADING[1]

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Abstract

A personal body armor or a ballistic vest is a personal protective equipment that provides protection against specific ballistic threats within its coverage area. Due to the low weight combined with high mechanical resistance, polymer matrix composite and their laminate are the current state-of-the-art body armor system. Modern structural composites are produced from a combination of two or more components. One component is generally made of reinforcing fibers or particles (dispersed phase) which confer rigidity and the other is a matrix (continuous phase) which keeps the fibers in position. When applied as ballistic panel, the composite must have the ability to: (a) absorb the projectile's kinetic energy locally through plastic deformation; and (b) spread out the absorbed energy fast before local conditions for the failure are met. Moreover, the continuous matrix in these composites plays an important role for energy absorption in the penetration direction and energy dissipation along ply direction. Today's ballistic systems use a variety of materials. Recently, high molecular weight polyethylene (HMWPE) have been used as matrix for ballistic panels providing excellent protection for people and vehicles. The present paper aims to study the ballistic resistant of HMWPE reinforced with cationic modified nanoparticles using a Davies Tension Bar at high strain-rates. The proposal is to modify the morphology, improving the absorbing impact energy behavior.

Keywords: Dynamic testing; Energy absorption; Nanocomposites; Ballistic protection.

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1 INTRODUCTION

A personal body armor or a ballistic vest is a personal protective equipment that provides protection against specific ballistic threats within its coverage area. The ballistic panels, the protective component, consist primarily of ballistic resistant materials enclosed in a nonremovable panel cover. The number of panels and the panel materials determine the protection level of the ballistic vest. The ballistic panels are designed according the ballistic threat posed by a bullet. It depends on its composition, shape, caliber, mass, angle of incidence, and impact velocity, among other things.

Today's ballistic systems use a variety of materials to provide excellent ballistic protection combined with low weight and enhanced mobility both for people and vehicles. Due to the low weight combined with high mechanical resistance, polymer matrix composite and their laminate are the current state-of-the-art body armor system.

Modern structural composites are produced from a combination of two or more components. One component is generally made of reinforcing fibers and/or particles (dispersed phase) which confer rigidity. The other one is a matrix (continuous phase) which keeps the fibers in position. Fiber-reinforced polymer composites have been widely used for protective structures. When applied as ballistic panel, the laminate must have the ability to: (a) absorb the projectile's kinetic energy locally through plastic deformation; and (b) spread out the absorbed energy fast before local conditions for the failure are met.(1-4)

Recently, high molecular weight polyethylene (HMWPE) fiber reinforced composite has been studied as protective component in ballistic systems. These homocomposite, composite in which the matrix and reinforcement have the same chemical composition, detain an impressive list of properties. The continuous matrix in these composites plays an important role for energy absorption in the penetration direction and energy dissipation along ply direction. Furthermore, unlike traditional structural composites, armor-grade composites, only contain 20% weight fraction matrix and are made to enables delamination and debonding, which are energy absorbing mechanisms. However, depending on the application, a certain degree of structural stiffness may be warranted, thus increased fiber-matrix adhesion may be used. However, HMWPE inertness and the lack of functional groups make it difficult to produce thicker laminates and jeopardize fiber-matrix adhesion and reduces the protection level.(5-6)

Stiffness and other mechanical properties of polymeric materials are dependent on the molecular weight, molecular orientation, oriented structures and overall structural morphology, features determined by composition, process and process condition.(7) Moreover, investigations on the behavior of polymers have demonstrated that the presence of interfaces affects properties as mechanical and morphological.(8) Materials properties might be enhanced introducing nanoparticles fillers thus shape, size, aspect ratio, specific surface area, dispersion and orientation of the filler are key factors to control the properties of the final nanocomposite.

Recently, montmorillonite have been studied as filler in order to produce nanocomposites with rather improved properties. Natural montmorillonite (MMT) (Cloisite® Na^+) is a mineral member of the smectite clay family. It particles are rightly packed layers about 1 nm thick and 500-2000 nm long. MMT has been widely used because of its specific surface and ion exchange capacity. However, modification of MMT structure is necessary in order to decrease the surface tension, decrease the wettability and making MMT organophilic.(9) Studied organic-modified MMTs usually employ methyl tallow bis-2-hydroxyethyl ammonium (MT2EtOH) and dimethyl dihydrogenated tallow ammonium (2M2HT) as intercalants. These ammonium salts are used to replace the cations in the natural MMT galleries improving the exfoliation of the MMT layers.(9,10)

