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EFFECTS OF DIFFERENT IMPACTOR NOSE ON THIN PLATE LAMINATE COMPOSITE UNDER DIFFERENT QUASI-STATIC LOADING

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ABSTRACT

This research focuses on the effect of three different nose designs on glass fiber reinforced polyester composite laminates under different quasi-static speed loading. Laminated composite which act as target material is fabricated in orientation of unidirectional with 6 layers of plies by using vacuum bagging. 75 samples were tested under quasi-static test using three different impactors which is blunt, conical and hemispherical nosed impactors under loading speeds of 10, 20, 30, 40 and 50 mm/min. A further comparison was made with the maximum force required of each of the impactor. The fracture behavior of laminated composite caused by different inpactor was monitored under the scanning electron microscope to determine the type of failure occurred after quasi-static test. The finding shows that conical nosed impactor required lowest force to penetrate the target material followed by hemispherical and blunt nosed impactor. In comparison with conical impactor hemispherical nosed impactor and blunt nosed impactor shows 15% and 74% reduction respectively in term of effectiveness. As the loading speed increased, the force needed for each impactor is increased. From the finding, loading speed of 30 mm/min shows the best speed for quasi-static to carry out. Furthermore, energy absorption that caused by three impactors show that conical nosed impactor produced smallest range of plastic zone where hemispherical nosed impactor and blunt nosed impactor create 1.8 % and 11.6 % respectively, higher range in plastic zone. Pull out of fibers and fibers breakage were observed on the sample after testing. The failure characteristic changed from fiber pull-out to fiber breakage. The nose surface area in contact with the target material produces high effect on the failure behavior of target material, the smaller the area, the higher the penetration resistance of target material.

Keywords: impactor nose, thin plate laminate, quasi-static, conical hemispherical blunt.

INTRODUCTION

The structural designer seeks for the best possible design by using least amount of resources. The measure of goodness design is typically related to the strength or stiffness of resources (materials) measured in terms of weight or cost. The cost of raw materials and fabrication cost are considered. Composite materials have properties with high strength and high stiffness which can compete with others materials. One of the advantages of composite over other materials is related to the cost. As noted by Kaw (2006), the world market for composite is only 10 x 109 US dollars as compared to more than 450 x 109 US dollars for steel. However, there is not much of scholar discussed about the using of composite materials for military proposes based on quasi-static testing.

Since there is lacking of research study on the quasi-static test using different impactor geometry, there is be short of information and knowledge regarding quasi-static test. In this case, the ballistic testing was adopted which are commonly used and studied with the different geometry of impactor in order to develop armour (Onyechi *et al.*, 2013). They studied specifically on the penetration phenomenon of composite armours. Even so, laminated composites are extremely susceptible to transverse impact, particularly at low velocities. The low-velocity impact can cause damage, including matrix cracks, delaminations, and fiber breakage, which is embedded within the composites (Li *et al.*, 2002).

Gupta *et al.* (2007) investigation used blunt, ogive along with hemispherical nosed steel projectiles to impact on aluminum target plates. Similarly, Onyechi *et al.* (2013) studied the development of an armour protecting body of glass fiber reinforced polyester (GFRP) composite laminates of varying thicknesses which targeted with a high velocity of 355 m/s by ogival and conical nose. In this case, the impactor geometry and parameter can influent the result of the laminated composites deformation. The different shapes of impactor nose applied to the laminated composite for identifying the mechanical deformation were on a certain thickness. The main consideration is on the energy absorption of the composite while impact by different impactor nose under low velocity.

Moreover, since the shape of impactor nose can causes the highest global deformation of the target plate, therefore the shape of impactor nose which has the lowest effective on penetration should be determined. One of the governing factors in the damage resistance is the nose shape of the impacting projectile due to the ballistic limit and failure mode of laminated composite. For that reason, to understand the shape of an impactor nose on thin laminated composite under quasi-static loading, this study was carried out experimentally using blunt, hemispherical and conical nose. This study focused on the using of laminate composite materials to provide a cost-effective investigation, thus parallel with current ballistic materials most made from structural composite. Specifically, through the quasi-static test that is performed with different velocities in order to determine the deformation result of thin laminated composite.

