Synthesis of Shear Thickening Fluid Using Sonochemical Method

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ABSTRACT

The term shear thickening is typically used to refer to the increase in apparent viscosity when the applied shear rate is increased. The Shear Thickening Fluid (STF) is composed of hard metal oxide particles such as silica suspended in a polyethylene glycol liquid. The combination of flowable and hard components at a particular composition, results in a material with unusual properties. The STF is being developed at U.S. Army Research laboratory at Aberdeen providing grounds. When Kevlar or nylon woven fabric is impregnated with STF it demonstrates a significant enhancement in ballistic penetration resistance and the ballistic impact characteristics of the fabric without any loss in material flexibility. STF could be used in bomb blankets, and even jump boots, which could be made to stiffen upon impact to support the ankle. In the present study we report on preparation of STF using sonochemical method, where moister contamination is drastically reduced. The known weight percentage of silica nanoparticles and polyethylene glycol is dispersed in ethanol and irradiated with high power ultrasound for 5hours. The ethanol is completely removed by vacuum and heat. The resultant STF is tested for its rheological and thermal properties. The advantages and disadvantages of this process have been discussed and compared with the solvent exchange method which is currently used by the U.S. Army Research lab.

Keywords: Shear thickening fluid, body armor, sonochemical

INTRODUCTION:

Shear thickening is a non-newtonian flow behavior observed as an increase in viscosity with increasing shear rate or applied stress [1]. This phenomenon can occur in colloidal dispersions. In more concentrated colloidal suspensions have been shown to exhibit reversible shear thickening resulting in large, sometimes discontinuous increases in viscosity above a critical shear rate. Two main causes of reversible shear thickening have been proposed: The order–disorder transition [2–6] and the ‘‘hydrocluster’’ mechanism [7–12]. This transition from a flowing liquid to a solid-like material is due to the formation and percolation of shear induced transient aggregates, or “hydroclusters,” that dramatically increase the viscosity of the fluid. Support for this hydrocluster mechanism has been demonstrated experimentally through rheological, rheo-optics and flow- SANS experiments [13, 14] as well as computer simulation [15]. It has been reported in the literature that shear thickening has been observed for a wide variety of suspensions such as clay-water[16], calcium carbonate-water[17], polystyrene spheres in silicon oil[18] iron particles in carbon tetrachloride[19] titanium dioxide-resin[20] silica-poly propylene glycol[21] and silica- ethylene glycol[22]. The phenomenon of shear thickening of suspensions in general has

no useful applications in industrial production. Recently Wegner's group and U.S .Army research lab developed a body armor using shear thickening fluid and Kevlar fabric [22]. These research results demonstrate that ballistic penetration resistance of Kevlar fabric is enhanced by impregnation of the fabric with a colloidal shear thickening fluid. Impregnated STF-fabric composites are shown to provide superior ballistic protection as compared with simple stacks of neat fabric and STF. Comparisons with fabrics impregnated with non-shear thickening fluids show that the shear thickening effect is critical to achieving enhanced performance. In the present investigation we report on the synthesis of STF using sonochemical method, which can be potentially used for the body armor applications.

EXPERIMENTAL:

Two different procedures have been used for the preparation of STF: a) Sonication route and b) Evaporation Route

Sonication Route

Known weight percentages of Polyethylene Glycol (4.5 gm, 45 wt %) and Silica nano particles (dry powder, 15 nm size, 5.5 gm, 55wt %) were mixed with of excess amount of ethanol (75 mL) & irradiated with high intensity ultrasonic horn (Ti-horn, 20 kHz, 100 W/cm^2 at 50% amplitude) for 5 hours at room temperature. The solvent ethanol was later removed from the reaction mixture by evaporation process by heating at about 100°C.

Evaporation Route

In this method Colloidal Silica solution (Nissan Chemicals: 50gms of 40% solution with 200 nm silica particles, 42 wt %) was used as the source of Silica. The water in colloidal silica was gradually exchanged with polyethylene glycol by heating and addition of polyethylene glycol in each step of the exchange process. The heating was continued until water was completely exchanged with polyethylene glycol over the period of 1 hour. The resulting STF theoretically should have 30gms (52.4 wt %) of silica nanoparticles (200 nm size) and 27.3gms (47.6 wt %) of PEG.

