International Journal of Engineering

Journal Homepage: www.ije.ir

Numerical and Experimental Study of Ballistic Response of Kevlar Fabric and Kevlar/Epoxy Composite

G. H. Majzoobi*, F. Mohammad Zaheri

Mechanical Engineering Department , Bu-Ali Sina University, Hamedan, Iran

P A P E R I N F O

Paper history:
Received 10 February 2017
Received in revised form 27 February 2017
Accepted 10 March 2017

Keywords:
Kevlar Fiber
Finite Element Simulation
Kevlar/Epoxy
Ballistic

A B S T R A C T

Kevlar is a type of aramid fibers which is characterized by high strength to low weight ratio. This material is widely used in bulletproof vests and helmets, in which it creates a barrier to projectiles to protect specific objectives, laminated tubes and pressure vessels, etc. In this study the ballistic behavior of Kevlar /epoxy composite and Kevlar fabric is investigated. The results showed that Kevlar fabrics were more resistant against projectiles. Tensile and punch tests revealed that although the Kevlar/Epoxy composite enjoys higher strength, undergoes lower deformation than Kevlar fabric. The results also indicated that the failure mechanism of Kevlar fabric was quite ductile whereas the presence of epoxy in Kevlar/epoxy changed the failure mechanism from ductile to brittle in the form of plugging in ballistic tests. Finally, the ballistic behavior of the Kevlar fabric was simulated by ABAQUS finite element software and the results were validated by the experiment.

***doi**: 10.5829/idosi.ije.2017.30.05b.20*

1. INTRODUCTION

The composites, having wide variety and growing applications, play important role in development and progress of industry. Polymeric composites belong to an important class of composites and Kevlar/epoxy composite in this category. Kevlar is a type of aramid fibers and the use of this matter is in bulletproof vests and helmets, creating a barrier to slow rockets and projectiles to protect specific objectives, etc.

Tapie et al. [1] studied the influence of weaving on mechanical response of aramid yarns subjected to high-speed loading. Their experimental results showed that virgin and woven yarns exhibited similar rate sensitivity. Both materials became stiffer with strain rate, their tensile strength increased and their failure strain decreased. Observation of broken fibers indicated that this may be due to the damage of the fiber during the weaving process, which affects the cohesion of the fibrils at the micro scale level. Sanborn & Weerasooriya [2] studied the damage of Kevlar KM2 Fibers due to weaving, finishing, and pre-twist at multiple loading rates. The results showed that fibers taken from the weft direction of the woven fabric decreased in strength 3 to 8% compared to the unwoven fiber. Sanborn & Weerasooriya studied the dynamic mechanical behavior of Kevlar woven fibers and the influence of factors such as the coefficient of friction between the fibers, weave and epoxy resin on the fiber strength. Also, the effects of strain rate and twisting fibers Kevlar fibers on the dynamic behavior were investigated. Das et al. [3] determined the inter-yarn friction and its effect on ballistic response of para-Aramid woven fabric under low velocity impact. Based on several numerical simulations, it was observed that higher inter-yarn friction may not always give better ballistic performance. Okafor et al. [4] optimized hardness strengths response of plantain fibers reinforced polyester matrix composites (PFRP) Applying Taguchi robust design. Volume fraction of fibers (A), aspect ratio of fibers (B) and fibers orientation (C) were considered as control factors in the determination of hardness strength of plantain fiber reinforced polyester composites. Tham et al. [5] investigated the ballistic behavior of helmet made of Kevlar. They attempted to design lighter and stronger helmet by experiment and to perform three-dimensional simulation with AUTODYN

*Corresponding Author's Email: gh_majzoobi@yahoo.co.uk (G. H. Majzoobi)

Please cite this article as: G. H. Majzoobi, F. Mohammad Zaheri, Numerical and Experimental Study of Ballistic Response of Kevlar Fabric and Kevlar/Epoxy Composite, International Journal of Engineering (IJE), TRANSACTIONS B: Applications Vol. 30, No. 5, (May 2017) 791-799

