A Review of Impactor Nose on Laminated Composite Structure under Quasi Static Loading

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***Abstract*— This review focuses on the previous researchers result on the experimental investigations of failure mechanism of glass fiber reinforced plastic (GFRP) composite laminates under different quasi-static speed loading. Many researchers have study about the impact test or compression test using different geometry of impactor nose. However, the review finding show that there is no specific scientific research for the failure of laminated composite impact using different impactor nose under different velocities. By conducting this extensive review, the relationship between different of quasi-static loading speed with different of impactor nose on the response of laminated composite can be understand clearly in order to prove experimentally in future.**

Keywords*— *Impactor Nose; Laminated; Cimposite; Geometry; Quasi Static

1.0 INTRODUCTION

Materials are one of the important element influences on our life. Barbero [1] stated that composite, ceramic and plastics have been dominated as human kind materials where the number and volume of application on composite material has grown steadily pass few decades. One of the important factor using composite is the weight reduction provides by composite material. Composite is lightweight because both fibers and polymers used as matrices have low density, and fiber has high value of strength to weight ratio than most materials.

One of the most common composite materials is fiber reinforced composites. Fiber reinforced composites is now widely used in application due to their superiority over metal such as lightweight with high strength. In addition, fiber reinforced composite have been more prominent than other types of composite because they are stronger and stiffer in the fibrous form than in any other form [2]. An instance, Chawla [3] mentioned about that glass fiber reinforced resins were applied since the early twentieth century. The glass fiber reinforced resins is very light yet strong materials. Now, glass fiber and carbon fiber are common reinforcement material used to fabricate laminated composite [4]. Glass fiber has been the most common reinforcements for polymer matrices due to its high strength, low cost, and high chemical resistance [5]. Other fibers with better performance that combine high strength with high stiffness are boron, silicon carbide, carbon and alumina. The arrangement of fibers and their orientations are crucial to determine the strength and stiffness of a composite [6]. In this case, fibers oriented in one direction give very high stiffness and strength in that direction. The main function of the matrix material is protect the fibers from environment attack, thus corrosion resistance is one of the properties to be considered. The studies of epoxy and polyester resin used as a binder is carried out by Onyechi *et al.* [7].

The research related the fiber reinforced composite for military application which considered the function of fiber and the influences of resins has been done by Gupta *et al.* [8]. The author showed the nose shape of a projectile is an important factor affecting the mechanism of deformation of the target plate. The different investigations have been carried out with various parameters in the study of the projectile nose shape effect on the target plate. An instance, the impact test using blunt, hemispherical and ogival shape of impactor nose done by Rittel and Dorogoy [9], while Rusinek *et al.* [10] used the conical impactor on thin steel plate. However, there is a systematic review required about the influence of projectile nose design, thickness of the target plate as well as the projectile impact velocity on deformation behavior of the laminated composite plate. Besides, Rittel and Dorogoy [9] as well as Onyechi *et al.* [4] discussed about the penetration and perforation on target by projectiles. The most convenient in this respect are those models that allow deriving formulas determining the dependence of the ballistic limit velocity on various parameters affecting perforation [11]. The increased contacting area between the projectile nose and target material may need to be considered when the penetration depth is comparable with the projectile nose length in a penetration problem or in the penetration stage of a multi-stage perforation process [12]. Furthermore, Filiatrault [13] discussed about quasi-static test performed to predict the behavior of structural on large scale structural elements based on strength, stiffness and ductility. Unlike dynamic test, quasi-static test may be interrupt at any time to assess the condition of the specimen. The main problem during testing is to know the specimen is overloaded or not. The quasi-static tests can replace the inertia forces generated by an earthquake on a structure with equivalent static loads. Zureick and Nettles [14] noted that the need of a quasi-static loading test proved to be very beneficial to researchers since more data can be obtained from quasi-static test than from an impact test since the amount of impact damage formed in a laminated composite is very sensitive to stacking sequence, regardless of thickness.

