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Research Article

Impact Study on Composite Targets by a Nylon Projectile

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Abstract

In the present paper, impact study of nylon projectile on composite targets using a water-jet disruptor was addressed with damage mechanism. The three different composite targets such as teak, ply and pine woods were used in the experiment. The strength of wood and the damage under impact load is very crucial. The failure under load is very intricate as it is made up of natural composite. The composite target damage mechanism depends on characterisation and impact velocity of projectile. Simultaneously stresses and strains are generated which makes it responsible to cause the damage. Disruptor using water-jet plays a very crucial role in neutralising Improvised Explosive Devices (IEDs) with the minimum risk. These devices are designed to generate a high velocity water-jet using an electrically initiated gas generator cartridge. This helps in separating the critical components of IED's and avoiding them from operating as anticipated. The damage caused by a water-jet disruptor is not quantified in assessing the performance. However, at present no technique was available to evaluate the performance. The terminal ballistics tests at the target end are found appropriate for solid projectiles, such as penetration of bullet into target plates or impact of fragments. These terminal effects are the good indicators considering the destruction. The available alternative measurement techniques are cost effective that forms a basis for future common test protocols. The authors suggested that craters made by a nylon projectile using the disruptor provide a quantitative measure. This should be considered as a potential for upcoming standard test for evaluating the performance. The impact caused by a nylon projectile is dependent on projectile kinetic energy and the dissemination of stress wave in the surrounding zone.

The energy dissipated by a nylon projectile gets absorbed by the targets through a certain mechanisms. Ballistic velocities for various targets are also worked out. Pinewood has less ballistic velocity limit as compared to other two targets. Study and methods for the disruptor performance on various composite targets (plywood, teak wood and pinewood with 15 mm thickness) at 0.5 and 1m stand-off distances are evaluated. This compares with the respective common target tests. From the experiments, it is concluded that a nylon projectile has potential to penetrate through composite targets.

Introduction

This article was focused on the damage mechanism by a nylon projectile on the composite targets using a water-jet disruptor. The damage mechanism of various composites i.e. wood were investigated and studied. The properties of composites and penetration capabilities study helps in understanding the characterising, failure modes, and damage mechanism for assessing the energy dissipation for the projectile and target. Target thicknesses of 15mm were considered to evaluate the damage performance. Penetration experiments were conducted on different types of flat wooden targets using a nylon projectile. Projectiles when impacted on composite targets, new surfaces created and energy was dissipated in the surrounding zone. The damage assessment mechanism consists such as generation of dimple, cracks, splits, fracture of fibers and delamination [1]. On impact with certain velocity on target, it results into the deep penetration to achieve the perforation with residual velocity. The projectile kinetic energy was absorbed by the targets after hitting. Usually the composite targets are made up of monolithic and have high hardness. Based on this design concept a weapon was designed, tested and evaluated under an extreme of environments. The damage mechanism of target is helpful in designing a weapon for destroying target. Savio and Madhu (2018) studied the impact of steel projectile on ceramic tiles and its ballistic evaluation using depth of penetration test. (Sanborn *et al*, 2019) investigated ballistic performance of cross laminated timber so as to generate database and empirical models [2,3]. These models help to predict the responses by empirical or classical. Mild steel characterisation with varying strain rate, stress triaxiality and temperature effect was reported by (Iqbal *et al,* 2015) [4].

The increased terrorism activity has translated the war scenarios involving threats to the personnel and properties. Study of disruption or destruction of suspected improvised explosive devices (IEDs) using water-jet is very crucial task. Disruption using this water-jet saves the human life and avoids the loss to the properties. The disruption mechanism helps as and when required in separating the critical components such as electrical circuit and preventing them from operating as planned. Various technologies and equipment's were available over the world for destroying such suspected objects remotely with the minimum risk. Varieties of the disruptors are available with different calibres and internal bore profiles, some have a choked or tapered section near the barrel, and others are parallel. The disruption process using explosively driven water-jet is most popular in the country. Consequently, a range of Explosive Ordnance Disposal (EOD) tools were developed to allow EOD operators to neutralise such IEDs rapidly. The most admired of these are the water-jet disruptor, which projects a high speed water-jet into the IEDs. Single base propellant or double base propellants were used to create the unidirectional water plume on the hazardous objects. The gas generator cartridge was responsible for generating a high velocity water-jet. The barrel is filled with water and is accelerated with nylon projectile driven by the gas pressure generated due to propellant combustion. Analytical model was presented considering damage mechanism and energy dissipation of projectile on the composite target after impact.

A water-jet disruptor is utilized safely to disrupt suspected objects. A 3D view of a water-jet disruptor is illustrated in (Figure 1). It consists of a breech plug, cap closure (top), breech module, spring, closure cap, barrel, sleeve, projectile, compensator, cap closure (bottom) and capture gate. The barrel and compensator are filled with water. The power cartridge is loaded inside the breech module. The aim of this present research article was to study the damage evaluation using a nylon projectile by conducting the various experiments on different targets at different stand-off distances. The composite materials such as woods of different varieties were used as this weapon is very effective against the soft material. The impact study of the projectile on composite materials is interesting in defence applications. This is due to high hardness and low density. The experimental studies presented were established. The innovation of the present research work was to study the damage evaluation on the composite materials.

