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Effects of different silica particles on quasi-static stab resistant properties of fabrics impregnated with shear thickening fluids

Xinya Feng, Shukui Li *, Yan Wang, Yingchun Wang, Jinxu Liu

School of Materials Science and Engineering, Beijing Institute of Technology, Beijing 100081, China

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ABSTRACT

The effects of fumed silica in shear thickening fluids at a weight fraction of 20% and submicron silica particles in shear thickening fluids at a weight fraction of 65% on quasi-static stab resistance properties of fabrics impregnated with shear thickening fluids were investigated on a basis of a similar shear thickening behavior. For better understanding of the effects of these two different silica particles on resistance mechanism of fabric during quasi-static stab, the single yarn tensile test was carried out to obtain tensile properties of single yarn and yarn pullout test was performed to examine interface friction among yarns. The results show that aramid fabrics treated with shear thickening fluid exhibit a significant enhancement in quasi-static stab resistance. Further, quasi-static stab resistant properties of treated fabrics containing submicron silica particles are better than that of treated fabrics containing fumed silica particles. Possible mechanism responsible for the enhancement is discussed in detail.

1. Introduction

Woven aramid fabrics are used to provide protection as soft body armour [1,2]. Conventional body armour requires many layers of aramid fabric, which make armour too bulky and stiff for application. In order to reduce the number of fabric layers, shear thickening fluid (STF) is used to improve impact resistance performance of aramid fabric. STF are non-Newtonian fluids and shear thickening behavior is often shown by concentrated colloidal dispersions which exhibit sudden increase in viscosity above a critical shear rate, from liquid-like to solid-like. A typical example of a discontinuous STF is a stabilized suspension of rigid colloidal particles with a high loading fraction of particles [3–6]. The solidification of STF can improve impact resistance of fabrics. Lee et al. [7] demonstrated that the ballistic properties of aramid fabrics can be improved by the addition of colloidal shear thickening fluids (STFs), and Egres et al. [3,8] reported that the stab resistance of STF treated fabrics exhibited significant improvement over neat fabric targets with equivalent areal density. For a better understanding on the effects of particle characteristics on the protection properties of STF treated fabric composites, some studies have been carried out. Lee and Wagner [4] found that particle aspect ratio had some influences on the resistance properties of STF treated fabrics. Lee et al. [9] investigated the effects of silica colloidal suspension produced using silica particles with average diameters of 100 nm, 300 nm, and 500 nm on the ballistic performance of plain woven fabrics, and the results indicated that the fabric impregnated with STF containing silica particles of 100 nm diameter showed better impact performance. Furthermore, Lee et al. [9] and Kalman et al. [10] explored the role of particle hardness on the penetration behavior of aramid fabric, and the observations suggested that silica particles treated fabric had better ballistic performance than polymethylmethacrylate (PMMA) particles treated fabric.

In this paper, two types of silica particles, submicron silica and fumed silica, as dispersing particles in STF are mainly used. Although much work has been done, no report focused on investigating which kind of silica particles is more effective to improve the stab resistance of STF treated aramid fabrics. The objective of this study is to illustrate the effects of these two kinds of silica particles on stab resistance of aramid fabric. In order to separate the effects of particle type from shear thickening behavior on stab resistance, the fumed silica-STF and submicron silica-STF with a similar shear thickening behavior are used to impregnate aramid fabrics. Also, single yarn tensile test and yarn pullout test are conducted to investigate the tensile properties of yarns and interface friction of fabric respectively. Comparing these data provides a better understanding of the effects of these two different silica particles on resistance mechanism of fabric during quasi-static stab.

* Corresponding author. Tel.: +86 010 68913937.
E-mail address: bitleesk@bit.edu.cn (S. Li).

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2. Experimental details

2.1. Materials

STFs were fabricated by dispersing fumed silica particles or submicron silica particles into polyethylene glycol. The fumed silica particles were purchased and the submicron silica particles were synthesized via ammonia-catalysed hydrolysis method in the laboratory. The microscopic images of silica particles shown in Fig. 1 were carried out by using S-4800 field emission scanning electron microscope (FE-SEM) together with subsequent images. It shows that fumed silica particles are agglomerate with aggregation size of about 100 nm, and submicron silica particles are mono-dispersed and regular spherical with particle size of about 500 nm. Polyethylene glycol (PEG) of molecular weight 200 was used as a dispersant because of its high thermal stability and low volatility.

For these two particles, different methods were used to prepare STFs. Submicron silica particles were dispersed into PEG200 by ball-milling technique and fumed silica particles were dispersed by means of ultrasonic and mechanical stirring. The rheological properties of STFs were tested by a TA Instruments Rheometer-AR2000.

