Study on Preparation and rheological properties of shear thickening fluid

Bi Meng [1, a], Guangyin Xie [2,b]

[1,2]Xi'an polytechnic university,Xi'an 710048,China

[a]1204612950@qq.com, [b]xgy164@126.com

Keywords: Nano-SiO_2,Polyethylene glycol,Shear thicking fluid,Steady theological properties

Abstract: The nano silica was used as the dispersed phase particle and the polyethylene glycol was used as the dispersed phase medium. The shear thickeing fluid(Thickening Fluid Shear, STF) which the SiO_2 solid content of STF was 9%, 12%, 15%, 17% and 20%. The different concentration different molecular weight and different temperaturesof the static theological properties was tested. Besides, the reversibility of STF was analyzed. The results show that different conditions have differernt effects on the static rheological properties of STF.However the shear rate changes from small to large or from big to small changes, two scanning curves almost coincide.It indicates that the shear thickening effect of STF dispersion system is reversible.

Introduction

In recent years, with the continuous development of science and technology and military, people pay more attention to the war on terror and the improvement of personal protection consciousness, and the demand of protective equipment is increasing. Not only is people in pusuit of the performance of Individual protective materials, but also the softness of the material and the wearer's comfort is ensured [1]. In order to overcome the disadvantages of high quality, large volume and non flexible of traditional stab resistant materials, a new type of soft protective material with excellent protection performance and flexibility is developing.The shear thickening fluid (shear Thickening Fluid, namely STF) [2] is a non-Newtonian fluid, which is composed of dispersed phase particles and dispersed medium.It exhibits good flow properties at no force or a slight force .Once more than the critical shear force, the phenomenon of the shear thickening occured[3]. when the force disappeared, the STF would be quickly recovered into a state of flow.

By using the characteristic of STF, it can be used to soak the high performance protective material, which can significantly reduce the quality of the individual protective material and improve the comfort of the protective armor while not changing the bullet proof performance of the material. The shear thickening fluids with different SiO_2 concentrations were prepared by mechanical mixing method, and the steady state rheological properties of SiO_2/ polyethylene glycol dispersions at different concentrations, different molecular weights and different temperatures were studied.

Experiment

Experimental materials and reagents

Due to non-toxic nano-silica, particle size distribution is concentrated, stabled nature, high hardness, and PEG is a non-toxic, non-irritating chemicals, good compatibility [4-7]. A hydrophilic

SiO_2(A200)which is produced by the Degussa company and the primary particle size is 12 nm .It is used as the dispersed phase particles.The average molecular weight of 400 and 600 of polyethylene glycol which is provided by the Chengdu Kelon Chemical reagent Factory were used as thedispersion medium.The different mass fraction of shear thickening fluid with was provided.

Preparation of Shear Thickening Fluid

At room temperature, respectively a certain amount of SiO_2 and PEG400 mechanical were mixed, and then placed in an ultrasonic cleaning ultrasonic dispersion 3h sufficiently dispersed.The sample is placed in a 25in a vacuum drying box defoaming 24h. The five different SiO_2 mass fraction of 9%, 12%, 15%, 17% and 20% of STF is made.The parameters shows in Table 1.

Table 1 Different mass fractions of STF solution

The Sample	TheParticle sizeof SiO_2/nm	PEG400/g	SiO_2/g	The concent of SiO_2/wt%
1	12	45.5	4.5	9
2	12	44	6	12
3	12	42.5	7.5	15
4	12	41.5	8.5	17
5	12	40	10	20

Testing and Characterization

The steady-state rheological properties of shear thickening system was tested by AntonPaar GmbH of MCR302 rheomete that a diameter of rotor mode is l25mm, taper is 2ºand shear rate scan range form 0.1 to 200s^{-1}.The rheological behavior of the shear thickening fluid and the reversibility of the shear thickening fluid were tested under different conditions.

Factors affecting the rheological properties of the shear thickening fluid and its analysis

(1) Rheological curve of STF with different mass fraction

Fig. 1 shows the flow curve of different mass fraction of shear thickening fluid viscosity and shear rate of the rheological, in which the particle size of SiO_2 is about12nm, and the dispersion medium is PEG400. When the SiO_2 mass fraction reached 20%, the system viscosity has been relatively large, liquidity is not very good, so it is not needed to go to a higher quality dispersion.The mass fraction of stf solution was 9%, 12%, 15%, 17% and 20% which were labeled as 1#, 2#, 3#, 4# and 5#.