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MATERIALS AND METHODS

Target Material and Testing

Target material is the sample that hit by the impactor in the quasi-static test. The target material use for this research is laminated composite using glass fiber with polyester resins. The glass fiber used in this research are woven roving E-glass fiber with density 2.55 Mg/m^3, and 72 GPa for Young's modulus. Meanwhile, the unsaturated polyester resin branded Norsodyne 3317AW which manufactured by Cray Valley Resin (M) Sdn. Bhd is used as binder material. Two percent of Methyl Ethyl Ketone Peroxide (MEKP) was added into the resin to make sure the chemical reaction happens in good manner. The MEKP was produced by P.T. Kawaguchi Kimia Indonesia.

The laminate composite which acts as the target material is fabricated using vacuum bagging technique in square with width of 125 mm so that the impactor can load at the centre of the target plate. The thickness of the laminate composite is depending on the number of ply and also the amount of polyester resin use used. In this research, six layers of reinforcement are used and oriented in unidirectional [0/90]. The laminated composite were undergoed flexural test, tensile test and shore durometer hardness test to obtain its properties. Flexural test carried out following the ASTM standard of D790 and tensile test followed standard of ASTM D 3039 while hardness of the laminated composites was checked on a shore D Hardness Durometer on ASTM D 2240. Quasi-static test is conducted to study the effect of blunt, conical and hemispherical shape of impactor nose on the laminated composite under five different loading speed. The quasi-static testing is performed using the Universal Testing Machine. The quasi-static this is conducted followed the ASTM D6264 standard which is standard test method for measuring the damage resistance of a fiber-reinforced polymer-matrix composite to a concentrated quasi-static indentation force.

Impactor

The design of an impactor is important where the dimension of an impactor can lead do different result of the test. Many aspects have to be considered including the diameter and length of the impactor, geometry of impactor nose and the mass of an impactor. The design of the impactors is shown in Figure-1. Basically, a cylindrical impactor is fabricated with same dimension of diameter and length but different impactor nose shape. The impactor with diameter of 20 mm and length of 80 mm is measured. The dimensions of the impactors have different geometries of impactor nose which are blunt, hemispherical and conical shape. Conical shape of impactor nose is measured with 45˚ slope.

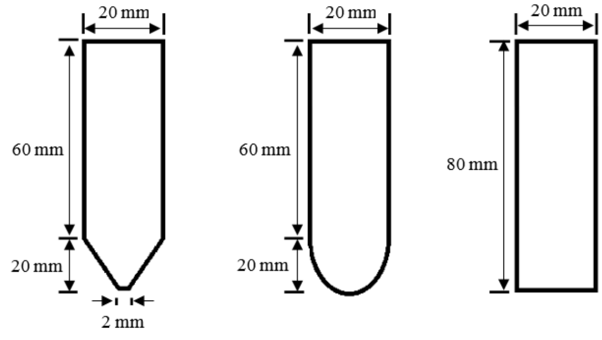

Figure-1. Dimension of impactor in **(a)** conical, **(b)** hemispherical and **(c)** blunt shape.

RESULTS AND DISCUSSION

Properties of Target Material

Thickness of target material is one of the important factors that will affect the impact resistance and subsequent load-bearing capacity as mention by Onyechi *et al.* (2014). Figure-2 shows the cross sectional view of laminated composite which the total of six layer of glass fiber can be seen obviously. The laminated composite is in good condition as can see from Figure-2, that is no voids or delamination occur. The thickness of laminated composite with six plies of glass fiber is measured with the average of 3.5 ± 0.5 mm.

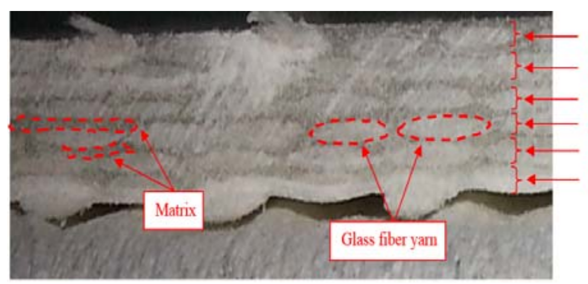

Figure-2. Cross sectional view of laminated composite.

According to Zukas and Scheffler (2001) multilayer targets can be grouped into three classes as follow;

Thin targets = $(T/D) < 1$ (1)

Intermediate thickness targets = $3 < (T/D) < 10$ (2)

Thick targets = $(T/D) > 10$ (3)

(T is the target thickness, and D, the projectile diameter)

Based on the equation (1), (2) and (3), the ratio value is ranging from 0.17 to 0.20. Thus this plate considered as thin targets. The composite thickness presents the distance for the impactor has to travel within the target. Large travel distances present a corresponding

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large surface for energy dissipation, thus increasing the ballistic limit of the material. The higher thickness required high impact energy to achieve a complete penetration of the composite. Onyechi *et al.* (2014) mentioned that the penetration resistance of fiber glass-reinforced plastics against small caliber projectiles shows that the energy absorbed increases linearly with the areal density or thickness of the laminate.

