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Investigation of Shear Thickening Liquid Protection Fibrous Material

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***Abstract*—**The stab resistance performance of newly developed fabric composites composed of hexagonal paper honeycombs, filled with shear thickening fluid (STF), and woven Kevlar® fabric or UHMPE was investigated in this study. The STF was prepared by dispersing submicron SiO2 particles into polyethylene glycol (PEG). Our results indicate that the STF-Kevlar composite possessed lower penetration depth than that of neat Kevlar. In other words, the STF-Kevlar composite can attain the same energy level in stab-resistance test with fewer layers of Kevlar fabrics than that of the neat Kevlar fabrics. It also indicates that STF can be used for the fabrication of flexible body armors and can provide improved protection against stab threats. We found that the stab resistance of the STF-Kevlar composite increases with the increase of SiO2 concentration in STF. Moreover, the silica particles functionalized with silane coupling agent can further improve the stab resistance.

***Keywords*—**shear thickening fluid, SiO2, Kevlar, stab

I. Introduction

OVER the years, considerable attention has been given to the development of warrior systems that would provide mostly ballistic protection for individual soldier. These systems, widely known as personnel armor, mainly protect torso and head. But it is also true that a significant number of battlefield casualties would actually happen due to injuries inflicted on body extremities such as hands, arms, necks, and legs[1]. Finding a suitable material to modify this disadvantage of body armor is becoming more and more important..

There are some non-Newtonian fluids showing that their viscosities increases with increasing shear rates. We hope that such materials can be used on the body armor or the impact resistance accessories. It is now widely accepted that the increase of viscosity of the non-Newtonian fluids subjecting high shear force is due to the consequence of the formation of jamming clusters bound together by hydrodynamic lubrication forces, often denoted by the term hydroclusters[2]. These fluids are known as shear-thickening fluids (STF). Basically, shear thickening fluid (STF) is prepared using fumed SiO_2 particles dispersed into Polyethylene Glycol (PEG). The shear-thickening fluid stiffens upon ballistic impact or stab threat, which absorbs the energy of impact. Previous studies have investigated the stab resistance of Kevlar fabrics impregnated with a shear thickening fluid[3-5].

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In the other research, silica nanoparticles were functionalized using a coupling agent to further improve the stab resistance[1]. Because that the silane coupling agent is made of a (CH2)n which is connected to an functional group (R) and a silicon atom. The silicon atom is in turn attached to three alkoxy (OH) groups. This bond is hydrolytically unstable and in presence of moisture hydrolyses to an intermediate Si-OH bond as shown. Si-OH bond then condenses with the surface bound OH groups present in the silica particles to form a stable Si-O-Si bond. The R group remains available for covalent reaction with PEG. The separation between the organic functionality and the silicon is by three carbon atoms.

In this study, drop tower tests and rheological experiments are performed to determine the effect of silica content and silane coupling agent on the puncture resistance of newly developed fabric composites composed of STF- hexagonal paper honeycombs and woven Kevlar® fabric or UHMPE.

II. Experimental

A. Materials

To prepare the STF , we used two ways to prepare it. One of them was to mix the silica particles and poly(ethylene glycol)(PEG) together .The other way was to mix the silica particles, poly(ethylene glycol)(PEG) and silane coupling agent. The weight percentages were shown in the Table I.

Fig.1 displays the photo of STF- paper honeycomb combination. The paper honeycomb was used to control the depth of STF. The fabricated composite was composed of STF-paper honeycomb combination and woven Kevlar® fabric or UHMPE.

Fig. 1 Photo of STF-honeycomb paper combination

B. Rheological test

The STF samples were tested for its rheological properties using a Rheometer-RS600. The test was carried out at room temperature in a steady state flow mode and shear rate ramp of 0–2000/s.

TABLE I
THE RECIPE OF STF

Sample	PEG (g)	SiO_2 (g)	Silane (g)
STF1	75	25	--
STF2	70	30	--
STF3	60	40	--
STF4	75	25	1
STF5	70	30	7

C. Stab test

Stab test shows that the different stab resistance between neat and composite targets. The knives were dropped from the same height with the same impact energy (3.8J).