As for any other material, the mechanical properties of the ballistic panel depend on the rate at which stresses are applied. However, ballistic panel must stand impact velocity higher than 300 m/s thus the determination of dynamic mechanical properties of these composites subjected to compressive impacts with high strain rates are crucial. Various test methods are available: Hopkinson bars, Volterra Bar, Kolsky Bar, Davies Bar, etc.(11) The Davies pressure bar (DPB) is a circular elastic bar used to study the dynamic compressive responses of engineering materials at high strain rates. In 1948, RM Davies devised a modification of the Hopkinson bar to study polyethylene deformation.(12)

In this method one face of a disc shaped specimen is placed on end of the transmitter bar, when the impactor, made by steel, impacts the Davies bar, a pulse elastic wave will occur and propagate in the bar.(13-16) The free end of the bar acts as one plate of a parallel plate capacitor which, with suitable circuitry, produces a voltage proportional to its displacement which can be recorded on an oscilloscope. The resulting trace can be differentiated to produce a pressure time curve for the pulse.(11) Figure 1 presents the DPB apparatus.

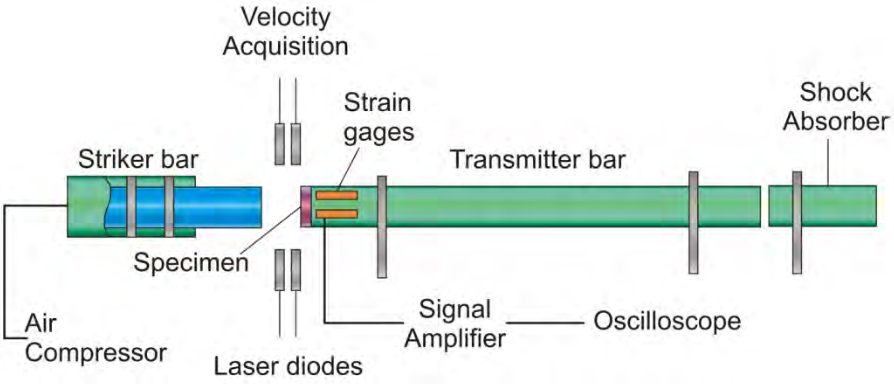

Figure 1 – Schematic diagram of the DPB apparatus.

Our project proposal aims to be effective in improving the ballistic properties of the ballistic panel matrix through the dispersion and orientation of second phase nanoparticles. In this study, HMWPE was employed as continuous phase and MMT particles as dispersed phase. HMWPE/MMT nanocomposites at five different volume fractions of MMT were produced and had their dynamic mechanical properties investigated.

2 EXPERIMENTAL

2.1 Materials

HMWPE was kindly provided by Braskem® (São Paulo, SP, Br). Organic-modified MMTs, Cloisite® 20A (MMT/20A) and Cloisite® 30B (MMT/30B), were provided by Southern Clay (Gonzales, TX, USA). All these chemicals were used throughout this work without any previous treatment.

2.2. Samples Preparation

HMWPE/MMT nanocomposites were produced by melt mixing. The melt mixing was done using a Thermo Haake Polylab mixing chamber fitted with a roller type rotors for 5 min at 120^{o}C. Nanocomposites with varying concentration of MMT 20A were prepared and numbered as HMWPE, HMWPE/20A-1, HMWPE/20A-3, and HMWPE/20A-5, corresponding to MMT 20A weight contents of 0, 1, 3 and 5 wt%, respectively. The samples with different MMT 30B weight contents were numbered as HMWPE, HMWPE/30B-1, HMWPE/30B-3, and HMWPE/30B-5, corresponding, respectively, to 0, 1, 3 and 5 wt% weight contents of MMT30B. The samples were compression molded at 120 C for 3min under 2 ton pressure in an electrically heated hydraulic press. Thin film samples of 1.0 mm thickness were obtained.

2.3. Dynamic Mechanical Analysis

DPB test setup is used to determine the dynamic constitutive behavior of the nanocomposites. The experimental setup consists of a striker bar and transmitter bar, they are all made of SAE 4340 steel. The bars have a diameter of 25.4 mm. The transmitter bar approximate length is 1.2 m. The striker bar used in these experiments is 203.2 mm. The test specimen is sandwiched between the striker and transmitter bar, as seen in Figure 1. To minimize the effect of friction between the specimen and the bars, a thin layer of lubricant is applied.

Strain gages are attached on the surface of the transmitter bar. For strain measurement a Wheatstone bridge is formed to convert the resistance change to a voltage change. The Wheatstone bridge was configured with 4 Kyowa® 250Ω gages. The strain gages provide time dependent strain pulses of the bars. A digital high-speed oscilloscope (LeCroy WaveSurfer44XS) was employed as an instrumentation amplifier and data acquisition.

