Experimental and Numerical Evaluation of Impact Strength for Carbon/ E-Glass/ Epoxy Composite Plate

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الخلاصة

في هذا البحث تم استخدام برنامج الأنسس لتحليل الاجهادات الناتجة عن اصطدام رصاصه عيار (9) ملم بالصفائح المركبة الهجينة. المواد المستخدمة في هذا البحث هي ألياف كربونية ذات اتجاه واحد والياف زجاجية مع الايبوكسي. التجارب العملية في هذا البحث تتضمن تصنيع صفائح هجينه من الألياف الكربونية والزجاجية مع الايبوكسي وبسمك مختلف وإطلاق الرصاص عليها بسرعه (371) م\ث ومن مسافة (5) م. لإثبات النتائج المتحصل عليها من برنامج الأنسس تم مقارنة سرعة خروج الرصاصة واقل سرعة لازمة لاختراق هذه الألواح والطاقة الممتصة من قبل الالواح مع النتائج العملية. وقد بينت النتائج أن إجهاد القص والانفعال يكون في أعلى قيمة في الطبقات الأولى بينما إجهاد الشد يكون في أعلى قيمة له في الطبقات الأخيرة وان اقل سرعة لازمة لاختراق لوح من الالياف الكربونية والزجاجية والايبوكسي بسمك (5) ملم هو (371) م\ث، استخدام الالياف الزجاجية مع الالياف الكربونية يقلل الكلفة ويحسن امتصاص الطاقة ويزيد من مقاومة الصدمة.

الكلمات المفتاحية

برنامج الأنسس، بالصفائح المركبة الهجينة، مقاومة الصدمة.

Abstract

In this work finite element ANSYS program is used to analyze the impact stresses of (9) mm bullet impact on hybrid composite plate using explicit dynamic and autodyne code. The material used in this work is unidirectional carbon fibers and plain weave E-Glass with epoxy as matrix. The experimental work includes manufacturing composite plates made from Carbon/E-Glass/Epoxy with different thicknesses subjecting these plates to impact by 9mm bullets at speed of (37) m/s from (5) m distance. The numerical results were proved by comparing the bullets residual velocity, the ballistic limit, and the energy absorption with the results from the experiment work. The results show that the shear and strain are maximum in the front layers while the tensile stress is maximum at the rear layers. The hybrid plates have good ballistic limit, and using E-Glass fibers with carbon fibers reduce the cost and improving the energy absorption and the impact resistance.

Keywords

ANSYS program, Hybrid composite plate, Impact resistance.

1. Introduction

Impact studies are so important in many fields like military, airspace and motivate the researchers to conduct more experiments and studies to get clear picture to the impact behavior. This search analysis and study the impact stresses of striking bullets on composite plate, and a unidirectional Carbon Fiber Reinforced polymer (CFRP), plain weave E-Glass fibers, with epoxy as matrix were used in this work. The high mechanical properties of composite material such as the high strength and low density compared to conventional material gave it important role in aerospace, automotive, and military manufacturing such as helmets and body armor. Harpreet and Puneet [1] conducted numerical and experiment analysis to find the impact damage of the composite materials using ABAQUS/Explicit. The material used in this work is graphite/epoxy and)6.5(g steel bullet with different speeds. The authors concluded that the numerical result in prediction the composite

damage matches well with the experiment results. V. Narayanamurthy et al. [2] performed numerical simulation to analyze the impact of steel bullets on steel target using ANSYS LS DYNA software and the authors proved this software can efficiently have calculated the impact parameter such as the damage, bullet residual velocity, and bullet displacement. Rimantas and Ausra [3] conducted a series of numerical analysis to prove that by using LS-DYNA software the bullet residual velocity can be accurately calculated. The authors have used Twaron textile in modeling the target and lead in modeling the bullet. The authors concluded that the residual velocity can be accurately calculated by using LS-DYNA software.

In this work impact stress analysis of Carbon/E-Glass/Epoxy composite plate is performed using ANSYS 16.1 software and the results proved by comparing the bullets residual velocity, the ballistic limit, the energy absorption with the experiment work. The result shows good agreement between the numerical and experimental work also shows hybrid plate with(5)mm thick can resist (9) mm bullet with speed of (371)m/s.

2. Projectile energy balance:

According to the conservation of the total energy, the projectile kinetic energy (KE_p) can be obtained by summing the projectile residual kinetic energy (KE_r) and the total energy absorbed by the target at that instant (KE_{abs}) which can be represented as follows [12]:

$$KE_P = KE_{abs} + KE_r \quad \text{..... (1)}$$

3.The Hybrid Fabrication:

In order to integrate the best characteristics of both carbon and glass fibers reinforcement composite hybrid composite are introduced. Carbon fibers make the specimen stronger and the glass fibers preventing the material from collapsing [12], this does not mean that there is no internal damage but the carbon fibers retain in their place by the strengthening effects of nearby glass fibers. The hybrid laminates were fabricated using a unidirectional carbon

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fiber type (sikawrap-230C), plain weave E-glass type (EWR600), and (sikadure-330) epoxy as matrix. The laminates were fabricated with volume fraction of (40%) fibers and epoxy volume fraction of (60%). In manufacturing the hybrid, the first ply was carbon fibers oriented in direction, the second ply was E-glass fibers in direction, the third ply was carbon fibers in direction and so on as in Table (1). All E-glass fibers plies placed in direction and carbon fibers ply alternating between and because according to [9] the ballistic limit and the energy absorption are maximum for the (0/90) lay-up laminate. The mechanical properties of the Carbon/Epoxy and E-glass/Epoxy were calculated according to the manufacturer data sheet and the lamination theory as in Table (2) and (3).

