Development of Shear Thickening Material

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Abstract. As a new kind of functional material, excellent mechanical properties make Shear Thickening Material one of the most important materials in the field of protection against external forces. According to different raw material and preparation technology, several kinds of shear thickening systems were classified and analysed, and the corresponding mechanism was analysed. On the basis, the effects of disperse phase, high polymer weight and composition on the thickening properties were discussed. The application field of shear thickening materials was reviewed, and the direction of potential research value was pointed out.

1. Introduction

As new materials, shear thickening materials include shear thickening gels and shear thickening liquids, the shear thickening liquid was developed by the U.S. Army Research Laboratory and the State University of Delaware synthetic research center in 2000, in order to create a new generation of military battle suit. This STF is a mixed fluid by the dispersion of Nano particles in polymer or long chain polymer formed, where nanoparticles can free movement, so STF is liquid; when subjected to external shear stress rapidly, the viscosity of the system increased, the area turns to kind of solid state, great loss of external stress energy. When the external force is removed, the system state gradually restored, which exhibited reversible properties [1]. In this paper, the mechanical properties of shear thickening materials in different systems, the corresponding thickening mechanism and influencing factors are reviewed.

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2. Nanoparticle / polymer suspension system

This kind of shear thickening fluid is a kind of suspension system with special properties. It is composed of the dispersed phase and the dispersed medium. At present, the research on the preparation and properties of this kind of system plays an important role in the field of shear thickening materials. The relationship between shear thickening effect and particle size of dispersed phase was studied through experiment to control fluid thickening effect conducted by Marzano² et al, the steady and dynamic analysis of rheological properties of STF are carried out by LGG [3] respectively, and the viscoelastic transformation rule of STF is obtained.
2.1. Shear thickening mechanism

There are two main theories about the shear thickening mechanism of nanoparticle / polymer system. One is the principle of ODT proposed by Hoffman et al through a series of light scattering experiments, the principle for the transformation mechanism of particles from "order" to "disorder"; the second is clusters formation mechanism proposed Brady according to the Stokes Ian Dynamic experiment, which holds that micro assembly "clusters" generated in fluid under the action of shear stress, which results in the viscosity increasing \[3\]. Later, some scholars have found that the particles with disordered distribution can also produce shear thickening effect, so the theory of particle cluster is more reasonable. Marzano et al \[4\] found there does exist a "particle cluster" formation in the shear thickening transition through small angle neutron scattering (SANS) experiments \[5\];

2.2. Preparation and characterization

The most commonly used methods for the preparation of nanoparticle / polymer shear thickening systems are ball milling and ultrasonic method. The properties of SiO2/PEG system prepared by different processes were studied by Xu Supping et al \[6\].

![The average particle size](image)

**Figure 1.** Dispersion of Nano- SiO2/PEG200 system with different preparation methods

The average particle size of Nano SiO2 prepared by the two different methods in Figure 1 is used to determine the size of the dispersion. Conclusion: (1) the system prepared by planetary ball milling method has better dispersion; (2) the dispersion of the dispersant A1120 is better than that of the system. By consulting the relevant materials, the author finds that the reason lies in the formation of hydrogen bond \[7\] on the surface of dispersant and dispersed phase -OH, which reduces the probability of aggregation.

The microstructure of STF nanoparticles / polymer system is tested by means of rheological optical experiment \[8\] and neutron scattering method \[9\]. Rhea optical experiments is based on the relations between tensor and optical pressure during particles suspension process, hereinto light dichroism is used to identify the effects of thermodynamics and rheology on particle motion, its advantages are mainly embodied in the no external mechanical force, the result is a viscoelastic zero modification; small angle neutron scattering method by observing the changes of STF radiation "to describe the formation of clusters. The rheological characterization technology is used less fully in China at present, mainly because of the limited equipment, and the research technique is not mature. In the next step of the study, we will attempt to characterize the micro rheological properties of the shear thickening system by diffusion spectroscopy.
2.3. Influence factors

2.3.1. Properties of dispersed phase. The influence of dispersed phase particles on the rheological properties of STF includes mainly two kinds of solid content. Lee et al [10] measured the steady-state rheological behaviour of SiO2 (PEG) / SiO2 system with SiO2 volume fraction of 57% and 62%, respectively. The results show that the higher the content of the particles, the higher the critical thickening point.

2.3.2. Properties of dispersion media. The viscosity, polarity, molecular weight and steric hindrance of the dispersed medium have some influence on the performance of STF. Wu Qiumei [11] studied on several different dispersion medium STF, according to the analysis, due to the long molecular chains of PEG, so there exist large steric hindrance, which contributes to the formation of clusters and the shear thickening liquid preparation.

3. Polymer solution system

3.1. Several kinds of polymers with shear thickening properties

3.1.1 Hydrophobic ally associating polymer Among STF systems, the most common and most representative is hydrophobic associating polymer. Near or below C* (The boundary concentration of fluid and colloid), the hydrophobic groups associate together, which leads to the formation of intramolecular or intermolecular aggregation, the polymer mainly based on intramolecular association. In the shear flow field, with the increase of shear rate, the polymer chain will be stretched, which leads to the formation of the association between macromolecules.