software. Zhu et al. [6] investigated the ballistic impact on multi-layer Kevlar 49 fabrics by finite element simulation. Lee et al. [7] studied the ballistic impact characteristics of Kevlar woven fabrics impregnated with a colloidal shear thickening fluid. Majzoobi and Moradi [8] studied the ballistic behavior of high strength, low alloy-100 steel at sub-zero temperatures. The effect of quenching on ballistic behavior of HSLA-100 is also studied. Nilakantan et al. [9] investigated Filament-level modeling of Kevlar KM2 yarns for ballistic impact. Also, the effect of friction coefficient between the fibers was studied. Their results showed that the increase of friction does not necessarily lead always to improvement of ballistic behavior of Kevlar. Gu [10] investigated the ballistic perforation of planar plain-woven fabric target by analytical method. Cheeseman et al. [11] studied the ballistic impact on fabric and compliant composite laminates. They reviewed the factors that influence ballistic performance; specifically, the material properties of the yarn, fabric structure, projectile geometry and velocity, far field boundary conditions, multiple plies and friction. Kumar and Tech [12] investigated the ballistic response of laminated composite plate using numerical simulation. The numerical simulations were carried out to determine the ballistic response of thick Kevlar/epoxy composite plates. The effect of mass and diameter of the projectile on ballistic limit velocity was also studied. The results obtained hereby were in good agreement with the experimental data presented by other researchers. Heydari and Choupani [13] introduced a new method to determine the fracture properties and strain energy release rate for carbon-polyester composite. Lim et al. [14] investigated the ballistic impact on warn fabric by proposing a material model in which viscoelasticity and a strain-rate-sensitive failure criterion was incorporated. Rao et al. [15] modeled the effects of yarn material properties and friction on the ballistic impact of a plain-weave fabric. They modeled the impact of a rigid sphere onto a high-strength plain-weave Kevlar KM2 fabric using LS–DYNA focusing on the influence of friction and material properties on ballistic performance. Silva et al. [16] reported the results of their study on ballistic impact problems on thin composite laminated plates reinforced with Kevlar 29. Omidvar et al. [17] established a relationship between the penetrating impacts with different parameters used in developing Kevlar–epoxy composites. They optimized the effective parameters on material resistance in the ballistic test using Taguchi test design method. Omidi and Mohammadi [18] investigated the low velocity impact response of aluminum plates, a numerical study has been conducted by developing a model based on ABAQUS commercial finite element code. The influence of strain rate effects on low velocity impact response of aluminum plates were examined by doing a comparative study between a model based on isotropic elasto-plasticity theory and another model based on the Johnson-cook material theory. Reis et al. [19] studied the impact response of Kevlar composites with nanoclay enhanced epoxy matrix. They investigated the ideal amount of nanoclays to obtain the best impact performance. Woo and Kim [20] investigated the characteristics of the failure progress in plain weave Kevlar composite under high-strain-rate impact loading by using an acoustic emission (AE) technique. Due to the extensive use of composites in various industries and the fact that defects reduce ultimate strength and efficiency during operation, detection of failures in composite parts is very important. Khamedi and Pedram [21] used Acoustic Emission (AE) non-destructive method in four-point bending test of carbon/epoxy composite to analyze and examine the failure mechanisms. Nassehi et al. [22] introduced the notion of an effective moduli for coated fibers. It is shown that such values can be numerically determined using experimentally measured bulk mechanical properties of coated glass filled composites. Khalkhali and Roshanfekr [23] optimized multi-objective shape of a projectile tip for impacting and normal penetrating. Velocity drop, weight and inner volume of projectile were considered as three conflicting objective functions.

In this study, the ballistic behavior of Kevlar fabric and Kevlar/epoxy composite is studied by experiment and simulation. Tensile and punch tests are performed to determine mechanical properties of the two materials at high strain rates. Finally, the ballistic behavior of the Kevlar fabric is simulated by ABAQUS finite element software and the results are validated by experiment.

2. MATERIAL AND SPECIMEN

Kevlar plain woven fabric, high-performance fibers for ballistic applications, have been used in this study. The Kevlar density is $1.44 g/cm^3$. The coefficient of friction between Kevlar fibers was calculated as 0.3 by using the belt and the capstan test. The Kevlar/epoxy composite were prepared from Kevlar woven fibers impregnated with resin epoxy, Araldite LY 5052 / Aradur 5052.

In ballistic tests, the projectile had a cylindrical shape with a diameter of 6 mm and a height of 12 mm. It was made of steel with a mass of 3.5 g. Two types of samples including Kevlar/epoxy composite and Kevlar fabric were used in this work. The samples had dimensions of 9 × 9 cm. In order to prevent slippage of samples during ballistic test, the samples were clamped between two sheets**.** In tensile tests, the samples were cut in rectangular shape with 2.5 cm width and different lengths. Special fixture was designed to prevent slippage of sample during tensile test. Two types of sample were used in tensile test: (a) Kevlar plain woven fiber, and (b) Kevlar/epoxy composite. The samples are shown in Figure 1. In the punch test, plain woven Kevlar and Kevlar / epoxy composite were used.

3. TEST DEVICES

In this study, the universal testing machines, Zwick, Instron testing machines and a gas gun were used for tensile, punch and ballistic tests, respectively.

4. EXPERIMENTS

In this study the ballistic behavior of Kevlar fabric and Kevlar/epoxy composite were investigated and mechanical behavior of two materials was characterized.

4. 1. Tensile Tests Tensile test were carried out at a constant rate of 20 mm/s. The failure mode of some samples re illustrated in Figure 2. In Figure 2(a) the failure of a Kevlar fabric sample and in Figures 2(b) and (c) the failure of Kevlar/epoxy composite in two samples are depicted. The deformation of Kevlar fabric shown in Figure 2(a) resembles a shear type failure which is usually observed in ductile materials. The failure mode seen in Figure 2(b) and (c) for Kevlar/epoxy composite is completely tensile indicating a brittle failure that is believed to be due resin epoxy of the composite. The stress-strain curves obtained at the loading rate of 20 mm/s for Kevlar fabric and Kevlar/epoxy composite are shown in Figure 3.