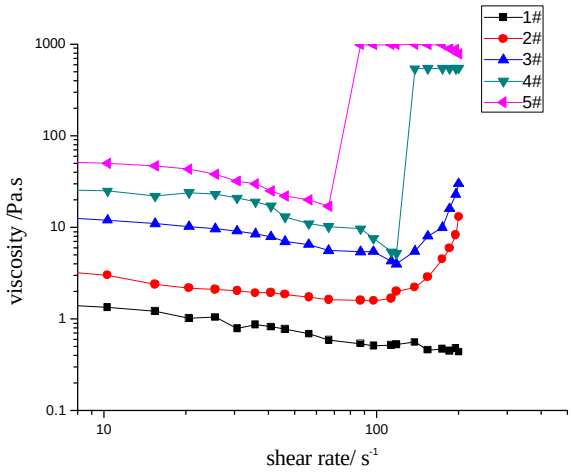


Fig.1. Rheological curve of STF with different mass fraction

As it can be seen from Figure 1, the steady-state flow curve of the shear thickening system with different mass fraction is basically the same.With the increase of the mass fraction of SiO_2, the

critical shear rate of STF system is decreasesd.The Mass fraction of 9% the shear thickening system did not appear the phenomenon of shear thickening, because the SiO_2 particle content of shear thickening fluid is less, resulting in the formation of "particle clusters" is relatively small, it can not produce shear thickening phenomenon.It can be seen that with the increase of SiO2 mass fraction, the initial viscosity and the maximum viscosity increase, and the increase of the amplitude is more and more large. When the mass fraction of SiO_2 reaches 17%, the shear rate is greater than the critical shear rate, the viscosity increases rapidly, and the maximum viscosity is far beyond the initial value.The main reason is followed this rule: with the increase of SiO_2 mass fraction, the solid particles in the system is increasing, and the force between it and PEG is enhanced, which makes the viscosity increased. In addition, with the increase of SiO_2 content, the formation of more and larger "particle cluster", which makes the system flow resistance increases, so the shear thickening effect is more and more obvious. Therefore, the size of SiO2 particle concentration plays an important role in the rheological properties of shear thickening fluids.

(2) Rheological curves of STF with different molecular weight of PEG

Fig 2 shows the viscosity of the dispersion medium under different shear thickening fluid shear rate change in the double logarithmic flow curves, which the SiO_2 particle size is 12nm, the molecular weight of PEG is 400 and 600, the mass fraction of SiO_2 is 15%.

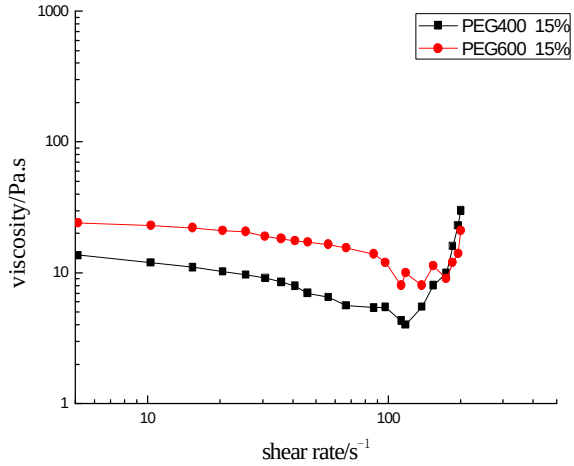


Fig. 2. Rheological curves of STF with different molecular weight of PEG

As it can be seen from Fig.2, different molecular weight of PEG also affect the rheological properties of shear thickening fluid. With the increase of shear rate, the viscosity decreases and then increases after the increase of the critical shear rate, The trend of the two curves is basically the same.The trend of PEG600 shear thickening fluid after the critical shear rate viscosity increases is not as good as PEG400 shear thickening system.At the same time, with the increase of the molecular weight of PEG, both the initial viscosity and maximum viscosity increase, the maximum viscosity of PEG600 shear thickening fluid is smaller than that of the initial viscosity, and the thickening effect is not as good as PEG400 shear thickening.