Table (1): The hybrid layup

E-Glass fibers
Carbon fibers
E-Glass fibers
Carbon fibers
E-Glass fibers
Carbon fibers

Table (2): Carbon/Epoxy properties

Density	1.49 g/
E_{11}	97.9 GPa
E_{22}	7.4 GPa
E_{33}	7.4 GPa
G_{12}	2848.71 MPa
G_{23}	2607.971 MPa
G_{13}	2848.71 MPa
ν12	0.27
σT	1768.6 MPa
εT	0.018

Table (3): E-Glass/ Epoxy properties

Density	1.584 g/
E_{11}	9.14 GPa
E_{22}	9.14 GPa
E_{33}	5.15 GPa
G_{12}	1823.124 MPa
G_{23}	1215.277 MPa
G_{13}	1215.277 MPa
ν12	0.112
σT	162.7 MPa
εT	0.034

4. Impact Testing:

The experimental test was created according to the guidelines given by the National Institute of Justice (NIJ) standards (MIL-STD-662E, NIJ standard 0108.01) which is the most reliable test that widely used by agencies and armor manufacturers for product acceptance test [10]. The schematic of ballistic setup of (NIJ) test are shown in Fig. (1). The test weapon used was (9) mm handgun and fixed on stand to insure that the bullets are fired in strait line with the target and the chronograph also laser beam is used to help in aiming as shown in Fig. (2), and in order to determine the velocity of the bullet a Caldwell chronograph was used which is shown in Fig. (3). The test procedure used to test the composite plates was done using specimens of different thicknesses. The test specimens were perpendicular to the line of bullet flight at the point of impact, and one bullet was fired on each specimen. The bullet used in this test has flat ended and conical nose, the core was made from lead and the jacket from copper, the bullet length was (15.38) mm and the diameter (9) mm, and its weight 8g. Fig. (4) shows a tested hybrid plate 5mm thick consisting of (6) layers of carbon fibers and (6) layers of E-Glass fibers.

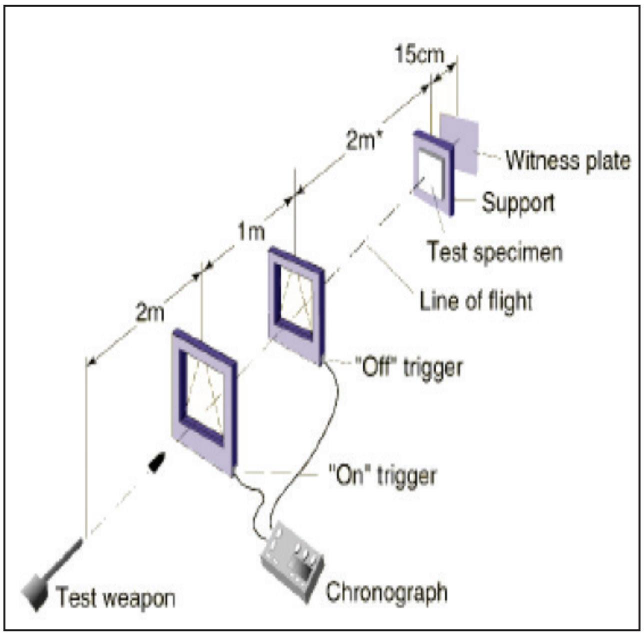

Fig. (1): The ballistic testing [10]

Fig. (2): Gun fixing mechanism

Fig. (3): The ballistic chronograph

Fig. (4): The front face of hybrid plate (5)mm thick [6 layers E-Glass and 6 layers Carbon fibers]

5. Projectile modeling:

For modeling the (9) mm bullet it has been used the lead metal as core and copper metal to encase the lead core as in Fig. (5). Jonson cook failure low is used in modeling the lead and copper metal [11]. The lead and copper metal properties are taken from ANSYS (16.1) engineering data sources- explicit materials. The projectile was modeled in detail according to the projectiles used in the experiments and in order to save computation time the planer symmetry condition in a quarter models is used as in Fig. (6), and in meshing the projectile a mesh of size 1 mm is used as in Fig. (7). The numerical analyzes is done by setting the bullet initial velocity of (371) m/s as it obtained from the experiments and due to the lack of thermal material data for the target material the heat generated during the impact is neglected.