Based on aforementioned above, the study on quasi-static testing is required to understand the performance of laminated composite for the different geometrical shapes of the impactor nose. It is also necessary to know the energy absorption of laminated composite under quasi-static testing with the different velocity to gain more information on the relationship between geometry of impactor nose and laminated composite structural.

2.0 TARGET MATERIAL

Target material is the sample or specimen that hit by projectile in an impact test. In general, target material can classified with several group of material such as metal, ceramic and composite material [15]. There have been several studies in the literature deal with the experimental and investigations of target material that impacted by the projectiles. According to Rittel and Dorogoy [9], glassy polymers, polymethylmethacrylate (PMMA), are used due to their material properties and it is an appealing choice for armor application. Author proposed to use the plate made of PMMA with density of ρ = 1190 kg/m^3 and weighted 1.732 kg. The width and thickness of PMMA square plate is 124 mm and 40 mm respectively.

In contrast, Gupta *et al.* [8] suggested that using 1100-H12 aluminum plate with various thickness impacted by steel projectiles. The aluminum plates with of 0.5, 0.71, 1.0, 1.5, 2.5 and 3 mm thickness was experimental at different velocities. Previous study has shown that projectile penetration through the aluminum target plate could potentially result in multiple cracks. Ben-Dor *et al.* [16] found difference suggesting that using a normal penetration of rigid striker into a concrete or limestone semi-infinite target under a constant velocity.

However, a monolithic semi-infinite fiber-reinforced plastic laminate is used as target material by Ben-Dor *et al.* [11] and Ben-Dor *et al.* [17]. The penetration and perforation of monolithic FRP laminates struck normally by projectiles with several kinds of nose shapes is proposed. As stated in Callister and Rethwisch [18], monolithic mean having a microstructure that is uniform and continuous and was formed from a single material.

Khan *et al.* [19] mentioned that carbon fiber-reinforced composites (CFRPs) are an advance engineering materials that exhibit high strength-weight and modulus-weight ratios. Nanoclays have been used to improve the properties of composite at low weight fraction of clay. In study of Onyechi *et al.* [7] and Onyechi *et al.* [20], the GFRP composite laminates with thicknesses of 8, 12, 16, 20, 24, and 28 mm are the target material of impact test experiment. Similarly, GFRP composites were subjected to ballistic deformation by Onyechi *et al.* [4] with the number of plies were 6, 9, 12, 15, 18, and 22 respectively. Table 1 shows the summary of target material used by previous researcher together with the thickness.

Table 1. Target material used

Target Material References	Thickness (mm)		Plies layer
GFRP	8, 12	6, 9	[7]
GFRP	16, 20	12, 15	[14]
GFRP	24, 28	18, 22	[20]
PMMA (glassy)	40	-	[9]
CFRPs	-	-	[19]
1100-H12 Al.	0.5 to 3	-	[8]
Concrete	-	-	[16]
Monolithic FRP	-	-	[11] & [17]

Most of the researches used composite materials as the target material especially fiber-reinforced composite. Carbon fiber and glass fiber are most common reinforcement used to fabricate laminate reinforced composite. Laminated composite are gain popularity due to the advantage of laminated composite offered as compared to other materials.

3.0 IMPACTOR NOSE DESIGN

According to Ochoa *et al.* [21], an impactor consists of three components, which is a dropping crosshead, an impactor rod and an impactor nose. During an impact test, the impactor is attacted to the dropping crosshead, a force transducer having certain capacity is mounted on the front end of the impactor rod. The impactor was set at a dropping height to give constant impact velocity for the test. Study by Gupta et al. [8], Ben-Dor *et al.* [11], and Ben-Dor *et al.* [17] have proposed that using steel or rigid material to make an impactor due to its ultimate properties such as high strength and resistant to fracture. However, the 15-5 ph stainless steel is used by Rittel and Dorogoy [9] as the impactor.

3.1 Type of Nose

There have been several studies in the literature reporting on effect of projectile nose shape on the deformation of the target plates. Type of impactor nose shape used in impact testing is shown in Table 2. From the table, type of impactor used by previous researcher can be seen clearly, the most common used of impactor nose are blunt, hemispherical, conical and ogival shape. The different geometry of impactors would cause different result in the deformation or response of impact target. Impactors used under loading helps in simulate the bullets applied in military application.

