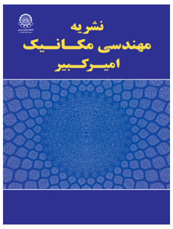

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(12) (2022) 1431-1434
DOI: 10.22060/mej.2021.19806.7119

A Study on the Ballistic Behavior of Kevlar Fabric Impregnated with Shear Thickening Fluid Containing Graphene Oxide Additive

A. Naghizadeh[1], H. Khoramishad[1], M. Jalaly[2*]

[1] School of Mechanical Engineering, , Iran University of Science and Technology, Tehran, Iran.

[2] Nanotechnology Department, School of Advanced Technologies, Department of Advanced Technologies, Iran University of Science and Technology, Tehran, Iran.

ABSTRACT: In this research, the effects of graphene oxide as an additive to Kevlar fabric impregnated with nanosilica/polyethylene glycol shear thickening fluid on the ballistic performance were investigated. In order to understand the influence of shear thickening fluid, pull-out tests were accomplished to assess the friction between yarns. The energy absorption in the high-impact ballistic test for the fabric impregnated with shear thickening fluid increased by 25.8% compared to that for the neat Kevlar fabric. This parameter for the fabric impregnated with shear thickening fluid-0.2 wt.% graphene oxide was 23.3% as compared with that of the neat fabric, demonstrating the deteriorating effect of graphene oxide additive. The results of the pull-up tests were in agreement with ballistic tests, meaning that the increase or decrease in the maximum forces in pull-up tests was followed by the increase or decrease in the energy absorption in ballistic tests. Compared to the sample impregnated with shear thickening fluid, adding graphene oxide causes the decrease in the maximum force in the pull-up test, resulting in a reduction in restriction of yarns movement, consequently facilitating their movement inside the fabric.

Review History:

Received: Mar. 31, 2021
Revised: May, 24, 2021
Accepted: Jul. 17, 2021
Available Online: Jul. 23, 2021

Keywords:

Shear thickening fluid
Graphene oxide
Kevlar
Ballistic

1. INTRODUCTION

The development of high-strength lightweight armors has been attracted considerable attention in recent decades. The advent of nanomaterials and nanotechnology has made significant progress in enhancing the performance of armors against high-velocity impact threats. With the advancement of polymer science, valuable polymeric materials such as high-strength polyamide yarns, aramid yarns, and high-density linear polyethylene yarns, and Kevlar have been produced for high-velocity impact applications. Fabrics can be strengthened by considering mechanisms of energy absorption. An approach for fulfilling this goal is promoting the interlocking between the yarns and restricting the relative movement of the yarns. This can be accomplished by impregnating the fabric with Shear Thickening Fluids (STFs), frequently composed of silica particles dispersed in Polyethylene Glycol (PEG) [1, 2].

After impregnation of the fabric with STF, the fluid containing nanoparticles penetrates the fabric yarns, preventing them from easy pull-out. In fact, using STFs leads to an increase in the friction between yarns, resulting in the improvement of the fabric impact resistance.

Other than silica (SiO_2) nanoparticles, STFs may contain second or third nanoparticles, which are called multi-phase STFs. Gurgen and Kuşhan [3] investigated the stab penetration resistance of the fabric impregnated with an STF containing SiC nanoparticles. They indicated that the penetration resistance of the fabric increased by adding SiC to the STF. Laha and Majumdar [4] reported an improvement in the low-velocity impact resistance of aramid fabrics by adding halloysite nanotubes to the SiO_2-based STF.

Tan et al. [5] added graphene additive to the spherical nanoSiO_2-based STF. They showed that graphene additive caused the maximum force in the pull-out test and energy absorption in the ballistic test to be increased, suggesting the fruitful influence of the graphene. On the other hand, Wang et al. [6] reported the decrease in the maximum force in the pull-out test by adding graphene to the STF, implying the destructive effect of graphene on the STF performance.

