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Energy balance modelling of high velocity impact effect on composite plate structures

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ABSTRACT

Purpose: In many military applications, composite materials have been used because of their high velocity impact resistance that helps absorption and dispersion energy. It is therefore used in armour and vehicles, aircraft and spacecraft that are subjected to impact of various shapes and velocities.

Design/methodology/approach: In the theoretical part, the absorption energy equation for the sample was established by constructing an energy balance equation consisting of five types of energies, it is the compressive energy in the first region (the impact region), the tensile energy in the first region, the tensile energy in the second region, the energy of the shear plugging and the friction energy.

Findings: It was found in the experiments that the tensile stress value increased by increasing the volume fraction of fibres to the polyester, and the value of compressive stress decreased. Also manufactured different types of impact samples with dimensions (20*20 cm^2) and deferent thickness. The results were an increase in the amount of energy absorbed by increasing the ratio of the fibre to the polyester. It is found that the greatest effect in the equation of energy balance is the shear plugging energy, in which the value of the energy absorbed reached 38% of the total energy. And in the second degree friction energy, in which the value of the energy absorbed reached 27% of the total energy. while the other energies are relatively small but with important values, except for the tensile energy in the second region, the Kevlar-Polyester (40-60)%, so that the increase was more than four times the previous case.

Research limitations/implications: Three types of reinforcing fibres were used: Kevlar, Carbon and Glass fibres with a matrix material as polyester. Six samples are made for tensile and compression testing, Kevlar-Polyester (30-70)%, Carbon-Polyester (30-70)%, Glass-Polyester (30-70)%, Kevlar-Polyester (40-60)%, Carbon-Polyester (40-60)% and Glass-Polyester (40-60)%.

Practical implications: On the experimental part, experimental work tests were carried out to determine the mechanical properties of the samples such as tensile and compression tests as well as conducting the natural frequency test conducting the impact test by bullet to identify the effects and penetration incidence and compare this with the theoretical results.

Originality/value: In this research high velocity impact is used with a bullet it diameter 9 mm, mass of 8 g, and a semi-circular projectile head with a specific velocity ranging from 210-365 m/s. The effect of the impact is studied theoretically and experimentally.

The elastic deformation is increased for increasing the ratio of the fiber to the polyester and the depth of penetration is decreasing. The hybrid sample is affected in absorption energy and decreasing the penetration. Finally calculated for penetration behaviour theoretically and experimentally for different composite materials and comparison for the results calculated.

Keywords: Energy balance, High velocity impact, Composite materials, Penetration, Contact force, Contact time

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PROPERTIES

1. Introduction

Failure and penetration in the structure of the composite material during the high velocity impact is one of the most important effects that occur in the sample for any purpose intended to be used in various fields, and to arrive at facts and conclusions based on past experiences and translate these results into a goal that can be exploited by dealing with deformation and penetration. The sample is influenced by factors such as the shape of the projectile, its size, mass, velocity and material. In addition to the characteristics of the mechanical properties for sample, the sequence and orientation of the composite material and the material itself. The impact was tested at a high velocity for various types of projectiles head as flat, conical (half Angle 30) hemispherical, ogive nosed (CRH 2.5) [1-3].

At, 2003, V. Tan et. al., [1], the energy absorption mechanism was studied for Twarons CT 716 Standard woven fabric, The results showed that the energy value absorbed by the fabric varies according to the projectiles shape. Increased absorbed energy leads to reduced critical velocity. The ability to absorb the impact energy from the Twarons woven shows how to convert energy through the strain energy and mobility of the fabric. A mechanism for balancing energy was calculated through various mechanisms – yarn rupture, Fibrillation, failure of friction, bending. Also, at 2005, V. Tan et. al., [2], tested the laminate of Spectra which sequence (0o/90o) with polyethylene reinforced in a thermoplastic resin, Where the flat and hemispherical bullet were cutting and rupturing the fibres at the strong at edges while the conical ogive nosed projectile had less rupture but greater penetration. At 2008, N. K. Gupta et. al., [3], a plate of aluminium was tested, with ogive nosed and conical projectiles having the greatest penetration efficiency for the target and the was the biggest defalcation flat-ended and hemispherical projectiles. The experimental and numerical investigation of an aluminium plate was examined. Reduced velocity by increasing the number of layers and the deformation was measured as a comparison between the experimental and numerical is found good Convergence of results.

Current interest in the study of foam, [4,5], as well as the process of impregnation, [6], in 2017, C. Liu et. al., [4], studied high-velocity impact responses of newly designed sandwich panels with Aluminium Foams and metal fibre laminate (FML), consisting of aluminium sheets and E-E-Plain woven glass fibre sheets was tested and the velocity of the projectile was 210 m/s for impacted types flat head, hemispherical head, spherical and conical head. The results showed that increasing thickness of the foam improves the absorption of energy and compares the results analytically to predict the failure and the type of penetration. At, 2014, R. Nasirzadeh et. al., [5], the effect of foam density changes on the sandwich structure was studied under the effect of high velocity impact. The structure consists of two polyester fronts filled with a density of rigid polyurethane foam (37, 49, 70, 95, 105 and 240) kg/m^3. A gun was used with a velocity range of 100-150 m/s and 10.7 g semi-spherical head steel bullet was used for high velocity impact tests. The results showed that the foam density of 49 kg/m^3 had achieved the highest level of performance of absorption impact energy. But if the density is more than that, it will cause an increase in weight and wall thickness. Fabric impregnation process. It gives enhanced fibre texture and improved mechanical properties and contributes to maintaining volume and great absorption of energy as in 2014, Y. Park et. al., [6], study of the effect of high speed impact using a high performance rifle with a speed of 700 m/s and its application of samples of Kevlar and Shear Thickening Fluid (STF) Provides improved impact resistance without affecting flexibility by the fabric impregnation process. The Kevlar woven was placed in a solution polyethylene glycol (PEG) with methanol for the effective infusion of Kevlar woven. The impact tests were then carried out at high speed on the sample. A large amount of impact energy was spotted on the impregnated sample.

A comparison was made between Kevlar without impregnation and Kevlar (STF) where each 8 layers from Kevlar were equal to 5 layers from Kevlar (STF) where the thickness reduced the cost and gave the performance of energy absorption by 70%.

In 2011 A. Sabet et. al., [7], studied of high velocity impact on glass fibre reinforced polyester (GRP) The bullet was used to cone the head at an angle of 30° a total length of 30 mm and a mass of 9.75 g. Five types of glass fibre reinforcement are chopped strand mat (CSM), plain weave, satin weave, unidirectional and cross-ply unidirectional fibre reinforcements were used. The gun was used to conduct a test in the velocity range of 80-160 m/s. The sample plates are dimensions (15 x 15) cm with a thickness of 3 and 6 mm. For 3 mm GRP plates results with a one-way boost showed penetration and the remaining velocity was zero and the other was approximately the same level , either 6 mm results were better. The best results for plain weave, cross-ply unidirectional fibre (0°, 90°), satin weave, chopped strand mat (CSM) and Finally unidirectional respectively.

In 2013 A. Kolopp et. al., [8], and at 2018 G. Sun et. al., [9], they studied the effect of the honeycomb and explained Its benefits and Possibility to develop absorption and dispersion of the impact energy, in 2013, [8], studied the effect of the impact at high velocity for space applications was measured using a ball weighing 127 g at 120 m/s speed. The sample was made of aluminium with the aramid fabrics for its lights weight and good penetration resistance. Aluminium plates was placed in the front with a thickness of 3mm thick and the dry aramid (between 8 and 18 plies), and honeycomb of aluminium where the results that the honeycomb better absorb the energy of the impact than aluminium sandwiches with a global weight decrease.

At, 2004, M. Tuttle, [10], explained the effect of impact on a spherical projectile of the steel was studied at a speed of 70-170 m/s on a sample of honeycomb sandwich panels from aluminium alloys 2024 and 7039. The results showed that increasing the thickness of the face sheet and reducing the size of the honeycomb cell led to increased efficiency to absorb the energy and reduce the failure in the sample and the improved sandwich panel showed a 23.7% increase in special energy absorption compared with the targeted design. After this, at, 2008, S. Katz, [11], tested. A sample of Kevlar-epoxy and Spectra1000-epoxy high velocity impact was tested for space applications up to 3000 m/s where the result should be 100 mm thickness to reduce the risk of penetration. To use of high-speed camera is very important to know the behaviour of the sample during impact, and helps to see the stages of deformation and knowledge of weaknesses as well as the contact time to accurately. In addition, at 2018, A. Klok et. al., [12], using high-speed cameras to detect damage on a sample made from the S2-glass / SC15 epoxy compound. to 6 to 10 layers under impact conditions at a speed of 338-406 m/s. Failure patterns and penetration behaviour were observed. impact energy was absorbed before penetration when the thickness of the sample increased.

