STAB RESISTANCE OF ARAMID FABRICS REINFORCED WITH SILICA STF

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1 Introduction

Most of present studies on protective armor are related with the protection against bullets. But recently, the studies on the protection against impact by sharp blade or spike have been studied actively too.

However, current stab resistant clothes have several weak points such as heavy weight, bulky shape, and uncomfortable characteristics. Therefore, one of the efforts to develop the new stab resistant fiber composites is to use of shear thickening fluid(STF) to overcome those problems. STF is the non-Newtonian fluid that if the fluid is stressed by shear stress, at first, the fluid appears shear thinning phenomena, and when shear rate reaches to a critical shear rate, viscosity of the fluid dramatically increases and then the fluid shows shear thickening phenomena.[2] Thus, it can be applied to the protective materials which need to act against high speed impact.

In this study, we analyze the characteristics of STF using colloidal silica and investigate the puncture, cut, and stab resistance of the aramid fabric reinforced by STF.

2. Experimentals

2.1 Rheological characteristic of Colloidal silica STF

The diameter of colloidal silica particle used in STF solution is 44 nm. PEG(Poly Ethylene Glycol, Mw: 200) was used as a continuous phase medium which has good properties in thermal stability and low volatility. Also, methanol is used as a diluent of the STF.

Rheological characteristics of STF was analyzed by a rheometer AR-2000(TA instruments), at 25℃, cone angle of 2˚, and free shear state.

Furthermore, rheological characteristics of STF were measured according to the concentration of colloidal silica in the range of 60wt%, 65wt% and 67.5wt% by using the cone and plate rheometer.

In this study, Kevlar® fabric consisted of 600 denier p-aramid filaments from Dupont Co. was used as aramid fiber. The morphology of STF treated Kevlar® fabric was observed by scanning electron microscopy (SEM).

2.2 Cut resistance test (BS EN 388:2003 standard)

About 30wt% of the STF impregnated Kevlar® fabric was used as the sample. STF impregnation of the Kevlar fabric was conducted by using the static press under proper pressure to squeeze excess STF. The cut resistance test was performed under the specification of BS EN 388:2003, English standard with a test apparatus shown in Figure 1.

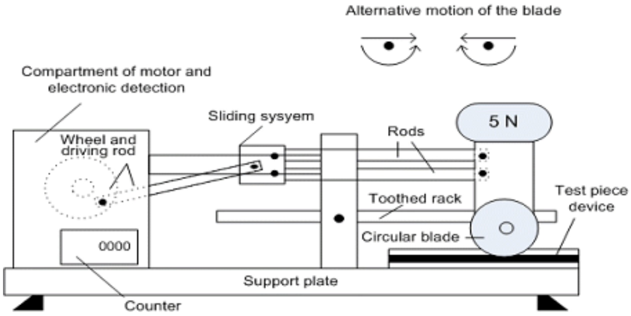

Figure 1 Schematics of the cut resistance test apparatus

2.3 Quasi-static stab resistance test (Puncture resistance test)

The puncture resistance test was performed by referring to ASTM F1342-05 using an Instron 4467 tester as shown in Figure 2. S1 blade(Figure 3) was used by referring to National Institute of Justice (NIJ) of United State standard (NIJ.0115.00).[3] In the test, the cross-head speed and displacement were fixed at 5 mm/min and 20 mm. The test was performed with 1, 2, 4 and 6 layer fabric sample to observe the influence of layers of STF composite. The STF add-on percent of sample was fixed at 30%.

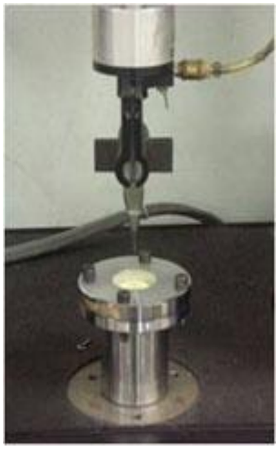

Figure 2 Photo of the puncture resistance test

Figure 3 Photo of the S1 blade used in this study

2.4 Dynamic stab resistance test

The stab resistance test was performed by referring to National Institute of Justice of United State standard NIJ.0115.00. The cut resistance test is conducted by placing backing materials and putting a sample on them like the picture 4. Backing material is composed of 1 piece of witness paper, 4 stories of neoprene sponge, 1 story of polyethylene foam, 2 stories of natural rubber, etc. It was organized by imagining human organs such as skin, muscle, internal organs, etc.