Therefore, the current work is intended to elucidate the effect of adding Graphene Oxide (GO) to the SiO_2-based STF on the high-velocity impact performance (ballistic) of Kevlar.

2. MATERIALS AND METHODS

Spherical nanoSiO_2 with an average size of 30-40 nm, Polyethylene Glycol (PEG) with a molecular weight of 400 g/mol, aqueous graphene oxide suspension with a concentration of 5 g/l, ethanol, and Kevlar fabric with an areal density of 200 g/m^2 were used in this work. The specimens were coded as follows:

- NF: the neat fabric.
- FS: the fabric impregnated with the simple STF (65 wt.% PEG, 35 wt.% nanoSiO_2).
- FSG: the fabric impregnated with the STF containing GO (64.8 wt.% PEG, 35 wt.% nanoSiO_2, 0.2 wt.% GO).

*Corresponding author's email: maisam_jalaly@iust.ac.ir

Table 1. The results of the ballistic test.

Sample	Initial projectile velocity (m/s)	Residual projectile velocity (m/s)	Energy absorption (J)
NF	235	215.3	12.0
FS	235	209.9	15.1
FSG	235	210.5	14.8

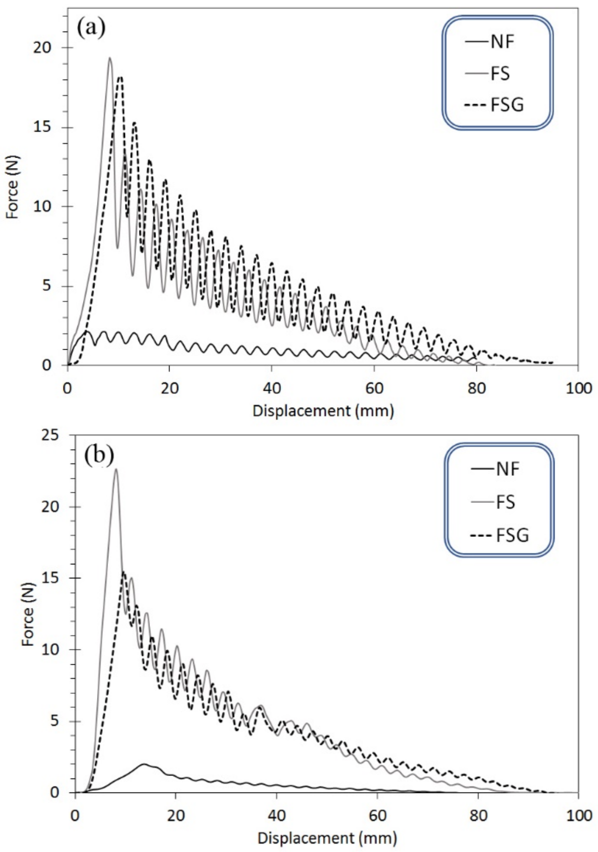

Fig. 1. The curves of force-displacement in the single yarn pull-out test performed at the velocity of (a) 50 and (b) 500 mm/min.

To assess the friction phenomenon, a yarn pull-out test was carried out. Furthermore, a high-velocity impact test was performed using the gas gun with a projectile velocity of 235 m/s.

3. RESULTS AND DISCUSSION

Fig. 1 shows the yarn pull-out test at two different projectile velocities (50 and 500 mm/min). As the maximum force is a critical parameter to analyze the friction, the maximum forces of different samples were plotted in Fig. 2.

It is clear from Fig. 2 that the maximum force is dependent on the pull-out velocity for FS and FSG samples, while the behavior of the neat Kevlar is independent of the pull-out velocity. For the FS sample, when the STF-impregnated yarn is pulled out of the fabric, the viscosity of STF increases, and the movement of the yarn is restricted, resulting in an increase in the pull-out maximum force. For the FSG sample, however, a decrease (~26.5%) in the pull-out maximum force was observed, implying the degradation of thickening behavior and easier yarn pull-out. This may be attributed to the lubricating nature of the graphene, which reduces the friction between yarns.