The reason that the SiO_2 content of the two systems is the same, but the -OH group of the PEG molecule is only in the ends of long chain molecules. With the increase of the molecular weight of the dispersion medium, the molecular chain growth, the same mass of PEG with a corresponding reduction in the number of hydrogen bonds formed with SiO_2, the interaction between the solid and liquid is decreased,

(3) Effect of temperature on the rheological properties of the steady-state

Fig.3 shows that the SiO_2 particle size is 12nm and the molecular weight of PEG is 400. The steady-state flow curve of the mass fraction 17% of STF is texted by 25℃ and 35℃. The tests

mainly is used to observe the temperature changes affect shear increases the changes in the performance of the thick liquid, so the two temperature is selected. It can be seen from the figure 3 that the change of temperature has great influence on the critical shear rate and the maximum viscosity of the shear thickening system, but the change of the initial viscosity is small and the general trend of the rheological curve is not changed much. So it can be seen that the temperature affects the shear thickening system, which needs to be considered when using the shear thickening system.

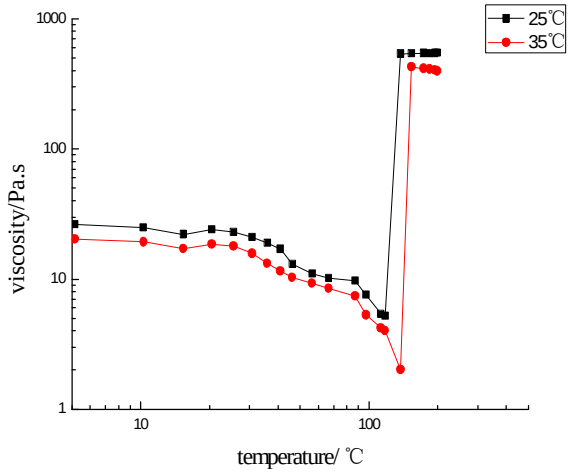


Fig.3. Effect of temperature on the rheological properties of the steady-state

(4)Reversible shear thickening fluid analysis

Fig.4 shows that the reversibility of the shear thickening system which the SiO_2 particle size is 12nm, the molecular weight of PEG is 400 , and the mass fraction of SiO_2 is 15%.

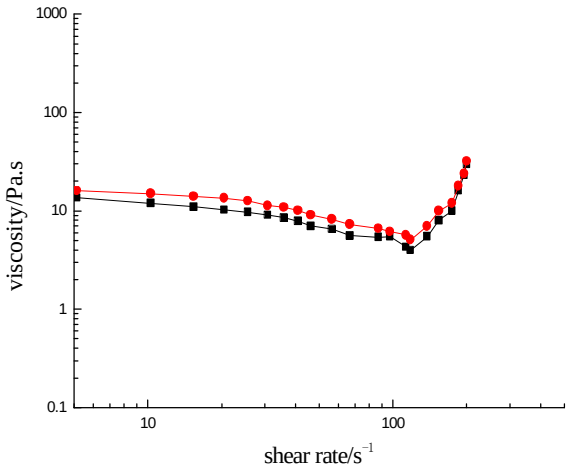
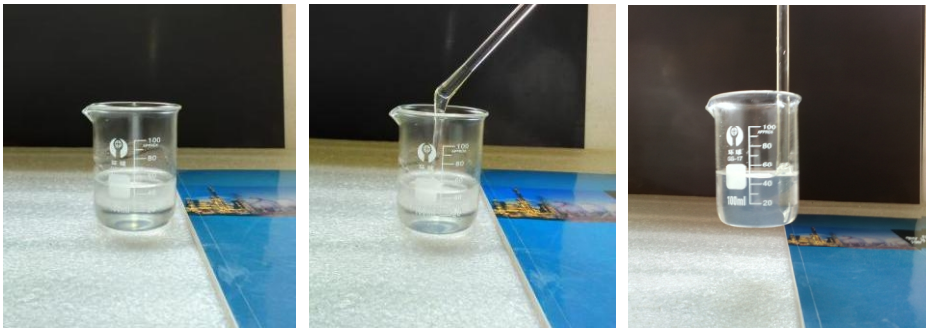


Fig. 4. Reversible shear thickening fluid analysis

Fig. 4 shows whether descending or descending shear rate, the trend of these two are basically the same flow curves, we have emerged after the first shear thinning shear thickening phenomenon, illustrate this scissors rheological properties of shear thickening system has excellent reversibility. From the figure 4 shows that whether the shear rate from large to small or from large to small, the trend of the two rheological curves are basically the same. STF will appear the phenomenon that shear thickening after Shear thinning, which shows that the rheological properties of this shear thickening system has a good reversibility. Therefore, when the shear thickening system is affected by the external impact, the shear thickening fluid will be changed into a solid state after the critical shear rate. When the particles are not affected by the external force, the particle clusters will be re decomposed, and the shear thickening solution can be recovered to the original fluid state.