The areal density of laminated composite was measured to be 5.37 ± 0.05 kg/m^2. As stated in Ubeyli *et al.* (2008), thick layer laminates allowed less penetration than thin layer laminates for the same areal density. Armour design favors maximum protection with minimum weight. To reduce the areal density of the armour, so that protection can be offered at less weight, this combines maximum energy absorbing capability with minimum areal density. For a particular value of areal density, more energy is absorbed per unit areal density with lower values of GFRP thicknesses.

For the tensile test, the average of ultimate tensile strength that obtained is 165.92 ± 0.8 MPa. From the study of Elanchezhian *et al.* (2014), the ultimate tensile strength for glass fiber with 3.5 mm of thickness obtained 114.01 MPa. This can shows that the laminated composite in this research is stronger and better in strength. As stated in study of Carroll and Daly (2014), the unidirectional fiber-reinforced composite material could have failure mode of delamination and local buckling.

Flexural strength of laminated composite which acts as target material is calculated which the flexural strength is up to 133.48 MPa. There are two failure modes occur which is bending and shear failure. The laminated composite fails when bending or shear stress reaches the point of 133.48 MPa. In brief of Joseph (2002), the glass fiber composites show high elasticity and lower extensibility. The high flexural strength of glass fiber is due to inherent property of glass fiber.

The laminated composite which acts as the target material have the average hardness of 76.6. Sreekala *et al.* (2002) stated that hardness and density of the composite are interrelated. The hardness of composite decreased as the density of the reinforcement decreased. As compared with research done by Chand and Dwivedi (2006), the jute fiber reinforced composite was measured to have hardness of 65 which is lower than the laminated composite used in this research. According to Grous (2011), hardness value of 80 represent very hard, 60 represent hard, 45 represent medium and 20 is soft.

Effect of Impactor Nose on Target Material

The impactors used in quasi-static testing were fabricated in same dimension in diameter. Three impactors are differing only by their head geometry which is conical, hemispherical and blunt shape. The conical and hemispherical heads have penetrated through the laminated composite while blunt head impactor do not achieved the complete perforation of the target material. The force applied to penetrate the laminated composite for conical impactor is the lowest follow by hemispherical impactor and blunt impactor as shown in Figure-3. The maximum force used by conical nosed impactor to penetrate the target material is 3.25 kN at speed of 10 mm/min and increase 54.46 % and 302.77 % for hemispherical and blunt nosed impactor respectively. At loading speed of 20 mm/min, the applied force for hemispherical is 61.4 % greater than conical nosed impactor while for blunt nosed impactor, the force is 287.72 % larger. At loading speed of 30 mm/min, conical impactor required 3.54 kN of force to penetrate the target composite. In comparison, an increase in 58.85 % and 282.73 % of force was recorded for hemispherical and blunt impactor. At 50 mm/min, the force applied for conical, hemispherical and blunt nosed to penetrate the target are 3.58, 5.77 and 13.58 kN respectively. Figure-4 shows the overall effectiveness of penetration where conical is the bench mark and percentage is calculated

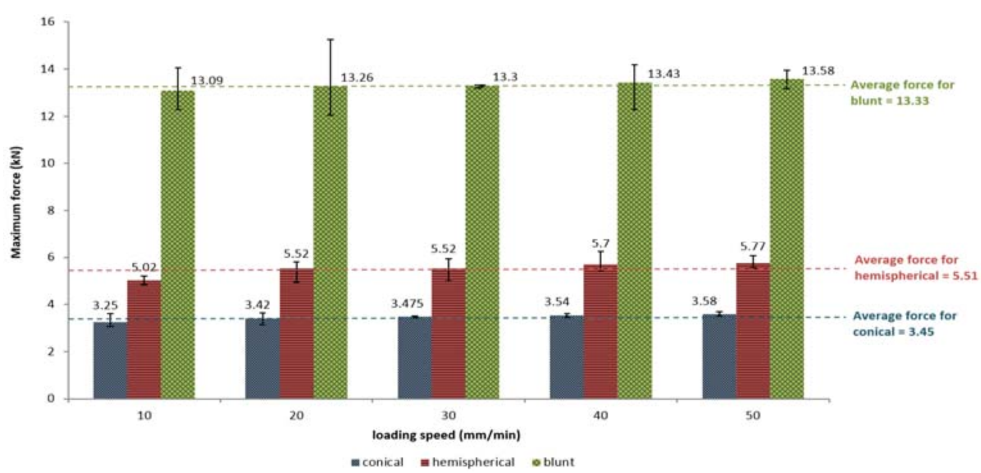

Figure-3. Force used for conical, hemispherical and blunt at different loading speed.

according to the shape of nose. Conical shows the most effective impactor while hemispherical nosed impactor and blunt nosed impactor show 15% and 74 % less effective respectively.