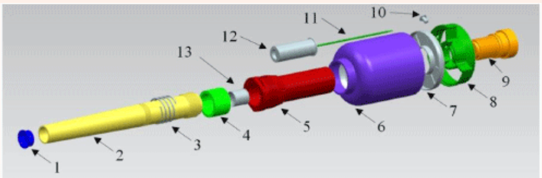


Figure 1: Model of Water-Jet Disruptor illustrating Various Parts. Cap closure, 2. Barrel, 3. Spring, 4. Sleeve, 5. Breech plug 6. Compensator 7. Closure cap (top) 8. Capture gate 9. Breech module 10. Screw 11. Leg wires 12. Power cartridge 13. Nylon Projectile.

The manuscript presents the perforation and penetration capabilities of three different types of composite targets focussing on damage shape and state of residual stresses.

Prior state of art

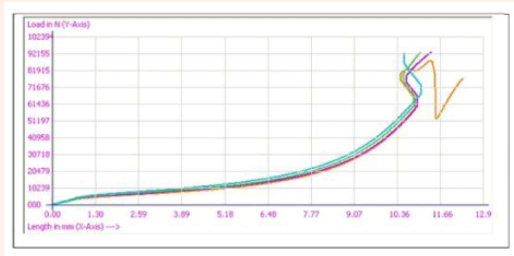
The penetration resistance studies about the behaviour of composite material such as Kevlar or HDPE materials with variation in thicknesses were investigated by Ömer and Bazle (2012) [5]. From the experiments, it shows that these materials exhibit no damage initially. This is because of behaviour of viscoelastic plastic composite material. This revealed a more dislocation of total energy dissipation on impact. Further, it dissipates an additional energy for the thinner sections and vice versa. A model for an analysis on impact was studied for the behaviour of ceramic-composite armours [6]. This was based on the propagation stress wave theory. The energy engrossed by the various mechanisms and the projectile kinetic energy was explained by the authors. The primary damage was attributed due to absorption of energy on the target in the near adjoining region by compression below the projectile. Projectile deformation and wear were considered. The various factors such as deceleration of the projectile, kinetic energy, velocity, contact force and distance travelled by the projectile were obtained and discussed as a function of time.

In general, the resistance offered by the projectile on impact with composite targets was studied. The study was depends on energy balance and stress wave propagation in the target [7]. Impact study by cylindrical shaped projectile for monolithic composite and spaced multi-layered targets was reported to assess the performance. This was depends on the energy balance and stress wave propagation within the structure on projectile impact. On impact of the projectile, the energy was dissipated and absorbed by the target through numerous absorbing mechanisms [8]. Naik and Doshi (2008), Naik and Shrirao (2004, 2006) and (Naik *et al.* 2005) discussed an analytical models to predict the ballistic impact behaviour of the composite structure [9-12]. Koene and Broekhuis (2017) reported the normal projectile impact of bullets on flat wooden targets having different chemical and physical properties [13]. The author concluded that, as the impact velocity increases the depth of penetration also increases. Sikarwar and Velmurugan (2014) have done experiments for the impact loading of conical bullet on composite material (Glass / Epoxy) [14]. Damage assessment of composite material such as carbon fiber reinforced in accelerated environment and (Dionysios et al. 2014) reported validation of model [15]. (Bandaru *et al.*, 2016) investigated the impact studies of three different composite armor material using Kevlar and polypropylene materials [16].

Various standards for armament weapons are available with the performance in terms of accuracy, precision, fragmentation, penetration and lethality, which are measurable and quantifiable. In the present scenario, especially for the disruption process by a water-jet disruptor such types of standards needs to be evaluated in terms of damage. In order to evaluate the damage mechanism of a water-jet disruptor at different stand-off distances on different targets. The authors were motivated and proposed to measure the crater size created by nylon projectile as a part of damage mechanism. In this paper, the damage mechanism failure in terms of performance assessment on different targets such as plywood, teak wood and pinewood were carried out using a water-jet. The damage mechanism of composite target using a projectile was the main aim of this research article. Composite targets are made up of teak wood, plywood and pinewood. These are subjected to a compressive loading as the projectile impact on them. Schematic configuration of a compressive testing of samples for plywood and pinewood are presented in (Figures 2a & 2b) using Universal Testing Machine (UTM). The teak wood is also subjected similar compressive testing. The corresponding compressive stress graphs for ply wood and pine wood are depicted in (Figures 3a & 3b) respectively. This graph shows the load versus displacement.

The compressive testing was carried out by placing a nylon projectile on the specimen. The specimen grains are orthogonal to the direction of the projectile. This situation is exactly same in the actual field firing trials. Four samples of pinewood and

Figure 2: Compressive testing of, 2(a): Ply wood, 2(b): Pine wood.



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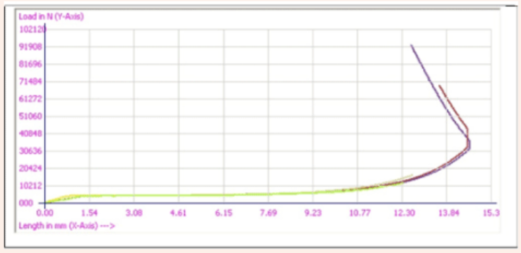

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Figure 3: Figure 3(a): Compressive testing of Pine Wood. Figure 3(b): Compressive Testing of Plywood.

Table 1: Physical and Mechanical Properties of Composite Targets.