Table 2. Types of shape nose

Shape of impactor nose	References
Ogival & conical	[4] & [7]
Blunt, ogive & hemispherical	[9] & [8]
Conical	[10]
Blunt, conical & hemispherical	[22]
Right circular cylinder	[23]
Blunt	[24]
Spherical	[25]
Flat-nose, sharp-cone & ogive	[11]
Awl-shape, sharp-cone, flat nose conical	[17]

3.2 Dimension and Size

As stated in Onyechi *et al.* [7] and Onyechi *et al.* [20], the projectiles are assumed to have density, ρ and mass, M with diameter D (or radius r), L and L_N are the lengths of the shank and nose of projectile as shown in Figure 1. It is common to define the ogive in terms of caliber–radius–head. The classification of bullets used is shown in Table 3.

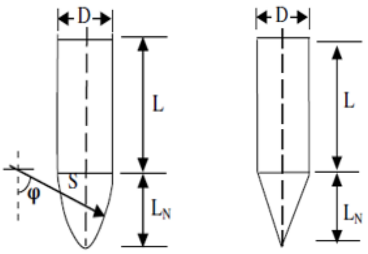

Figure 1. Projectile nose geometry (a) ogival, (b) conical [7]

Table 3. The classification of bullets used [20]

Parameter	Ogival	Conical
Projectile caliber	5.6 mm	45˚ conical tipped
Cartridge size type	27 grain	27 grain
Nominal type	1.7 gram	1.7 gram
Bullet diameter	5.7 mm	5.7 mm
Velocity	355 m/s	355 m/s
Effective range	200 meters	200 meters
Mass density of Bullet	11,400 kg/m^3	11,400 kg/m^3

Study of Rittel and Dorogoy [9] using steel projectiles with diameter D = 6 mm and lengths of L = 56 mm and 72 mm. The value of L/D =9.3 and 12 respectively, which considered as long projectile where typical AP projectiles has 3 < L/D < 5. Three head geometries were used: blunt, hemispherical and ogive. The weights of 56 mm length of projectile are 12.4 g, 12.1 g and 11.4 g respectively.

However, Gupta *et al.* [8] proposed to use 52.5 g of hard steel projectiles with diameter of 19 mm and length of 50.8 mm as shows in Figure 2. To get a constant mass of the projectiles, author measured the wall thicknesses of the blunt, hemispherical and ogive nosed projectiles were slightly varied which were 2.44, 3.65 and 2.5 mm, respectively.

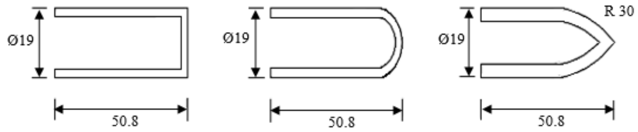

Figure 2. Geometry of projectiles [8]

The experiment set-up by Arias *et al.* [22] where normal impact θ = 90˚ configuration has been carried out. The projectile are machined with a high strength steel that have same diameter, D = 20 mm and average mass of m = 197 g. Figure 3 shows the geometry of projectile used during numerical simulation.

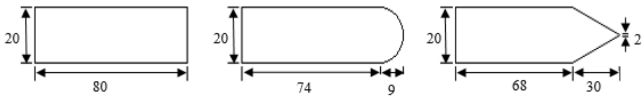

Figure 3. Geometry of projectiles used in the simulation [22]

Another study proposed that using the projectile mass, m = 0.2 kg and the nose angle ϴ = 18.5˚ are the same in all numerical simulations [10]. The projectile diameters D_p, were changed from D_p = 25 mm to D_p = 10 mm with an interval decrease of 5 mm between each configuration different configurations by Equation 1. The evolution of the nose area with the projectile nose length is shown in Figure 4.