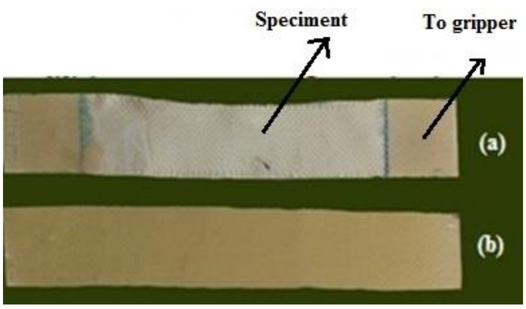


Figure 1. Samples used in tensile test: (a) Kevlar plain woven fiber, (b) Kevlar/epoxy composite

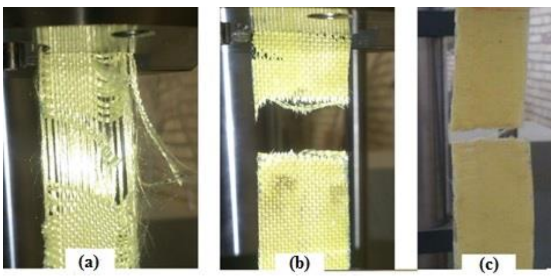


Figure 2. Failure of samples in tensile test: (a) Kevlar fabric (b) and (c) Kevlar/epoxy composite

As the figure suggests, the composite Kevlar/epoxy exhibits quite a linear behavior, whereas, the behavior of Kevlar fabric is non-linear. From the figure, the strength of Kevlar fiber and Kevlar/epoxy composite were obtained as 2.5 and 2.8 GPa, respectively. The small non-linear region (up to displacement of around 0.01) seen in the figure for both types of samples is believed to be due to the looseness of the samples fibers before testing. This non-linear behavior, however, disappears when the test begins and the fibers are tightened enough at the early stage of the tensile test.

The failure of Kevlar /epoxy composite is triggered by crack initiation in the matrix (resin epoxy) followed by separation of fibers from the matrix. This leads to non-uniform distribution of force between the fibers, and ultimately failure of fibers. In the case of Kevlar fabric, all fibers were broken simultaneously.

4. 2. Punch Test In order to investigate the shear load-extension behavior of Kevlar fabric and Kevlar/epoxy composite, punch test was carried out using Instron testing machine. The punch test is basically a quasi-static ballistic test that is carried at very low loading rate by piercing the specimen using a punch. Typical Kevlar fabric and Kevlar/epoxy composite samples pierced by 6 mm in diameter rounded punches are shown in Figures 4 and 5, respectively.

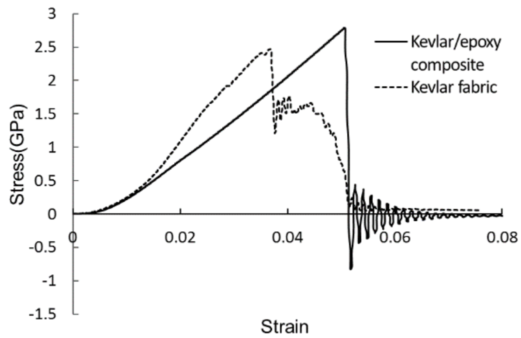


Figure 3. The stress-strain curves obtained at the loading rate of 20 mm/s for Kevlar fabric and Kevlar/epoxy composite samples

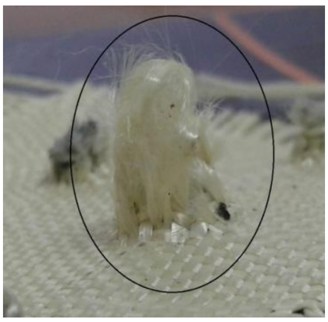


Figure 4. A typical Kevlar fabric sample pierced by 6 mm in diameter punch.

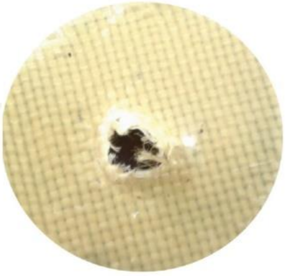


Figure 5. A typical Kevlar/Epoxy composite sample pierced by 6 mm in diameter punch

From each punch test, the load-displacement curves were recorded. As the figures suggest, two quite different failure mechanisms are observed for the two types of specimens.

The load-extension curves for four samples (two samples of each material) are illustrated in Figure 6. As the figure indicates, compared to Kevlar fabric samples, Kevlar/epoxy composite can bear higher loads against perforation in punch test. The Kevlar/epoxy composite, however, experiences extension significantly lower than that of the fabric samples. The results of punch test confirms that the failure mechanism of Kevlar fabric is quite ductile whereas the presence of epoxy in Kevlar/epoxy changes the failure mechanism from ductile to brittle, failure which is evident from plugging shown in Figure 5.