Figure-4. Effectiveness of impactors to penetrate the target plate.

This means that conical nosed impactor required least energy to perforate the target plates. The resisting force to penetrate laminated composite for blunt nosed impactor is the highest. In other words, the energy required by conical nosed impactor to penetrate the laminated composite is less than hemispherical and blunt nosed impactor. This result is similar with the results of research studied by Rittel and Dorogoy (2014). According to them, the resisting force is found to be highest for blunt projectiles and 10% lowest for hemispherical head. Besides, Onyechi *et al.* (2014) also stated that conical nosed projectile has a higher penetration than the ogival nosed projectile. Both of the studies carried out for ballistic testing. This shows that the results obtained from quasi-static test and ballistic test is the same.

The region of damage is observed where a narrow region close to impactor is produced in conical impactor while wider region of damage in hemispherical impactor as shown in Figure-5 (a) and (b). A radial cracks is developed due to impact of blunt impactor, these cracks is propagate until the impactor have reached its maximal depth of penetrate (DoP) as shown in Figure-5 (c). The effect of different impactor nose shape on plastic deformation behavior on the laminated composite plate is observed. A greater impactor nose area induces a larger plastic zone directly affected by impact. As the impactor nose area raise, the impactor nose surface area in contact with the composite plate during penetration increase. Hence, the resistance of the composite plate to perforate will be increase.

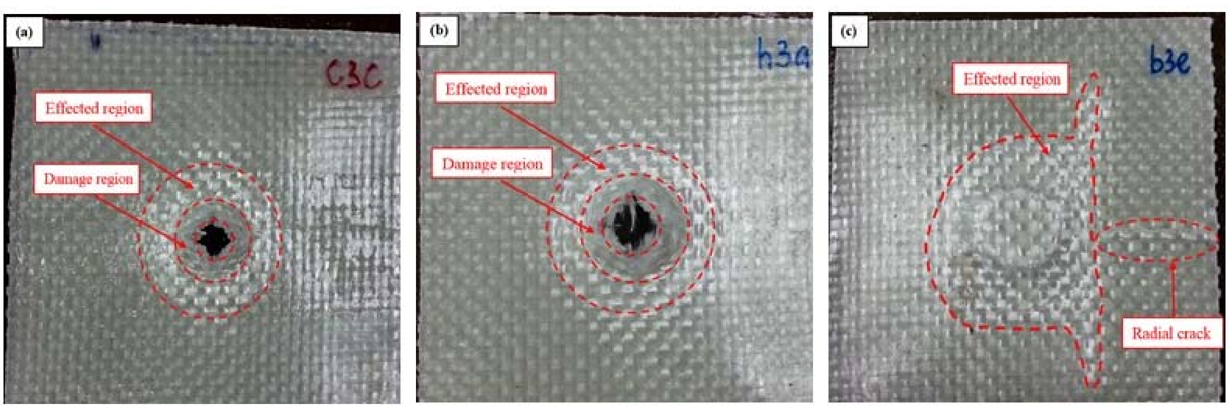

Figure-5. Fracture of composite plate for (a) conical, (b) hemispherical and (c) blunt nosed impactor.

During quasi-static test, blunt nose impactor which has higher nose area compare to conical and hemispherical nose impactor lost more energy as the resistance force is higher compared to others. Thus, it is observed that blunt nosed impactor caused highest plastic deformation of the composite plate followed by hemispherical and conical nosed impactor. Based on study by Rusinek *et al.* (2008), greater projectile calibre 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. The increase of the size of the affected zone induces a high plastic work.

The energy absorption of the target laminated composite which caused by different impactors produce different range of plastic zone. The diameter of composite plate which affected by the impact force is measured where D_0 is refer to the upper diameter and D_1 is bottom diameter. The height of the fiber break out, h is also measured. Figure-6 shows the schematic of the measure dimension after quasi-static testing where the diameter of

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three impactor are 20 mm and thickness of laminated composite plate, t is 3.6 mm. the percentage for dimension of failure on composite plate is measured and shown in Table-1. The negative value represent increase in dimension. The affected area of diameter is shows in Figure-7 where the damage region caused by conical, hemispherical and blunt nosed impactor is obviously different.