$$Ac = (\pi Dp^2) / (4\sin\theta) \qquad \text{Equation 1}$$

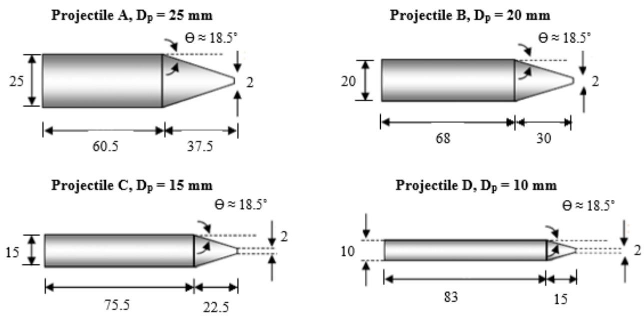

Figure 4. Projectiles shapes applied in the simulation [10]

4.0 EFFECT OF DIFFERENT NOSE IN ENERGY ABSORPTION

Gupta *et al.* [8] investigated the effect of impactor nose shape, target thickness and impact velocity on the deformation behavior of aluminum plates. Authors discovered that hemispherical nosed projectile caused greatest global deformation on the target plates. Besides, authors stated that blunt nosed projectiles required the least energy to perforate the target plates with thickness 2.0, 2.5 and 3.0 mm while ogive nosed projectiles were the most efficient penetrator for 0.5, 0.71, 1.0 and 1.5 mm thick of plates. However, the hemispherical nosed projectiles are the least effective penetrator of the target plates as the ballistic limit velocity was found to be highest as compared to the other two projectiles. In contrast, Onyechi *et al.* [4] investigated the effect on the response of the plate. The result showed that one of the governing factors in the damage resistance is the nose shape of the impactor. The ballistic penetration test showed that the conical nosed impactor has a greater penetration effect on the GFRP samples than the ogival nosed impactor which showing the best penetration resistance.

The penetration process in thick PMMA plates under low velocity was carried out by Rittel and Dorogoy [9] showed that the average deceleration during the penetration process is constant. The resisting force to the penetration is higher for blunt projectiles. It is 10 % lower for the hemispherical head and 50 % lower for ogive-headed projectiles. In contrast, study by Ben-Dor *et al.* [17] on optimization of the nose shape of an impactor against a FRP laminate showed that the optimum shape depends on the given depth of penetration (DOP). The optimum impactor for a relatively small DOP is sharp, awl-shaped. The optimal nose geometry of the impactor becomes close to a blunt cone with the increased in DOP. It has been proven that a flat-nosed cylinder requires the most impact velocity in order to penetrate at a given DOP. Ben-Dor *et al.* [11] proposed the optimal nose geometry of the impactor against FRP laminates. Authors found that optimal impactor with the lowest ballistic limit velocities (BLV) has plane bluntness and its BLV is very close to BLV of optimal blunt conical impactor. However, the flat-nosed cylinder is the impactor with the maximum BVL. Comparison of different shapes showed that the advantage of the optimal impactor over the sharp cone and ogive impactor is significant.

5.0 QUASI STATIC LOADING

According to Ambrosio [26], a quasi-static method is used often an engineering practice for the design of structures subjected to dynamic loadings. The accuracy regarding the quasi-static procedure is usually acceptable, especially when admitting any uncertainties of the material in the dynamic properties, the characteristics of the dynamic loading as well as the structural support conditions. It is time-dependent, in reality a sequence of states of static equilibrium. As stated in Haddad [27], typical illustrations of a quasi-static deformation process are the quasi-static creep and relaxation processes of engineering materials. In contrast, author of Ambrosio [26] stated that the deformation profile of quasi-static analysis is assumed to be time-independent for a structure subject to dynamic loadings.

Zureick and Nettles [14] noted that the need for a quasi-static loading test prove to be very beneficial to researchers since more data can be obtained from quasi-static test than from an impact test. However, there are many questions about whether or not a quasi-static indentation test represent low-velocity impact event. Author described that one study has suggested that the impactor to target frequency ratio governs the type of the event with a low ratio implying a quasi-static event. Another study was obtained a simpler method which a rule has been established that if the impactor mass is more than ten times the lumped mass of the target, then the impact event will be quasi-static in nature. The lumped mass is a function of the target shape and boundary conditions but is generally about one-half the mass of the entire target.