4. 3. Ballistic Test Ballistic tests were conducted using projectiles at the speeds of 60 to 178 m/s and 140 to 260 m/s for Kevlar/epoxy composite and Kevlar fabric, respectively. Two typical Kevlar/epoxy composite and Kevlar fabric samples tested at the velocities of 76 and 140 m/s are depicted in Figures 7 and 8, respectively.

The results of ballistic test for Kevlar/epoxy composite and Kevlar fabric are given in Table 1. The variation of residual velocity vs the impact velocity, known as ballistic curve for Kevlar/epoxy composite and Kevlar fabric are illustrated in Figures 9 and 10, respectively.

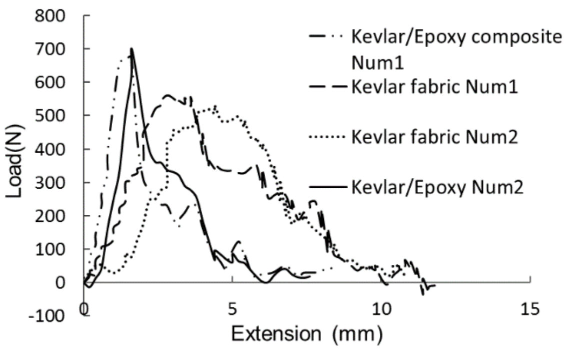


Figure 6. Load- extension curves obtained from punch test

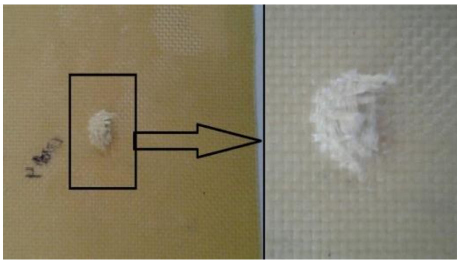


Figure 7. A Kevlar/epoxy composite sample tested at the velocity of 76 m/s

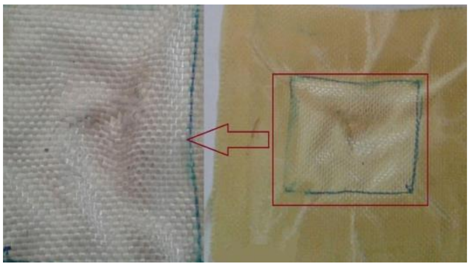


Figure 8. A Kevlar fabric specimen tested at the velocity of 140 m/s

TABLE 1. The results of Ballistic test for Kevlar/epoxy composite and Kevlar fabric

Test Number	sample	Input velocity (m/s)	Residual velocity(m/s)	Number of Layers
1	Kevlar/epoxy composite	60	No perforation	1
2	Kevlar/epoxy composite	76	6	1
3	Kevlar/epoxy composite	107	71	1
4	Kevlar/epoxy composite	125	95	1
5	Kevlar/epoxy composite	125	98	1
6	Kevlar/epoxy composite	125	90	2
7	Kevlar/epoxy composite	125	37	4
8	Kevlar/epoxy composite	136	108	1
9	Kevlar/epoxy composite	157	143	1
10	Kevlar/epoxy composite	178	151	1
11	Kevlar fabric	140	6	1
12	Kevlar fabric	176	105	1
13	Kevlar fabric	200	168	1
14	Kevlar fabric	214	201	1
15	Kevlar fabric	243	219	1
16	Kevlar fabric	260	251	1

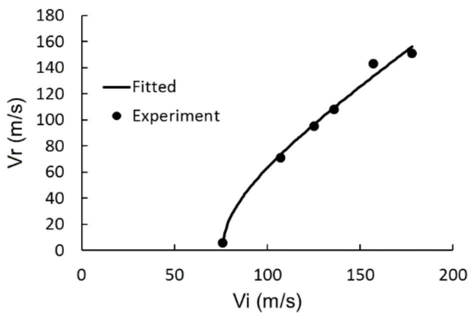


Figure 9. Kevlar/epoxy composite ballistic curve

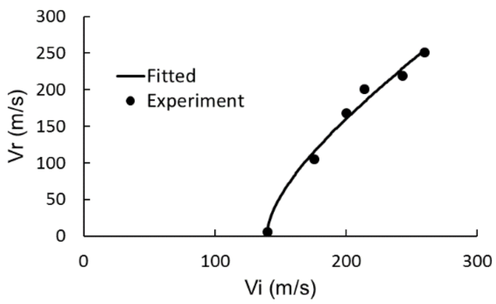


Figure 10. Kevlar fabric ballistic curve

The V_r–V_i data were curve fitted using Lambert-Jonas equation [24] defined by Equation (1)

$$v_r = (A v_i^p - B)^{1/p} \quad (1)$$

where, Vr and V_i, are the residual and initial velocities of the projectile, respectively. A and B are constants and P is the power and was considered 2 and 1.75, for Kevlar/epoxy composite and Kevlar fiber, respectively.