Plain woven aramid fabric with areal density of 198 g/m^2 was used in the research, and the linear density of yarns is 1100 denier. In order to facilitate impregnation of STF into fabric, STF was first diluted using ethanol to reduce the surface tension and viscosity. Then the fabric was squeezed by a 2-roll mangle to remove extra STF on the surface of fabric and put into an oven to remove ethanol at 70 °C for 2 h. The images of the fabrics are shown in Fig. 2. Fig. 2(b) and (c) present that STFs are well distributed on the surface of fabrics, and STFs also fill the vacancies between the yarns. In Fig. 2(b), some cracks were observed which formed because of the evaporation of ethanol during preparation.

2.2. Single yarn tensile test

In order to explore the influence of the two different silica particles on tensile behavior of single yarn, the tensile test was carried out using a universal testing machine (Instron 3300) according to ASTM: D2256 at a tensile rate of 300 mm/min. Park et al. [11] found that the crimp ratio of warps was different from wefts, and warps had a higher crimp ratio than wefts in all fabrics, so yarns of the fabrics in the warp directions were used in the test.

2.3. Yarn pullout test

The yarn pullout test was performed to examine the effects the two different silica particles on inter-yarn friction of fabrics. The pullout force and displacement were measured using the mechanical tester (AGS-J). Details of the test method are available in the published literature [12], and specimens were clamped using a fixture, as shown in Fig. 3. The yarn in the center of the fabric was pulled at a tensile rate of 50 mm/min.

2.4. Quasi-static stab test

The test equipment was self-designed based on the universal tester (Instron5985), as shown in Fig. 4. The knife blade P1 [13] used in National Institute of Justice (NIJ) of United State is shown in Fig. 5. Five layers of fabric were clamped in a ring clamp with the outside diameter of 13 cm and the inner diameter of 8 cm. A sufficient force was used to clamp the specimen in order to avoid its slippage. Then the impactor was pushed into the center of the

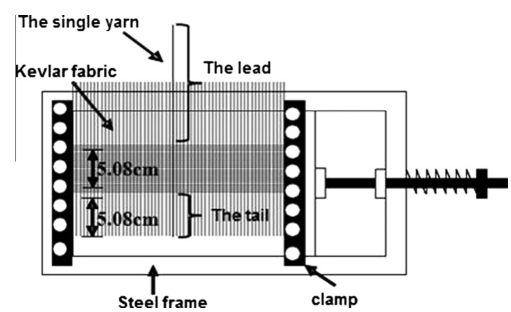

Fig. 3. Schematic illustration of clamp fixture for yarn pullout test.

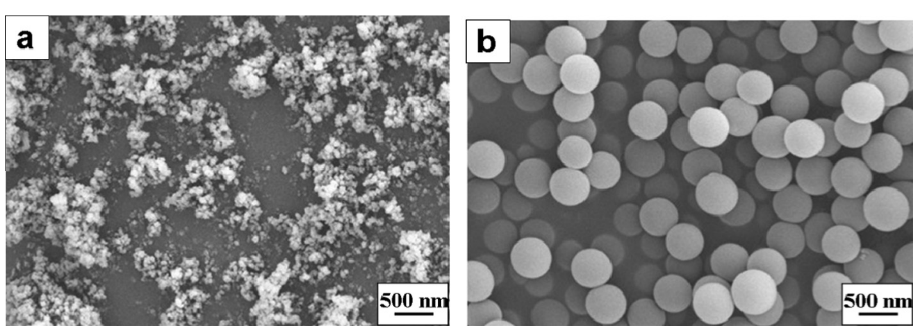

Fig. 1. Scanning electron microscopy of silica particles: (a) fumed silica and (b) submicron silica.

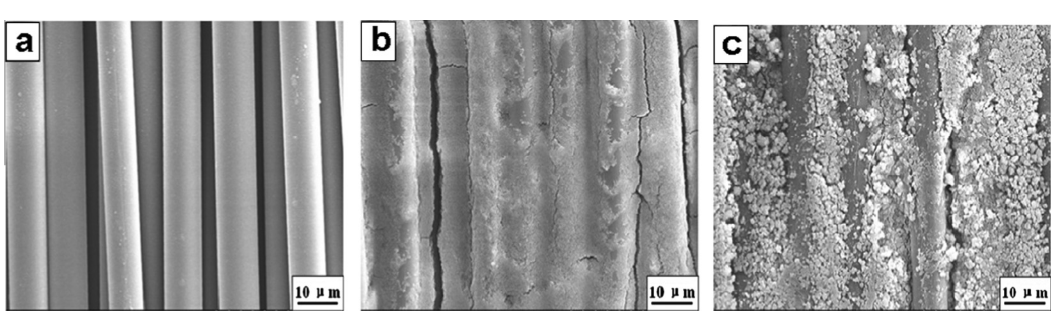

Fig. 2. Surface morphology of fabrics: (a) neat fabric; (b) fumed silica-STF treated fabric and (c) submicron silica-STF treated fabric.