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Kaolin shear thickening fluid reinforced UHMWPE composites for protective clothing

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This study reports the designing and reinforcing of impact resistant textile composites using kaolin based shear thickening colloidal dispersions as the filler material. The reinforced fabric is targeted for the chest protection of cricketers. A shear thickening fluid (STF) has been prepared using kaolin and glycerol, at kaolin volume fractions of 34% and 38%. A combination of mixing techniques including mechanical blending and ultra-sonication are used to prepare the colloidal dispersions. Ultra high molecular weight polyethylene (UHMWPE) woven fabric structures are reinforced with the STF. The fabric coated with STF are then measured for their flexibility, and impact resistance using Shirley stiffness tester and a series of modified drop tower tests respectively. Kaolin STF at 38% volume fraction shows best results in impregnated fabric samples. STF reinforced fabrics provide better impact resistance with improved moisture absorption and flexibility in comparison to the conventional chest guard material.

Keywords: Critical shear rate, Kaolin, Protective clothing, Shear thickening fluid, Sportswear, Ultra high molecular weight polyethylene composites

The concept of flexible and comfortable, but highly impact resistant fabrics has been influenced to a great extent by the current research of applying shear thickening fluid (STF) composites to protective clothing and body armors[1–4]. These fluids contain increased energy dissipation as well as increased elastic modulus, making them efficient materials for impact absorption and damping applications[5].

Shear thickening occurs in highly concentrated colloidal dispersions. The viscosity of the fluid rises exponentially when a shear stress, which is larger than its critical shear rate, is applied[5]. There are several theories explaining this behavior, such as the hydro-cluster theory[5] and the order - disorder theory[6]. Shear thickening behavior has been reported in various dispersions including silica suspended in polyethylene glycol, silica suspended in ethylene glycol, kaolin clay in glycerol, poly methyl methacrylate in polyethylene glycol, fumed silica in propylene glycol and polyvinylchloride in dioctylphtalate[7].

Flexible woven and unidirectional fabric structures have shown their capability in providing light weight protection against ballistic and fragment impacts[8]. Their heterogeneous construction on multiple scales enables them to absorb kinetic energy and these include yarn rotation, crimp interchange, translation, plastic deformation, and yarn fracture[9–11]. STF incorporated fabric structures have shown the capability of better impact resistance[12,13].

This study focuses on reinforcing ultra high molecular weight polyethylene (UHMWPE) fabrics using shear thickening fluid (STF) to develop impact resistant composite structures. The composites are intended to be used for the chest protection of cricketers, in order to overcome the disadvantages of conventional chest guard materials which are composed of polymer foam and derivatives.

Kaolin is a naturally occurring mineral which is commonly used as an indirect food additive, cosmetics, health products and has GRAS (general recognized as safe) status under 21 CFR 186.1256. In this study, kaolin clay is used in its powder form to prepare the STF solution, considering the better packing density of the platelet shape particles. Impact resistance and other fabric parameters are measured in relation to the conventional chest guard material using drop tower tests and other standard textile testing methods.

Experimental

Kaolin clay powder was obtained from Sigma-Aldrich (USA) with a mean particle size of 500 nm. Glycerol (AR 99.5%) was supplied by SRL (India). Ultra-high molecular weight polyethylene (Dyneema) filaments (1200 denier and 0.75 g/cm^3) were used to construct plain woven fabric structures of 29 EPI, 29 PPI, and 320 gsm.

An industrial heavy duty blender was used to disperse the kaolin particles in the initial step at the medium speed setting (12,000 rpm). The prepared

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dispersion was sonicated using the Hielscher® UP400S Ultrasonic processor at 20 kHz and 50% amplitude for 15 min. Dispersions with kaolin volume fractions of 34% and 38% were prepared depending on the previous observations. A Fungilab® rotating disc viscometer was used to obtain the viscosity of STF against the rotational speeds of the spindle. R6 spindle type was used throughout the test.

Dyneema fabric samples of 34cm x 33cm were impregnated with 34% and 38% volume fraction shear thickening fluids, with a wet pickup of 25%. Ethanol was added to STF at a volume ratio of 3:1 to facilitate impregnation, and then oven dried at 80 °C for 30 min to evaporate ethanol. A glycerol impregnated Dyneema sample was prepared with the same take up percentage, to be used as the control sample.

A drop tower test was designed to simulate the energy dissipation during a cricket ball impact at an average speed of 130 km/h. The drop mass weighed 1.72 kg, and consisted a standard cricket ball fixed at the lower end (at the area of impact). The load was dropped from a height of 6.5m, guided by a vertical support of 3.8 inch diameter. A metal box of 15cm x 15cm x 25cm filled with processed clay was used to record the indentation depth of the impact. Each of the fabric samples was placed on the top of the recording box and fixed using a wooden frame. After each drop, the indentation depth was measured using a Vernier caliper and recorded. Microscopic images of each fabric structure were analyzed under a digital microscope, soon after the impact.