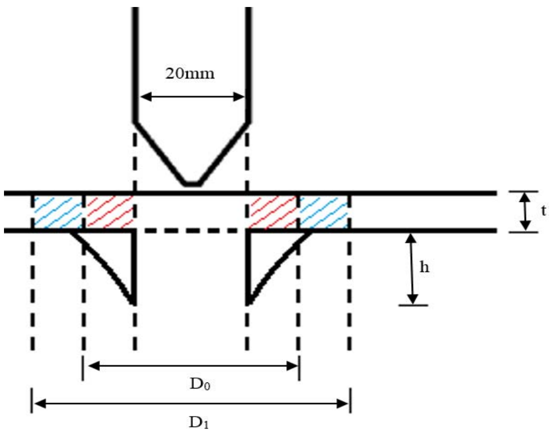

Figure-6. Schematic of the measure dimension of target plate.

Table-1. The percentage of failure dimensions on laminated composite plate.

	Loading speed (mm/min)	Decrease in Diameter, D_0 (%)	Decrees in Diameter, D_1 (%)	Decrease in Height, h (%)
Conical	10	-	-	-
	20	0.47	0.51	-3.45
	30	8.12	-0.94	-2.03
	40	2.58	2.59	-5.12
	50	-0.39	4.43	6.77
Hemispherical	10	-	-	-
	20	0.49	27.50	2.13
	30	3.41	-33.04	6.53
	40	8.63	2.14	-1.60
	50	-4.57	5.46	4.58
Blunt	10	-	-	-
	20	3.32	-13.35	-17.62
	30	0.72	18.02	14.04
	40	7.40	-5.09	2.83
	50	-0.13	-0.33	-8.74

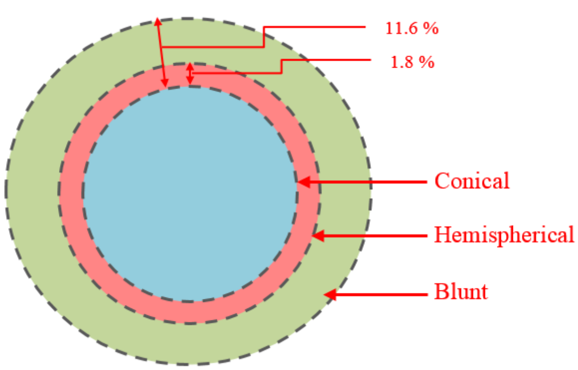

Figure-7. Diameter of plastic zone caused by impactors.

As has been noted by Xiao *et al.* (2007), the composite plays the crucial role of absorbing energy due to various interlaminar and intralaminar damage mechanisms such as delamination, fiber breakage and matrix cracking. The fracture of composites could be a combination of fiber breakage and pull out. The fiber and matrix interfacial failure is occurred as mentioned in Skreekala *et al.* (2002). Pulled out of glass fiber after quasi-static test are visible. As stated in Zhang *et al.* (2014), the bond between the fiber and the matrix is in good condition at perfect bonding phase. When the force applied on the free end of fiber reaches a critical value, the debonding of the fiber takes place. In the debonding part, the shear stress at the interface between the fiber and matrix decrease. When the length of the debonding part of the fiber reaches the embedded length, the applied force reaches its maximum value, the pure friction occurs and then pull out of fiber happened.

Conical nosed impactor has lowest nose area with the least nose surface area in contact with the composite plate. When the impactor contact with the composite plate, the sharp nose of conical nosed impactor incite the energy focus on one point, the force concentrate on one area and caused the fiber to bear more force, which lead to the microcrack to initiate faster and breakage occur easier. Palanivelu *et al.* (2010) described that the reason for the lower energy absorption is due to higher stress concentrations at the corner edges of the tubes which lead to the formation of the axial cracks only at those locations. They found that the specific energy absorption increases with decreasing the angle.

As the nose surface area in contact with the composite plate increase, the surrounded fiber faced tension and causing the pulling force between fibers. The pulling force of surrounded fibers which act as stress transferring medium caused the impact resistance of the composite become higher and fracture of composite plate hard to form. The reasons for the lower specific energy absorption were the non-progressive failure modes and the absence of delamination.

