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Shear behavior of a shear thickening fluid-impregnated aramid fabrics at high shear rate

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ABSTRACT

Shear-thickening fluid-impregnated aramid (STF-im-AR) fabrics have been manufactured for advanced soft body armor applications for which they provide improved ballistic and stab resistances. It is not yet clear whether or not such improvements can be attributed solely to the STF. In this study, the rate-dependent behavior of an STF-im-AR fabric was investigated at the fabric level, using uniaxial tensile, bias-extension, and picture-frame tests. Rate-dependent behavior of the STF-im-AR fabric was observed during uniaxial tensile testing; however, the effect of the STF treatment was slight and consistent with only the inherent effect of the polymeric nature of its constituent fibers. The shear rigidity of the STF-im-AR fabric increased, due to the presence of the STF and the sensitivity of the fabric's shear stiffness to changes in the shear strain rate also increased slightly. This rate-sensitive shear stiffness of STF-im-AR fabrics may contribute to improved ballistic and stab resistances.

1. Introduction

Woven fabrics made of high-performance fibers, such as aramid (for example, Kevlar) or ultra-high molecular weight polyethylene, have been used in many protective applications, including ballistic and stab body armors [1,2]. These fibers have been chosen as soft body armor materials mainly due to their high strengths, light weights, flexibility, and heat resistances, which provide better mobility and protection, particularly in military applications [3–5]. The agility and mobility of soldiers wearing such soft armor depend on the performance-to-weight ratio of the materials. Especially polyamide fibers (aramid fibers), which have strong primary (the amide bonding in single fiber chain) and secondary bonding (hydrogen bonding between the fiber chains) in molecular structure, are used for soft armor applications due to the high strength and toughness [6–12]. Thus, many studies have focused on improving the fiber properties, in particular stiffness and strength [13,14] and heat resistance [15]. On the other hand, the effect of fabric structure, including textile laminating and stitch pattern [16–22], weaving pattern (and resulting elastic properties) [23,24], and uncertainty of textile [25], on ballistic and stab resistance have been investigated to design the soft body armor. Although these endeavors have improved the bullet and stab resistance of soft body armor, further improvement is still needed. One approach is to consider other functional materials, such as those developed through nanotechnology.

A shear-thickening fluid (STF) is one of these materials [26–28]. Shear-thickening behavior refers to a non-Newtonian fluid phenomenon, i.e., the viscosity increases with the shear strain rate. This behavior is frequently observed in dense suspensions [29–31]; an STF consisting of a suspension of nanoparticles has been reported [29]. When nanoparticles are included in a suspension at high volume fractions, the suspended colloidal particles can form hydroclusters when subject to high shear stresses, leading to highly viscous and even solid-like behavior [7,30]. In previous works, STF-impregnated aramid (STF-im-AR) fabrics were manufactured, demonstrating enhanced stab and ballistic resistance [7,20,26,32]. Experimental research has suggested many cooperative mechanisms to explain the improvement during penetration testing

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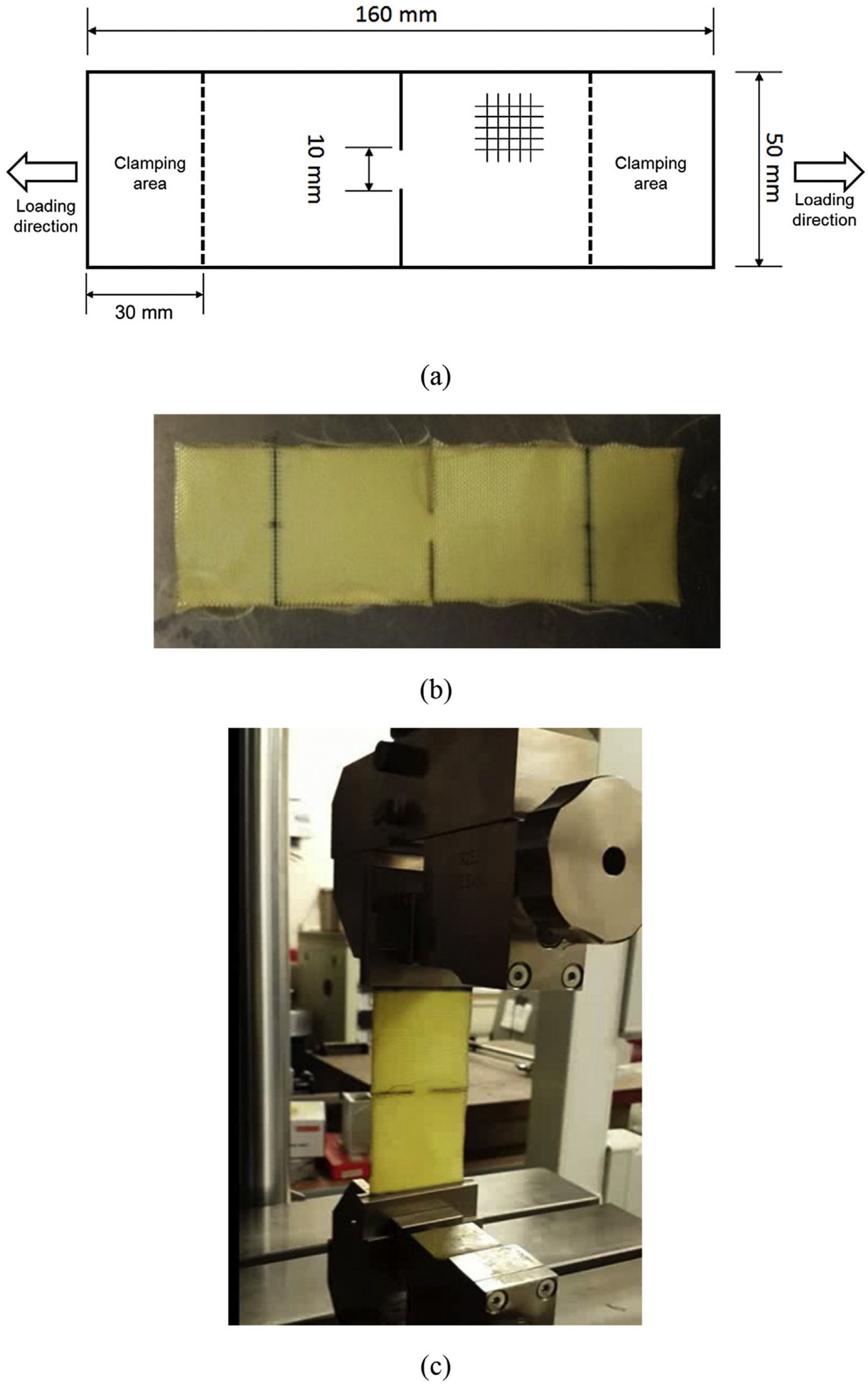

Fig. 1. (a) Specimen geometry and (b) an aramid (AR) fabric specimen used for uniaxial tensile (UT) testing and (c) testing set-up.