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TRIBOLOGICAL PROPERTIES OF IMPREGNATED GLOVES FOR HIGH TEMPERATURE APPLICATIONS

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Abstract: Intervention during an unintentional fire puts a tremendous weight on the shoulders of the heroic first responder—and while his/her safety equipment is often overlooked supposedly for practicality, fire-resistant gloves with better insulation and increased dexterity would help dramatically. We are developing gloves using two kinds of glove materials—each impregnated with a ternary material containing a flexible matrix and two fillers, one with very high thermal conductivity and the other surviving high temperatures. Extant first fire responder gloves contain Kevlar and/or leather, while our materials allow gloves 'survival' at temperatures significantly higher than that of the Kevlar or organic material thermal decomposition. Essential here also are low water absorption and high scratch resistance of the gloves.

Keywords: fire first responder; fire-resistant gloves; multi-phase composites.

1. INTRODUCTION

Industrial building and households are being destroyed by fires, sometimes with the loss of life. Important in fire prevention is using better materials. We have already done some work along these lines. Thus, with the front door subjected to 950 ^{o}C for 1 hour, temperature at the back door made with xonotlite-type calcium silicate hydrate slabs does not exceed 70 ^{o}C after that hour; this while the standard allows temperatures up to 150 ^{o}C [1].

Intervention during the fire puts a tremendous weight on the shoulders of the heroic first responder. Safety equipment for him/her is often overlooked – supposedly for practicality. Fire-resistant gloves with better insulation and increased dexterity would help dramatically. Currently, the supposedly best fire first responder gloves are made of Kevlar. While Kevlar performs outstandingly as the material for bullet-proof vests, its rigidity hinders dexterity, a trait first responders need. The first responder needs flexible gloves to allow for sufficient dexterity.

In this situation, there is a critical need for developing better fire fighter gloves. There are several requirements; flexibility was already noted above. "Survival" of high temperatures by the glove is obvious. There are, however, more requirements. First, low absorption of water or of vapors from the environment by the glove is needed. Imagine a glove which has absorbed much humidity or other vapor. Exposed to fire, the glove is likely to disintegrate into pieces because of water conversion into steam and that steam escaping outside. The same applies to other liquid penetrants. The glove surface needs to have relatively high friction; the glove cannot be slippery. High scratch resistance is also necessary since the gloves will frequently contact a variety of surfaces. While designing our gloves, we have taken all these factors into account.

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2. EXPERIMENTAL

Materials

We use two kinds of materials to create the bases of the gloves, one of them is cellulosic, the other kind has not been used before for the purpose. The base is impregnated while the impregnation is a ternary composite. There is, first, a polymer matrix which must provide good impregnation. Second, there is Kevlar or another high temperature polymer (HTP), which is used as a filler, namely subjected to comminution into fine powder particles by cryomill. The use of these fine powder reduces the size of grain boundaries and thus reduces the brittleness of the material used. The third component of the composite is a ceramic powder; its role contributes to rapid dissipation of the heat, hence it needs to have a high thermal conductivity z. Needless to say, we are working with several candidates for the matrix, for the high temperature filler (thus not only Kevlar) and also several candidates for the ceramic filler.

Thermogravimetric analysis (TGA)

This is of course the main tool for evaluation of the thermal stability for each of our selected materials at elevated temperatures. The technique is explained in some detail in [2]. Materials we have opted to use perform well at high temperatures and are decidedly good candidates for their intended purpose.

Solvent absorption

Solvent absorption was determined by swelling experiments for several polymer matrices. Each sample was studied first in the dry state and then after a 24-hour exposure to a given solvent. Such solvents include toluene, benzene, cyclohexane, and acetone among others. Samples were either made by injection molding or compression molding, depending on the respective polymer. Each polymer sample was then completely submerged in their respective solvent and covered with parafilm.

Tensile testing

This testing was performed according to ASTM standards. It was performed for dry samples and for samples subjected to swelling. The key parameters are the tensile modulus E determined in the elastic region and the elongation at break ε_b. We recall that that elongation is inversely proportional to the brittleness B [2–4,].

Dynamic friction

This technique is well explained in [5] and in [2]; thus, we do not provide many details here; 5.0 N of force was applied to the surface of each sample. The counterphase material used was 440 steel ball bearings. Determination of dynamic friction using a pin-on-disk tribometer provides also an opportunity to determine wear – while for the present purpose dynamic friction is quite important to avoid slipping of the gloves.

Scratch resistance testing

The instantaneous depth at the time the indenter reaches a certain location is called the penetration depth R_p, the depth after 2 minutes of viscoelastic recovery (healing) is the recovery depth R_h. A linearly increasing force up to 5.0 N was applied. A diamond indenter with the diameter of 0.10 μm was used. The depth resolution is ± 0.5 nm according to the manufacturer (Anton Paar). The sliding speed was 5 mm/min, the distance covered 5.0 mm. During each test an acoustic signal is created along the indenter trajectory. This technique is also explained in [5] and [2].