Material	Thickness (mm)	Compressive Strength (MPa)	Poisson's Ratio	Density (kg/ m³)	Young Modulus (GPa)
Teak wood	15	19.523	0.4	540	12.99
Ply wood	15	15.63	0.25	520	10.684
Pine wood	15	6.08	0.35	340	7.7

two each samples of plywood and teak wood were subjected to compressive loading. The standard elastic and strength properties of the composite target and a nylon projectile are given in (Tables 1&2) respectively.

Development of Analytical Formulation of Model

To develop an analytical model, the projectile is considered rigid. During the penetration, friction between projectile and wooden target was neglected. The failure damage along the target thickness was assumed uniform. In this section, the energy absorbing and damage mechanisms were presented. The energy engrossed by the composite targets and a nylon projectile were described. The analysis was presented for composite material comprising of teak wood, pinewood and plywood. This was based on following presumption

i. Impact of nylon projectile was orthogonal on composite target at the time of impact.

ii. A nylon projectile is in cylindrical shape having small curvature at front.

iii. A nylon projectile has homogeneous or uniform material.

iv. The thickness of composite target is considerably less than that of the projectile diameter. Therefore, edge effects were neglected.

v. The motion of projectile is uniform and the velocity assumed constant through trajectory as the stand-off distance between the target and muzzle is restricted to one meter.

vi. In the penetration process, the size and shape of projectile does not change.

vii. The damage to the target takes place on impact as the fibres are oriented in perpendicular direction. Outer piles get damage along the fibres. Let us consider C_d as damaged elasticity matrix. The analytical model for damage mechanism in 2-D stress elements can be expressed as

$$C_d = \begin{bmatrix} c_{11} & c_{12} & 0 \\ c_{12} & c_{22} & 0 \\ 0 & 0 & c_{33} \end{bmatrix} \quad (1)$$

d_f, d_f and d_s are damage variables and E_L, E_T & G_{LT} are the elastic modulus of composite material for the matrix C_d

$$c_{11} = \frac{(1-d_f)E_L}{D} \quad (2)$$

$$c_{12} = \frac{(1-d_f)(1-d_m)\,\upsilon_{LT}\,E_T}{D} \quad (3)$$

$$c_{22} = \frac{(1-d_m)E_T}{D} \quad (4)$$

$$c_{33} = (1-d_s)G_{LT} \quad (5)$$

Here υ_{lT} is Poisson's ratio

$$D = 1-(1-d_f)\upsilon_{LT}{}^2\,E_T\,/\,E_L \quad (6)$$

Constitutive equation of damaged elasticity matrix is given as

$$\sigma = C_d.\varepsilon \quad (7)$$

σ & ε are the stress and strain

$\sigma = [\sigma_L \quad \sigma_T \quad \tau_{lT}\,]^T$ Is 2-D stress vector pertaining to 2-D strain vector

$$\varepsilon = [\varepsilon_L \quad \varepsilon_T \quad \gamma_{LT}]^T$$

The damage variable d_f is estimated with fibre rupture and kinking with the direction of impact loading –compression or tension

$$d_f = \begin{cases} d_{ft}\,,\sigma_L \geq 0 & \text{- Fibre rupture} \\ d_{fc}\,,\sigma_L < 0 & \text{- Fibre kinking} \end{cases} \quad (8)$$

The damage variable d_m is estimated as

$$d_m = \begin{cases} d_{mt}\,,\sigma_T \geq 0 & \text{- matrixrupture} \\ d_{mc}\,,\sigma_T < 0 & \text{- matrix crushing} \end{cases} \quad (9)$$

and

$$d_s = 1-(1-d_{ft})\,(1-d_{fc})\,(1-d_{mt})\,(1-d_{mc}) \quad (10)$$

Acco $$F_{ft} = \left[\frac{\sigma_L}{X_T}\right]^2 \quad (11)$$

$$F_{fc} = \left[\frac{\sigma_L}{X_C}\right]^2 \quad (12)$$

$$F_{mt} = \left[\frac{\sigma_T}{Y_T}\right]^2 + \left[\frac{\sigma_{LT}}{S_{LT}}\right]^2 \quad (13)$$

$$F_{mc} = \left[\frac{\sigma_T}{2S_{RT}}\right]^2 + \left[\left(\frac{Y_C}{2S_{RT}}\right)^2 - 1\right]\frac{\sigma_T}{Y_C} + \left[\frac{\tau_{LT}}{S_{LT}}\right]^2 \quad (14)$$

Here X_T is tension strength in longitudinal direction, X_C tension strength in L direction, Y_T tensile strength in tangential direction, Y_C compressive strength in T direction, S_{lT} in plane shear strength, S_{lT} in transverse shear strength. The equivalent displacement for the fibre breakage modes is determined by using equation.

$$\delta^{eq}{}_{ft} = \delta^{eq}{}_{fc} = L_c\,\sqrt{\varepsilon_L{}^2} \quad (15)$$

And matrix damage mode are given by

$$\delta^{eq}{}_{ft} = \delta^{eq}{}_{fc} = L_c\,\sqrt{\varepsilon_T{}^2 + \gamma^2{}_{LT}} \quad (16)$$

Determination of force experienced by the target

The total force experienced by the target is sum of compressive force and inertia force.