S1 blade was used and impact energy was 24 J (NIJ.0115.00, E1 Level 1). The stab resistance of the untreated and STF treated fabric was compared with 24 layer of Kevlar fabric. Also, add-on percent of the STF treated fabric was fixed at 30%.

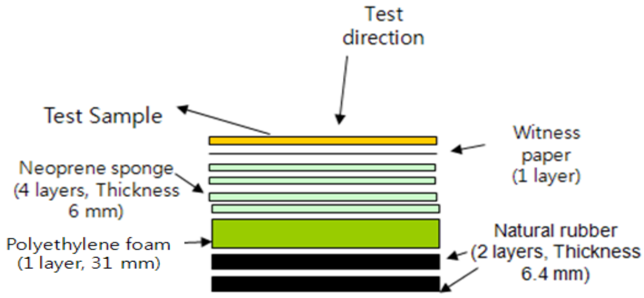

Figure 4 Stab resistant test method by NIJ 0115.00 Standard

3. Results and Discussion

3.1 Analysis of stab resistance material

The currently used puncture·cut resistance clothes for constabularies has total 4 forms of fabric-typed and felt-typed fiber materials. For all of raw materials, Kevlar® which is aramid fiber of American DuPont Company was used. 4 forms of fiber material are plain fabric weaved by 500 De thread including a little twist, plain fabric weaved by 200 De filament's thread, plain fabric weaved by cotton yarn of filament, felt combined with needle punching.

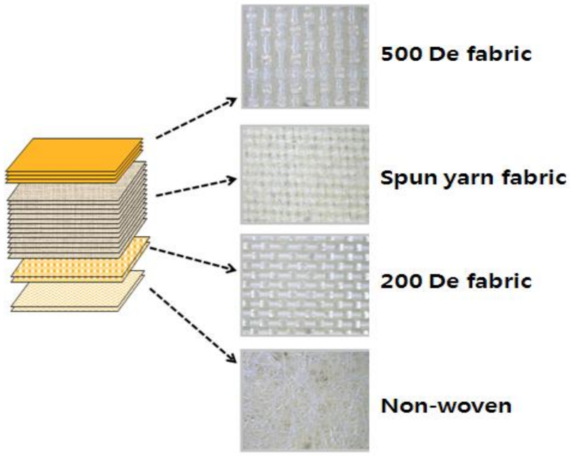

Figure 5 Detail configuration of current stab resistance armor material

3.1.1 Dot process and laminated design of cut resistance material's surface

By improving Dot process of cut resistance material's surface and enhancing penetrating resistance and cut resistance, the gap among the Dots was planned to be dense. Method using metal mold, method using plastic mold, method using silicon rubber mold, etc, were studied.

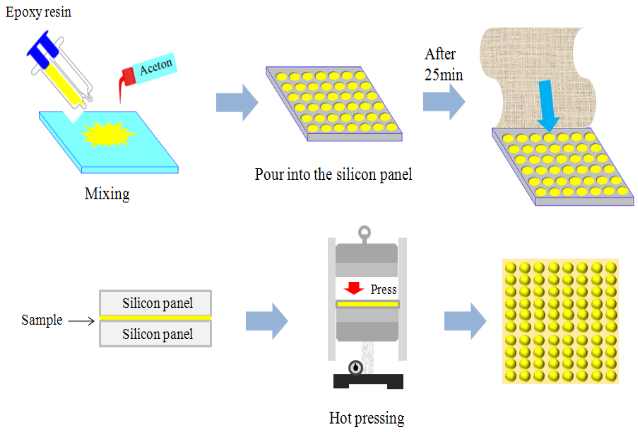

Figure 6 Schematic of 'dotted shape' resin treatment process of stab resistant armor. And it's application to the molding process.

3.1.2 Process and laminated design of hard particle

For confirming the effect of introducing hard particle to cut resistance material, silica which is hard particle was applied to cut resistance fabric. After combining fumed silica particle whose size is about 1um with solution diluted by glue, it was applied to the surface of cut resistance fabric and hardened in drying machine. In the picture 13, the surface of cut resistance fabric applied by hard particles was observed. Hard particles are relatively applied evenly and densely.

