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"A REVIEW ON APPLICATION OF SHEAR THICKENING FLUIDS"

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ABSTRACT

Shear thickening fluids (STFs) draw more and more attentions as they have been considered as suitable materials for liquid body armour, sports and personal protection because of their unique properties. This paper presents a review of the state of the art in STF technology. Shear thickening fluid is a kind of non-Newtonian fluid whose rheological properties takes place as an abrupt change when encountering an impact. This apparent viscosity of STF changes so dramatically under a high speed strike that it may transform from a liquid-state suspension to a solid-state status. This change is a reversible behavior as the viscosity of STF would suddenly come back to the lower value when the impact is removed. Fig. 1 shows the behavior of shear thickening fluid by the schematic form. Most of the specific patent applications, particularly in body armor, as well as other industrial applications, such as smart structures, and devices with adaptive stiffness and damping, are also summarized. Recent advances, including the effects of particle surface properties, relationship to carrier fluids, electric or magnetic fields applied on the transition of STFs are included in the review.

Key Words: *Body armour, damping, field activated, nano particles, Newtonian fluid, shear thickening fluids, smart structure, viscosity.*

I. INTRODUCTION

A shear thickening fluid (STF) is a material whose viscosity increases dramatically when the shear rate is above a critical value. It is an example of a non-Newtonian fluid and also termed a dilatant fluid. At low shear rates, the liquid has low viscosity and acts as a lubricant, and it flows easily; however, at higher shear rates, the hydrodynamic forces overcome repulsive inter particle forces and hydroclusters form. The liquid is then unable to fill the gaps created between particles, and friction greatly increases, causing an increase in viscosity. In addition, this increased viscosity is seen as being both field activated' due to the dependency on shearing rate, as well as reversible. This can readily be seen with a mixture of cornstarch and water, which acts in counter intuitive ways when struck or thrown against a surface. It has been demonstrated that reversible shear thickening results from hydrodynamic lubrication forces between particles, often denoted by the term "hydroclusters".[1] The particles repel each other slightly, so they float easily throughout the liquid without clumping together or settling to the bottom. But the energy of a sudden impact overwhelms the repulsive forces between the particles, and they stick together to form hydroclusters. When the energy from the impact dissipates, the particles begin to repel one another again and the hydroclusters fall apart, so the apparently solid substance reverts to a liquid. Support for the hydrocluster mechanism has been demonstrated experimentally through rheological, rheo-optical and neutron experiments , as well as computer simulations.

Steady shear research indicated the common feature of the STF materials rheograms is a sharp increase in viscosity that decays at higher shear rates, often referred to as a discontinuity.This increase occurs at a critical shear rate. In addition, the suspension behaves as a Newtonian fluid during a large spectrum of shear rates, except for the transition shear rate period that causes the fluid's specific critical shear rate transition. These types of fluids have been

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characterized as Newtonian fluids with a low viscosity before the critical shear rate transition, and as quasi-Newtonian fluids but with a higher viscosity, after the transition [9].

II. Materials

A STF is composed of a carrier liquid and rigid, colloidal particles. A typical kind of particles is Colloidal silica and the most commonly used carrier liquid is polyethylene glycol. The tiny particles suspended in the liquid in a very high concentration (maximum 55-65 vol%) can be utilized for the shear thickening purpose. The actual nature of the shear thickening depends on physical parameters of the suspended phase: phase volume, particle size (distribution) and particle shape, as well as those of the suspending phase: viscosity, details of deformation (including shear or extensional flow, steady or transient, time and rate of deformation) [4]. For the last two decades, intensive research has been focused on the effects of the volume fraction of the particles in the suspension and particle dimension on the critical shear rate. Extensive amounts of patenting activity have documented the effect of different particles and their volume fractions on the critical shear rate. The particles are generally selected from a number of the groups consisting of titanium oxide, calcium carbonate, cornstarch, polyvinyl alcohol-sodium borate mixtures, aqueous solutions of polymethacrylates and poly (alkyl methacrylates), gum arabic and borate ions, and 4 guar gum and borate ions, synthetically occurring minerals, naturally occurring minerals, polymers and a mixture. Some of these shear thickening fluids are discussed in the patents issued to Savins and Wagner et al. The concentration of the thickening compounds utilized should be sufficient to impart the desired shear thickening qualities and effect. The concentrations of polyvinyl alcohol and borate ions which can be used were discussed in one patent while the concentrations of polymethacrylates and poly (alkyl methacrylates) were discussed in another patent [2]. Other useful shear thickening materials, and their concentrations can be found in the literature in which materials also include the category of dilatent materials and sometimes gels[6].