Using Newton's second law of motion, Inertia force can be expressed as

Inertia force (F_I) = mass of projectile (m) × deceleration (d) of projectile

$$\text{Or} \quad d = \frac{F_I}{m} \qquad (17)$$

Using the linear equation of motion, displacement (s) is expressed as

$$s = u \times t - \frac{1}{2}\, d \times t^2 \qquad (18)$$

Here t is the time interval and u is projectile velocity on impact

Table 2: Physical and Mechanical Properties of Nylon Projectile.

Material	Size (mm) Diameter and length	Shape	Compressive strength at 1 % nominal strain (MPa)	Poisson's Ratio	Density (kg/m³)	Young Modulus (GPa)
Nylon	ø18.5, L 20	Cylindrical	28	0.4	750	1.8

Table 3: Chemical Composition and Physical Properties of the Double Base Propellant.

Chemical Composition		Physical Properties	
NC	89%	Propellant shape	Spherical grains
NG	8.5%	Density	1.55g/cc
DBP	2%	Calorific Value	880cal/g
DPA	0.95%	Average Diameter	0.483mm
		Average Web	0.40mm

Materials and Methods

Material - Propellant composition

The method for water-jet velocity measurement using high-speed camera comprises of disruptor and gas generation by burning the given mass of double base propellant inside the cartridge. The chemical composition in percentage and various physical properties of double base propellant are elucidate at (Table 3).The images of double base propellant utilised in the assembly of cartridges required for disruptor firing and a nylon projectile are shown in (Figures 4a & 4b) respectively.

Projectile

The projectile is defined as a cylindrical shape and has a length (L) and diameter (Ø) [L 20mm, Ø18.5 mm]. The projectile material is Nylon 66. A nylon projectile used in compression and disruptor trials. The engineering drawing of projectile is shown in (Figure 5). The length-to-diameter ratio is 1.018 and the average mass of the projectile is 8g. During the firing, the projectiles were moving inside 20mm diameter smooth barrel at the striking velocities ranging from 330 to 365m/s on the composite target.

Target

The wooden targets are made of teak, pine, ply has size of height (460mm), width (300mm), and thickness (15mm) utilised in all the firing trials to assess the damage performance and its mechanism during projectile impact.

Figure 4: 4(a): Double base propellant 4(b): Nylon projectile

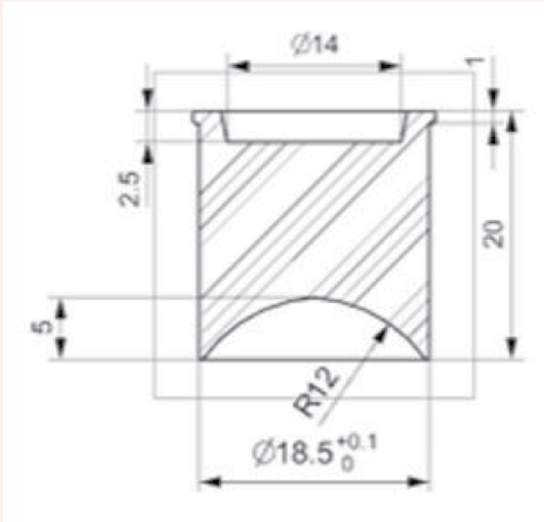

Figure 5: Engineering drawing of nylon projectile.

Figure 6: Photograph of trial set up before Firing of Water-Jet Disruptor.

Methodology and Experimental Testing

Experiment - Test Set Up

The impact test were performed on composite targets by projectile in the Pashan Range. The trials were carried at ambient temperature. Each projectile was impacted with velocities between 333.52m/s to 384.23m/s. The projectile velocities are measured by high-speed camera. The projectile was impacted on the target with 15 mm thickness. The arrangement for experimental set-up includes a water-jet disruptor, power cartridge and the wooden targets. The target was placed at stand-off distance of 0.5 and 1m from the muzzle end of the barrel. Experimental trials were carried out for, plywood, teak and pinewood each having average thickness of 15mm.Wooden targets were impacted by a nylon projectile. Three following set-ups of wooden targets were used

- Set-up 1: Teak wood plate, 15mm (thickness).
- Set-up 2: Ply wood plate, 15mm (thickness).

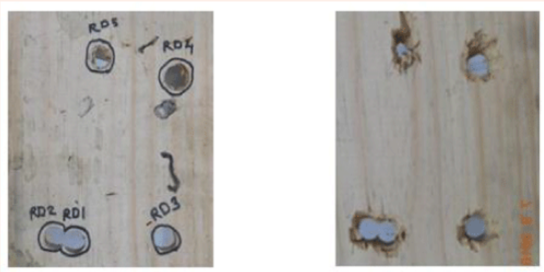

Figure 7: 7(a): Damage on Ply wood-Front side. 7(b): Damage on Ply wood-Back side.

- Set-up 3: Pine wood plate, 15mm (thickness).

The trial set up photograph before firing and during motion of projectile is depicted in (Figure 6). The images of damage caused by the projectile on plywood after firing of a water-jet disruptor are shown in (Figures 7). Similar damages were noticed on teak and pine wood targets.The impacted rear and front faces of the composite target images were illustrated at (Figure 7). It was observed from the (Figures 7) that damage at the rear faces are more than front faces. The damage incurred on the composites targets appears to be more local around the penetrating site.This gives the indication that damage was very significant and effective for all these composite targets. Personnel handling IEDs with significant relevant experience are able to make reasonable judgments of disrupter performance.