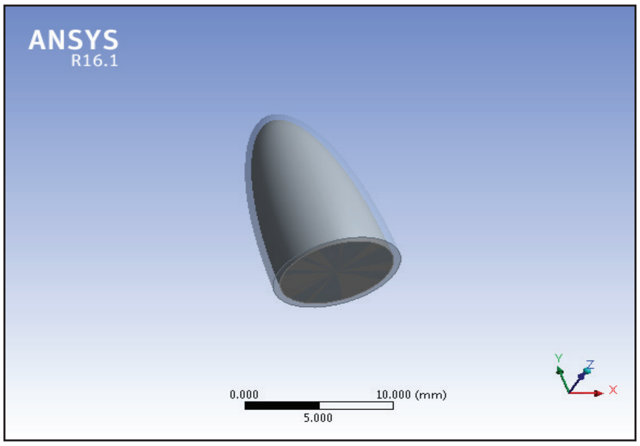

Fig. (5): Bullet modeling in ANSYS

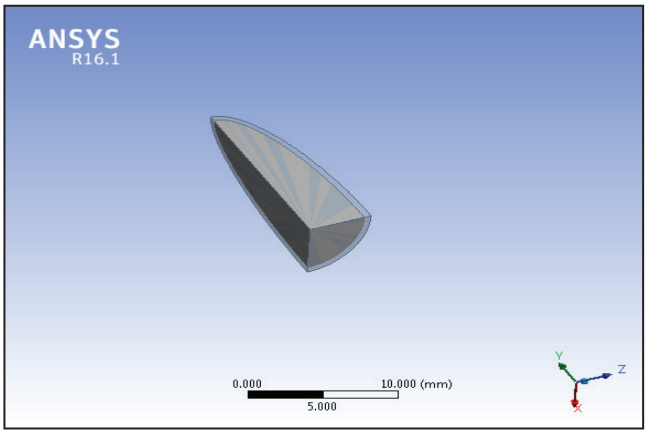

Fig. (6): Bullet symmetry

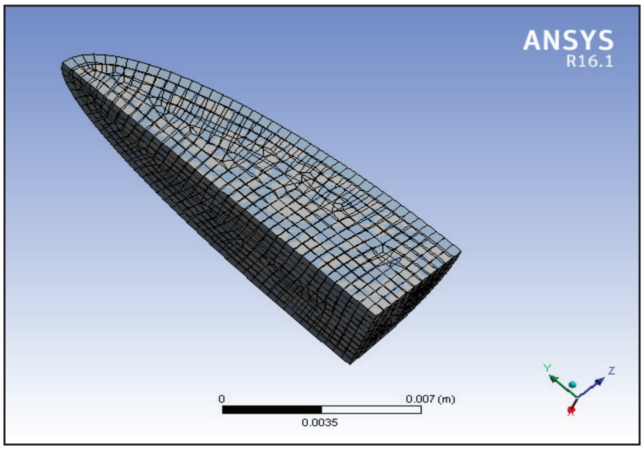

Fig. (7): Bullet meshing

6. Hybrid modeling:

In modeling of the hybrid composite plate the plies are layup in the same way that used in the experiment work. Ply to ply contact for the composite were defined using automatic contact, that because in the experimental work all the layers are fully bonded to each other, and the friction between the bullet and plate is set (0.2) [12]. All the plates are modeled in the same size and details as in experiment with (15)cm length, (15) cm width, and different thicknesses, and meshed with size of (1) mm. The boundary condition that has been used is fixing the four edges of the plate. In this work the numerical analysis of the stresses of the impact is made using ANSYS 16.1 and a comparison with the experimental work were made. Symmetry boundary condition of (and are used to save time as shown in Fig. (8).

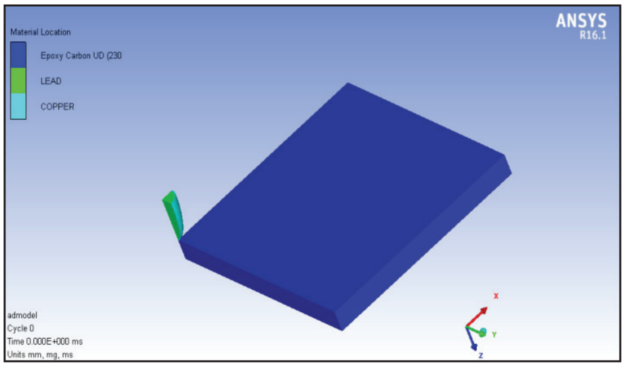

Fig. (8): Quarter model with symmetry condition X=Y=0.

7. Comparison between the Numerical Solution and the Experiment Work Results:

Fig. (9) shows the change in the residual velocity with plate thickness for the hybrid plate in both experimental and analytical solution. The residual velocity decreases with plate thickness increment and reaches zero at (5) mm thickness. The numerical solution shows reducing in the error with increasing plate thickness to reach zero in (5) mm case, that because the bullet temperature and the weather condition has been neglected due to the lack of data available, and this effects the bullet residual velocity.

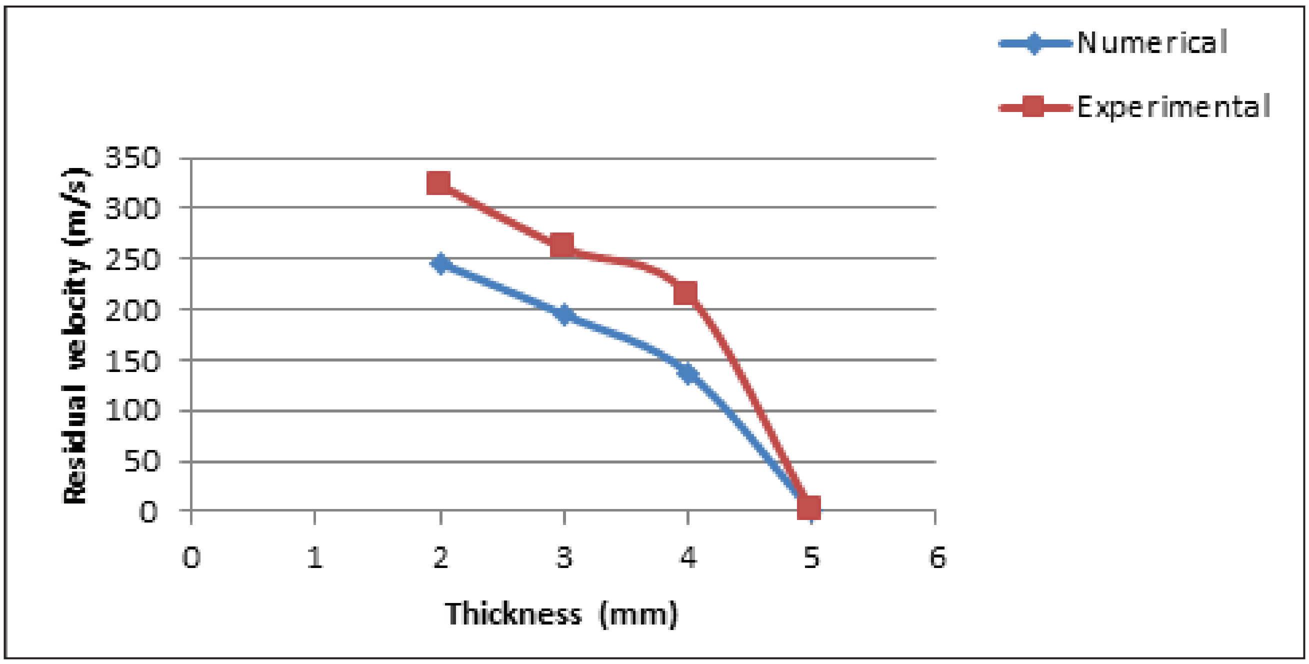

Fig. (9): The change in the residual velocity with plate thickness for the hybrid plates in both experimental test and numerical solution.