Also, at 2018, Y. Gao et. al., [13], studied the effect of the adhesive layer used to connect the ceramic with the background made of aluminium alloy, which is used in the design of shields and effect the impact at high speed on the target where he tested two types of targets the first is monolithic ceramic structure and second is laminated ceramic structure contents are TiB_2 and B_4C, with variants thickness of adhesive layer of epoxy (0.5-1 – 1.5-2) mm. Where the results showed that the volume of broken ceramics decreased by increasing the thickness of the adhesive layer and that the volume of broken ceramics decreased with laminated ceramic structure compared with monolithic ceramic structure. Many researchers have developed equations of energy balance, because they are important in the knowledge of theoretical analysis and the knowledge of failure and penetration, and the ability to absorb and dissipate energy. Where researchers interested in some terms and effects because of their important and effective impact in the general equation and neglected others because of their importance and small value.

Therefore, others have developed equations based on experimental basis to reach a degree of balance, dependable on the stresses and strains of the sample to be examined for the various tests, in 2014 Y. Park et. al., [6], an analytical model was used on a sample of glass-fibre laminates. A mechanism for calculating the energy balance equation was developed based on the deformation of the plate and the failure of the fibre, as well as the delamination and matrix cracking in the sample. He found that the value of the delamination and matrix cracking in the sample is too low to absorb the impact energy.

Then, at, 2006, A. Al-Hilli, [14], the impact of high-velocity impact on three types of samples was studied were glass fibre and carbon fibre and Kevlar fibre the equation of energy balance was developed. Four terms of energy absorption were developed. They were the strain energy, delamination energy , large deformation and friction losses. After this, in 2001 S. Abrate, [15], and 1985 K. Shivakumar, [16], the effect of impact on theoretical calculations was analysed and models were adopted and categorized into three points, Energy balance models, spring mass models and complete. These models can give a close idea of the problem but are limited and not complete. The equation of energy balance was based on four terms are bending, shearing, membrane stiffness's and contact energies. Also, in 2015, H. Shanazari et. al., [17], compare the armour made of Kevlar woven fabric and Kevlar unidirectional fabric where the Kevlar woven fabric was better than Kevlar unidirectional fabric in terms of absorbance of impact and dispersing the energy. It was adopted in the equation of energy balance on the shear plugging as a key force for its importance and Kevlar high tensile strength.

In 2012, N. Naik et. al., [18], his theoretical investigation of the equation of energy balance, he calculated the deformation that occurs in the target, the deformation and erosion that occurs in the projectile, as well as the shear plugging energy calculation of the armour. Also, in 2016, V. Silberschmidt, [19], the equation of the energy balance was based on several methods of absorption of energy refer to conical deformation energy, compression in Region 1and 2 energy, shear plugging energy, tension in the region 1 and 2 energy, delamination energy, matrix cracking energy , and friction energy. The effect of shear plugging was large based on the large based on tensile strength of the sample and the effect of energy absorption by the friction was large when increasing the thickness of the ballast either at the small thickness is almost the effect is simple. Finally, at 2002, X. Chen et. al., [20], study the effect of the impact and the occurrence of penetration at the target at different velocity and the relationship between the depth of the impact with the characteristics of the target and the development of tables showing the values of parameters that enter the relationship of some minerals and concrete taking into account the shape of the head of the projectile.

So, in the presenting years, the researchers increasing for the mechanical properties modifying of composite materials, by using different reinforcement natural and artificial fibres. Which are used in different applications as impact resistance, prothesis and others [21-24].

The review is based on several issues; the effect of the projectile tip type, the different materials used, whether they are composite materials, or metal or cement materials. For composite materials, different types of weaving are woven, or inclined at certain angles, honeycomb and Metal materials. Also, the literary review includes the calculation of the equilibrium of the energy balance and any of the partial energies that comprise the equation that has a significant effect of or not, and also the calculation of penetration depth under different velocity conditions.

Therefore, because that the theoretical solution is important in knowing the behaviour of the sample when exposed to the impact through the existence of a logical formula for the equation of energy balance because of a lot of variables and effects that contribute to the formation of a particular type of energy, then in this research the effect of high velocity impact is studied theoretically and experimentally. In the theoretical part, the absorption energy equation for the sample was established by constructing an energy balance equation consisting of five types of energies, it is the compressive energy in the first region (the impact region), the tensile energy in the first region, the tensile energy in the second region, the energy of the shear plugging and the friction energy. On experimental work tests were carried out to determine the mechanical properties of the samples such as tensile and compression tests as well as conducting the impact test by bullet to identify the effects and penetration incidence and compare this with the theoretical results.

2. Theoretical investigation

The analysis of the material properties of the plates is used in a composite material for woven fibre. Therefore, an theoretical solution is provided for the effect of the impact force at high velocity on the target of a composite material made of fibre woven in the matrix. Through the projectile, the impact energy is calculated, the energies of the plate are analysed and the penetration state of the impact is determined by the effect of the impact on the plate. The laminate layer consists of a number of layers of several materials arranged in a particular order and at certain angles to form a plate of compound material to give it the desired purpose to withstand impact and absorb energy. There, the analytical solution included drive and solution for general equation of motion analytically [25], and using the experimental mechanical properties determined of materials as an input data for analytical technique [26,27].

2.1. Energy balance models

They are a group of partial energies effective and effective on the absorption of shot energy at any moment, where the effect of the sum of the forces impeding and anti-shot movement multiplied by the displacement (depth of penetration) [28]. In the case of energy equilibrium, the kinetic energy of the shot is equivalent to the set of impedance energies of the sample to be the remaining energy is zero, then no penetration in the sample. When the set of impedance energies of the sample is less than the kinetic energy value of the shot in this case there is a value of the remaining energy and the penetration occurs,

$$E_{bullet} - E_{residual} = \sum E_{absorb} \quad (1)$$

where, E_{bullet} is the kinetic energy of the bullet $= \frac{1}{2}mv^2$. $E_{resudal}$ is the residual kinetic energy of the bullet. E_{absorb}

is the sum of the factors that lead to the absorption of kinetic energy of the bullet [28],

$$E_{absorb} = E_{cr1} + E_{sp} + E_f + E_{ty1} + E_{ty2} + E_{other} \quad (2)$$

where, Ecr_1 is the energy absorption by compression in regain 1, E_{sp} is the energy absorption by shear plugging in the target, E_f is the energy absorption by the friction between the bullet and the target. E_{ty1} is energy absorption by tensile yarns in regain 1. E_{ty2} is energy absorption by tensile yarns in regain 2. E_{other} are the sum of energies as compression in regain 2, delimitation, matrix crack and there are other effects. All these did not count for its small value [29,30].

The compression in regain-1 energy

The target is compressed along the thickness direction due to the effect of the bullet, the resulting the strain in thickness direction (z-direction), the total energy resulting from this effect is [31],

$$E_{cr1} = A_p\left[\int_0^{\epsilon_{cz}} \sigma_{cz}\, d\epsilon\right] h_c \quad (3)$$

where, A_p area of the cross section area for bullet, σ_{cz} the compression stress, ϵ_{cz} the compression strain, and h_c the compression distance in z direction.

The shear plugging energy

The point of contact between the bullet and the sample results from the thickness of the plate and shear plugging stress as absorbed by layers and calculated the shear plugging stress for the sample as well as the effect of shear area to resist it of the bullet, calculate the energy of [32]

$$E_{sp} = \pi d_p {h_p}^2 \tau_{sp} \quad (4)$$

The shear plugging stress calculating from the equation below,

$$\tau_{sp} = \frac{F_1}{\pi d_p h_o} \quad (5)$$

and F_1 calculating from sum initiation and compressive force as

$$F_1 = F_I + F_c \quad (6)$$

then,

$$F_I = \frac{1}{2}\rho K A_p v^2 \quad (7)$$

$$F_c = \sigma_c A_p \quad (8)$$

where, τ_{sp} is the shear plugging stress, d_p is diameter of the bullet, h_o failure layer thickness, ρ density of the projectile, K shape factor, v, velocity of the projectile.