Disruption damage evaluation

Interaction of a water-jet disruptor with the IED during disruption is a complex phenomenon. This is due to formation of water droplets. It mixed with the air and impact on the target, which is multi-phase interface. A water-jet damage phenomenon has two desirable outcomes. The first one is the irreversible severing of the initiation train (battery, switch etc.) from the main explosive train thereby preventing the device from functioning. The second is a noticeable separation of intended IED components. It helps the EOD technician to ensure that the device has been rendered safe prior to a final manual approach.

Evaluating the damage performance of a water-jet disruptor i.e. how well they achieve these two desired outcomes, are crucial. The best existing methods essentially rely on post - shot assessments of the damages on the targets, which is meant to represent an IED. This damage assessment may be subjective. The test outcome is susceptible to bias. The necessity in the consistency of the target was required to build standards. It is resource rigorous, time consuming to conduct such trials. The numbers of tests to be performed are expensive. Many disruptors produce jets with significant velocity gradients. As the higher velocity fluid from the rear flows into the lower velocity, front jet produces a mushroom shaped plume whose diameter can be an order of magnitude larger than the barrel calibre. This increases the radial pressures exerted within hazardous objects. These characteristics are the good indicator for a disruptor as damage scope. Therefore, the approach adopted during this study was to measure the physical parameters of disruptor in terms of damage. These results were compared from common target tests with a damage mechanism. Consideration was focused on the measurement of crater size made by a water-jet disruptor for assessing the damage.The various experimental trials were carried out to investigate the damage criterion of a nylon projectile on the composite materials made up of wooden materials. This is in the longer term could be evolved into standard test methods for assessing the damage performance.

Common damage assessment in armament studies

Many armaments weapon such as small arms or field gun in which the performances were measurable as penetration of bullet in the target or designated damage at the target. The damages were measurable and quantifiable. The damage evaluations of disruptor using projectile were conducted for different wooden targets. All these tests were subjective to evaluate the damage performance. It is very simple in principle that the disruptor was fired at the common target, usually a wooden box or brief case which is filled with loose material such as sand or soil or mud, and a judgement is made that all these gets destroyed.

Damage evaluation on composite target

The different composite targets such as teak wood, plywood and pinewood were used during conduct of various experimental trials. The major energy absorption by a nylon projectile was provided by the composite materials. This is due to the fact that composite target material is soft in comparison with a nylon projectile. The composite target material absorbs this energy. Eventually, a nylon projectile makes the crater on it. The key damage and mechanisms for absorbing the energy are:

(1) Composite target material front

- There is compression at the target wherein the projectile hits (zone 1).
- There is compression near the surrounding zone (zone 2).
- Tensile failure creates circular cracks in the radial directions.
- Plugging of the target takes place due to shearing action.
- Bulge development at the back side of the composite target.
- Friction between a nylon projectile and the composite target.

(2) A nylon projectile

- Wearing and
- Deformation.

With certain velocities, the wearing of a nylon projectile tip may occurred to some extent as front face is blunt. After the impact, the velocity of a nylon projectile decrease, the wearing action on the surface will stop. The projectile deformation may occur. The deformation and wearing action of nylon projectile would absorb certain energy in the penetration process. This will results in velocity reduction and the kinetic energy of a nylon projectile after the impact. (Figures 8(a-f)) depicts the various stages of normal impact cum penetration of nylon projectile on the composite targets. In the process of projectile impact through the composite materials, shear stress waves were generated. With this, the composite target initially would offer some resistance to impact. The mechanisms for absorbing the energy in the target were attributed due to compression and shear action for plugging. This is shown in (Figure 8a), where in the portion of material just under the projectile is known as zone 1. A nearby material offers the confrontation to impact is known as zone 2. On impact of the projectile on the composite target, shear stresses followed by tensile stress were developed. These stresses pass through in all directions.

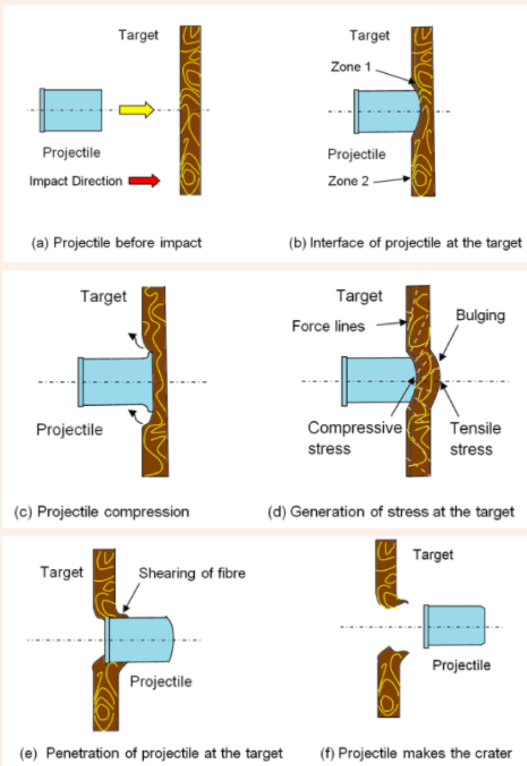

Figure 8: Scheme of Different Stages of Normal Impact cum Nylon Projectile penetration on the composite target.