Fig. (10) shows the change in the bullet residual kinetic energy with plate thickness for the hybrid composite in both the experiment and the numerical work. Both the residual kinetic energy curves are decreasing with thickness and reach zero at (5) mm plate thickness that because with increasing the thickness the plates become stronger and therefore absorb higher energy.

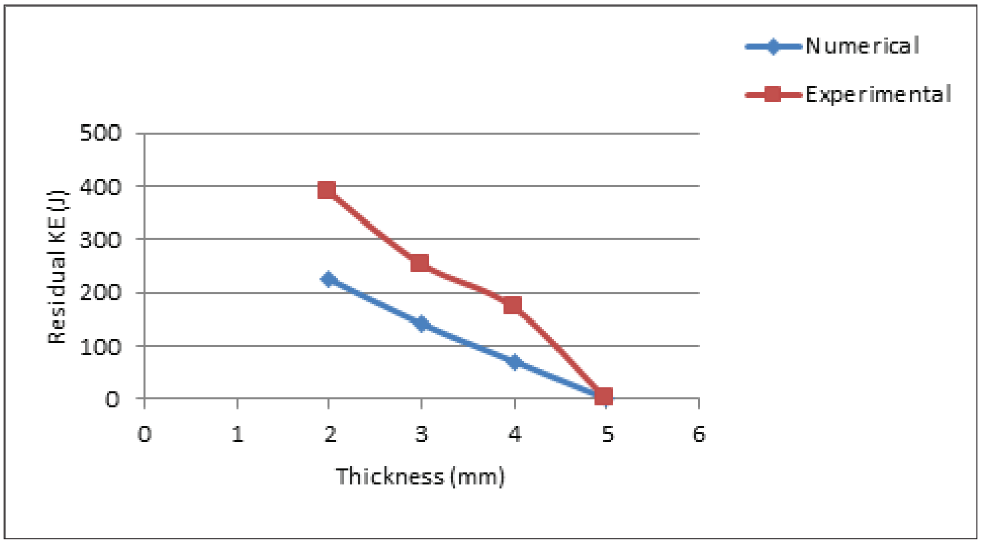

Fig. (10): The change in the bullet residual KE with plate thickness for the hybrid composite plate

Fig. (11) shows the change in the bullet energy absorbed with plate thickness in both the experiment and the numerical work. Both energy absorbed curves in this Fig. shows increasing with plate thickness until absorbed all the bullet energy at (5) mm plate thickness.

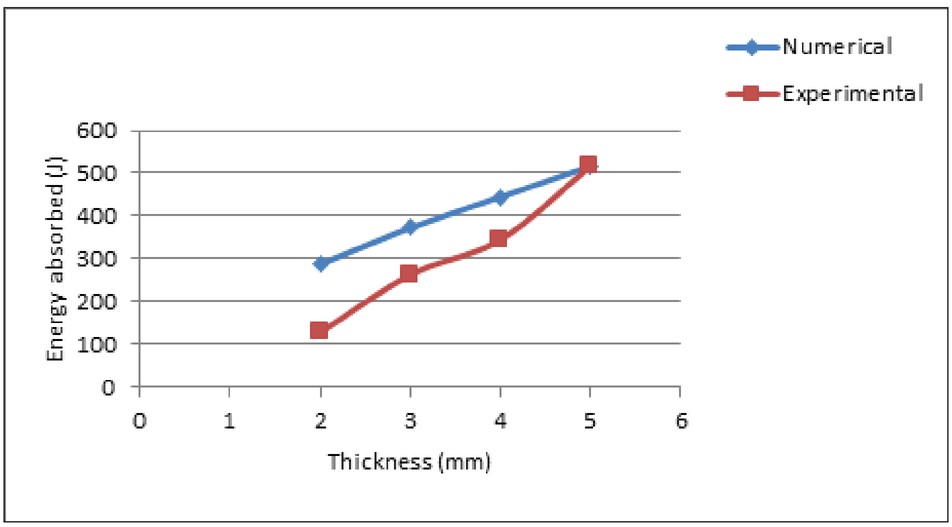

Fig. (11): The change in the energy absorbed with plate thickness for the hybrid composite plate

Fig. (12) shows comparison in ballistic limit for the hybrid plate (5) mm thick between experimental work and the numerical solution. The ballistic limit in the experimental work is (371) m/s and the experimental and numerical solution shows good agreement.

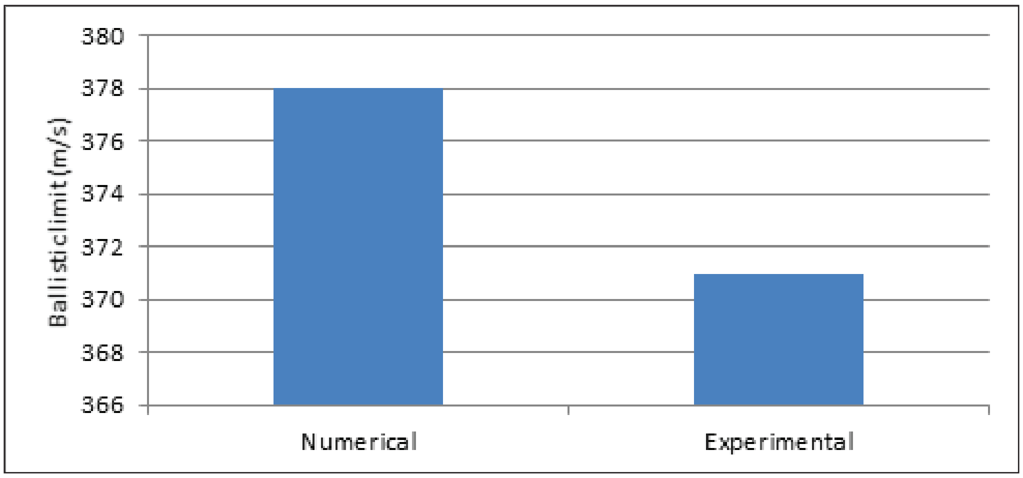

Fig. (12): Comparison in the ballistic limit for the hybrid plate (5) mm thick impacted by (9) mm bullet.