Friction energy

When the bullet penetrates the target, the effect of the friction is increased by increasing the thickness of the target depending on several factors, including the nature of the target, friction coefficient and thickness, in addition to diameter, length and bullet metal. The value of friction energy calculation by following equation, [29]

$$E_f = \int_0^{h/\cos\left(\frac{\varphi}{2}\right)} F_f ds \quad (9)$$

The friction force calculating from below equation,

$$F_f = \mu F_N \quad (10)$$

where, F_N is normal force and μ friction coefficient.

Energy absorption by tensile yarns in regain-1

Resistance is formed in the primary yarns of the composite material of the target as a result of impact by projectile, resistance results from the effect of tensile strength of the yarns under the effect of the direct failure of the projectile, The factors that help the resistance are tensile stress which is borne by the target, the tensile strain, depth reached by the projectile and the failure of layers of as Figure 1 energy absorption by tensile yarns in regain (1) is, [19],

$$E_{Tpy1} = A \sum_{j=1}^{n_{f1}} \int_0^{x_1} \int_0^{\epsilon_t} \sigma_t\, d\epsilon_t dx \quad (11)$$

where, $A = 4d_p h_p$, σ_t is tensile stress, ϵ_t is tensile strain, x_1 the distance from the centre to the end of the contact between the bullet and the fibre yarn, and, nf is number of layers failed.

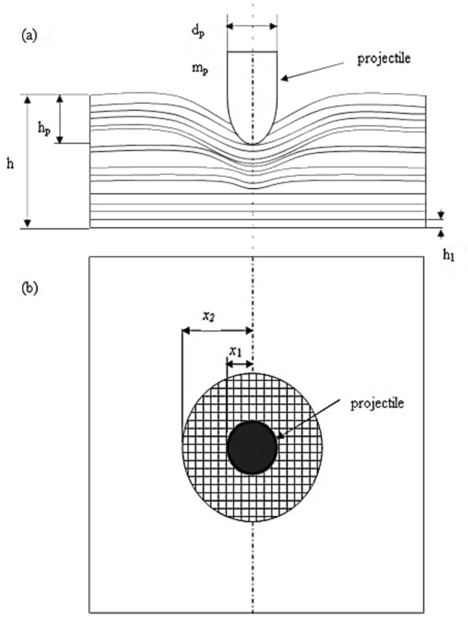


Fig. 1. Scheme representing the deformation during contact of the bullet with the sample

Energy absorption by tensile yarns in regain-2

There is a deformation caused by the penetration of the secondary yarns due to the link between the yarns The secondary yarns contribute to the force of tension, as Figure 1. The energy is calculated from the following relationship [19]

$$E_{Tpy2} = \sum_{j=1}^{n_{f2}} \int_{0.5d_p}^{x_2} \int_0^{\epsilon_t} \sigma_t \, h_p d\epsilon_t (2\pi r - 4d_p) dr \quad (12)$$

where, ϵ_t is tensile strain, σ_t is tensile stress, hp is depth of penetration, r is a variable in radial direction.

2.2. The projectile and the target

The investigation of the effect of the deferent parameters of the projectile mass of m and the velocity of v against a flexible for sample by a stiffness spring k. The kinetic energy for the bullet is [28]

$$K.E = \frac{1}{2} mv^2 \quad (13)$$

As it is clearly dependent on the mass and velocity of the bullet, this energy is absorbed by deflections of the sample, internal damage and local deformations in the contact zone. By expressing the effect of the local indentation, as part of the absorption of kinetic energy when the bullet touches the sample, Using Hertz's contact law to the penetration process

$$F_{max} = k_c . \alpha^{\frac{3}{2}} \quad (14)$$

where, k_c is the contact stiffness. α is the indentation depth. the contact stiffness is calculated from below relation,

$$k_c = \frac{4}{3} E^* R^{\frac{1}{2}} \quad (15)$$

where R is the equivalent radius, can be calculated, as,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \quad (16)$$

E^* is the effective modulus, can be calculated from,

$$\frac{1}{E^*} = \frac{1-v_1^2}{E_1} + \frac{1-v_2^2}{E_2} \quad (17)$$

where, subscripts 1 and 2 refer to the radius, elastic moduli and Poisson ratios of the bullet and the sample. And the contact force is,

$$q_o = \left(\frac{5}{4}\right)^{\frac{3}{5}} . (m)^{\frac{3}{5}} . (v)^{\frac{6}{5}} . (k_c)^{\frac{2}{5}} \quad (18)$$

where, m, v are mass and velocity of the bullet. k_c is contact stiffness.

3. Experimental work

The laminated composites are made up of several layers that are bonded together. The laminated use the best combination of layers, and this is appropriate for fibrous compounds that are in a woven form so that the two-sides geometry is uniform. One of the best materials used in this application are aramid fibre (Kevlar), Carbon and glass fibre, and the typical resin matrixes such as polyester in addition to other compounds. The main subject in the experimental investigations is the calculation of the response to the sample manufactured from the composite materials, so using the rifle type (A1) and the bullet in this research to find the penetration of different types of samples, and manufacture different samples based on the results of theoretical analysis, and then find the mechanical properties of the sample by conducting several tests to obtain the values of stresses and strains to be used for the purpose of calculating different types of energies, involved in the equation of energy, which helps in absorbing and dispersing energy. Therefore, the procedures for preparing samples and testing shown in Figure 2.

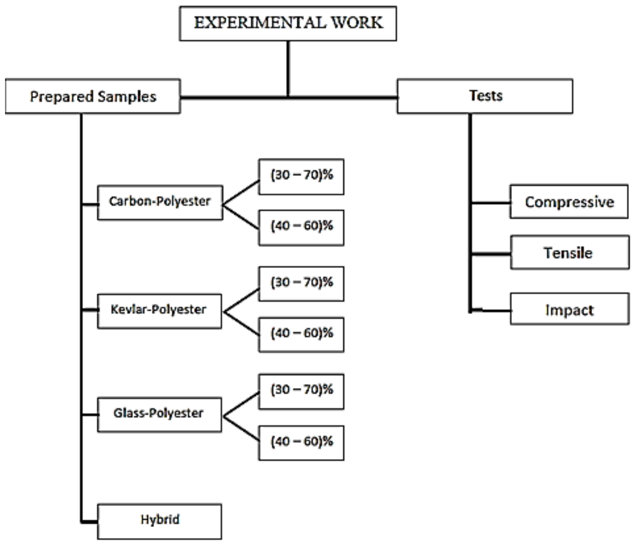


Fig. 2. Experimental samples preparing and testing

3.1. Specimen fabrication

The components of this research consist of fibre reinforced with Kevlar and carbon fibres in addition to polyester resins. The layers of the slides are a hybrid of a standard Kevlar and Carbon texture in an polyester adhesive layer manufactured by hand technique, [33-39]. The thickness of the Kevlar fibre is approximately (0.2) mm with the density is 1400 kg/m^3, the carbon fibre is (0.18) mm with the density1800 kg/m^3 and the glass fibre is (0.25) mm with the density 2400 kg/m^3.Cutting the carbon, Kevlar and glass fibres (Fig. 3), into slices (20*20) cm, then preparing the resin from the polyester by adding the catalyst and mixing it together after measuring by Electronic Digital Scale, by using a plate of steel as a base (lower layer) and put a film of hard nylon over it. Then moulding the resin onto the nylon and put the fibre layer on it layer after layer (Fig. 4), the resin is between the layers of the fibres, it's surrounded by a template to control the dimensions, [40-47], when you finish the desired number place a film of nylon, advantage the nylon film to avoid adhesion the sample to the mould, then put the top layer of steel to applied pressure on the sample and leave to dry. After drying the sample, do the extraction and removal of nylon films and do the surface finish. The weight of fibre is calculated before adding the resin and after adding the resin to the volume fraction for the fibre and resin.