The results of 4 ballistic tests have been compared in Table 2. As the results show, for the same impact velocity (140 m/s) the residual velocity of the projectile is around 100 m/s for Kevlar/epoxy composite while no perforation occurs for the Kevlar fabric. This implies that Kevlar fabric can absorb 100% of the energy of the projectile at the impact velocity of 140 m/s while the Kevlar/epoxy composite is able to absorb only 50% of the energy which can be worked out from $E=mv^2/2$.

TABLE 2. A comparison between the ballistic behavior of the Kevlar fabric and Kevlar / Epoxy composite

	Test number	Initial velocity(m/s)	Residual velocity (m/s)
Kevlar/epoxy composite	1	140	107
Kevlar/epoxy composite	2	136	106
Kevlar fabric	1	140	6
Kevlar fabric	2	140	No perforation

5. NUMERICAL SIMULATION

In this section, the ballistic response of Kevlar fabric is simulated by ABAQUS finite element software. The simulation of ballistic test can is a cheap tool to study the effect of projectile geometry, the arrangement of Kevlar laminates and the number of layers and the input velocity on ballistic limit and behavior of the Kevlar composites. At the beginning, the warp and weft main model was constructed using TEXGEN textile fabrics software. Then, the plain woven fabric similar to the fabric used in this study was modelled using ABAQUS software. Figure 11 shows the schematic view of a warp and weft model. As the figure indicates, both of warp and weft has an elliptic cross-section with 2a×2b dimension.

The difference between Kevlar/epoxy composite and Kevlar fabric in the simulation was defined by incorporating their properties obtained from tensile test as discussed in section 4.1. A brittle failure for the Kevlar/epoxy composite was considered by using a VMAT subroutine. For Kevlar fabric a ductile behavior was considered as revealed by tensile and punch tests.

The initial velocity of the projectile and the boundary conditions at the outer boundary of fabrics were defined in the simulation. Figure 12 illustrates some sequences of the impact of the projectile on the specimens.

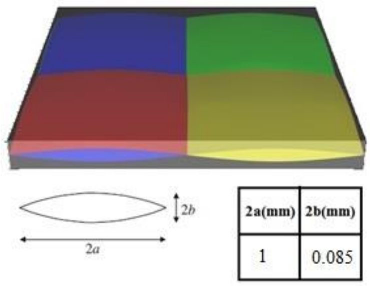


Figure 11. The schematic view of warp and weft model

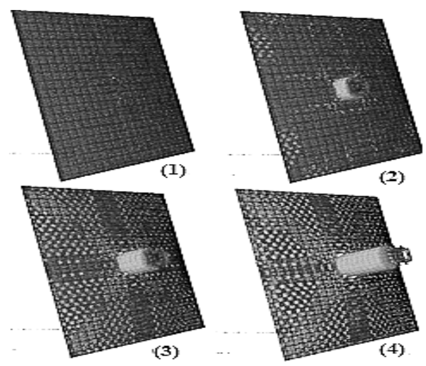


Figure 12. The sequence of a projectile on the composite Kevlar / epoxy with an initial speed of 122 m/s

6. NUMERICAL RESULTS

The numerical ballistic curve for the Kevlar / epoxy composite is shown in Figure 13. Also, the perforation of Kevlar / epoxy composite samples as predicted by simulation and obtained from experiment are shown in Figure 14. As the figure suggests, there is a reasonable agreement between the simulation and experiment. The ballistic limit obtained from test and simulation is 66 and 63 m/s, respectively.

Figure 15 indicates that the projectile impacted at the velocity of 140 m/s on the Kevlar/epoxy composite sample rebounds at a velocity of -40m/s. So, no perforation occurs. The figure also suggests that the projectile passes through the Kevlar fabric with no significant reduction in the input velocity.

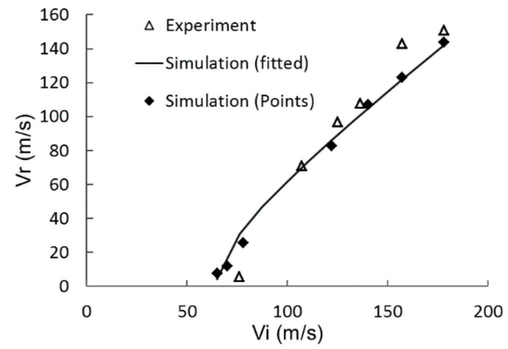
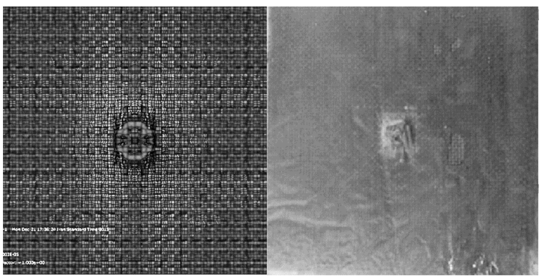


Figure 13. Ballistic behavior of Kevlar/epoxy composite



(a) (b)

Figure 14. The ballistic response of a Kevlar/epoxy composite sample from (a) simulation and (b) experiment