3.1.2 High molecular in bad solvent the paper learned that some bad solvent, although the lack of hydrophobic groups, there is also a shear thickening phenomenon, bad solvent with large molecular greatly, such as the ten ethanol solution of hydrogenated naphthalene solution, polystyrene polyiso butylene and poly ethylene oxide. The mechanism of shear thickening is usually considered to be a thickening phenomenon due to the change of the structure induced by collision, In recent years, Brown's kinematic mechanics model has proved that the polymer chains in the inferior solvents collide or form higher order structures to produce shear thickening effect [12]. Briscoe he [13] found the shear viscosity rises very slowly, and the amplitude is also very limited through the study of rheological behavior of Hydrolysis degree of 20% to 40% high molecular weight polyacrylamide (PAM) in aqueous solution of glycerol. In this paper, the author considers that the principle of shear thickening of high molecular weight polymer is the hydrogen bond interaction between polymer chains.

3.2. Shear thickening mechanism

According to the relevant information provided by the shear thickening theory model, the mechanism of polymer shear thickening fluid can be roughly summarized as the following three kinds from different angles [14,15]: (1) shear induced crosslinking; (2) extensional shear induced non-Gauss chain; (3) the formation of space network structure. From the micro level, it is explained as polymer chain interaction transfer to interaction between polymer chain [16, 17]. The polymer chains are stretched in shear flow, with the further increase of the shear rate, this effect will be destroyed, and the polymer chain interaction will be gradually replaced by the interaction between the polymer chains of different molecular chains by the strong interaction of strong association together. Therefore, the macroscopic behaviour is the increase of fluid viscosity, i.e., shear thickening behaviour.
3.3. Influencing factors

3.3.1 Concentration of polymer solution: The effect of concentration on polymer shear thickening fluid is especially prominent. With the critical concentration of \( C^* \) as the marker, the shear effect is different. According to the author's understanding and understanding of the shear thickening material, the higher the concentration, the longer the chain density, the less the space between the chain and the chain.

3.3.2 Polymer composition currently: What is mostly studied as additives of nanoparticles / polymer system is associating polymer, such as Gong Xinlong [18] put PEG4000, PEG6000 and PEG10000 to use as additives of long chain polymer to discuss the effect additive of concentration on the rheological properties, results show that the system is the critical point of thickening advance with the addition of long chain molecules concentration. On the basis of mechanism analysis, the long chain polymer is adsorbed on the surface of Nano particles, and the flocculation resulted in the increase of the viscosity of the system. Similarly, the hydrophobic group has a significant effect on the rheological behaviour of hydrophobic ally associating polymer [19].

4. Major application areas

4.1 Liquid Armor
In recent years, shear thickening materials are mainly used in software protection field, especially in the military field. According to the characteristics that shear thickening fluid rapidly harden while received a force to resist the external force, and restored the soft state the moment external force removed, foreign scientists since the 90s last century studied STF as a function of individual protective armor. Professor Wanger of material research center of the State University of Delaware made composite fabric through the collocation of different composition shear thickening fluid and Kevlar fiber, namely "liquid armour" [20] the stab resistance of the which was tested. Wanger also had different infiltration of dispersed phase particles of fabrics characterized by SEM, the results show that the infiltration of Kevlar fiber SiO2 particles can be better than PMMA particles, with nano SiO2 particles as the dispersed phase combination of shear thickening fluid and fiber fabric can absorb more energy, so pullet proof performance better.

4.2 Shock absorption field
According to the characteristics of shear thickening fluid in the presence of external impact force, it is widely used in the field of shock absorption. The shear thickening material is used in the shock absorber of the military vehicle equipment or the shock absorber of the machine tool in the military industry, which is not only convenient to carry, but also to reduce the loss of equipment in the process of transportation [21].

5. Summary and Outlook
Due to its excellent protective ability and light characteristics, the application prospect of the shear thickening material in the fields of national defines, military industry, automobile, transportation, transportation, construction and sports is bright. However, the domestic and foreign research shows that the higher standard of preparation of shear thickening of composite materials, in order to ensure the minimum critical shear stress, and more efficient combination of the shear thickening material as a function of phase and matrix phase, so the preparation process needs to be further improved, by means of comprehensive diversification, for example as well as the rheological characteristics of oscillating scanning study on STF by
steady-state scanning and frequency of STF, in view of the strain rate sensitivity [22]. It is significant to study its response under shock loading mechanics will provide guidance for the application of the material in the door. At present, there is still a gap between the domestic shear thickening materials and that in foreign countries relative to the protection technology, which requires academia and industry hand in hand, so as to achieve constant progress day by day in this field. In addition, the author is currently not yet access to application at home and abroad about the shear thickening material in the foaming material, as a commonly used dual-use carrier material, strength of foam material needs to be improved, in consideration of the properties of shear thickening materials. An application technology breakthrough will achieve in shear thickening material field, if a kind of a foamed material with shear thickening effect can be developed.

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