Many carrier fluids have been used, including water, ethylene glycol (EG) and polyethylene glycol (PEG). However, EG or PEG is the most widely used carrier fluid in STF due to its high stability, high boiling point and non-flammable properties. A typical STF was made of silica nanoparticles suspended in polyethylene glycol, so many reports describe this fluid as a form of nanotechnology. The carrier fluid was typically added to the powder, and a blender used to mechanically mix the two components. The concentration of the nanoparticles ranged from 40% to 60%. The shear thickening effect is due to general mechanisms such as hydrodynamics or dilation and thus all suspensions are expected to show shear thickening under certain conditions [9].

Despite the longstanding expectation that shear thickening is a generic type of suspension behaviour, very recently, apparent contradiction is found that shear thickening can be masked by a yield stress and can be recovered when the yield stress is decreased below a threshold. In typical suspensions, attractions are often due to particle-fluid surface tension. An example is the common observation that cornstarch (a hydrophilic particle) shear thickens in water but not in hydrophobic liquids. Apart from the surface properties (e.g. hydrophilic or hydrophobic), the surface roughness, the particle shape and the measuring conditions plays a role in being observed shear-thickening effect. It is found that at a variety of suspensions consisting of particles including cornstarch, glass and polyethylene glycol (PEG), in a variety of fluids with different density matching, modified surface properties, roughness, shapes and measuring conditions, “discontinuous” shear thickening was always observed. Inductively, the discontinuous shearing thickening is general to all hard-particle suspension at near-sedimentation packing fractions provided that the shearing-thinning stresses are below a threshold [10].

III. Literature Review

Wang et al.[2011] study the effect of test temperature on shear thickening of the waxy maize starch (WMS) suspensions. In their study, the WMS suspensions show shear thickening under different temperatures, however, they did not develop a model to predict the critical shear rate as well as the shear thickening effect at various temperatures [1].

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Rivero et al. [2011] explained that the property changes induced by temperature to the PEO-water system are the consequence of two effects. First, the PEO solubility in water decreases with temperature, which is an indication that the polymer coils shrink to a more compact conformation and hence intermolecular entanglements diminish. Second, temperature increases lead to an increase of the system internal energy, resulting in an increase in the free volume of the system [2]

Boersma et al. [1998] used Stokesian dynamic computer simulations to imitate the movements of equally sized sphere particles on the onset of shear thickening. The particles monolayers microstructures were observed at various shear flow in their simulation.[3]

Brown et al. [2010] used a simple model to predict the shear-thickening phase boundaries when the detailed particle properties or microstructure are not given.[4]

Dratler et al. [1997] proposed an order-disorder transaction in suspensions microstructure at the onset of shear thickening. A particles doublet structure was also proposed in their study to analyse the particles' movements.[5]

Galindo-Rosales et al. [2011] used an apparent viscosity function with 11 parameters to describe the three characteristic regions of shear thickening including the slight shear thinning at low shear rates, followed by a sharp viscosity increase over the critical shear rate, and a subsequent pronounced shear thinning region at high shear rates. Their numerical simulation provides an excellent fit the some independent experimental data sets.[6]

Zhang et al. [2008]used small sized fumed silica (14 nm) and large sized silica particles (1 to 5 µm) to fabricate STF with ethylene glycol. It turns out that the 14 nm silica has a clearly shear thickening effect, however, the large particles in the suspension do not show notable shear thickening effect [7].