The residual section of the composite target could not influenced by the projectile impact. Over a period of time, the stress waves would disseminate move ahead and bigger component of the target offer the resistance to penetration. The composite material on impact of projectile is under compression. The nearby material is under compression in the direction of thickness. When the compressive or shear or tensile stress is more than the allowable limit, the composite target failure takes place. The projectile impacts the composite target, micro- cracks were formed in the target.

In the course of penetration process, the micro-cracks transforms into macro-cracks. During this process, supplementary micro cracks were created. As the penetration advances, the resistance to the composite target increases. In the other way, through perforation or penetration or shearing may takes place at the target. This local damage comprises such as fibre breakage, matrix failure, delamination and fibre matrix de-bonding. This finally causes the breakdown of the composite target. At a later impact stage, a nylon projectile velocity is decreases. In this process, the composite target absorbs the frictional energy. As this damage and energy was absorbed by the projectile, it leads to decrease in a nylon projectile energy. (Figure 8a) shows the original position of the projectile when it is approaching to the composite target. The impact is normal to the target and grains are also normal during impact. The nylon projectile interface with target is illustrated in (Figure 8b). A paths traced by the various stresses were shown in the figure. The compression by a nylon projectile is illustrated in (Figure 8c). The compressive stress wave reaches to the ear side of composite target, and bulging occurred to the target. This bulging causes the formation of cracks and creates the crater at the back face of the composite target. The force lines were shown in dotted colour and shown in (Figure 8d). This generates cracking action of fibre which is shown in (Figure 8e). This is due to shearing of fibre planes. Finally, the projectile passes through the target as shown in (Figure 8f).

Results and discussions

Actual firings of disruptor against the various targets were carried out at stand-off distance of 0.5 m and 1m from the muzzle end of the barrel. After the conduct of each trial, the measurements of crater dimensions were noted. The test results of the disruptor are shown in (Table 4). Disruptor trials for number of samples against the each target were carried out. The damage assessment and clear perforation or penetration was valuable information considering a water-jet disruptor performance during the impact.

Damage assessment on impact

Typical post impact damages patterns of specimens made by a nylon projectile were shown in (Figures 9). The crater sizes created on each targets after every firing were measured. In each firing, the projectile penetrates and generates the crater on the composite target after the impact. The tearing action of the composite, circumferential fracture and fibre breakage were observed. Similar trends were observed on the targets. In all targets cases, the craters as well as clear penetration were experienced [17]. The normal impact behaviour of a nylon projectile on composite materials was studied. A water-jet performance is strongly depends on the velocity of the projectile. The damage due to compression perpendicular to grain was similar to ductile failure with plastic deformation.The compressive stresses are determined on various targets using UTM as depicted in (Figures 2&3). The stress values are illustrated in (Table 5).The experimental

Table 4: The Test Results of the Disruptor Firing.

Sample No.	Target Types (Stand-Off distance 0. 5 and 1m)			Observations after the firing
	Damage Criterion - Crater Dimensions (mm)			
	Ply wood (15 mm thick)	Teak wood (15 mm thick)	Pine wood (15 mm thick)	
1	19X20	15X20	16X20	In all the trials craters were made clearly by a projectile.
2	20X20	16X22	15X19	
3	19X21	17X21	16X21	
4	20X22	16X23	15X21	
5	20X21	15X19	16X22	

Figure 9: 9(a):Teak wood (15mm), 9(b): Pine wood (15mm), (c):Ply wood (15mm).

records were analysed and studied. Further, it revealed that the penetration resistance by the wooden targets depends on the target strength and stresses of the material. The projectile penetration depths, material of construction and the shape are related to physical properties of the wooden targets.

From the above table, it is seen that pinewood has less compressive strength as compared to other composite materials i.e. ply and teak woods. Anderson has reported that the critical velocity of impact for flat projectile is generally related to projectile diameter.

Parameters related to projectile and target

The maximum pressure and velocities of the projectile were measured by a suitably designed velocity test rig and high-speed camera.

Kinetic energy (KE) of nylon projectile is determined as Here V_i, V_r and V_{bl} are initial impact, residual and ballistic limit velocity, a & p are model constants.a and

$$Kinetic \quad energy = \frac{1}{2} v^2 \times m \tag{19}$$

$$\text{Force} = \text{Pressure} \times \text{Area} \tag{20}$$

$$\text{Where area } = \frac{\pi}{4} d^2$$

d is the diameter of the projectile (18.5 mm)

Area of the projectile worked out as 2.688 × 10-4

$$\text{The work done by the projectile } = \int_0^x F \times dx = \text{ Force} \times \text{displacement} \tag{21}$$

The work done by the projectile during penetration is dissipated in the materials using this damage mechanism. The same amount of projectile kinetic energy will be imparted to the various targets. The force experienced by the projectile and the target will be same considering small stand-off distances and neglecting the losses. Using equations (1), (2) and (3) kinetic energy, forces and work done by the projectile at stand-off distance of 0.5m were determined as explained above. The pressure acting on projectile is measured by data acquisition system. An example data were used to calculate the various parameters. The residual projectile velocity varies from 201.75m/s and 232.12m/s, respectively. The experimental results are given at (Table 6). The various parameters from Sl. No. 1 to 3 for pine wood, 4 to 7 on teak wood and 8 to 10 for ply wood respectively.From the above table, it was observed that maximum pressure, velocity, kinetic energy, force and work done by the projectile are 50.12MPa, 384.23m/s, 590.53J, 13.472kN and 6.736kJ respectively. Pressure measurement and and velocity measured by data acquisition system as discussed by Parate *et al.*[17].(Figure 10). Depicts variation of impact velocity *vs.* time for Teak, Pinewood and Plywood.

