1.0 Introduction

A group of materials that have recently gained a lot of attention in research are shear thickening fluids (STF). Under normal circumstances STFs act like slightly viscous fluids; however when a force acts to shear the material, the STF turns solid at the point of the attempted tear. When the force is released, the STF returns to its normal fluid state.

Recent research in the area of STF has focused on the use of STF to strengthen body armor. The use of STF in body armor seems natural for the material. With the shear stress a ballistic impact would impose upon the material, the STF should solidify at the point of the impact causing resistance to rupture. The true bonus is that while it is protective, it is also flexible allowing the wearer to move while wearing the armor.

The purpose of this paper is to review what STFs can be used for and the manufacturing techniques used for some existing STFs. STFs used for body armor will be examined in particular.

This paper begins by explaining a general overview of what a shear thickening fluid is as well as manufacturing techniques. The following sections give details on STF's impact on the production of body armor. These sections will explain the manufacturing techniques used for these particular applications, as well as the success of tests that were performed on the materials used.

2.0 Overview of Shear Thickening Fluids

Newtonian fluids are fluids such as water or air. When Newtonian fluids are plotted on a graph of shear stress vs. shear rate, the result is a strait line with a constant slope [Subranian, 2006]. A graph of shear stress vs. shear rate is shown in figure 1. However, some fluids act in a non-Newtonian way. The study of non-Newtonian fluids is known as the field of "rheology" [Subranian, 2006]. One type of fluid studied in rheology is shear-thickening fluids. Shear thickening fluids can be defined as fluids that, when the shear rate is increased, the viscosity increases [Subranian, 2006]. This increase in viscosity makes raising the shear rate further difficult. A plot shear stress vs. shear rate for STFs is shown in Figure 2.

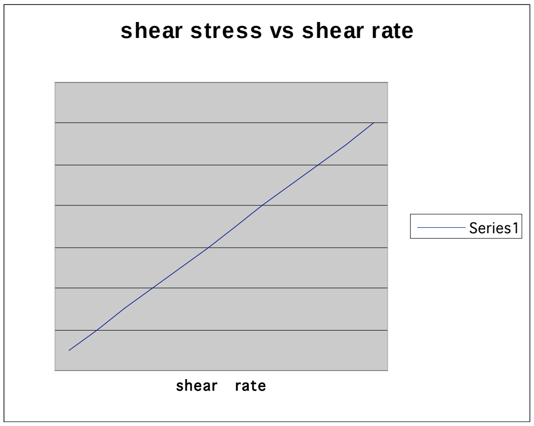


Figure 1: Shear stress plotted against shear strain in a Newtonian fluid.

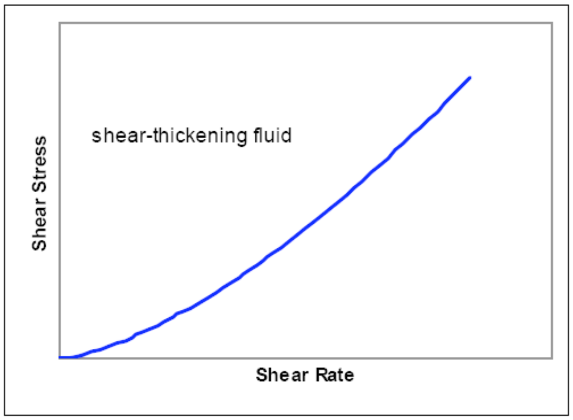


Figure 2: Shear stress vs. shear rate of a non-Newtonian shear thickening fluid [Subranian, 2006].

2.1 Manufacturing of STFs

Most shear thickening fluids are created using a suspension of solid particles in a liquid matrix. This allows solidification of the fluid by congregation of the particles under stress. As stress increases, the particle solute reacts to the shear by strengthening bonds to adjacent particles in reaction to the stress.

A very simple STF is corn starch in water. A cornstarch slurry will harden as shear stress is increased. If stirred or compressed, the slurry will solidify; however, if no shear stress is applied, it returns to liquid form [Johnson, 1998].

3.0 Uses for STFs

Traditionally shear-strengthening fluids had little commercial appeal [Johnson, 1998]. In most applications, shear-thickening fluids are difficult to work with. If one tries to pump a STF through a pipe, it would go slower as more pressure is applied to push the fluid. A recent trend for STF research has been spurred by oil industry and military applications of STFs.

3.1 STFs in the Oil industry

The oil industry uses many drilling fluids with interesting properties. Some fluids used in drilling are shear-strengthening materials. The basis behind using shear thickening fluids is to protect a well from blowouts. A blowout usually occurs when a drill reaches a gas pocket. The sudden release of gasses often causes damage to the drill and has caused fatalities before [Hamburger, (1983)]. If a blowout occurs in the wellbore, the STF acts as an immediate patch. The STF reacts to the stress caused by the sudden blowout and solidifies at that location effectively patching the blowout [Hamburger, 1983].

Figure 3: Wellbore blowout [Hamburger, (1983)]

3.2.0 Shear thickening fluid used for body armor

The main objective for body armor development is to develop a garment that is lightweight, cost efficient, and wearable, in addition to incorporating ballistic impact resistance [Cunniff, 1992]. STF body armor uses Kevlar as a matrix to imbed the STF in.