8. ANSYS Results of the Hybrid Models:

8.1. The Directional Deformation Result:

Fig. (13) shows the directional deformation in Z-direction for the hybrid plate)4(mm thick impacted by (9) mm bullet. The Fig. shows complete penetration to the hybrid plate, also it shows conoid formation and the maximum directional deformation is (0.035173) m. Fig. (14) shows the change in the directional deformation with time. The maximum directional deformation curve increasing with time and reach maximum at the end of impact setting time.

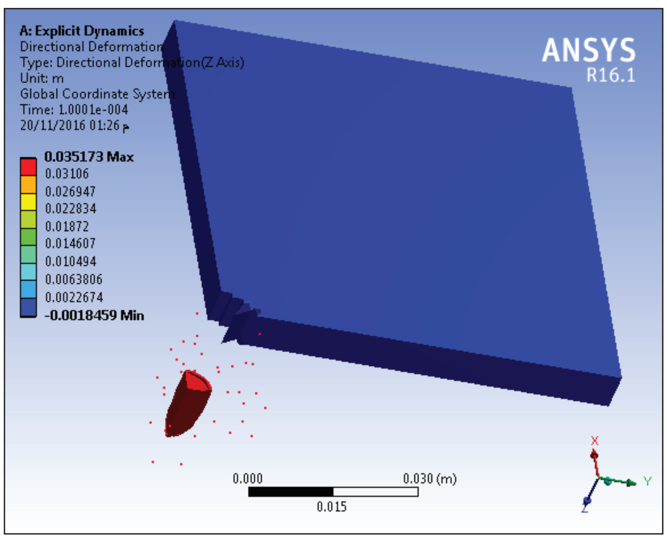

Fig. (13): The directional deformation in Z-direction

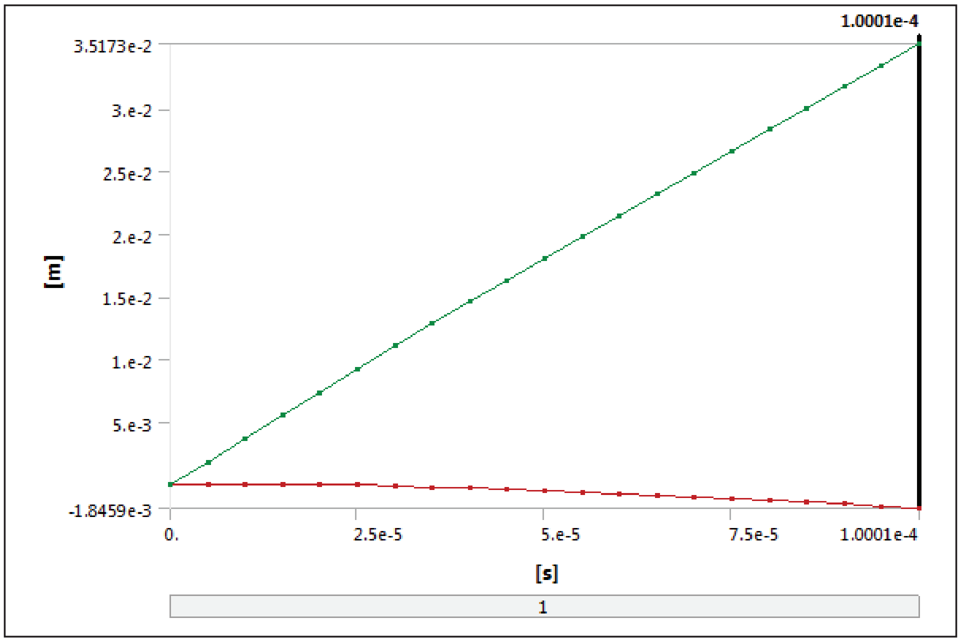

Fig. (14): The change in the directional deformation with time

8.2. The Maximum Principal Stress Result for The Hybrid Composite Plate:

Fig. (15) shows the stress distribution in hybrid plate at 0.0001s and the maximum principal stress at this time is 9.5536×10^7Pa. Fig. (16) shows the change in the stress with time. The maximum principal stress curve increases with time to reach maximum value 2.2791×10^8) Pa at (1.5×10^{-5}s. After that time the stress decreases because of the failure in the hybrid layers.