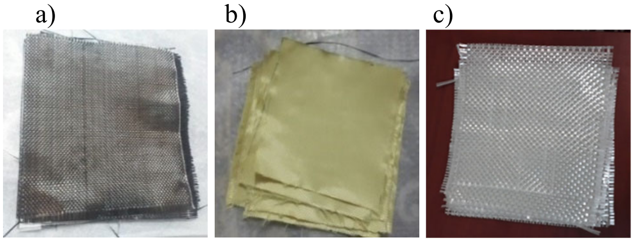


Fig. 3. a) carbon, b) Kevlar and c) Glass fibres.

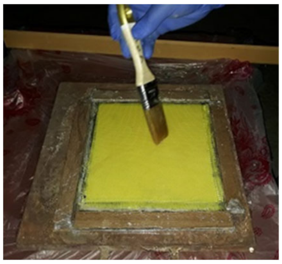


Fig. 4. Layers of Kevlar fibres with polyester resin

3.2. Test for composites materials

To know the mechanical properties of the composite material because it is included in the equations of the energy balance, so it was necessary to conduct several tests to know some values such as, ultimate stress, strain, modules of rigidity and modules of elasticity, etc. These tests are the mechanical properties for composites are measured by using tensile test, compressive test [48-55].

Tensile test

The tensile test devices used to know ultimate tensile strength, modules of elasticity, modulus of rigidity, deformation and strain. Which has a maximum load for this device is 100 KN, data appears on the calculator screen with a load-deformation curves, the strain values can be calculated by $\epsilon = \delta/L$ and ultimate tensile strength by $\sigma_{ult} = F/A$ and modulus of elasticity from a load-deformation curves [56-60]. The tensile test according to ASTM D3039, [61] is used to measure the force applied on the specimen of composite materials, [62-68]. The specimen are placed in the grips in tensile test device, has two grip the upper grip is fixed and lower grip is moving.

The lower grip is moving downward to pulling the specimen from two-way, a typical test speed is 2 mm/min until the failure occurs in the specimen. The specimen size a constant rectangular, 25 mm wide and 200 mm long The data shown on the computer screen is calculated the ultimate tensile strength, the modulus, Poisson's ratio and ultimate strain, Figure 5. In Figure 6, show the samples of the composite materials made of carbon, Kevlar and glass fibres with polyester before and after the test and the failure of the sample. The shape of the failure in the sample shall be in the form of cuts in the fibres in a transverse manner as shown in Figure 6b.

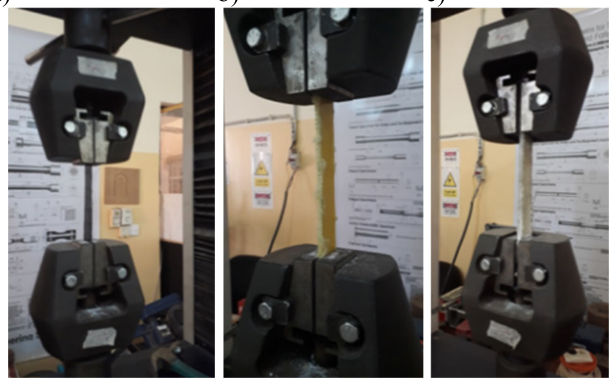


Fig. 5. Composite materials specimen tensile tested: a) carbon sample, b) Kevlar sample, c) glass sample

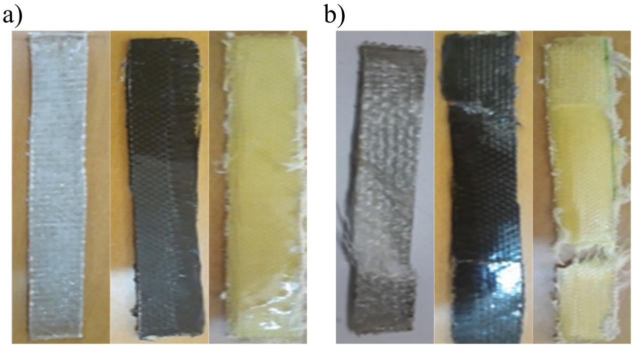


Fig. 6. Carbon, Kevlar and glass fibres composite materials specimen a) before test, b) after test

<u>Compressive test</u>

The compressive test devices used to know ultimate compressive strength, and other mechanical properties (Fig. 7). Which has a maximum load for this device is 100 KN, data appears on the calculator screen with a stress-strain curves, Same procedure in tensile testing. The compressive test according to ASTM D6641, [69] is used to measure the force applied on the specimen of composite materials. The specimen are placed in the grips in compressive test device, has two grip the upper grip is moving and lower grip is fixing. The upper grip is moving upward to compressive the specimen internally, a typical test speed is 2 mm/min until the failure occurs in the specimen.

a) b) c)

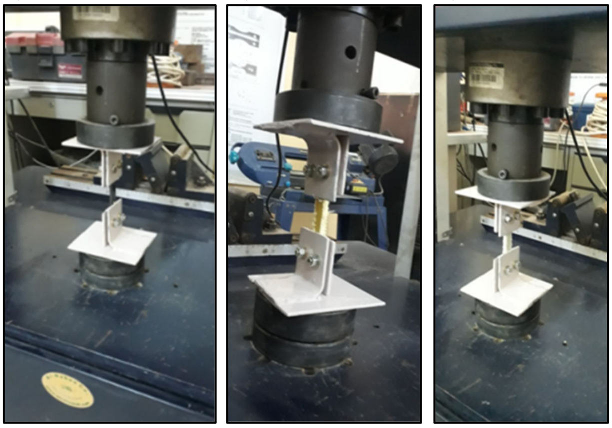
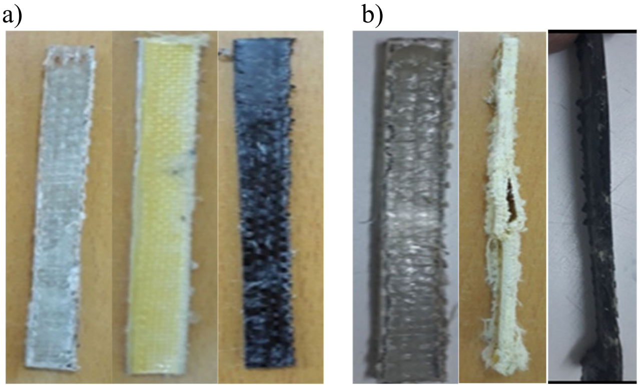


Fig. 7. Compressive tested for different composite materials specimens: a) carbon, b) Kevlar, c) glass

a) b)



Glass Kevlar Carbon Glass Kevlar Carbon

Fig. 8. Composite materials specimen for different fibres a) before test, b) after test

The specimen size a constant rectangular, 12.5 mm wide and 140 mm long, the data shown on the computer screen is calculated the ultimate compressive strength, compressive modulus, Poisson's ratio in compression and ultimate compressive strain. In Figure 8 show the samples of the composite materials made of carbon , Kevlar and glass fibres with polyester before and after the test and the failure of the sample. The shape of the failure in the samples shall be in the form of cuts in the fibres in a longitudinally, as shown in Figure 8.

3.3. The target holder

Hold the target so that the projectile is vertically fired of the gun type A1 horizontally and be vertically on the target, where the target is installed on a sample supported plate as in Figure 9, taking into account the boundary conditions of this research, the impact of the projectile in the sample directly.

a) b) c)

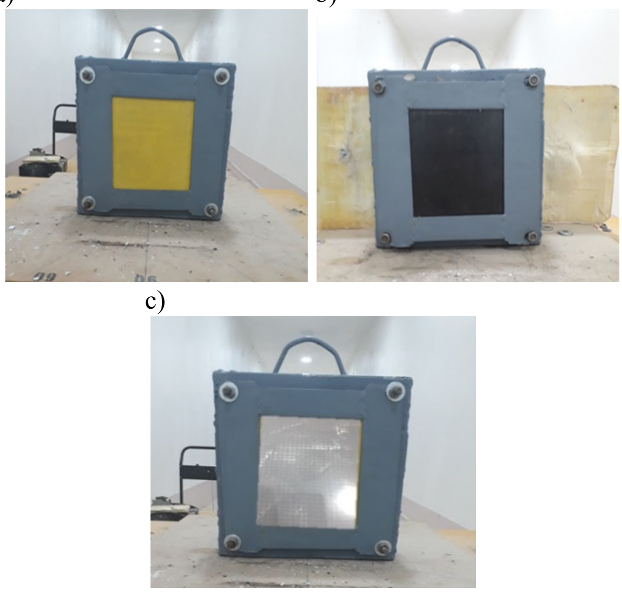


Fig. 9. Composite specimen installed in the holder: a) Kevlar, b) carbon, c) glass

3.4. Velocity measurements

The basic rule for measuring velocity is to measure the time spent by the projectile to cross a limited distance between the two sensitization circuits described in Figure 10. The bullet passes in the first circle, the time is determined and the bullet continues to reach the second circle, the time is also recorded. The velocity of the relationship is calculated by dividing the distance between the two sensors on the time difference between them $v = \text{distance}/\text{time}$.