STF shear thickening macroscopic appearance

Fig.5 shows that the phenomenon of Macro shear thickening that the Nano SiO_2 mass fraction is 20%. When the beaker is allowed to stand on the table, without any external force, STF is almost transparent liquid state, similar to the colloidal and slightly shiny pan-blue light, as shown in Fig.5 (a) . In the Fig. 5(b), When the glass rod was slowly lifted from the beaker, effortlessly, STF not produce additional resistance of the glass rod, shear thickening fluid will gradually back into the beaker with a glass rod, and at the same time you can see the obvious flow lines and fluid gloss. However, if the glass rod Mengchuo beaker shear thickening fluid shear thickening fluid found quickly hardens, showing a solid nature, in which case the glass rod quickly withdrawn from the STF, since the shear increase thick fluid shear thickening effect, stood STF beaker with a glass rod will be lifted to a certain height, as shown in Fig.5(c). After the glass rod stop motion, shear thickening effect disappeared, due to gravity, the beaker will fall back on the desktop. The fluid will flow back slowly on a glass rod in a beaker, and ultimately return to the liquid state. Therefore, it can be seen from the macro, shear thickening fluid state solution with different shear rates and different,which is a non-Newtonian fluid. At the same time, the rheological properties of the test results with the previously microscopic tests consistent.



(a) (b) (c)

Fig.5. STF shear thickening macroscopic appearance

Conclusion

(1) The nano-SiO_2 is used as a dispersed phase,and low molecular weight PEG is configured as a dispersion medium.The shear thickening fluid has good shear thickening properties. When the shear rate is small, shear thickening fluid shear thinning phenomenon occurs. With the continuously increasing shear rate, shear thickening fluid will be varying degrees of thickening effect.

(2) The mass fraction of SiO_2 particles, the dispersion medium of different molecular weight and the temperature and other factors affect the steady-state rheological properties of SiO_2/PEG dispersion system. With the increase of the mass fraction of SiO_2 particles, the viscosity of the system increased, the critical shear rate of STF system decreased, and the shear thickening effect was more and more obvious. With the increase of the molecular weight of the dispersed medium, the thickening of the system is more obvious. But with the increase of temperature, the trend of the rheological curve of the dispersion system is not much changed, but the critical shear rate of the dispersion system is increased, and the maximum viscosity value is decreased.

(3) Whether the change of the shear rate is from large to small or from small to large.The dispersion system will appear before the shear thinning. Meanwhile, when the dispersion system is subjected to external force disappears, it will quickly recover from the class of solid material to a fluid state. These instructions shear thickening system has a good reversibility.

Reference:

[1]XiaoFei Sha,Jing Yuke,HaiJian Cao,Kun Qian,Lingling Jiang.Preparation technology of STF/ UHMWPE flexible stab resistant composite material[J]. Journal of materials science and Engineering.2013,31 (4):282-286.

[2] XiaoFei Sha,JingYuke,KunQian.Effects of different molecular weight PEG on rheological properties of shear thickening fluids[J]. New chemical materials[J], 2013,41 (5):100-102.

[3] Fang Xiong,Dali Zhou, Jianwen Gu, Hua Jian,Wei ZhongYang,Qin Zhang, Lin Chaoyang. Kevlar fiber cloth / shear thickening fluid composite material Preparation and stab performance [J].Sichuan Ordnance Technology, 2013,34 (4):130-133.

[4] Konghu Li.Shear Thickening Processing Besed On Knitted Fabric of stab-resistant of performance[D].Shanghai:Donghua University, 2012.

[5] Hoffman R L.Explanations for the cause of shear thickening in concentrated dispersions[J]. J.Rheol,1998,42(1):111-123.

[6] Egres R G,Lee Y S,Kirkwood J E,et al.Novel flexible body armor utilizing shear thickening fluid(STF) composites[C].San Diego:Proceedings of the 14th International conference on Composite Materials,2003.

[7] Wetzel E D,Wagner N J.Protective fabrics utilizing shear thickening fluids (STF)[R].Pittsburgh: 4th International Conference on Safety and Protective Fabrics,2004.