Jiang et al. developed an evolution equation to describe the functional dependencies of the relaxation times, modal concentrations, and coupling parameter as functions of Besides the above influencing factors, temperature is another very important factor affecting the shear thickening behavior. Based on the two coupled Maxwell modes model.[8]

Tongfei Tian et. al [2013]This paper presents the study of temperature effect on a shear thickening fluid made of ethylene glycol and fumed silica with a 20% weight fraction. Four typical temperatures, ranging from 20˚C to 80˚C, were selected to study the shear rate dependence of viscosity. The temperature tests show that the high temperature increases the critical shear rate and lower the shear thickening ratio. A viscosity function is proposed to represent the three characteristic regions in typical shear thickening fluid and to predict the viscosity at different temperatures.[9]

Haris et. al [2015] This study reports on the shock wave protective performance of woven Twaron fabric impregnated with shear thickening fluid (STF). The STF was prepared from a combination of mechanical and ultrasonic mixing of fumed silica nanoparticles dispersed in liquid polyethylene glycol (PEG) polymer. The shear thickening characteristics were determined from rheological tests. Two shock wave parameters governing blast related injuries are used to evaluate the performance of the STF treated fabrics – peak pressure and rate of pressure rise. The results of our shock tube tests demonstrate that the STF treated fabric composites offer superior shock wave protection as compared to untreated (neat) fabric and fabric impregnated with PEG only. After STF treatment, the normalised average peak pressure amplification is significantly reduced from 2.46 to 1.49 while the attenuation in normalised maximum rate of pressure rise is even more pronounced – from 2.3 to 0.76. Apparent material density is found to correlate with the average peak pressure and maximum rate of pressure rise. This implies that the density increases enough to increase the equilibrium sound speed in the fabric, and therefore preclude the formation of shock wave in the fabric. Ballistic tests using steel projectiles were also conducted to check that the STF treated fabrics continued to enhance ballistic protection as reported by other researchers. Overall, the results show that the STF treated fabrics have potential applications not only for ballistic protection but also for shock wave mitigation.[10]

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SelimGürgen et al [2017] Shear thickening fluid (STF) treated high performance fabrics have attracted much attention in the applications of body protection. In order to improve the contribution of STF treatments, we designed multi-phase STFs and investigated the stab resistance of fabrics impregnated with these novel fluids. Silica and polyethylene glycol (PEG) based STFs were synthesized with various particle size of silicon carbide (SiC) additives to constitute the multi-phase suspension systems. The influence of the additive particles on the thickening behavior of the STFs was analyzed via rheological testing. The stab resistance of the fabrics was investigated in a drop tower against spike and knife threats and therefore, the role of the STFs was discussed in detail. According to this study, multi-phase STFs realized further improvement in the stab resistance of fabrics with respect to single-phase STFs.[11]

IV. APPLICATIONS

The STF has held promises in many industrial applications. Some patents protected certain applications while others invented certain shear thickening fluids with potentials of various applications. For example, one patent described a shear thickening fluid used in conjunction with fabrics utilized in an expandable spacecraft. The combination of the fluid and the fabric allowed the fabric to resist penetration by hypervelocity particles in space. On the other hand, the other patent studied the rheology of a colloidal PEG-based shear thickening fluid emulsified with silicone oil and found that a shear thickening response was observed in the viscosity-shear rate curves for volume fraction as low as 10% of STF in the silicone emulsion. Potential applications for such STF covered in the patent incorporated into pads for sport equipments: such as a mouth guard for improved energy dissipation, reducing the like hood of concussion or dental damage; gloves for reducing vibration or protecting the hands from jarring impact; directly into sports shoe designs for energy dissipative construction. The comfortable composites comprised of discrete droplets or co-continuous networks of STF could also be used in seat cushioning and neck supports in automobiles, airplanes and trains to provide more protection during accidents. Smart components could be fabricated where the stiffness or hardness of a flexible component can change as a result of deformation, such as from elongation, bending, torque, twisting, or compression. The materials could be used as a medium to control mechanical actuation of one object relative to another, etc. The three main application streams, however, including devices with adaptive stiffness and damping, smart structure and body armor, will be reviewed in more details below.

A) Devices with adaptive stiffness and damping

The basic idea here is to use STF in a viscoelastic damper and to obtain adaptive stiffness and damping. A device filled with functional fluids, one of which was a shear thickening fluid to provide variable dampings. When subjected to a predetermined shear rate, the shear thickening composition would undergo a dramatic and substantial increase in viscosity and shear stress. A viscoelastic damper, filled with a STF, was invented to control the vibration of a structural member, a tank, a pipe, etc. The vibration might be caused by an earthquake or wind. The damper would produce minimum reaction force when the structural member and so on was slowly displaced as a result of the thermal deformation of the member itself or another member connected thereto. STF could present relatively small resistance when the speed of the motion is small and produces progressively resistance as the speed of the motion increases.