Fig. 10. Velocity sensors

3.5. High velocity impact test

High velocity impact tests were carried out for the purpose of examining specific targets to determine the susceptibility of targets to absorbing and dispersing energy. The projectile type pistol bullet and various samples of the sample from composite materials from Kevlar, carbon and Glass fibres. The 20 cm * 20 cm plates was sample supported plate in the target holder in order to produce a plate, the cartridge and projectile were placed at their positions, to ready for firing. The velocity of projectile is measurement by velocity sensors' in front the target as in Figure 10. The bullet is fired from the type A1 gun as in the Figure 11. The bullet is passed to the speed sensor to calculate its speed immediately before impact. The gun is 2 meters away from the sensors. The distance between the sensors is 2 meters. The plate of composite materials is far from the last sensor about 1 meter. The total distance is 5 meters. The mass of the bullet about from 8 g and velocity of bullet about 200 m/s to 365 m/s. Samples are subjected to under multi shots and a different speed to see when the penetration occurs as in Figure 12, the information on the computer screen shows the speed and kinetic energy.

Fig. 11. The riffle type A1

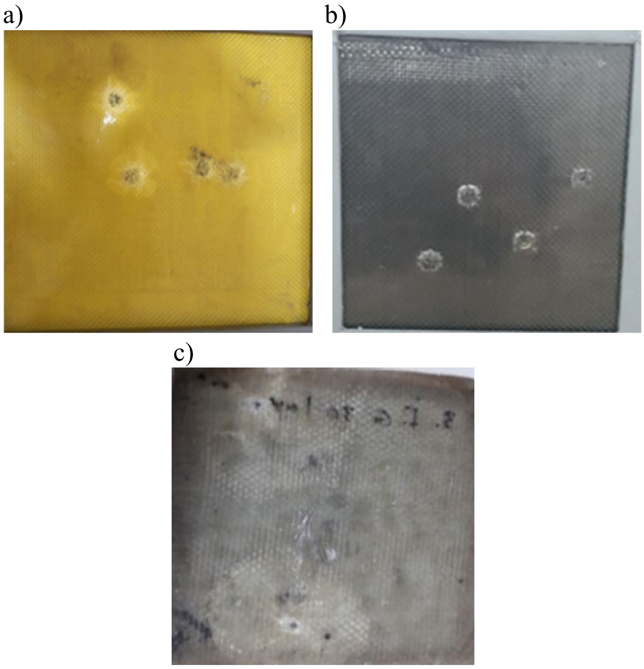


Fig. 12. The samples under multi shots: a) Kevlar, b) carbon, c) glass

4. Results and discussion

The results of the theoretical model and experimental work are listed and discussed in this paper. The materials used in the models were studied to show their possibilities and limitations. The kinetic energy of the projectile was studied absorption by the target and knowledge of the effectives for the dispersion and absorption of energy based on the mathematical laws. Calculate the numerical values of effective energies and know the important type of energy that helps to absorb energy, and know the effect of the properties of the sample (target) on energy absorption. The experimental results included the mechanical properties of the composite materials of the target and the depth of penetration and comparison with the theoretical model and knowledge of the optimal model to be used to absorb the projectile energy. The results of the impact test for various composite materials are displayed and a list of target thickness, projectile velocity, type of composite material and the effect of its mechanical properties are presented.

Note that the samples used are reinforcing of a matrix of polyester with fibre materials such as Kevlar and carbon fibres and glass with different volume friction of fibre. The impact test was carried out on samples of composite materials at a limited velocity about from 210 m/s to 365 m/s, the mass of the projectile head (8 g) and the type of the semi-circular projectile head. Mechanical properties were extracted such as, modulus of rigidity, modulus of elasticity, ultimate strength and strain, Poisson's ratio, to determine the ranges and limits that the sample can withstand the impact and applied the values of these properties on the equations as in the Tables 1 to 4. In addition to, the number of layer used to manufacture the laminated plate samples were presenting in Table 5, and, the dimensions for plate manufactured are, plate length l = 20 cm, plate width w = 20 cm, and plate thickness used shown in Table 5 for each samples used.

Table 1.
Tension Mechanical Properties for Composite Materials (30-70%)

Samples	E, GPa	σ, MPa	ε	G, GPa
K-P	9.44	286	0.0305	3.4
C-P	12.77	238	0.0231	4.61
G-P	8.8	249	0.0283	3.24

Table 2.
Tension Mechanical Properties for Composite Materials (40-60%)

Samples	E, GPa	σ, MPa	ε	G, GPa
K-P	9.75	341	0.035	3.48
C-P	13.2	243	0.0236	4.78
G-P	9.13	256	0.0285	3.4

Table 3.
Compressive Mechanical Properties for Different Composite Materials

Samples	Reinforcement Ratio			
	30-70%		40-60%	
	σ, MPa	ε	σ, MPa	ε
K-P	43	0.038	32	0.035
C-P	58	0.043	42	0.037
G-P	66	0.048	60	0.044

Table 4
Density and Poisson's Ratio for Composite.

Samples	Reinforcement Ratio			
	(30-70%)		(40-60%)	
	ρ, kg/m^3	υ	ρ, kg/m^3	υ
K-P	1200	0.4	1230	0.4
C-P	1320	0.385	1390	0.38
G-P	1500	0.355	1620	0.34

Table 5.
Number of Layers and Thickness for Composite Plate

Composite	Number of Layers	Plate Thickness, cm
K-P (30%-70%)	35	11
G-P (30%-70%)	30	11.2
C-P (30%-70%)	40	10.3
K-P (40%-60%)	28	10
G-P (40%-60%)	26	11.5
Hybrid	10-C(40%-60%)+ 20-G(30%-70%)+ 10-C(40%-60%)	11.5

4.1. Tensile test results

The results of the tensile test were obtained in experimental from the tests on tensile samples for various types of composite materials consisting of Kevlar, carbon and glass fibres with polyester material. Values of mechanical properties of composite materials were obtained and deduced from the stress-strain curve for each of these compounds. Two types of volume fraction were used for different samples. The behaviour of tensile specimens is observed in Tables 1 and 2, in the general framework having almost the same curve, but there are variations in the values of stresses and strains. Stress for a Kevlar-polyester samples, the stress value in the second sample increased significantly when the fibre to polyester ratio increased. Also Tables 1 and 2, has a strain for the carbon-polyester samples and the stress values increased, as well as in the glass fibre-polyester samples. In general, when the ratio of fibre to polyester increased, the value of stress and strain increased, giving greater value and flexibility and more tolerance for energy absorption and non-penetration. The stress value of the Kevlar sample was greater than glass fibre and finally carbon fibre, also the value of strain was the largest of Kevlar then glass fibre and finally carbon fibre.

4.2. Compressive test results

The compressive test results were obtained in experimental from the tests carried out on compressive samples. The procedure is similar to the past tensile test. The results were also obtained from the stress-strain curve from the compressive test. As in the tensile test, the same ratios were also used in the compressive samples. Here the process was reversed. In Tables 3 and 4, of the Kevlar-polyester sample, the compressive stress value and strain were reduced. Also for the samples of glass fibre-polyester and carbon fibre-polyester. It is noted that these samples have a relatively low compressive stress than the tensile samples, the compressive stress values decreased when the fibre to polyester ratio increased. The stress value of the glass fibre is higher than that of carbon-polyester and finally Kevlar-polyester, in the same manner as the strain.