Optical microscopy

After scratch tests were performed, the samples were examined under a microscope which was part of the micro-scratch machine assembly. Panoramic photos were taken of each sample under each condition to observe the effect scratching the surface of each polymer before and after swelling has.

3. SOLVENT ABSORPTION AND MECHANICAL TESTING

Results of determination of the tensile elastic modulus are provided in Figure 1 for low density polyethylene (LDPE). Results for other polymers are not included here for brevity.

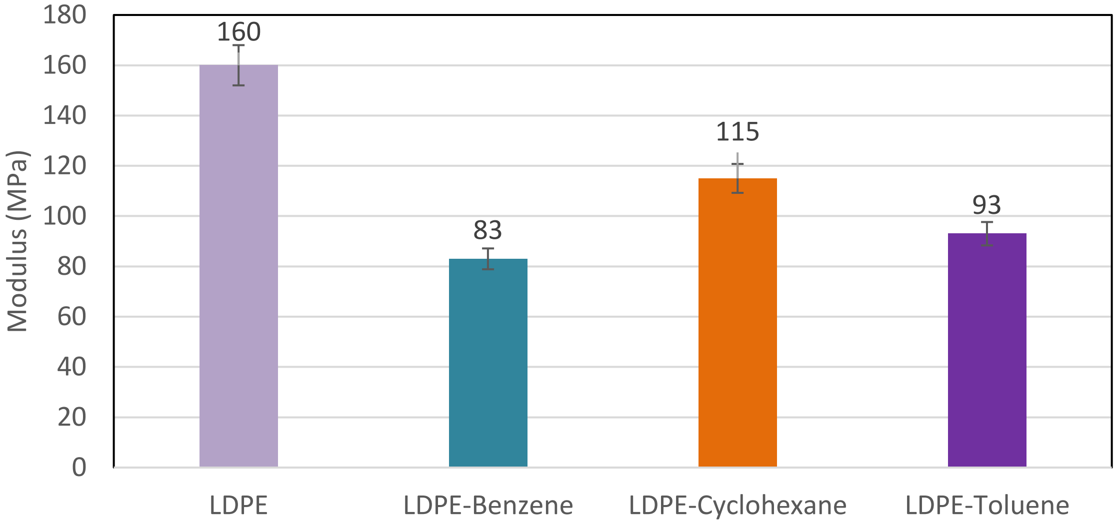

Figure 1. Tensile modulus values for dry LDPE (left) and for LDPE subjected to swelling in several liquids.

We see that the liquids penetration into the polymer results in lowering of the modulus E – an expected effect. The least lowering is observed in cyclohexane. Here, we can explain the effect that the solvents have on the mechanical properties of the material. The modulus of LDPE is compromised due to interactions between the functional groups on the polymer chain and the solvent – and its strength is weakened.

In the same testing, we have obtained also the values of the tensile elongation at break. These values are displayed in Figure 2.

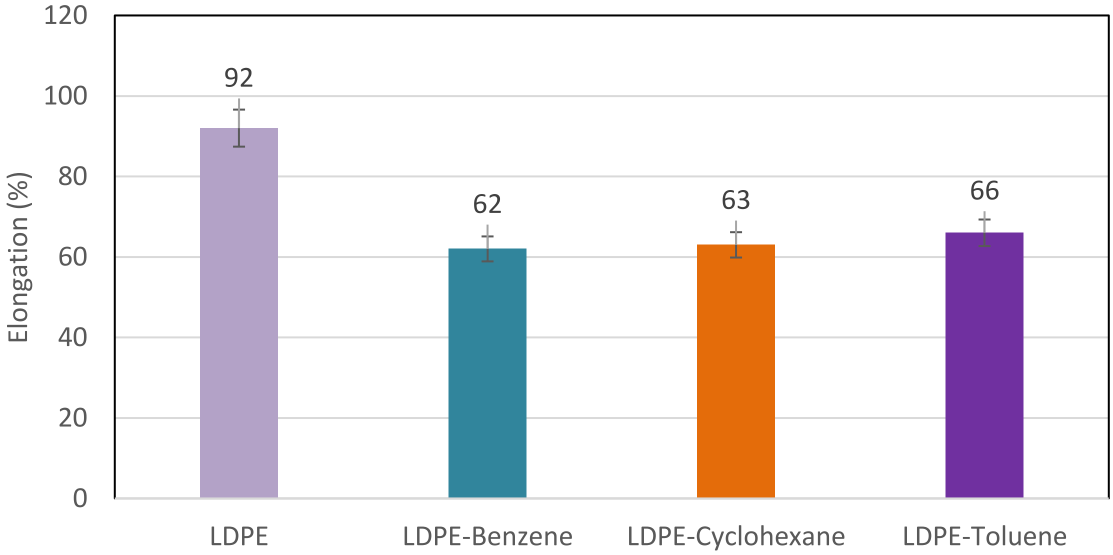

Figure 2. Tensile elongation at break for dry LDPE (left) and for LDPE subjected to swelling in several solvents.