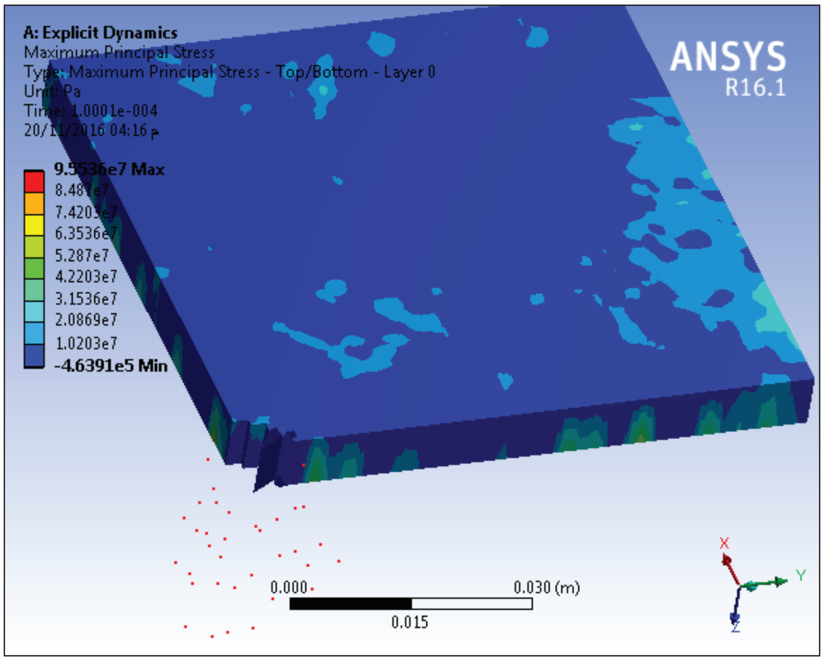

Fig. (15): The maximum principal stress distribution

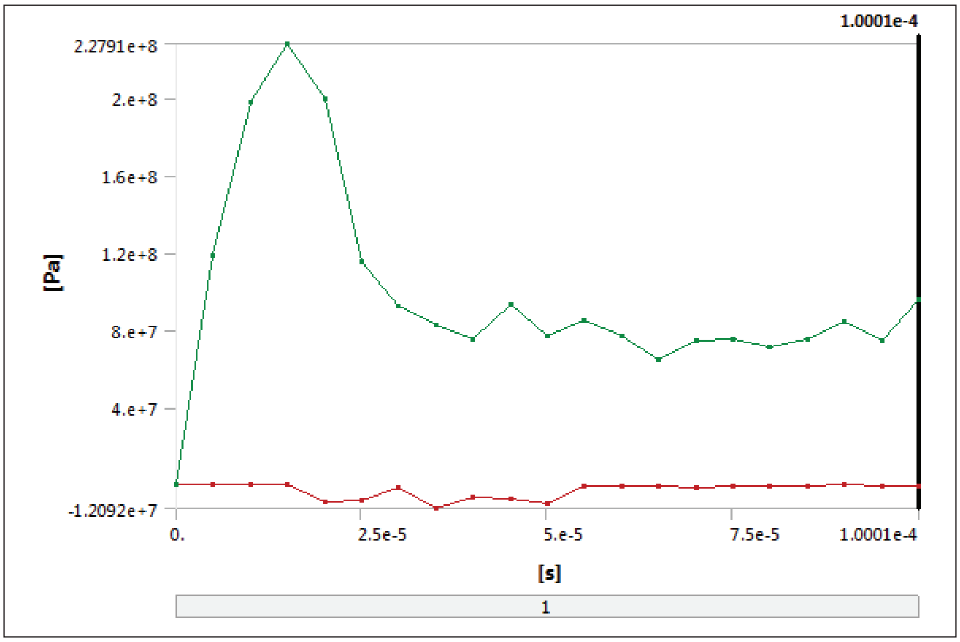

Fig. (16): The change in the maximum principal stress with time

8.3. The Maximum Principal Stress Result for The 9mm Bullet:

Fig. (17) shows the stress distribution in the bullet at the time 0.0001s and the maximum principal stress at this time is (1.129) Pa. The Fig. also shows deformation in the front end and the middle of the bullet, and the copper jacket has slide backward. Fig. (18) shows the change in the stress with time. The maximum principal stress increases with time reaching its maximum value (5.31 Pa at (2.5s. After that time the bullet are begins to leave the hybrid plate and therefore the stress is decreasing.

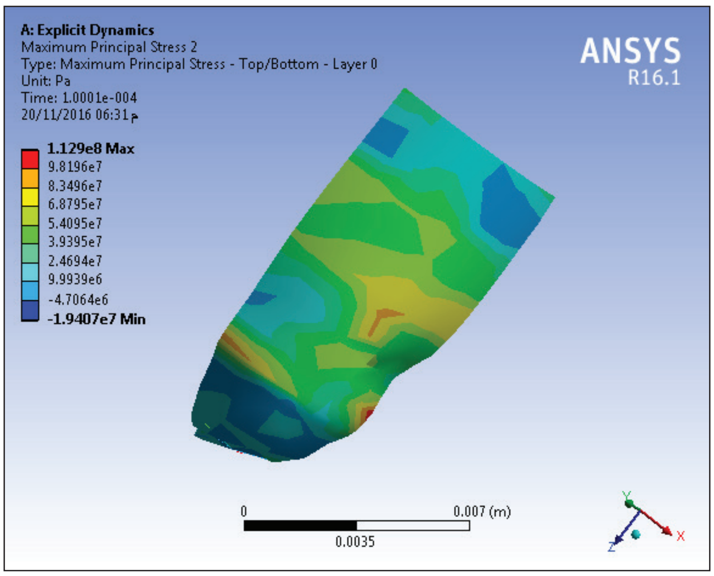

Fig. (17): The maximum principal stress for the 9mm bullet

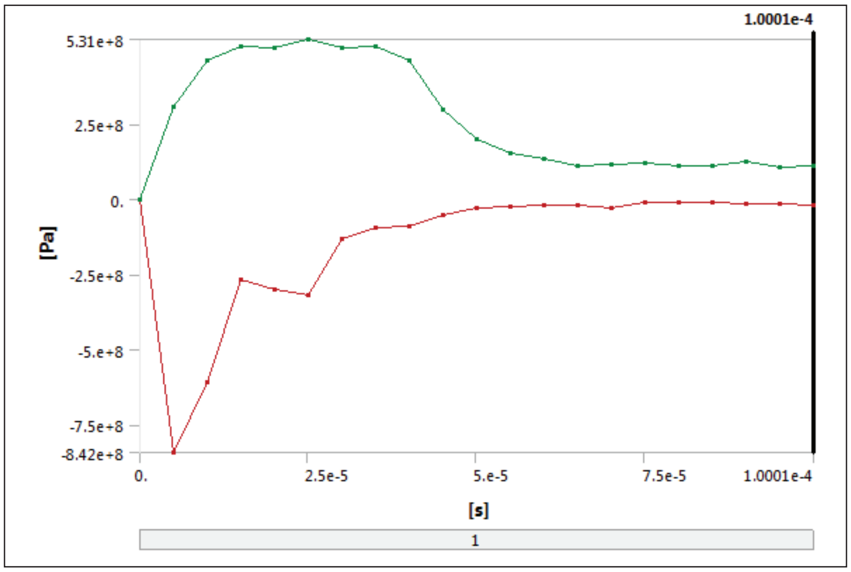

Fig. (18): The change in the stress with time for the 9mm bullet

8.4. The Maximum Shear Stress Result:

Fig. (19) shows the shear stress distribution in the hybrid plate at the time (0.0001)s and the maximum shear stress at this time is (4.8015 $\times 10^{-5}$) Pa. Fig. (20) shows the change in the shear stress with time. The maximum shear stress curve are increasing with time to reach maximum (1.201 $\times 10^{8}$) Pa at the time (1.5 $\times 10^{7}$s). After that time the hybrid layers start failing and therefore the shear stress carve decreases.