4.3. Energy absorption results

In the theoretical part, the energy equation was reached Eq. (2), where the total energy of absorption is equal to the sum of each of the partial energies represented by Eqs. (3), (4), (9), (11) and (12), where in this research, the energies of significant values were relied upon in calculating the total energy and ignoring the other for its small value. The values of these important energies were calculated in above equations, where these values enabled us to obtain a total value of energy absorbed approximate as shown in the subsequent results. In Figure 13, impact test for K-P (30-70)% sample explain the values of calculating the effective energies of all the samples used, the energy absorption values increase by increasing the projectile velocity to reach the ballistic limit, where the ability of the sample to absorb energy becomes zero and penetration occurs. Figure 13.e, of the Kevlar sample at speed 365 m/s is the projectile energy is 533 J, while the energy that can be absorbed by the sample is 505 J and the remaining energy is 28 J that causes complete penetration.

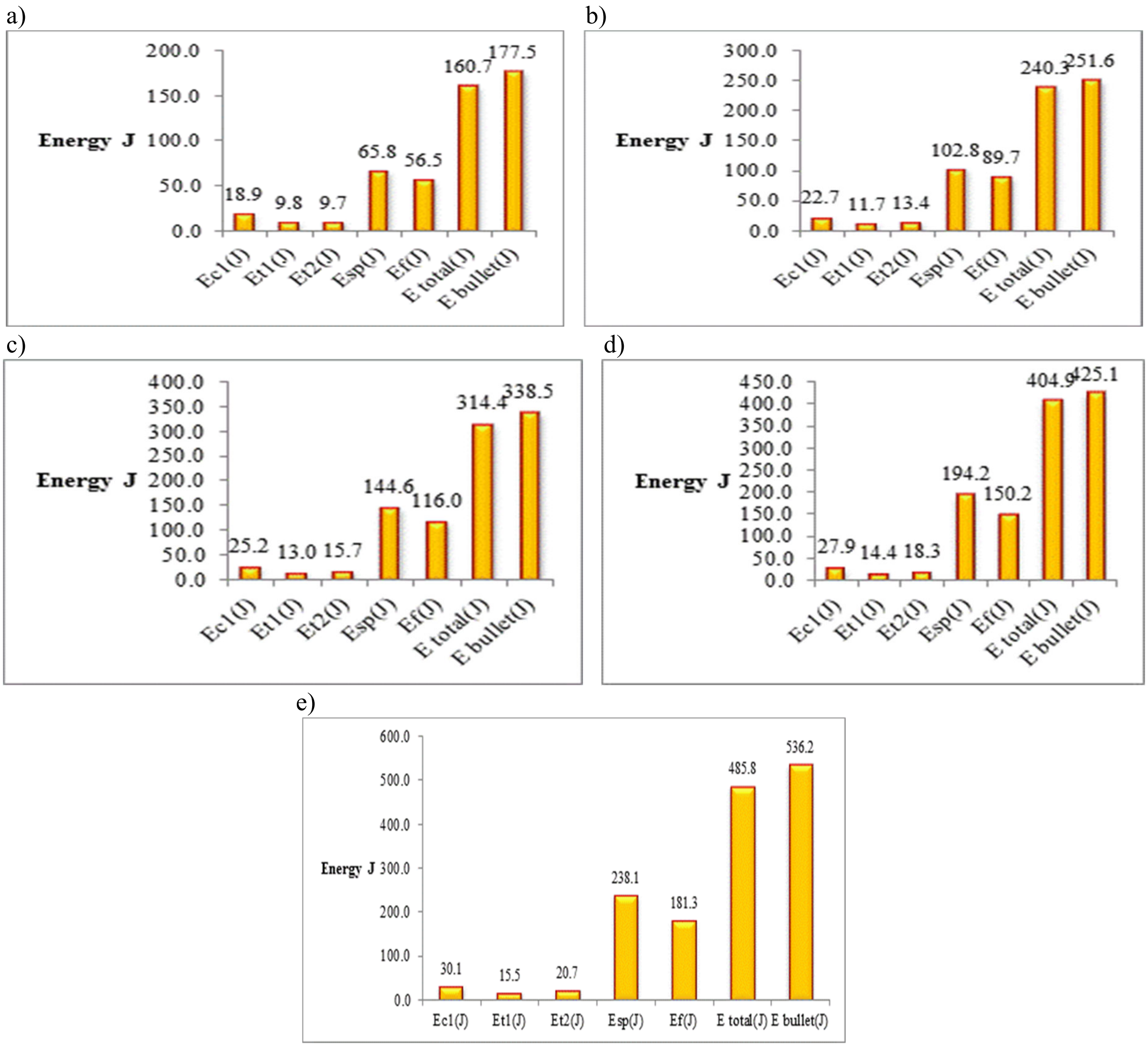


Fig. 13. Energy absorption for K-P (30)% at different impact velocity: a) 210 m/s, b) 250 m/s, c) 290 m/s, d) 325 m/s, e) 365 m/s

Also, Figure 14, of the C-P(30-70)% sample observed that at velocity 290 m/s, the projectile energy was 336 J penetration of the sample is occur but the launch stopped at the end of the sample, absorbability was 332 J, so this value was the greatest value for energy absorption, at speed 325 m/s occurred full penetration of the sample did not rise the amount energy absorbed as it reached the ballistic limit. In addition, for G-P composite with 30%, as shown in Figure 15, can be see that the energy of composite decrease due to decrease mechanical properties for glass fibre. Then, at Figures 16 and 17, can be see that the predication for composite plate, with fibre 40%, occurred with impact velocity greater than impact velocity for composite with reinforcement fibre 30%. At the same way in Figure 17b, of the glass sample, the sample reached the ballistic limit at speed 340 m/s where partial penetration occurred.

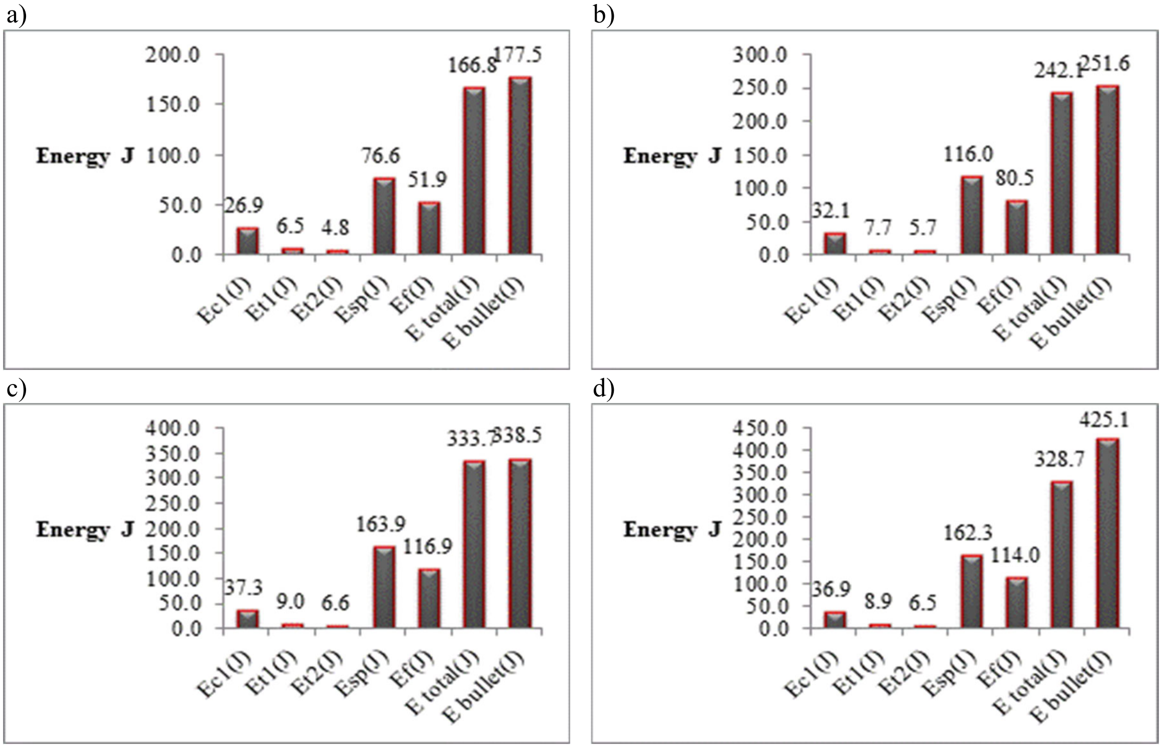


Fig. 14. Energy absorption for C-P (30)% at different impact velocity: a) 210 m/s, b) 250 m/s, c) 290 m/s, d) 325 m/s