We see in Figure 2 that the presence of liquid penetrants results in lowering of the elongation at break, and thus in higher brittleness of LDPE. This can be explained by the absence of the functional groups in neat LDPE and the presence of such groups in all liquid penetrants.

4. TRIBOLOGICAL RESULTS

Importance of tribology of materials in a variety of applications is discussed by Hutchings and Shipway [6] and of friction and scratch resistance in particular in a textbook [2]. The question was, whether the two fillers increase or decrease the dynamic friction of the composite glove structure material + impregnating matrix. The same statement applies to the scratch resistance.

We have noted above the role of liquid penetrants in the performance of polymeric materials– including the tribological properties. Interactions between polymers and liquids are well represented by the Flory-Huggins-Staverman polymer-solvent interaction parameter χ [7] (as it happens, three researchers came up with the same idea within a few months from one another). In Figure 3 we present dynamic friction obtained by pin-on-disk tribometry as a function of the parameter χ. Values of χ have been taken from [7].

Here, we only discuss the interactions between appropriate solvents and PP and LDPE for brevity. After swelling affects the polymers, their surfaces are obviously compromised, as we see in the results. Prior to swelling, the polymers have relatively low dynamic friction. Once swelled by different solvents, the polymers have considerably higher dynamic friction as compared to their original state.

We have identified polynomial trends with both sets of data, indicating a possible prediction of how each material will perform with other given solvents. These generated trendlines have above 99.5% accuracy, and determine a maximum value of dynamic friction to be expected from these materials after swelling.

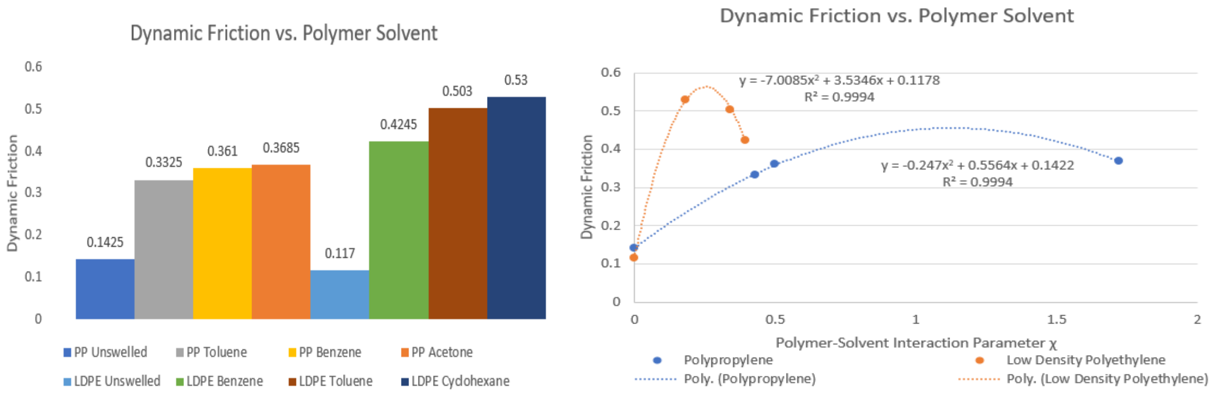

Figure 3. Dynamic friction values as a function of the polymer-solvent interaction parameter χ.

We see in Figure 3 that increasing the χ parameter leads first to an increase of the friction for both polymers. The physical significance of that parameter is based on the following fact: the *worse* is the miscibility of the two components, or in other words the poorer is their interactions, the larger is the χ parameter. Thus, for $\chi = 0$ we have the full solubility of the polymer in the liquid, thus a homogeneous phase. Increasing the χ parameter, we are looking at the appearances of small inhomogeneities which impede the movement of the counterphase, 440 steel ball bearings. However, when the number of those inhomogeneities increases, the bump mechanism as explained in [8] takes over. Namely, the effective area of contact decreases dramatically, we have largely the contact between the bumps and the counterphase. Necessarily, an increase in χ is now accompanied by a small real area of contact and thus by low friction.

5. GENERAL DISCUSSION

Loss of homes and infrastructure may be threatening to individuals and the economy. Often overlooked are those who are serving and risking their lives to preserve and protect the livelihood of those who are most vulnerable. We owe it to our public servants to design equipment which will not only protect them from direct injury, but also save them time. This saved time can make all the difference between life and death.

We believe that connections between various macroscopic properties–including tribological ones–deserve to be pursued. The basis for such search is the fact that all macroscopic properties are determined by structure and interactions at the atomic and molecular level [2].

We have successfully outlined the requirements for gloves which will outperform all those currently available on the market. We are exploring the use of high temperature polymers and composites to use as materials in our design. Our presented work proves the damage to the microstructure of polymers after exposure to solvents – something which may affect firefighters, as they are trained to handle fires under multiple conditions – high humidity, high chemical content in the air, and much worse. Future works will include honing in on one fabric which provides stable reinforcement, good hygiene, superior thermal conductivity, and sufficient dexterity to get the job done safely and in a timely manner.

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