B) Smart structures

Based on the STF and STF devices, the smart structures used for industrial applications were also investigated.They used shear thickening fluid as a tamp in controlled pulse fracturing (CPF). The fluid would become more viscous and more resistant to flow up the production string or tubing when fluid velocities increased under the force generated by the ignited propellant. It would slow or even stop the upward movement of structures and the damage to the equipments would be lessened. The invention presented a method to process composite structures with tailored stiffness and damping performance incorporating STF, preferably at the interface between two elements belonging to the same structure and moving to each other.

C) Body Armor

Up to now, the widest application of the STFs has been for liquid body armors in military applications. Throughout the history, personal armour systems have been practical only when they have been able to provide significant protection against the prevailing threats whilst not impairing the wearer's ability to perform the tasks required to them. The materials which were used for current body armour applications were not capable to provide whole body protection due to their stiffness and bulky properties. The key issue is that if we provide the same level of protection as the torso with current body armour materials, they would be far too stiff and bulky to allow the wearers to carry out the normal movements of their arms and legs. Novel liquid body armour based on the STFs has shown promising prospects including towards improved protection and flexibility. Most liquid body armours in recent patents were formed by immersing a fibrous substrate or a porous media in a STF.

V. CONCLUSION

In summary, greater shear thickening effects could be achieved through the following particle parameters; applying higher flow acceleration, aligning particle layers perpendicularly to the expected shear force loading, employing a higher concentration of particles, using a smaller particle size to improve the wet surface area, and using particles with high aspect ratios and with the longer surface aligning perpendicular to the expected shear flow. This study suggested that particles could further improve the shear thickening effect of non-Newtonian fluids, although a further investigation is required for the non-linear response at low shear strain rates. Successful numerical analysis of the shear thickening effect would allow more optimized and improved STF design.

REFERENCES

[1] B. Wang, L. J. Wang, D. Li, Y. G. Zhou and N. Özkan, "Shearthickening properties of waxy maize starch dispersions," Journal of food engineering, vol 107, pp. 415-423, 2011.

[2] D. Rivero, L. M. Gouveia, A. J. Muller and A. E. Saez, "Shearthickening behavior of high molecular weight poly(ethylene oxide) solutions," Rheologica Acta, vol 51, pp. 1-8, 2011.

[3] W. H. Boersma, J. Laven and H. N. Stein, "Computer-Similation of shear thickening of concentrated dispersions," Journal of Rheology, vol 39, pp. 841-860, 1995.

[4] E. Brown, N. A. Forman, C. S. Orellana, H. Zhang, B. W. Maynor, D. E. Betts, J. M. Desimone and H. M. Jaeger, "Generality of shear thickening in dense suspensions," Nature Materials, vol 9, pp. 220-224, 2010.

[5] D. I. Dratler, W. R. Schowalter and R. L. Hoffman, "Dynamic simulation of shear thickening in concentrated colloidal suspensions," Journal of fluid mechanics, vol 353, pp. 1-30, 1997.

[6] F. J. Galindo-Rosales, F. J. Rubio-Hernández and A. Sevilla, "An apparent viscosity function for shear thickening fluids," Journal of Non-Newtonian Fluid Mechanics, vol 166, pp. 321-325, 2011.

[7] X. Z. Zhang, W. H. Li and X. L. Gong, "Study on magnetorheological shear thickening fluid," Smart Materials and Structures, vol 17, pp. 015051, 2008.

[8] B. Jiang, D. J. Keffer, B. J. Edwards and J. N. Allred, "Modeling shear thickening in dilute polymer solutions: Temperature, concentration, and molecular weight dependencies," Journal of Applied Polymer Science, vol 90, pp. 2997-3011, 2003.

[9] Tongfei Tian, Weihua Li, Jie Ding, Gursel Alici, and Haiping Du2013 "Study of the temperature effect of shear thickening fluid" IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM) Wollongong, Australia, July 9-12, 2013.

[10] A.HarisH.P.LeeT.E.TayV.B.C.Tan "Shear thickening fluid impregnated ballistic fabric composites for shock wave mitigation" International Journal of Impact Engineering, Volume 80, June 2015, Pages 143-151.

[11] SelimGürgen[a] Melih CemalKuşhan[b] " The stab resistance of fabrics impregnated with shear thickening fluids including various particle size of additives" Elsevier Composites: Part A 94 50–60, 2017