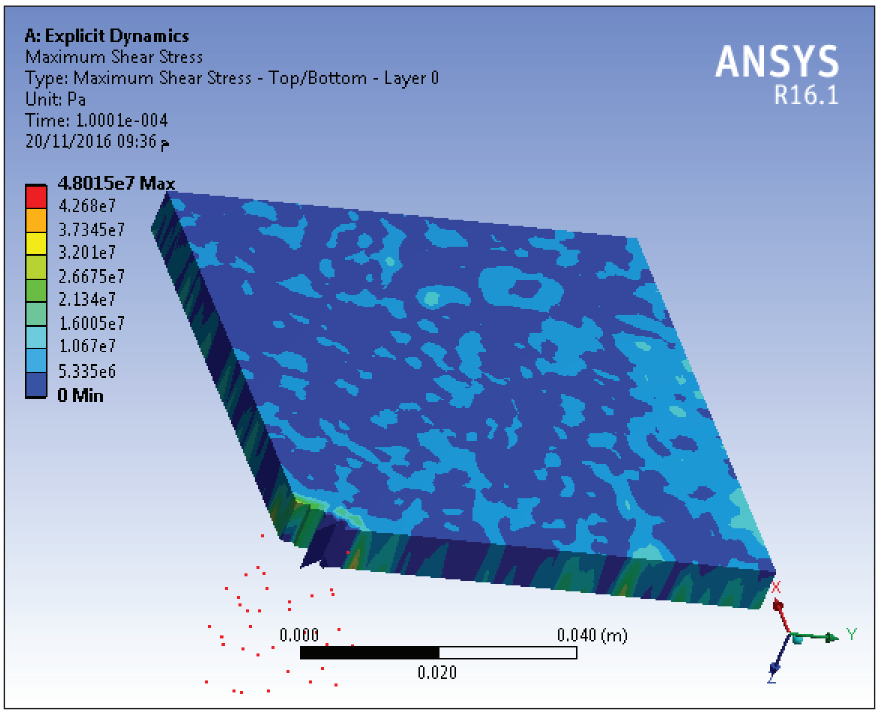

Fig. (19): The maximum shear stress distribution

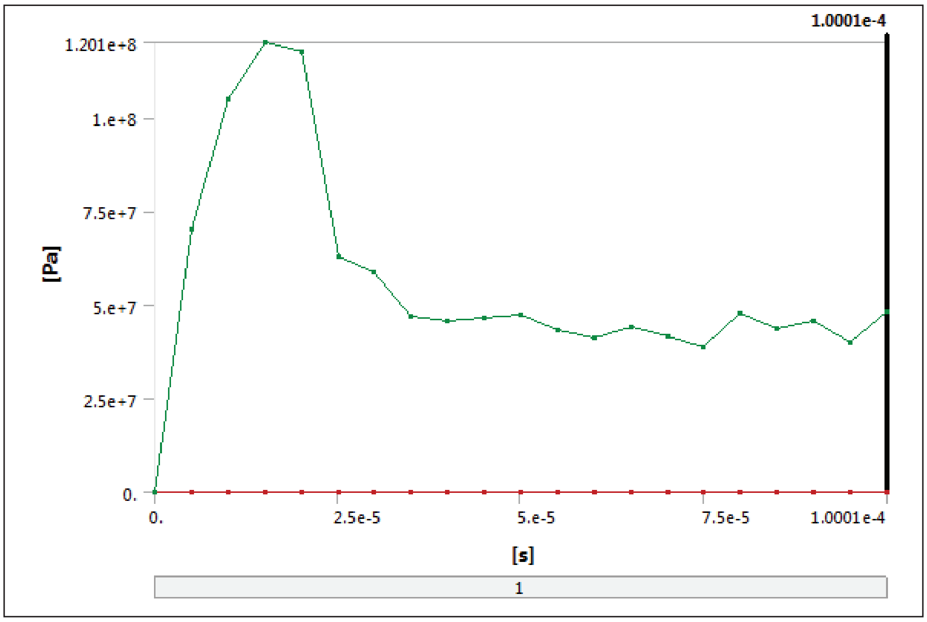

Fig. (20): The change in the maximum shear stress with time

8.5. The Maximum Principal Strain Result:

Fig. (21) shows the strain distribution in the hybrid plate at the time 0.0001s and the maximum principal strain at this time is (4.2696%). Fig. (22) shows the change in the strain with time. The maximum strain curve shows increasing with time to reach maximum at the end time.