Residual velocity

To determine the residual velocities for various targets, the following model is proposed

$$V_r = a\,(V_i^p - V_{bl}{}^p)^{\frac{1}{p}} \tag{22}$$

p are empirical constant and determined using data fitting as 0.6 and 1.9 respectively. Using these values and taking maximum velocities and corresponding residual velocities, theoretical velocities by above equation gives 218, 211.87 and 209.26 for teak, pine and ply wood as against 232.12, 212.83 and 227.58 respectively.

Ballistic limit velocity

With the above projectile impact velocities clear perforations through craters were noticed in all cases. This indicates that the most of energy is absorbed by the target. After passing through the target the projectile is decelerating. The main aim of the projectile on composite target was to evaluate the damage. In all the trials, a nylon projectile exhibits the clear perforation of composite target at different stand-off distances of 0.5 and 1 m from the muzzle end. It is the work done to shear a target-using projectile and generate crater of similar shape and size. It is defined as the minimum velocity to penetrate the target. (Figure 13) exhibits the wooden target and shear stresses (τ) due to projectile action.

Using the law of conservation of energy, the work done by impacting the projectile is equated to shear resistance offered by the target.

Work done due to shearing = Shear stress × Area

$$= \int_0^h \tau \times \pi \times d \times (h - x)\, dx \qquad (23)$$

Here h is the thickness of target, τ is the shear stress,and d is the diameter of projectile.

Solving the equation (23) gives

$$= \frac{\tau \times \pi \times d \times h^2}{2}$$

As per conservation of energy, equating this with kinetic energy

$$\frac{1}{2} v^2 \times m = \frac{\tau \times \pi \times d \times h^2}{2}$$

This gives minimum ballistic velocity for the projectile

$$v = \sqrt{\frac{\tau \times \pi \times d \times h^2}{2 \times m}} \qquad (24)$$

The ballistic impact response limit velocities for various targets are calculated using equation (24) and given at (Table 7). From the table, it is seen that teak wood has maximum ballistic limit velocity than the other wooden targets. This is due more density and compressive strength as compared other two materials. The impact projectile velocities are more than ballistic limit velocities, clear craters were observed in all cases. The ballistic limit velocity for teak and plywood is 36.64% and 31.47% in comparison with the pinewood.

Conclusion

In this study, damage caused due projectile impact on the composite materials was investigated. The experiments were carried out on composite targets such as woods of different types. The penetration of a nylon projectile into the composite targets was to understand the damage on IEDs when impacted by a blunt projectile moving with high speed.In this researcharticle, the damage evolution of a nylon projectile on the composite

Table 5: Compressive Stresses.

Sl. No.	Material	Load (N)	Dia (d) & thickness(t) (mm)	Stress (MPa)
1	Pine wood	5021	d=18.5, t=15	5.76
		5579	d=18.5, t=15	6.4
2	Ply wood	13010	d=18.5, t=15	14.93
		14230	d=18.5, t=15	16.33
3	Teak wood	17024	d=18.5, t=15	19.527

d- Diameter of the nylon projectile
t- Thickness of target

Table 6: Kinetic energy, Force and Work done by the Projectile.

Sl. No.	Pressure (MPa)	Projectile mass (g)	Velocity Before Impact (m/s)	Kinetic Energy Before Impact (J)	Force (kN)	Work done (kJ)	Residual Velocity After Impact (m/s)
1	42.781	8	361.91	523.91	11.499	5.749	212.83
2	40.84	8	343.21	471.17	10.977	5.488	207.15
3	39.26	8	333.52	444.94	10.553	5.276	201.75
4	41.21	8	353.87	500.89	11.077	5.538	210.45
5	50.12	8	384.23	590.53	13.472	6.736	232.12
6	43.78	8	362.8	526.49	11.768	5.884	215.9
7	42.76	8	360	518.4	11.493	5.746	212.78
8	46.12	8	366.6	537.58	12.397	6.198	221.06
9	44.91	8	364.82	532.37	12.071	6.035	218.87
10	47.01	8	367.12	539.1	12.636	6.318	227.58

Table 7: Ballistic Limits for Various Targets.

Target material	Shear strength (MPa)	Projectile mass (g)	Ballistic limit velocity (m/s)
Teak	14.7	8	109.58
Ply	8	8	101.31
Pine	5.9	8	69.42

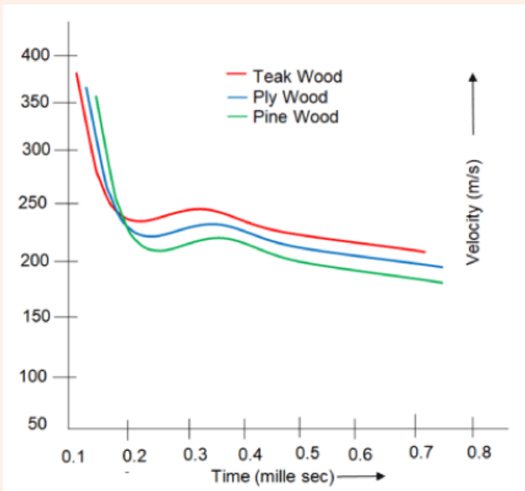

Figure 10: Variation of impact velocity *vs*. time for Teak, Pine wood and Ply wood.