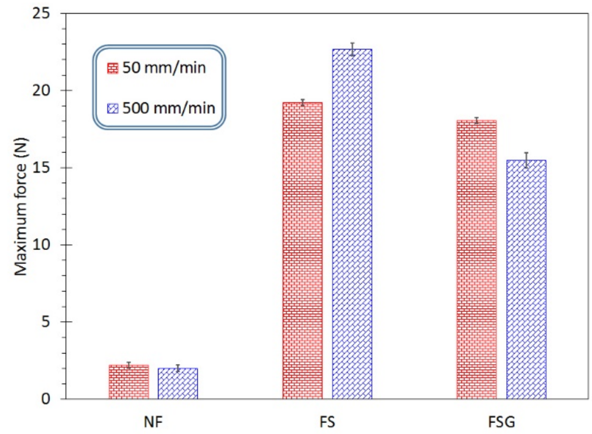

Fig. 2. The pull-out maximum force values in the tests performed at the velocity of 50 and 500 mm/min.

The results of the ballistic test were tabulated in Table 1. The presence of simple STF coverage on the yarn surfaces caused the reduction of residual projectile velocity, and thus, the energy absorption increased by 25.8% compared to NF. The sample FSG also had a 23% higher energy absorption compared to NF, but this is lower than that of FS. This is in agreement with the results of the pull-out test, demonstrating the deteriorating role of graphene oxide additive in the shear thickening fluids.

4. CONCLUSIONS

Kevlar was impregnated with a nanosilica-based Shear Thickening Fluid (STF). The effects of adding graphene oxide to the STF on the pull-out and high-velocity impact behaviors of the impregnated fabrics were investigated. The results revealed that the presence of graphene additive reduced the maximum pull-out force due to the increase in the lubricating nature of the yarn surfaces, suggesting that graphene had a negative effect on the shear thickening behavior. The sample impregnated with simple STF exhibited a 25.8% increase in energy absorption in the ballistic impact test compared to the neat Kevlar, while the sample impregnated with STF containing GO exhibited a 23.3% increase compared to the neat fabric, indicating GO additive weakened the ballistic performance of the STF-impregnated Kevlar.

REFERENCES

[1] V. Tan, C. Lim, C. Cheong, Perforation of high-strength fabric by projectiles of different geometry, International Journal of Impact Engineering 28 (2003) 207-222.

[2] V. Shim, Y. Guo, V. Tan, Response of woven and laminated

high-strength fabric to oblique impact, International journal of impact engineering 48 (2012) 87-97.

[3] S. Gürgen, M.C. Kuşhan, The stab resistance of fabrics impregnated with shear thickening fluids including various particle size of additives, Composites Part A: Applied Science and Manufacturing 94 (2017) 50-60.

[4] A. Laha, A. Majumdar, Shear thickening fluids using silica-halloysite nanotubes to improve the impact resistance of p-aramid fabrics, Applied Clay Science 132-133 (2016) 468-474.

[5] Z. Tan, W. Li, W. Huang, The effect of graphene on the yarn pull-out force and ballistic performance of Kevlar fabrics impregnated with shear thickening fluids, Smart Materials and Structures 27 (2018) 075048.

[6] F. F. Wang, Y. Zhang, H. Zhang, L. Xu, P. Wang, C.-b. Guo, The influence of graphene nanoplatelets (GNPs) on the semi-blunt puncture behavior of woven fabrics impregnated with shear thickening fluid (STF), RSC advances 8 (2018) 5268-5279.

HOW TO CITE THIS ARTICLE

A. Naghizadeh, H. Khoramishad, M. Jalaly, A Study on the Ballistic Behavior of Kevlar Fabric Impregnated with Shear Thickening Fluid Containing Graphene Oxide Additive, Amirkabir J. Mech Eng., 53(12) (2022) 1431-1434.

DOI: 10.22060/mej.2021.19806.7119