Author concludes that static indentation test can be used to represent low velocity events when the damage is compared by maximum transverse force. The only difference in damage between statically loaded and impacted specimens may be the split length that forms on the underside of the specimen, although this difference is small and does not seem to affect the delamination area. In addition, the result of study by Li *et al.* [28] shows that no distinct differences could be seen between quasi-static indentation testing and low-velocity impact, thus indicating that quasi-static indentation testing can be used to represent low-velocity impact testing.

According to Zureick and Nettles [14], several studies show similarity between quasi-static indentation and drop weight impact test, while a limit to the applicability of using quasi-static indentation to represent impact event was study by other researchers. There are many variables involved in these tests such as boundary conditions, specimen size, specimen thickness, stacking sequence, impactor shape, impactor size, and type of fiber/resin used. Author summarizes that the amount of impact damage formed in a laminated composite has been shown very sensitive to stacking sequence, regardless of thickness.

6.0 TESTING PARAMETER AND PROCEDURE

The study of Ochoa *et al.* [21] set the impactor at a dropping height of 0.91 m with a constant velocity of 4.22 m/s. The impact velocity range of the projectiles was set at 33 to 126 m/s by Gupta *et al.* [8]. In contrast, Rittel and Dorogoy [9] stated that the maximum achievable velocity at impact is slow compared to the velocity of armor-piercing (AP) projectiles 0.75 km/s $< v <$ 2 km/s. Yet, such a velocity is highly representative of impact of various kinds of debris. In the experimental of Onyechi *et al.* [4], the distance between the target and the gun was measured to be 50 meters.

During an impact test, the impactor is attached to the dropping crosshead and a force transducer having certain capacity is mounted on the front end of the impactor rod. The impactor was set at a dropping height to give constant impact velocity for the test [21]. In each impact test, a composite specimen is placed between two steel plate holders, namely top holder and the bottom holder. The top holder was removable while the bottom one was attached to the frame of the impact testing machine which was fixed on a solid foundation. The specimen and the top holder were then C-clamped at four corners to the bottom steel holder. As the impactor dropped and approached a composite specimen, its time trigger passed through a time sensor right before contact-impact occurred. The initial impact velocity was then calculated from the distance between two edges on the time trigger and the time interval they passes through the sensor. Once impact began, the contact forces at many consecutive instant were detected by the force transducer attached to the impactor. The force history was recorded in computer and corresponding velocity and displacement history of impactor could then be calculated.

7.0 EFFECT OF TARGET THICKNESS

The effects of penetration not only depending on the geometry of impactor nose, but it also influence by the thickness of laminated composite and diameter of the projectile. Different in composite thickness and diameter may affect the ballistic limit, perforation and the residual velocity. Impact and residual velocities of the projectiles are plotted by Onyechi *et al.* [7] and Gupta *et al.* [8] to compare the resistance offered by the target plates of all thicknesses. It is found that the increased in the thickness of target plate will increased the resistance that offered by the target plate to the perforation of the impactor. In the case of 0.5 mm thick plates, lowest ballistic limit velocity of the projectiles is observed whereas for the case of 3 mm thick plates, the ballistic limit velocity is found to be highest. Furthermore, the energy required to perforate the target plate for the case of blunt and ogive nosed impactor is comparable however target plate absorbed higher energy for the case of impact by hemispherical nosed impactor. Similarly, experimental and analytical investigation have been performed by Onyechi *et al.* [4] concerning the static and ballistic resistance of woven roving GFRP laminate plates of thicknesses 8 mm up to 28 mm penetrated and perforated by ogival and conical projectiles. It is deduced that the ballistic limit is linearly related to the thickness of the GFRP laminate composite investigated.