Figure 7 Pictures of the surface of the fabric coated with hard particles.

3.1.3 Introduction and laminated design of mesh material

The most important standpoint of this study was selection and production of material making sword dull while it was placed in front of cut resistance material and prevented the entrance of sharp sword. Therefore, as new trial for it, the introduction of iron mesh material was studied. The iron mesh material has very high cut-resistance because of the hardness and ductility of iron. But, if considering the performance in contradistinction to the weight, it wasn't so superior material, but it was intended to improve cut resistance effect by applying it to one part touched by sword. This study used 3 things manufactured while the standards of mesh unit were about 40, 32 and 20.

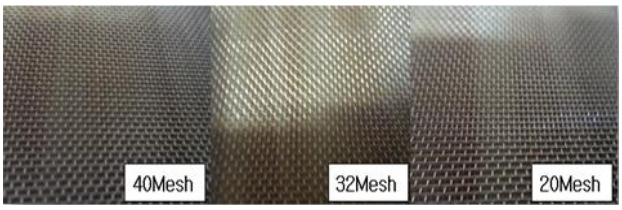

Figure 8 The shape of stab resistance mesh material.

Shear thinning phenomena was observed in the colloidal silica STF according to the increase of the concentration. The higher concentration, the lower initiation of shear strain was observed. The reason is that when the higher concentration, the interaction among the particles increased, thus, shear thickening phenomena appear quickly.

As the result of cut resistant test, comparing cut resistance of the untreated, STF treated Kevlar® fabric showed lower value, because as the fabric was hardened by STF treatment, the stress was not evenly spread but concentrated on a specific point and thus cut of the fabric easily took placed. On the other hand, in the spike resistance test, the STF treated Kevlar® fabric had very higher resistance than the untreated one, because STF works properly against to the penetration of high speed spike impact. In this case there was almost no damage or cut of the Kevlar® fabric, but a puncture between the filaments.

As the result of puncture resistant test, STF treated fabric showed higher energy absorption than the untreated sample.(Table 1). In the puncture test, two types of impact mode were occurred such as penetration and cut of the fabric. STF treated fabric had very high resistance to penetration of the impactor as described above, and thus it absorbed much of impact energy. Also, the other mode of impact energy absorption was the cutting of the fabric which absorbed the rest of the impact energy. Therefore, most of the puncture test specimen showed the mixed fracture behaviors by penetration and cutting.

Table 1 - The results of puncture resistance test by S1 blade.

Sample	Untreated fabric	STF treated fabric (add-on 30%)
Absorption Energy(J)	0.157	0.206

4. Conclusions

In this study, we analyzed the characteristics of nano-particle reinforced fluid which shows the shear thickening behavior, and also analyzed its rheological characteristics according to nano-particle fraction. By rheological analysis, we selected the most suitable nano-particle material into STF. Indeed, after dipping protective fabrics(i.e. p-aramids and UHMWPE fabrics) into the STF, we observed surface of the fabrics. The yarn pull-out test was conducted for observation of friction influence by shear thickening behavior of STF. Furthermore, cut-resistance test was performed.

Shear thickening phenomena was observed in the colloidal silica STF with the increase of the STF concentration. STF treated Kevlar® fabric showed low cut resistance than untreated one because of localization of the cut damage.

However, STF treated fabric showed higher energy absorption than the untreated sample in the pucture resistance test because STF treated fabric had very high resistance to penetration, and thus it absorbed much of impact energy. Most of the puncture test specimen showed the mixed fracture behaviors by penetration and cutting.

In case of hard particle, an effect of glue attaching particle to fabric material was very great, so it was difficult to obtain stable data.

(a) (b) (c)

Figure 9 Pictures of the surface of the fabric. (a) applied dot, (b) coated hard particles, (c) applied metal mesh

In addition, PE fiber material had a little friction of surface, the interfacial force with STF material was weak and cut resistance performance was insufficient, so it was unsuitable for the material for containing STF. Therefore, as the result of various studies and experiments in this study showed that the optimization of laminated design by characteristics of each story with high concentration STF studied at the stage of application and study was judged to satisfy cut resistance performance, production and economics of cut-resistance laminated materials.

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