The manufacture of STF body armor, as well as its performance under ballistic and stab tests, will be investigated.

3.2.1 Imbedding STF in body armor

For body armor, the STF that is most commonly used in research is colloidal silica particles suspended in an ethylene glycol matrix. A transmission electron microscopy image of this suspension is shown in Figure 3. To prepare the Kevlar fabric the STF wets the fabric and then the fabric is heated [Lee, 2003]

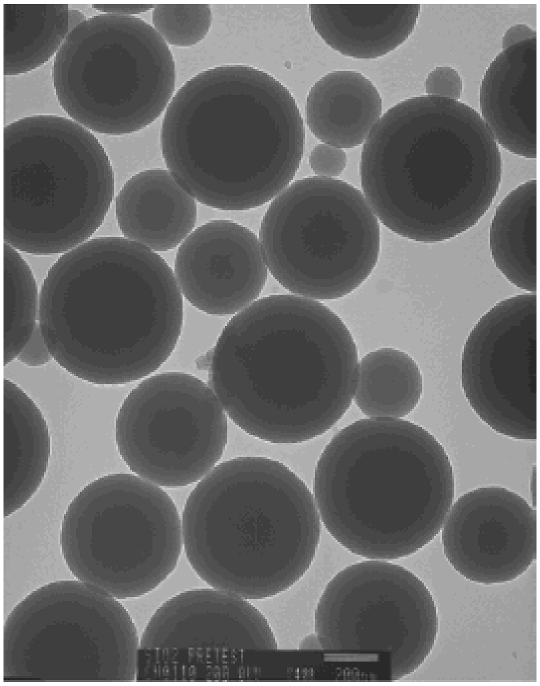


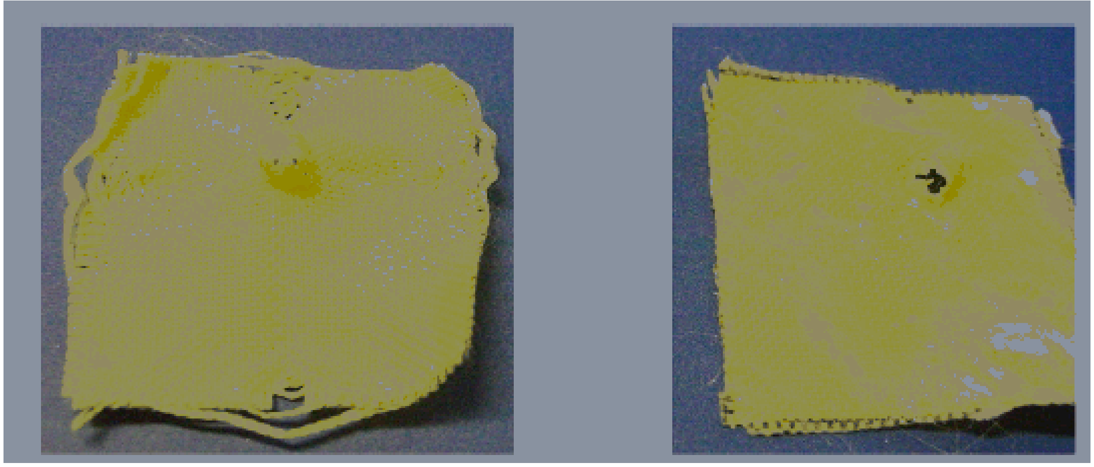
Figure 4: Transmission electron microscopy of colloidal silica obtained from Nissan Chemicals (MP4540) at a magnification of 40,000 [Lee, 2003]

Colloidal silica particles are used for the suspension because the onset of shear thickening can be quantitatively predicted for colloidal suspensions of hard-spheres [Marazano, 2001]. The reason for using ethylene glycol as the solvent for the suspension is that ethylene glycol has a low volatility and is thermally stable. Ethylene glycol also has an index of refraction similar to that of the silica particles, providing for enhanced colloidal stability [Lee, 2003]. Kevlar is used as the material to imbed the suspension in because it has known ballistic protection capabilities.

3.2.2 Ballistic tests on STF impregnated material

The basis of ballistic testing is the use of a clay witness. A clay witness reveals the damage done to an object from the depth of penetration into the material. Body armor standards require that a projectile should be stopped under ballistic impact, and that the depth of penetration into the clay witness behind the body armor should not exceed 1.73 inches (4.4 cm) [NIJ standard, 2001]. If the depth of 1.73 inches is exceeded, this represents the potential for severe blunt trauma in humans [Bazhenov, (1997)].

Ballistic tests performed by Young S. Lee show an impressive strengthening of STF impregnated Kevlar in comparison to non-impregnated Kevlar. Figure 4 shows visually the difference after ballistic tests on two Kevlar specimens.



A B

Figure 5: Comparison of (A) 4 layers unimpregnated Kevlar against (B) 4 layers STF impregnated Kevlar after ballistic tests [Lee, 2003].