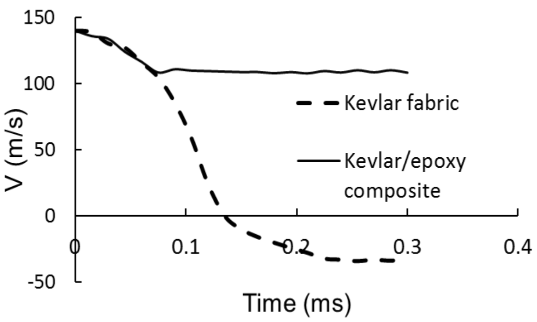


Figure 15. Projectile velocity-time histories during ballistic test

6. 1. Influence of the Friction Coefficient

In this section, the influence of friction coefficient between the fibers on the velocity of the projectile is investigated by considering the friction coefficients of 0, 0.3 and 0.9 for the input velocities of 140 and 70 m/s. The ballistic curves for different coefficients of the friction are shown in Figure 16. As the figure indicates, the friction coefficient is slightly affects the residual velocity for the input velocities lower the 75 m/s. However, for velocities higher the 75 m/s the friction coefficient effect is nearly negligible.

6. 2. Influence of Projectile Head Geometry

To evaluate the effect of the projectile head geometry on residual velocity, flat and oval geometrics are considered in this investigation. Two geometries are shown Figure 17. The velocities-time histories obtained for the two geometrics and the impact velocities of 140 and 70 m/s are shown in Figures 18 and 19, respectively. The figures indicate that the oval head geometries give higher residual velocity. However, the projectile head geometry is more influential for the lower impact velocities, so that for the impact velocity of 140 m/s this effect is not as significant. The perforation of a composite Kevlar/epoxy specimen by an oval head projectile for the impact velocity of 140 m/s is illustrated in Figure 20.

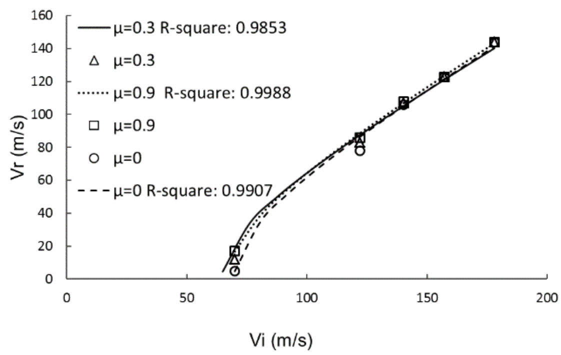
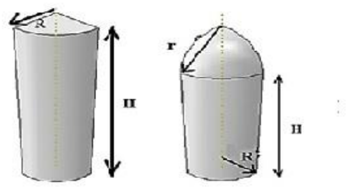


Figure 16. Ballistic curves for various friction coefficients



r (mm)	H (mm)	R (mm)	
3	10.8	3	Spherical projectile
0	12	3	Cylindrical projectile

Figure 17. Projectiles head geometries

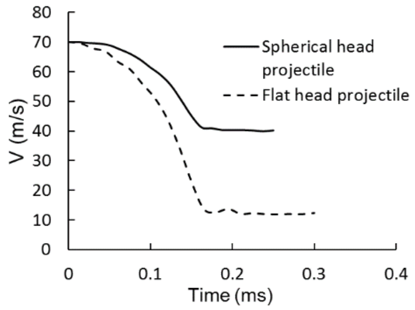


Figure 18. Velocity-time histories for the impact velocity of 70 m/s

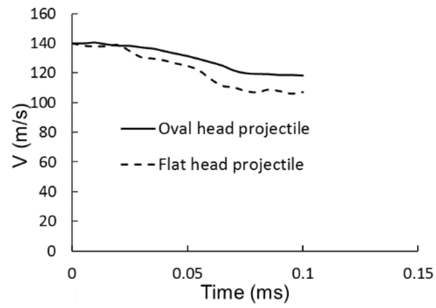


Figure 19. Velocity-time histories for the impact velocity of 140 m/s

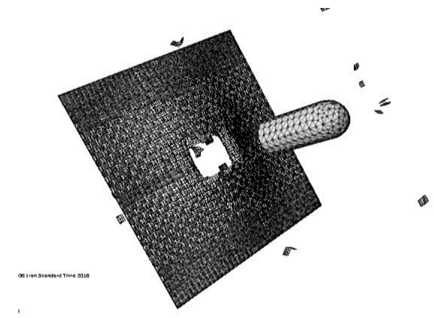


Figure 20. The perforation of a composite Kevlar/epoxy specimen by an oval head projectile for the impact velocity of 140 m/s

The ballistic curves for the two types of projectile are shown in Figure 21. The ballistic limits for flat and oval head projectiles, obtained from the figure are 65 and 50 m/s, respectively.