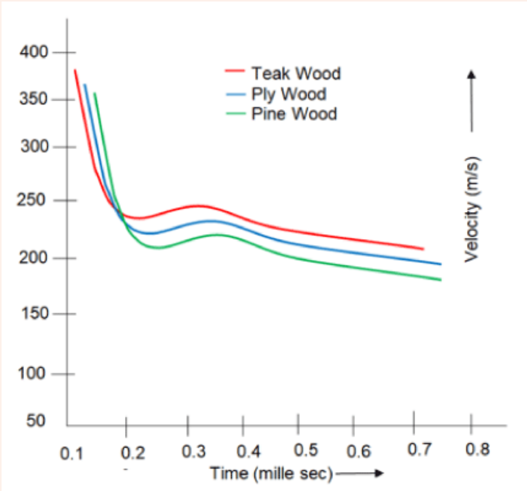

Figure 10: Variation of impact velocity vs. time for Teak, Pine wood and Ply wood.

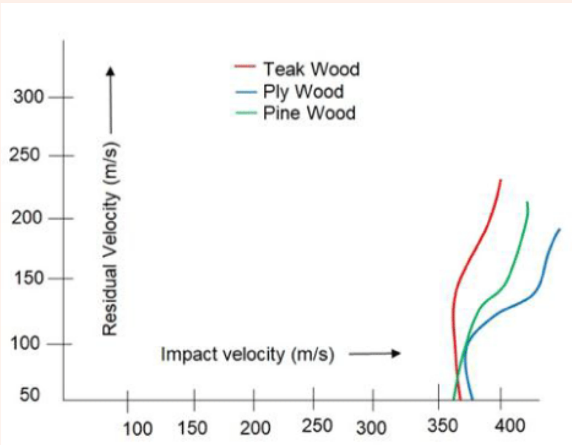

Figure 11: Variation of residual velocity for Teak, Pine wood and Ply wood. The variation of residual velocity vs. impact velocity for Teak, Pine wood and Ply wood are illustrated in

target materials was addressed. This paper demonstrates an experimental procedure of the damage mechanism of a water-jet disruptor and its performance at different stand-off distances. Actual dimensions of crater were measured on the different targets. The craters were noticed in all the cases, which indicate that dimensions are more than that of a nylon projectile i.e. 15 to 25mm. The authors proposed that this study should be included in a future standard test protocol for assessing the damage on composite materials[18]. The present study provides precious information about damage assessment on the wooden target. It deals with the impact of projectiles as engineer or designer does his best job to design the projectiles for disrupting suspected IEDs. The entire principle was presented using impact test where a nylon projectile strikes a composite target. The images and results clearly show the damage mechanism. This would make it possible to consider phenomena related to the deformation of materials, potentially with striking velocity.This experimental study aids to envisage the penetration and post-penetration performance of composite targets using the different properties. The ballistic velocity limits for various targets were estimated. These velocities are less than the projectile velocities, which clearly indicates that targets would penetrate by the projectile.

Experimental studies were conducted on the composite target materials using a nylon projectile to evaluate the damage performance.

As a summary of this work, the following inferences were drawn:

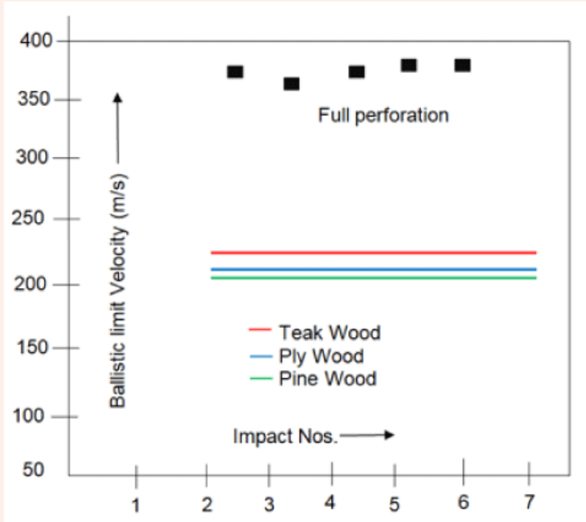

Figure 12: Ballistic limit velocity *vs.* Impact No.

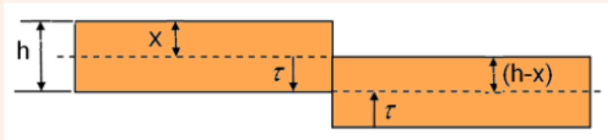

Figure 13: The Wooden Target Exhibiting Shear Stresses due to Projectile Action.

- The main damage on the targets is attributed due to compression in the front, shear action for plugging of composite material in the rear side. This paper is concerned about the perforation process on impact.
- The current study emphasis the impact study of nylon projectile on composite target such as woods of different types
- This paper demonstrates the ballistic limit velocities of various composite target such as wood on impact of nylon projectile. This helps to compare ballistic limit velocities of targets.

This research paper presents the systematic impact study of projectile on composite targets for understanding the cratering phenomena on the soft target such as woods. Further, this helps in proper understanding of wood strength [19].

Conflict of Interest

The authors affirm that there are no financial relationships with any organization or person that could affect research work. The work and experiments are exclusively belongs to my supervisor and the institute.

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