The Shirley stiffness tester was used to determine the stiffness of the fabric samples using BS 3356:1961 standard. Moisture transmission and absorption of the fabric samples were measured in a customized test. A steel cylinder, with 3cm diameter and 15 cm height (with the bottom side covered) was filled with water to a height of 14.75 cm. Treated samples and the conventional chest pad material with 3.5cm diameter was used as the test specimen. The initial oven dried weights of the samples were recorded. The samples were kept at the open end of the cylinder for 15 min, and the final weight was recorded to calculate the percentage weight difference.

Results and Discussion

Viscosity readings at different spindle speeds (rpm) values of the rotating disc viscometer at 34% and 38% kaolin volume fractions are shown in Fig. 1. It is observed in the case of 38% volume fraction that after reaching 4 rpm, the viscosity of the dispersion increases sharply from 61 Pa.s to 1600 Pa.s within a small increase in the spindle rotational speed. A similar behavior is apparent in 34% volume fraction, as the spindle speed reaches 1.5 rpm. This behavior matches with the characteristic curves of shear thickening fluids reported in literature[14], and provides strong evidence for the shear thickening behavior of these colloidal dispersions.

The indentation depths recorded during the drop tower test are shown in Fig. 2. Both 34% and 38% kaolin STF impregnated samples display lower average indentation depths in comparison to the conventional chest pad material, indicating better impact absorbance properties. It is important to notice the drop of the indentation depth at 38% kaolin volume fraction, indicating higher impact resistance when the solid volume fraction is increased. This

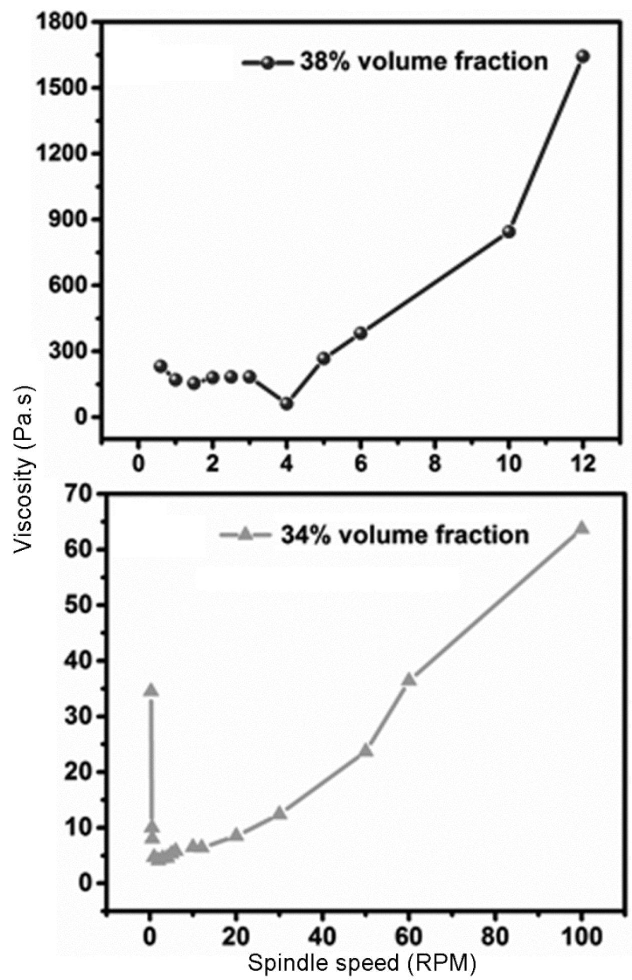

Fig. 1 — Viscosity *vs*. RPM of 38% and (b) 34% volume fraction STF

could be accounted by the higher tendency to form stronger hydro coupling, when a larger number of solid particles are present in the dispersion.

Microscopic images of the samples just after the drop test (x10 magnification) are shown in Fig. 3. Non-treated sample shows the signs of fibre damage and structural distortion. STF impregnated samples do not show such significant symptoms. Due to the poor quality of the images, comparison between the STF volume fractions is not possible.