III. RESULTS AND DISCUSSION

A. Rheological properties

Rheology test results show that STF sample exhibits shear thickening behavior. This behavior is very much evident as seen from the graph in Fig. 2. The sample viscosity changes from ~0.4 Pa s at shear rate of 250/s to ~0.6 Pa s at 2000/s shear rate. Fig. 3 shows that in the same shear rate, increasing the weight percentages of STF the viscosity also increases.

Fig. 4 shows that using silane coupling agent can enhance the viscosity under the same weight percentages. The viscosity of STF4 changes from ~4.5 Pa s at shear rate of 250/s to ~13 Pa s at 1500/s shear rate.

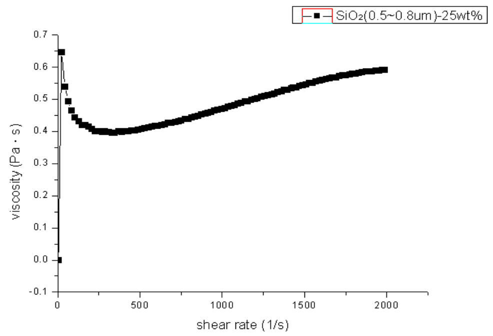

Fig. 2 Viscosity as a function of shear rate for STF1. The shear rate was set from 0/s to 2000/s

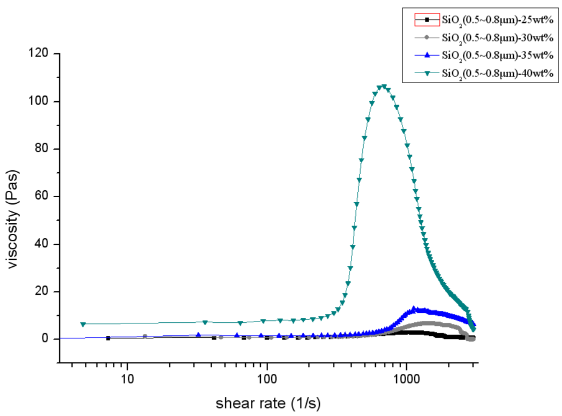

Fig. 3 Viscosity as a function of shear rate for STFs with different SiO2 content. The shear rate was set from 0/s to 2000/s.

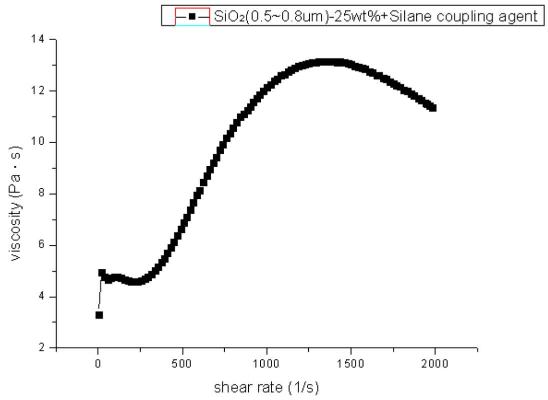

Fig. 4 Viscosity as a function of shear rate for STF4. The shear rate was set from 0/s to 2000/s

B. Stab test results

TABLE II
THE RECIPE OF STF

Kevlar layer/ STF / Kevlar layer	Penetration through or not
17 / 0 / 0	No penetration through
16 / 0 / 0	Penetration through
1111 / STF2 / 1	No penetration through
10 / STF2 / 1	Penetration through
10 / STF5 / 1	No penetration through
9 / STF5 / 1	Penetration through

Kevlar is a fabric armor used to protect body, but it would be thick and difficult to protect our joints. The fabric composites and their corresponding stab testing results under the same impact energy (3.8 J) are listed in table II. It shows from table II that the STF-honeycomb-Kevlar protective fabrics can offer stab protection with fewer layers of Kevlar fabrics than the neat Kevlar fabrics. Our results also indicate that using STF with the addition of silane results in further enhancement in the stab resistance of fabrics.

IV. CONCLUSION

In this study, STF was prepared using submicron SiO2 particles dispersed into Polyethylene Glycol (PEG). The stab resistance performance of newly developed fabric composites composed of hexagonal paper honeycombs filled with STF and woven Kevlar® fabric was investigated. The rheology test shows the rheological behavior of STF with silica content of 25 and 30 Wt%, respectively. It reveals that the strength of the shear thickening response increases as the SiO2 content increases. The silane coupling agent addition also provides an strength increase in the shear thickening response.

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