The transmitter bar compression strain, ε, was experimentally determined as a function of the voltage change and gage factor by Equation 1:

$$\varepsilon = \frac{v_{out}}{4 * k * v_{in}} \qquad (1)$$

where k is the gage factor of strain gage, v_{in} is the Wheatstone bridge voltage and v_{out} is the amplifier voltage. The transmitter bar compression stress, σ, was determined according to Equation 2:

$$\sigma = E_b * \varepsilon * \frac{A_b}{A_s} \qquad (2)$$

where E_b is the transmitter bar elastic modulus, A_b transmission bar area and A_s sample area.

3 RESULTS AND DISCUSSION

The transmitter bar compression stress results are presented in Figure 2.

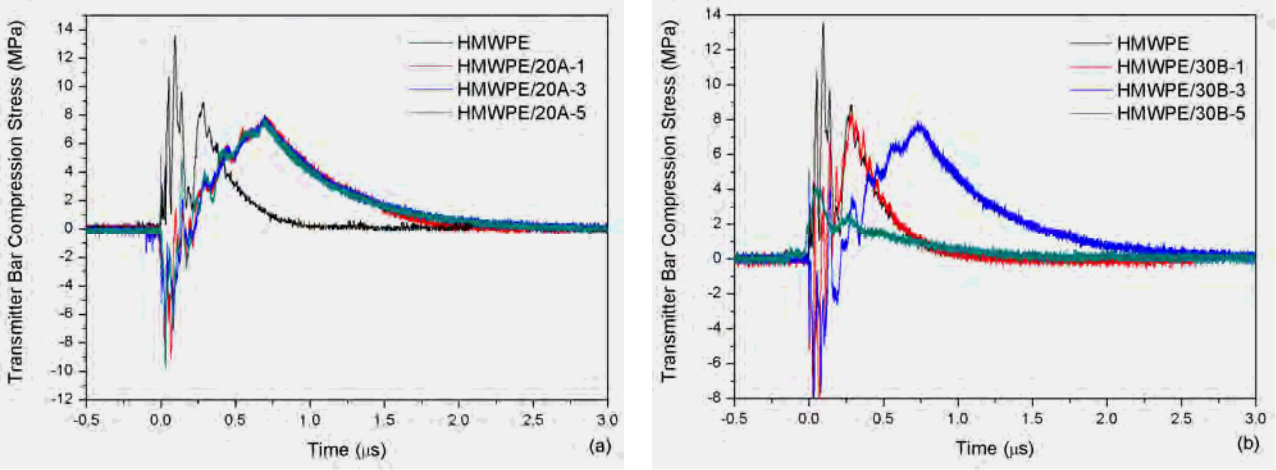

Figure 2 – The transmitter bar compression stress results: (a) HMWPE/MMT20A specimen and (b) HMWPE/MMT30B specimen.

When comparing the dynamic response of samples, it is possible to notice two different behaviors which are characterized by two time responses: 0.293 µm and 0.724 µm. Since the specimen needs at least 0.05 µm to approach stress equilibrium, we are not considering the first peaks.

According to Equation 1 and 2, the experimental set-up did not allow any accurate characterization of samples strengths. Results suggest that dispersed phase did not improved specimen impact resistance, from Figure 2, it is possible to conclude that σ values are approximately the same for any sample composition. Nevertheless, the experimental set-up allowed any indirect measurement of nanocomposites ability to absorb the impact energy.

It can be noticed from the Figure 2(a) that HMWPE/MMT20A nanocomposites is more efficient in absorbing impact energy than HMWPE at any volume fractions of MMT. The absorbing impact energy behavior of HMWPE/MMT30B nanocomposites is however, dependent on volume fractions of MMT 30B. Apparently, the HMWPE/MMT30B-3 sample represents the optimum concentration, indicating the maximum degree of phase mixing. Cloisite® 30B contains two ethanolic side groups on the chains of the cation. These hydroxyl groups are able to interact with the surface of the clay platelets (10). Cloisite® 20A has no such hydroxyl groups which led to materials having an enhanced degree of phase mixing. The introduction of MMT30B into HMWPE in concentrations higher than 3 wt% could lead to the production of agglomerates which would obstruct the energy absorbing mechanisms

4 CONCLUSION

The dynamic response of samples was characterized by two different time response. The experimental set-up allowed any indirect measurement of nanocomposites ability to absorb the impact energy. Data suggests that the HMWPE/MMT 20A nanocomposites are more efficient in absorbing impact energy than HMWPE at any volume fractions of MMT. The incorporation of MMT 30B up to 3 wt% resulted in well dispersed clay platelets. The filler did not improve specimen impact resistance.

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