8.0 EFFECT OF PROJECTILE DIAMETER

Regarding investigation by Rusinek *et al.* [10], the velocity lost by the projectile is directly proportional to the projectile-nose area. Greater projectile caliber induces a larger plastic zone directly affected by impact. At the same time, the projectile-nose surface area in contact with the plate during perforation increases. These effects increase the resistance of the plate to perforation. Thus when cylindrical or hemispherical projectiles are used, the energy lost by the projectile increases with impact velocity. In addition, close to the ballistic limit condition, a strong gradient is found in terms of residual velocity with projectile diameter increase. Therefore, the perforation process is more efficient for smaller diameters since, as previously reported, less kinetic energy is lost. In this case the ballistic limit is lower in comparison to projectiles of larger diameters as shown in Figure 5.

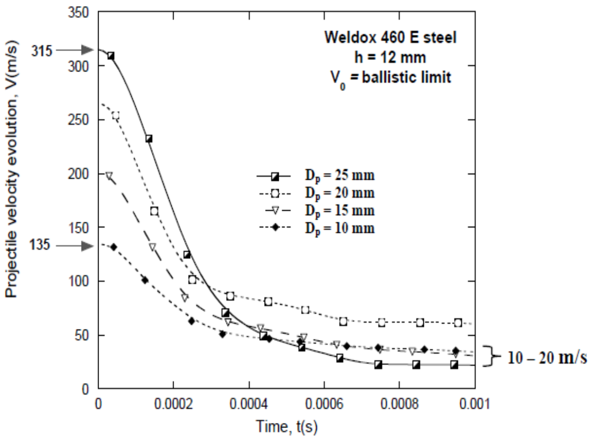

Figure 5. Velocity evolution at ballistic limit for each nose configuration [10]

In relation to the effect of the projectile diameter in terms of the level of plastic work, when the diameters of projectile become smaller, the ballistic limit is decreasing. A larger bending effect is observed as the projectile diameter increases, inducing a higher dissipation of plastic work. Thus large projectile diameter induces a high plastic work.

9.0 DEPTH OF PENETRATION

The study of Rittel and Dorogoy [9] carried out the experimental using impact at 220 m/s of three types of steel projectiles having the same diameter and length but with different head geometries. The normalized vertical displacements of the tips of the heads of the projectiles vs. normalized time are plotted in Figure 6. Displacements are normalized by the diameter of the projectile. Time is normalized by the time needed for the blunt head projectile to reach its maximum depth of penetration (DoP). The tips are the center point on the surface of the head. The DoPs obtained from these curve are 7.9, 10.1 and 19.8 mm respectively and they are reached at time 83, 92 and 171 µs. At greater times, the displacement changes direction and the projectiles move backwards as observed in the experimental results.

The ballistic or resistance to penetration tests was carried out by Onyechi *et al.* [20]. There are six composite laminate armour sample plates were targeted using ogival and conical nosed impactor of equal diameter and mass. After the ballistic experiment, the ultrasonic thickness measurement/penetration and inspection was carried out on the samples. The thickness of the composite sample undeniable affects the penetration results. For a projectile with same value of diameter and mass, conical nose shape of projectile results in deeper depth of penetration as compared to ogival nose shape.

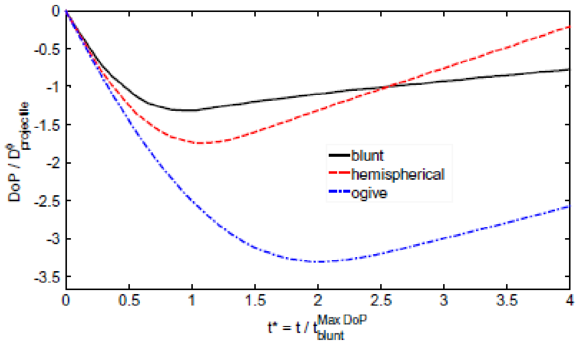

Figure 6. Vertical displacement of blunt, hemispherical and ogive nose projectile which at 220 m/s with PMMA plate of 40 mm width [9]

10.0 REVIEW SUMMARY

Studies in this literature show that the effect of projectile nose on the target plates varies with various parameters such as impact velocity of the impactor, thickness of the target plate, target thickness to impactor diameter ratio and nose angle or nose radius of the impactor. Different researchers have different parameters to study the effect of impactor nose shape on the target plates. The diameter of an impactor can varied from 5 mm to 25 mm. Figure 7 shows the overview of studies on impact testing that done by previous researcher.