Table 1 shows numerical data to support the fact that STF impregnated Kevlar body armor provides superior protection from blunt trauma. The table shows that four layers of STF impregnated Kevlar is comparable in protection to ten layers of non-impregnated Kevlar.

Table 1: Numerical comparison of (A) 4 layers unimpregnated Kevlar armor (B) 4 layers impregnated Kevlar armor (C) 10 layers unimpregnated Kevlar armor [Lee, 2003].

Target Description	Sample weight (g)	Penetration depth (cm)	Impact velcelocity (m/s)	Bending angle (degrees)
A) 4 layers Kevlar	1.9	2.12	244	51
B) 4 layers impregnated Kevlar	4.8	1.23	243	50
C) 10 Layers Kevlar	4.7	1.55	247	13

3.2.3 Flexibility tests of STF impregnated material

One of the most impressive features of STF impregnated body armor is its ability for it to remain flexible while providing equal protection as thicker, less flexible body armor. Figure 5 shows the test used to find the flexibility of the Kevlar specimens. The specimen used is a 5.1 cm square of Kevlar. 1.3 centimeters of the specimen is placed in a vice the rest is bent with a 20 gram weight the angle between the original position and the new weighted position is measured to determine the flexibility of the material.

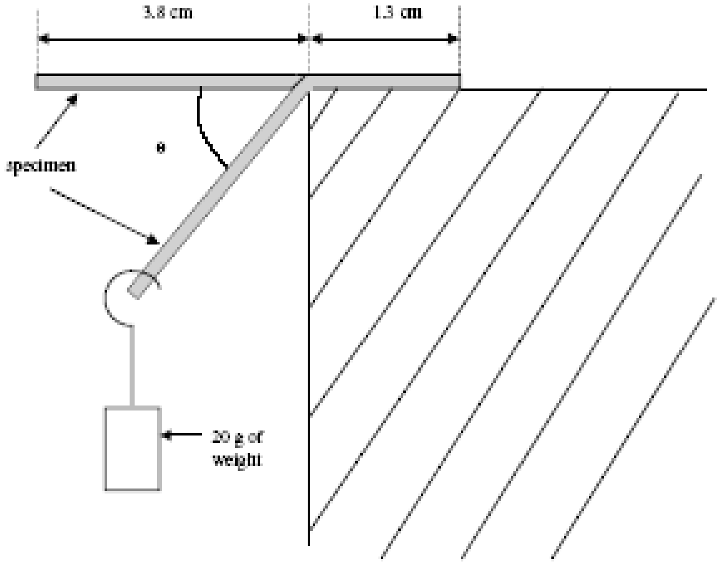


Figure 6: Test set up to measure the flexibility angle for the armor [Lee, 2003].

Table 1 demonstrates that while four layers of STF impregnated Kevlar are comparable to ten layers of non-treated Kevlar in weight and protection from blunt trauma. Four layers of STF impregnated Kevlar are comparable to four layers of non-treated Kevlar in the bending angle flexibility test.

STF impregnated Kevlar therefore demonstrated the best qualities of both four and ten layers of non-treated Kevlar. It demonstrates flexibility and protection from blunt trauma.

3.2.4 Stab resistance of STF impregnated body armor

Kevlar provides adequate protection from ballistic threats; however, Kevlar was not manufactured for protection from stab threats. By impregnating Kevlar fabric with an STF tests demonstrate that the fabric becomes effective at protection from stab stresses.

In order to test the efficiency of STF impregnated fabrics against stab threats a drop tower test is used. The drop test consists of a spike with a mass attached this spike is dropped from a specified height on the body armor target. Behind the target are layers of witness paper. The required energy to penetrate each layer of witness paper is already known, to find the effectiveness of the armor all that is needed is to count how many layers of witness paper were penetrated. The spike penetrates more than five layers of witness paper correlates to the point where injury is likely to occur [Egress, (2005)].

STF impregnated fabrics show remarkable stab resistance when tested. Non-impregnated Kevlar reaches the maximum allowable penetration of five witness paper layers when the drop tower test at an energy of around four Joules. However, even at the maximum energy tested on the STF impregnated material which is around 17 Joules the spike penetrated only three layers demonstrating the effectiveness of STF for strengthening Kevlar fabric against stab threats [Egress, (2005)].

4.0 Conclusion

Shear thickening fluids may have seemed just a novelty just a few years ago. Recent tests have shown that STFs have very useful applications, even if the applications seem specific.

STF in oil drilling is already being put into use to plug well-bore blowouts. Practical applications like these can save quite a bit of money and even lives. The manufacture of the STF is inexpensive and is well worth it to the oil industry as a preventative measure.

The use of STF in body armor is an incredible advance. The manufacture of STF impregnated Kevlar fabrics is very simple. The advantages of STF impregnated Kevlar over regular Kevlar is incredible. Fewer than half the layers of a normal Kevlar vest are required to provide the same protection. With fewer layers of the material the mobility of the person wearing the protection is greatly increased providing the potential for enormous benefits to law enforcement and military personnel. The stab resistance of STF impregnated Kevlar is also impressive. The benefit a better stab resistant material would be of particular use to correctional officers who are far more likely to be threatened with stabbing weapons than with ballistic weapons.

5.0 References

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