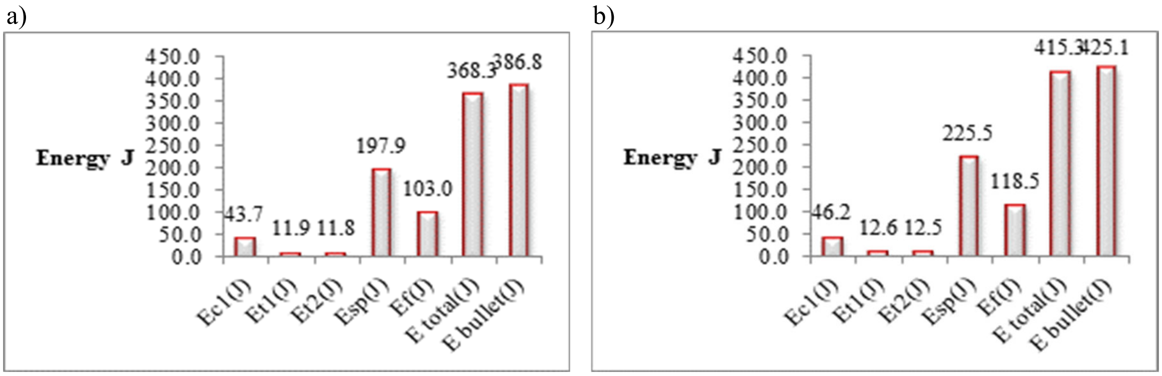


Fig. 15. Energy absorption for G-P (30)% at different impact velocity: a) 310 m/s, b) 325 m/s

It can be seen from the results in the following figures that the shear plugging and friction energy have great values in the absorption of energy for all samples, while increasing the value of the energy absorption by tensile yarns in regain 2 in the Kevlar sample, this is because of its characteristics, it is characterized by high tension and high flexibility contributes to energy absorption. So when the ratio of polyester to Kevlar increases, saturation of Kevlar fibres and the sample becomes more solid and lose this feature. When the polyester to Kevlar ratio decreasing, this property increased and helped absorb energy but had a higher elastic deformation value.

In Figure 18, the results of the impact on the hybrid samples, note that the hybridization was made of carbon and

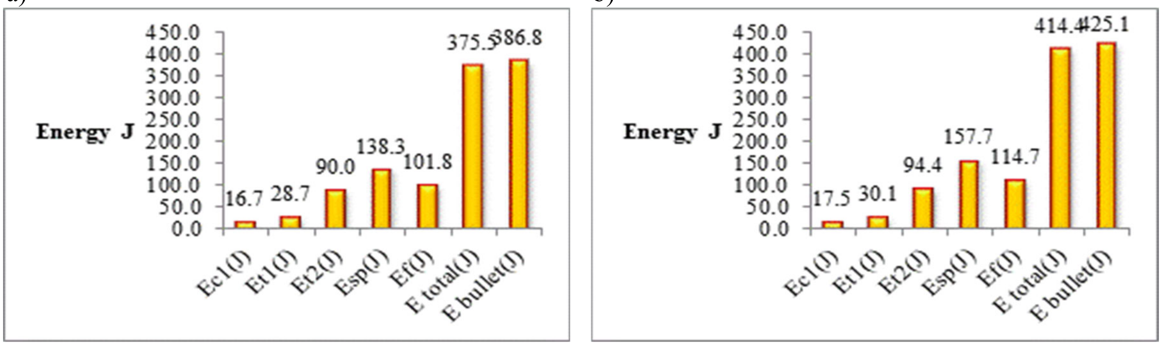


Fig. 16. Energy absorption for K-P (40)% at different impact velocity: a) 310 m/s, b) 325 m/s

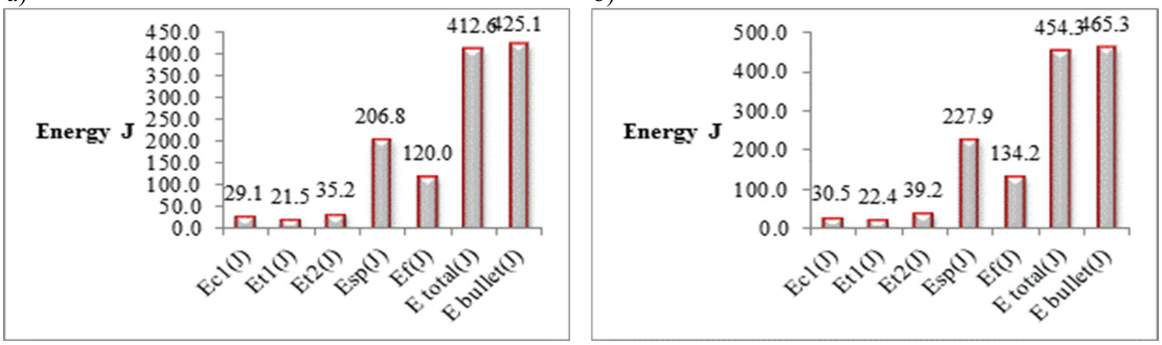


Fig. 17. Energy absorption for G-P (40)% at different impact velocity: a) 325 m/s, b) 340 m/s

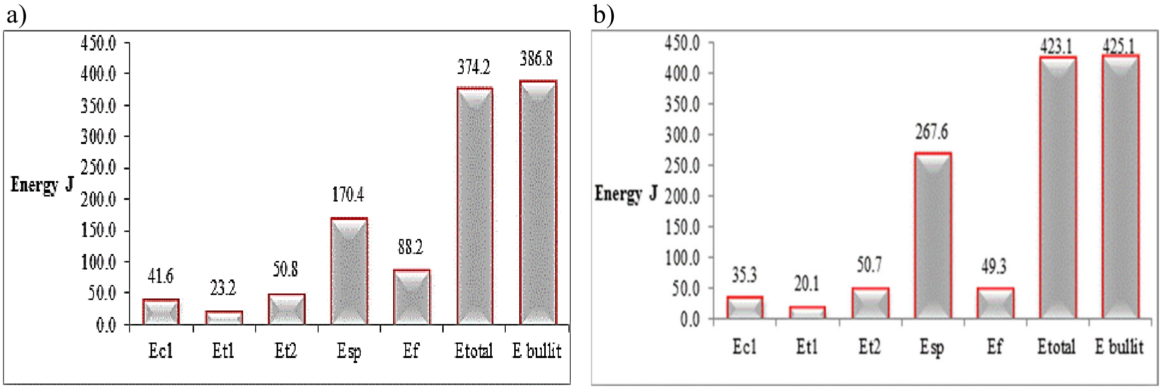


Fig. 18. Energy absorption for C-G-P at different impact velocity: a) 310 m/s, b) 325 m/s

glass fibre in the following order 10 layers of carbon with a thickness of 2 mm and then 20 layers of glass fibre with a thickness of 7.5 mm and finally 10 layers of carbon with a thickness of 2 mm, the total thickness should be 11.5 mm. The volume fraction of the carbon-polyester are (40-60)% and the glass-polyester was (30-70)%. In the case of velocity 310 m/s, the penetration reached a depth of 9 mm, meaning that the bullet penetrated the first plate of carbon of 2 mm and then penetrated the second plate of glass to a depth of 7 mm. Therefore, the calculation of the absorption energy is different from the non-hybrid samples as shown in Figure 18a. At 325 m/s, the penetration value was 9.65 mm, meaning that the penetration occurred in the first carbon plate and the second plate of glass 7.5 mm, and the third of carbon plate is 0.65 mm, absorption energy was also calculated as in Figure 18b.

4.4. Penetration results

To study the state of penetration, several factors must be considered to understand the mechanism of penetration. The fabric type is woven with the of failure similar behavior. The reason for choosing a woven fabric has a homogeneous tolerance for failure at the plane. The tensile stress has the largest effect in the dispersion of the kinetic energy of the projectile. The shape of the projectile has a significant impact on penetration. In the case of a more penetration, a cone-shaped head with a small surface deformation is chosen. In the event of less penetration, the choice of a projectile with a flat surface with a surface deformation is greater than the sample.