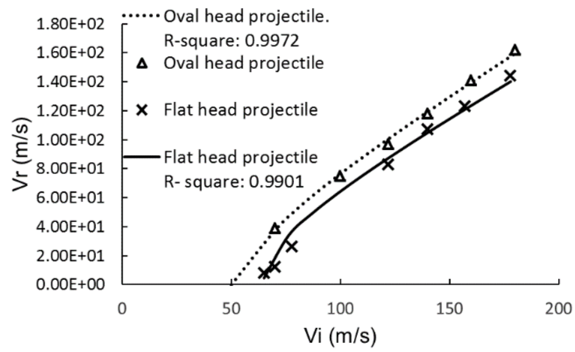


Figure 21. Ballistic curves for the two types of projectile

7. CONCLUSIONS

Mechanical and ballistic behavior of Kevlar/epoxy composite and Kevlar fabric were investigated in this work. The mechanical behavior of the materials were studied by tensile and punch test and their ballistic behavior was investigated by ballistic test. The following conclusions may derived:

1- From the tensile tests, the strength of Kevlar fiber and Kevlar/epoxy composite were obtained as 2.5 and 2.8 GPa, respectively. The tearing of the fibers indicated a brittle failure mode and the stress-strain curve showed a linear behavior for Kevlar/epoxy composite. For the Kevlar fabric, however, the failure mode and the behavior were ductile and non-linear, respectively.

2-The load-displacement curves obtained from punch test showed that Kevlar fabric significantly bear higher shear loads than Kevlar/epoxy composite against perforation. The Kevlar/epoxy composite, however, experiences extension significantly lower than that of the fabric samples. The results of punch test confirmed that the failure mechanism of Kevlar fabric was quite ductile whereas the presence of epoxy in Kevlar/epoxy changed the failure mechanism from ductile to brittle in the form of plugging.

3- For the impact velocity of 140 m/s the Kevlar fabric absorbed 100% of the projectile energy (no perforation) whereas the Kevlar/epoxy composite could absorb only 50% of the impact energy indicating a significantly higher absorption capability for the Kevlar/epoxy composite.

4- For the materials and the test conditions used in this work, the ballistic limit for Kevlar fabric and Kevlar/epoxy composite were obtained 140 and 64 m/s, respectively indicating significantly higher resistance against perforation for Kevlar/epoxy composite.

5- The ballistic test was simulated using finite element method. A reasonable agreement was achieved between the numerical results and the experiments by assuming a brittle failure model for the composite Kevlar/epoxy in the VMAT and a ductile model for the Kevlar fabric.

6- The friction coefficient between the fibers can slightly influence the ballistic curve at low impact velocities but for higher impact velocities it is almost ineffective.

7- The oval head projectile gives higher residual velocity, but the difference between the oval and flat head on residual velocity is not as significant for higher impact velocities.

8. REFERENCES

1. Tapie, E., Shim, V. and Guo, Y., "Influence of weaving on the mechanical response of aramid yarns subjected to high-speed loading", ***International Journal of Impact Engineering***, Vol. 80, (2015), 1-12.

2. Sanborn, B. and Weerasooriya, T., "Quantifying damage at multiple loading rates to kevlar km2 fibers due to weaving, finishing, and pre-twist", ***International Journal of Impact Engineering***, Vol. 71, (2014), 50-59.

3. Das, S., Jagan, S., Shaw, A. and Pal, A., "Determination of inter-yarn friction and its effect on ballistic response of para-aramid woven fabric under low velocity impact", ***Composite Structures***, Vol. 120, (2015), 129-140.

4. Okafor, E.C., Ihueze, C.C. and Nwigbo, S., "Optimization of hardness strengths response of plantain fibres reinforced polyester matrix composites (pfrp) applying taguchi robust resign", ***International Journal of Science & Emerging Technologies***, Vol. 5, No. 1, (2013).

5. Tham, C., Tan, V. and Lee, H.-P., "Ballistic impact of a kevlar® helmet: Experiment and simulations", ***International Journal of Impact Engineering***, Vol. 35, No. 5, (2008), 304-318.

6. Zhu, D., Vaidya, A., Mobasher, B. and Rajan, S.D., "Finite element modeling of ballistic impact on multi-layer kevlar 49 fabrics", ***Composites Part B: Engineering***, Vol. 56, (2014), 254-262.

7. Lee, Y.S., Wetzel, E.D. and Wagner, N.J., "The ballistic impact characteristics of kevlar® woven fabrics impregnated with a colloidal shear thickening fluid", ***Journal of Materials Science***, Vol. 38, No. 13, (2003), 2825-2833.

8. Majzoobi, G. and Moradi, S., "The ballistic behavior of high strength, low alloy-100 steel at sub-zero temperatures", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 29, No. 12, (2016), 1747-1756.

9. Nilakantan, G., "Filament-level modeling of kevlar km2 yarns for ballistic impact studies", ***Composite Structures***, Vol. 104, (2013), 1-13.

10. Gu, B., "Analytical modeling for the ballistic perforation of planar plain-woven fabric target by projectile", ***Composites Part B: Engineering***, Vol. 34, No. 4, (2003), 361-371.

11. Cheeseman, B.A. and Bogetti, T.A., "Ballistic impact into fabric and compliant composite laminates", ***Composite Structures***, Vol. 61, No. 1, (2003), 161-173.