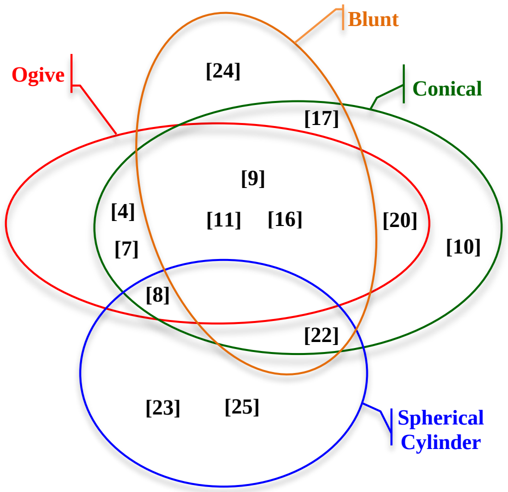

Figure 7. Graphically representing the overview of study on different nose shape

The finding of previous experiment indicate the thickness of laminate composite in range of 0.5 mm to 3 mm for aluminum plate while the thickness used in composite is thicker with the range 8 mm to 50.8 mm. Number of plies used to manufacture a laminated composite also can have high different. For the thickness of 8, 12, 16, 20, 24 and 28 mm, the number of plies were 6, 9, 12, 15, 18 and 22 respectively that used by previous study.

Many researchers have study about the impact test or compression test using different target material which included polymer, concrete, aluminum and also laminate composite. Most of the studies proposed composite as the target material like Glass Fiber Reinforced Polyester (GFRP), Carbon Fiber Reinforced Polyester (CFRP) and Fiber-reinforcement Polymer (FRP). Composite materials have relative advantages in terms of specific energy absorption, weight and strength. Hence, in this research laminate composite has been chosen for the target material of the test.

Most of the investigations previously indicate glass fiber like E-glass fiber as the reinforcement, only a few studied suggested carbon fibers as reinforcement of composite. Furthermore, many studies prefer to use polyester resin rather than epoxy resin to fabricate composite material. Due to a higher performance to cost ratio and the acceptance in many applications, the E-glass reinforcement and the polyester resin were chosen. Few studies demonstrated that the fiber used in target material made from different orientation, fiber with matted woven roving, uni-directional and random orientations were indicated by different studies. All the laminate composite proposed as target materials have been manufactured by hand lay-up due to low tooling cost and simple process of fabrication. There is lack of research addressing the vacuum bagging method to fabricated laminate composite. Vacuum bagging process provide better fiber wet-out and lower void content. Thus in the present report will consider vacuum bagging process as manufacturing method.

Most of the previous research studied using high velocity of impact test, the velocity used can up to 600 m/s. There is not much of research discussed using composite laminated as military based on quasi-static test. Therefore it is worth to indicate impact the impacted target using different low velocities. In summary, most of the prior explore the different nose of impactor affect in result in term of deformation, ballistic limit as well as depth of penetration. Hence, it is worth to investigate the role of different impactor nose on the energy absorption of non-uniform geometry shapes.

11.0 CONCLUSION

The experiment of using different impactor nose on laminated composite under quasi-static loading brings beneficial which generates deep understanding on the phenomenon of the reaction or response of laminated composite under quasi-static loading. By changing the geometry of impactor nose, new scientific information can be obtained based on structural of laminated composite under quasi-static testing. Most studies focus on ballistic testing which is high velocity impact. However, quasi-static loading with low velocity creates new possibility on the output of the experiment. The information gain from the experimental can help in development of engineering and technology. This review helps to simulate field test to lab test where the performance or response of impact target can be observe clearly and analyze in lab. This help to acquire knowledge with high accuracy. The data obtain can be used in relevant defense or military technology.

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