In Figures 19-24, shows the impact of the bullet on the samples, in Figure 19a, the impact of multi bullets at a different velocity was shown on a sample of K-P (30)%, the penetration did not occur for all types of velocity except at the velocity 365 m/s where the penetration occurred as shown in Figure 19b. In comparison with the results of the energy balance equation shown in Figure 13. In Figure 20a, the impact test was done for a sample of C-P (30)%, where a partial penetration occurred at velocity 290 m/s and a complete penetration at velocity 325 m/s as shown in Figure 20b. It also corresponds to the results of the energy balance equation shown in Figure 14. Thus the impact results of the samples shown in the figures are shown in the same manner as before.

a) b)

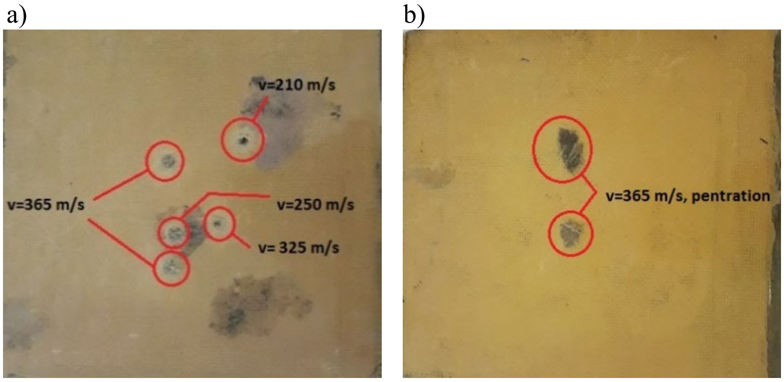


Fig. 19. Kevlar (30-70)% sample under multi shot: a) front view, b) back view

a) b)

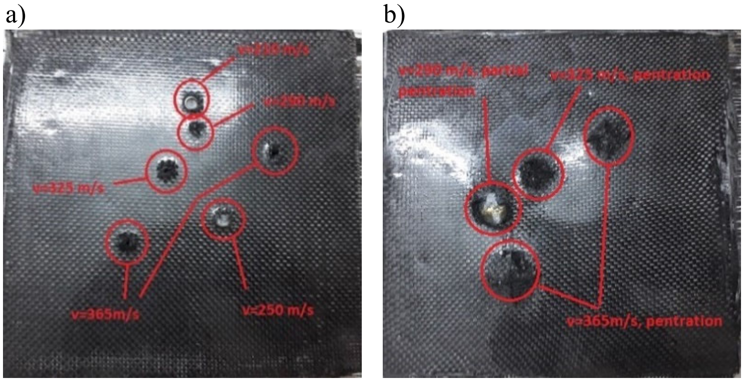


Fig. 20. Carbon (30-70)% sample under multi shot: a) front view, b) back view

Table 6 shows the depth of penetration in the different samples. There is a variation in the depth of penetration between the results of the practical tests and theoretical values. In the theoretical results, the penetration represents the depth of failure, whereas in the experimental test results, the depth of failure with the expansion of the fibre is woven with the movement of the bullet. This is clear in the Kevlar sample, where the penetration value reaches about (8.2 mm), while in the experimental test there is a limited number of layers where failure has occurred and the rest has expanded with the launch to prevent penetration. This characterizes composite materials from metallic materials, especially metallic metals in the different quality of failure. There, a good agreement was calculated with a comparison of the experimental with theoretical work.

Fig. 21. Glass fibre sample (30-70)% under multi shot: a) front view, b) back view

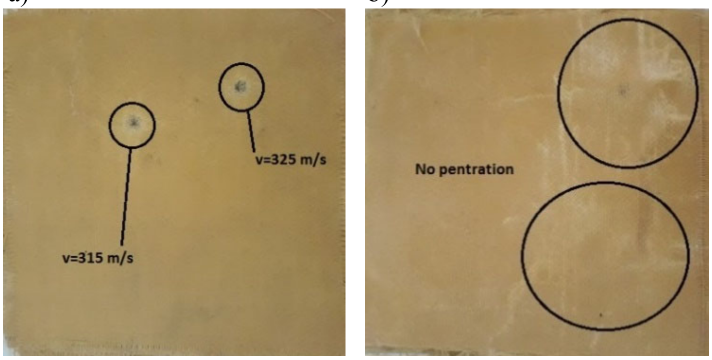


Fig. 22. Kevlar sample (40-60)% under multi shot: a) front view, b) back view

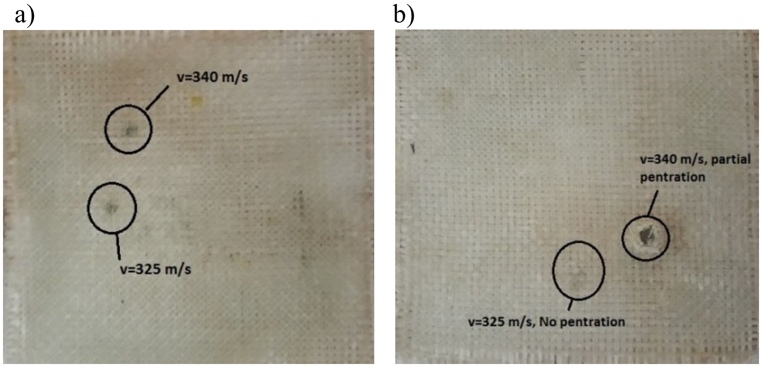


Fig. 23. Glass fibre (40-60)% sample multi shot: a) front view, b) back view

a) b)

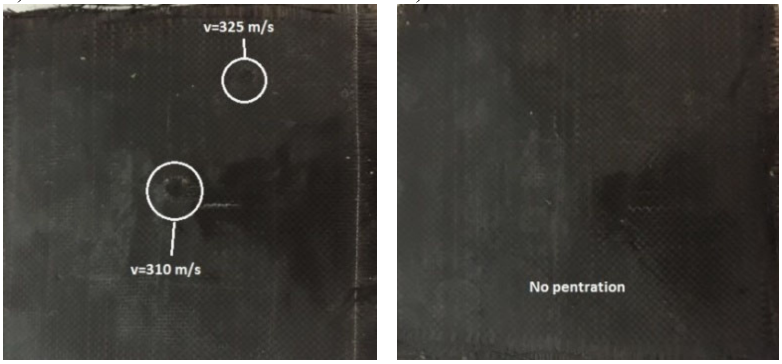


Fig. 24. Hybrid (C-G-P) sample multi shot: a) front view, b) back view

Table 6.
Theoretical and experimental penetration depth for samples at various velocity

Samples	Thickness, mm	Velocity, m/s	h_p Eq.2, mm	h_p Exp., mm
K-P (30-70)%	11	210	7.3	6.7
		250	8.5	8
		290	9.6	8.8
		325	10.5	10
		365	11.8	p
C-P (30-70)%	10.3	210	7.6	7
		250	8.9	8.5
		290	10.2	p.p
		325	11.8	p
G-P (30-70)%	11.2	310	10.7	10
		325	11	10.5
K-P (40-60)%	10	310	8.4	8
		325	8.7	8.2
G-P (40-60)%	11.5	325	11.1	10.7
		340	11.9	p.p
Hybrid	11.5	310	9.5	9.2
		325	9.7	9.8

Note: p – refers to penetration, p.p – refers to partial penetration

5. Conclusions

From theoretical investigation and experimental results, can be conclude the following points:

1. Experimental tests were carried out on the samples to determine the mechanical properties of the tensile and compression tests. The results showed the K-P has a higher tensile stress value than G-P and then C-P. Also higher strain for the K-P than the G-P and finally C-P.
2. The G-P has a higher compressive stress value than C-P and then K-P, as well as higher strain for G-P than C-P and finally K-P.
3. When the fibre to polyester volume fraction increased, the tensile stress value increases and the compression stress value decreases.
4. Kevlar has higher kinetic energy absorption than glass fibre and finally carbon fibre. Also, the absorption energy of the target increases as the thickness increases, the number of layers and increased the volume fraction of fibre on the polyester.
5. The maximum absorption energy value is the shear plugging energy and friction energy of all samples. And, the Energy absorbed due to tensile deformation of yarns by secondary region increased at K-P (40-60)% to increase the flexibility of the fibres.
6. In general, as the tensile stress value of the target increases, the absorbability increases and the penetration depth decrease.

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