Flexibility of the fabric structure is an important property, which helps to minimize the restriction of the chest protector towards the movement of the player. Stiffness test was conducted to measure the average flexural rigidity of the fabric samples, in order to obtain an idea about the flexibility, as they have an inversely proportional relationship. Average flexural rigidity values obtained during the stiffness test are also observed. Impregnating fabric structures with STF increases the flexural rigidity of the fabrics and the stiffness further increases with increasing volume fraction of kaolin in the dispersion. This is evident with the fact that the non-impregnated sample displays an average flexural rigidity of 2180.86 mg.cm and the values for 34%, and 38% kaolin samples are 3611.02 mg.cm and 4502.05 mg.cm respectively. Conventional chest pad material with the similar dimensions does not indicate an adequate flexibility to provide an accurate reading from the instrument, indicating a higher stiffness value. Hence, the Dyneema samples impregnated with the STF combinations as mentioned above provides better flexibility than the traditional chest pad material.

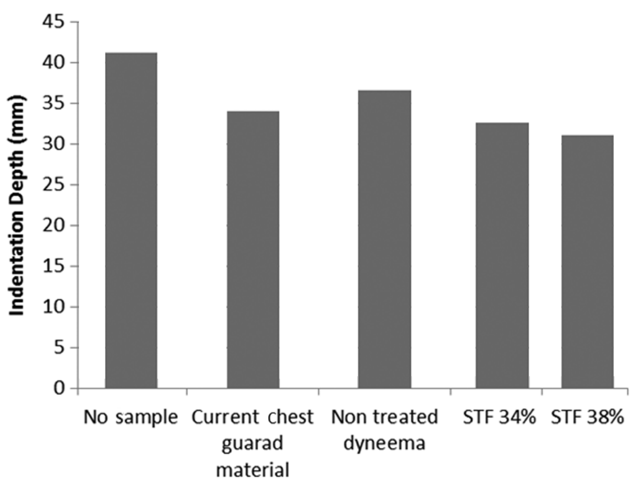

Fig. 2 — Indentation depths during the drop tower test

Moisture transmission and absorption play a major role in comfort properties relating to protective textiles. Percentage moisture absorption is measured to determine the absorption capability of each sample type. Conventional chest pad material displays a minimum absorption of 0.15%. Dyneema samples displays better moisture absorption characteristics than the conventional chest guard material. Impregnation of kaolin STF increases the percentage moisture absorption, and with the increasing volume fraction of kaolin, the value is further increased. Maximum absorption is recorded to be 5.67% for the 38% kaolin volume fraction sample, whereas 34% volume fraction sample shows a absorption of 4.14%. This can be attributed to the hydrophilic nature of kaolin, resulting in higher affinity to the moisture, as the volume fraction increases.

Conclusion

Kaolin – glycerol dispersions at volume fractions of 34% and 38% display shear thickening behaviour. These fluids are successfully intercalated to high modulus fabrics (Dyneema) to improve the impact resistant properties. Kaolin STF at a volume fraction of 38% performs the best in impact absorption, when they are impregnated in to Dyneema woven structures. At a pickup of 25%, Dyneema STF impregnated fabric provides better impact resistance and comfort properties than the conventional chest pad material. This concept can be spread towards other areas of sports protective wear.

Fig. 3 — Microscopic images of samples after drop test [(a) non-treated Dyneema, (b) 34% STF treated Dyneema, and (c) 38% STF treated Dyneema]

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References

1 Lee Y S, Wetzel E D & Wagner N J, *J Mater Sci*, 38 (2003) 2825.
2 Barnes H A, *J Rheol*, 33 (1989) 329.
3 Maranzano B J & Wagner N, *J Rheol*, 45 *(*2001) 1205.
4 Decker M J, Halbach C J, Nam C H, Wagner N J & Wetzel E D, *Compos Sci Technol*, 67(2007) 565.
5 Wagner N J & Brady J F, *Phys Today*, 62 (2009) 27.
6 Boersma W H, Baets P J M, Laven J & Stein H N, *J Rheol*, 35 *(*1991) 1093.
7 Kalman D P, Schein J B, Houghton J M, Laufer C H N, Wetzel E D & Wagner N J, *Proc SAMPE*, 52 (2007) 35.
8 Wagner N & Wetzel E D, *US7226878*, 2007.
9 Roylance D, Wilde A & Tocci G, *Text Res J*, 43(1973) 34.
10 Carr D J, *J Mater Sci Lett*, 18 (1999) 585.
11 Cheeseman B A & Bogetti T A, *Compos Struct*, 61(2003) 161.
12 Kirkwood J E, Kirkwood K M, Lee Y S, Egres R G, Wagner N G & Wetzel E D, *Text Res J*, 74 (2004) 939.
13 Kirkwood K M, Kirkwood J E, Young Sil Lee Y S, Egres R G, Wagner N J & Wetzel E D, *Text Res J*, 74 (2004) 920.
14 Laun H M, Bung R & Schmidt F, *J. Rheol*, 35(1991) 999.