12. Kumar, S., Gupta, D.S., Singh, I. and Sharma, A., "Behavior of kevlar/epoxy composite plates under ballistic impact", ***Journal of Reinforced Plastics and Composites***, Vol. 29, No. 13, (2010), 2048-2064.

13. Heydari, M. and Choupani, N., "A new comparative method to evaluate the fracture properties of laminated composite", ***International Journal of Engineering***, Vol. 27, No. 6., (2014), 1025-2495.

14. Lim, C., Shim, V. and Ng, Y., "Finite-element modeling of the ballistic impact of fabric armor", ***International Journal of Impact Engineering***, Vol. 28, No. 1, (2003), 13-31.

15. Rao, M., Duan, Y., Keefe, M., Powers, B. and Bogetti, T., "Modeling the effects of yarn material properties and friction on the ballistic impact of a plain-weave fabric", ***Composite Structures***, Vol. 89, No. 4, (2009), 556-566.

16. Silva, M.A., Cismaşiu, C. and Chiorean, C., "Numerical simulation of ballistic impact on composite laminates", ***International Journal of Impact Engineering***, Vol. 31, No. 3, (2005), 289-306.

17. Omidvar, H., Azari, K., Taheri, A.M. and Saghafi, A., "Impact and ballistic behavior optimization of kevlar–epoxy composites by taguchi method", ***Arabian Journal for Science and Engineering***, (2012), 1-7.

18. Jamal-Omidi, M. and Suki, M.M., "A numerical study on aluminum plate response under low velocity impact", ***International Journal of Engineering-Transactions C: Aspects***, Vol. 30, No. 3, (2017), 439.

19. Reis, P., Ferreira, J., Zhang, Z., Benameur, T. and Richardson, M., "Impact response of kevlar composites with nanoclay enhanced epoxy matrix", ***Composites Part B: Engineering***, Vol. 46, (2013), 7-14.

20. Woo, S.-C. and Kim, T.-W., "High-strain-rate impact in kevlar-woven composites and fracture analysis using acoustic emission", ***Composites Part B: Engineering***, Vol. 60, (2014), 125-136.

21. Khamedi, R. and Pedram, O., "Cluster analysis of acoustic emission signals for carbon/epoxy composite in four-point bending test (research note)", ***International Journal of Engineering, Transaction C: Applications***, Vol. 28, No. 9, (2015), 1336-1342.

22. Nassehi, V., Hashemi, S. and Beheshty, M., "A numerical method for the determination of an effective modulus for coated glass fibers used in phenolic composites", ***International Journal of Engineering***, Vol. 13, No. 3, (2000), 1-10.

23. Khalkhali, A., Roshanfekr, S. and Toraabic, M., "Multi-objective optimization of a projectile tip for normal penetration", ***International Journal of Engineering-Transactions A: Basics***, Vol. 26, No. 10, (2013), 1225.

24. Lambert, J. and Jonas, G., "Towards standardization in terminal ballistics testing: Velocity representation" (1976), DTIC Document.

Numerical and Experimental Study of Ballistic Response of Kevlar Fabric and Kevlar/Epoxy Composite

G. H. Majzoobi, F. Mohammad Zaheri

Mechanical Engineering Department , Bu-Ali Sina University, Hamedan, Iran

PAPER INFO

Paper history:
Received 10 February 2017
Received in revised form 27 February 2017
Accepted 10 March 2017

Keywords:
Kevlar Fiber
Finite Element Simulation
Kevlar/Epoxy
Ballistic

چکیده

کولار نوعی از الیاف آرامید بوده که دارای مشخصه استحکام بالا نسبت به وزن پایین می‌باشد. این ماده به طور گسترده‌ای در جلیقه‌های ضد گلوله و کلاه خود برای ایجاد مانع در برابر پرتابه به منظور حفاظت از اهداف خاص، لوله‌های چند لایه و مخازن تحت فشار و غیره استفاده می‌شود. در این مطالعه رفتار بالستیک کامپوزیت کولار/ اپوکسی و پارچه کولار بررسی شده است. نتایج نشان داد که استحکام پارچه کولار نسبت به کامپوزیت کولار/ اپوکسی بیشتر است. نتایج به دست آمده از آزمایش‌های کشش و سوراخ برشی نشان داد که اگر چه کامپوزیت کولار/ اپوکسی استحکام بالاتری دارد، اما تغییر شکل آن نسبت به پارچه کولار کمتر است. همچنین، نتایج نشان داد که مکانیزم شکست پارچه کولار کاملاً نرم است در حالی که حضور اپوکسی در کامپوزیت کولار/ اپوکسی موجب تغییر رفتار کولار در هنگام شکست از نرم به ترد می‌گردد. در پایان، رفتار بالستیک پارچه کولار با استفاده از نرم افزار اجزای محدود آباکوس شبیه‌سازی شده و نتایج شبیه‌سازی با نتایج آزمایش‌های انجام شده مقایسه شد.

doi*: 10.5829/idosi.ije.2017.30.05b.20*