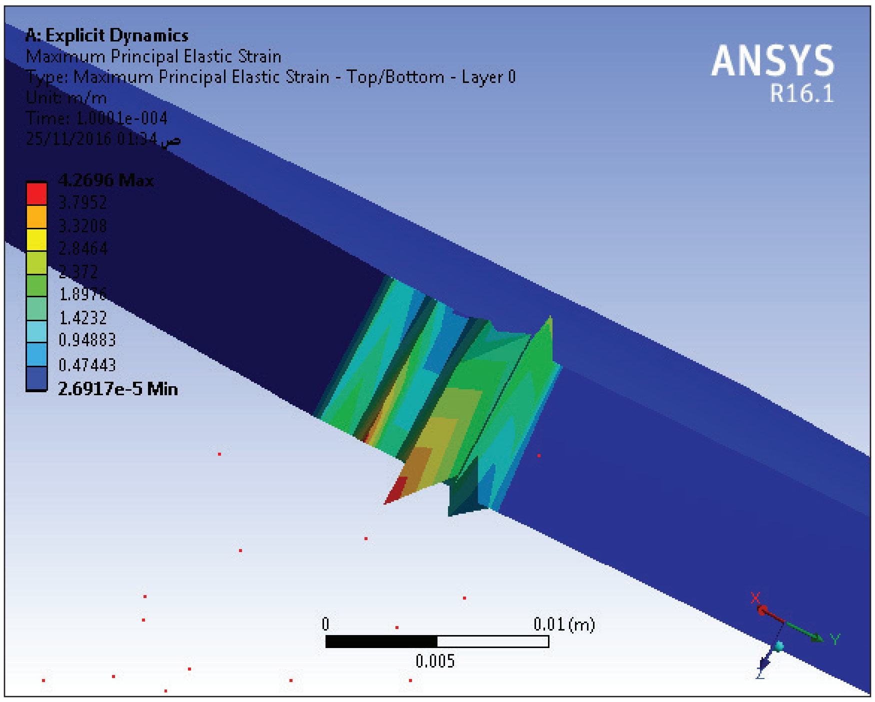

Fig. (21): The maximum principal strain

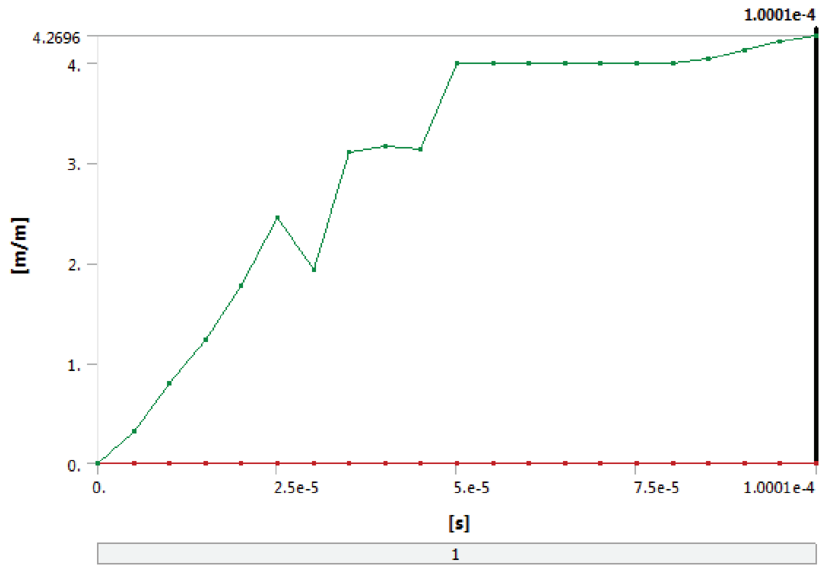

Fig. (22): The change in the maximum principal strain

8.6. The Internal Energy Result:

Fig. (23) shows the change in the internal energy with time for the hybrid plate. Both E-Glass/Epoxy and Carbon/Epoxy shows increasing in the internal energy with time until (0.0264) s. after that time the bullet start to exit the hybrid plate therefore both curves show fluctuation because of the stress waves acting on the plate until the time (0.0496) Ms. After that time the bullet is completely exit the plate therefore sharp decreasing in the internal energy happen.

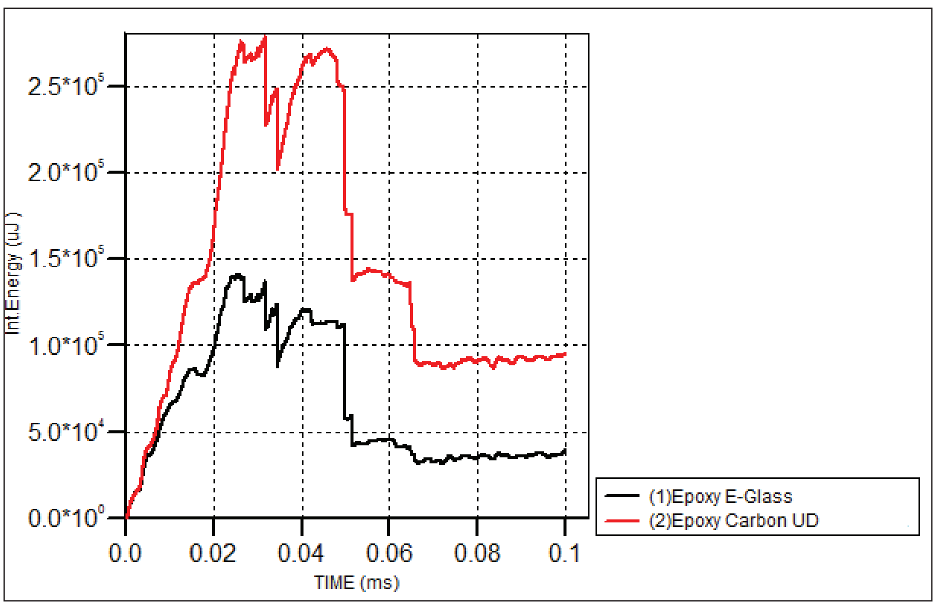

Fig. (23): The change in the internal energy with time

9. Conclusions:

1. The absorbed impact energy is increasing with the increase in the plate thickness.

2. In all cases for the bullet velocity which are above the ballistic limit the damaged area are decreasing with the increase of the bullet velocity.

3. In all cases for the bullet velocity which are below the ballistic limit the damaged area are increasing with the increase of the bullet velocity.

4. In all cases the damage was more towards the exit side of the laminates than the entry surface.

5. Adding E-Glass fibers to the carbon fibers increase the energy absorption and reduce the co

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