Results and Discussion:

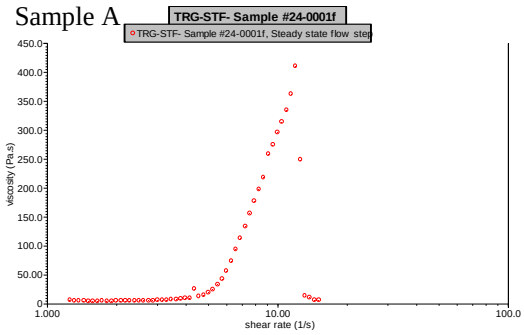
TGA experiments were carried out to determine the weight percentage of silica and polyethylene glycol in as-prepared STF samples. Heating rate was maintained at 5°C /min under nitrogen atmosphere from room temperature to 800°C. The TGA results are presented in table 1

Table1. As-prepared STF samples and their TGA results

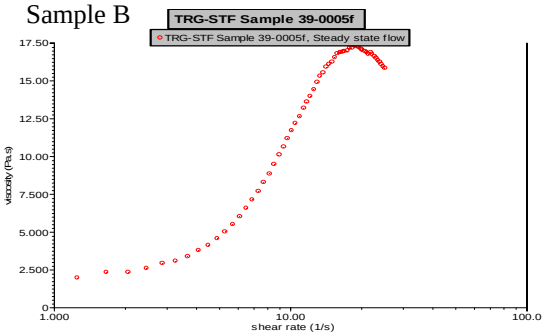
Samples	Material	Weight Ratios %
Sample A	PEG + SiO_2 (powder nano particles 15 nm) sonicated for 5 hours	60:40 / 65:30(TGA)
Sample B	PEG + 1040 Silica nano particles (200 nm) sonicated for 5 hours	60:40 / 62:38(TGA)
Sample C	PEG + 1040 Silica nano particles (200 nm) without sonication	55:45 / 56:44(TGA)

Rheology tests were performed for all the samples including sample A to sample C, using a TA Instrument Rheometer-AR2000. Testing was carried out in a steady sweep mode and shear ramp rate of 0-125/s using a parallel plate of size 25 mm.

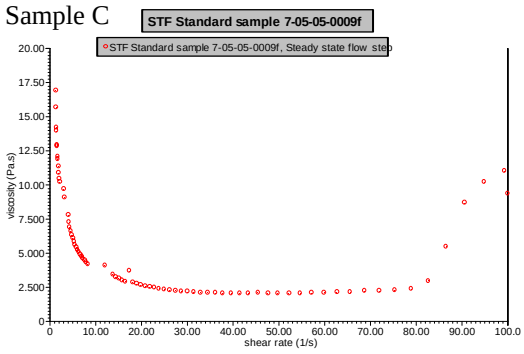
Sample A



Sample B



Sample C



Rheological test results for the sample A as shown in figure clearly show the signature of the shear thickening effect and viscosity changes from 20 to 410 Pa.s at shear rate of 5/s and continues to about 12/s before reversal trend is seen. For sample B the shear thickening effect is very much evident as seen from the graph. Viscosity changes from about 2.5 to 17.5 Pa.s. Shear thickening effect shows at a shear rate of about 3/s and continues up to about 18.6/s before a reversal trend is seen. Sample C rheological results very well match with the results previously (Viscosity changes from 2-11Pa.s and shear rate 80/s to100/s) reported by Dr.Wegners group prepared by evaporation method. These results clearly show that the sonochemical mixing before evaporation drastically improves the shear thickening effect.

Conclusion

- Sonochemical method can be efficiently used for synthesis of Shear Thickening Fluid with out any water contamination.
- We are currently working on systematic experimentation using sonochemical followed by evaporation approach.
- This method can be used for the synthesis of STF from colloidal solutions and nanopowders as well.

Acknowledgements:

The authors would like to thank Dr.Wetzel, Army Research Laboratory, and Dr. Wagner, Department of Chemical Engineering and Center for Composite Materials, University of Delaware for their valuable suggestions.

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