Study by Rusinek *et al.* (2008) found that this kind of configuration like impact of projectile on a plate, the projectile-nose shape determines the failure mode and strongly affects the amount of energy absorbed by the plate. In additions, Onyechi *et al.* (2014) studied the penetration resistance of fiber glass-reinforced plastics against small caliber projectiles. Their experimental results indicated that the energy absorbed increases linearly with the areal density or thickness of the laminate.

Effect of Impactor Nose at Different Speed Loading

Three impactors which are conical, hemispherical and blunt shape were undergoed quasi-static test at loading speed of 10, 20, 30, 40 and 50 mm/min. Figure 8 shows the maximum force used by three different impactors to penetrate the laminated composite plate at different loading speed.

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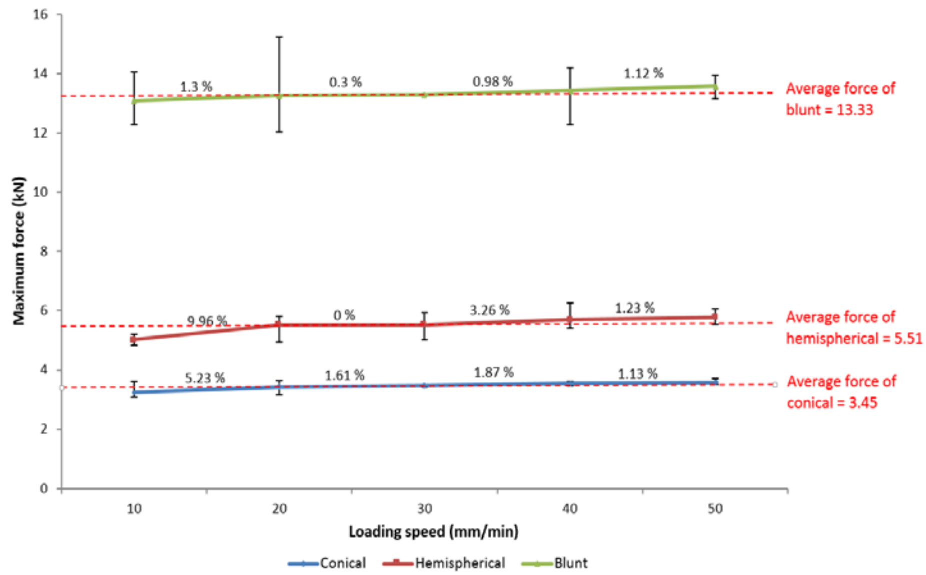

Figure-8. Force evolution at different loading speed for each nose configuration.

Generally, the applied force to penetrate the laminated composite is increase as the loading speed increase for three of the impactors. The conical nosed impactor used least force to penetrate the composite plate at loading speed of 10 mm/min which is 3.25 kN. As the loading speed increased to 2 mm/min, the force used is increase 5.23 % in order to penetrate the composite plate. When comes to loading speed of 30, 40 and 50 mm/min, the force needed is increased 1.61, 1.87 and 1.13 % respectively.

In the test of using hemispherical nosed impactor, it shows higher raise in force from speed of 10 mm/min to 20 mm/min which there is total of 9.96 % increase in force. However, the applied force at the speed of 20 mm/min is the same with the applied force at speed of 30 mm/min. At loading speed of 40 and 50 mm/min, the percentage of force raised is 3.26 % and 1.23 % respectively. For blunt nosed impactor, the average force used to penetrate the composite plate was increased as the loading speed increased from 10 to 50 mm/min. Yet, blunt nosed impactor does not achieve the complete perforation on the target material. The force is differing about 1.3 % from loading speed of 10 and 20 mm/min. Besides, that are only a slightly increase in force which are needed for impactor to penetrate the composite plate at 20 to 30 mm/min where the force only increase 0.3 %. The force used in loading speed of 50 mm/min is the most which is 13.58 kN which increase total of 1.12 % from 40 mm/min.

As Figure-8 shows that the force required for conical at different loading are ± 3.25 to 3.58, this shows almost the same in value pattern for conical even at different speed loading. While for hemispherical and blunt, the value of force needed is ± 5.02 to 5.77 and ± 13.09 to 13.58 respectively, there is not much different in forces required to penetrate the target material from loading speed of 10 to 50 mm/min. From the trend shows that loading speed of 30 mm/min is the best speed for quasi-static to respond due to the average force required is closed to that in speed of 30 mm/min. Based on Skreekala *et al.* (2002), the fibers crowding lead to easy debonding at higher loading where increases the impact resistance. The impact fractured portion of the composites was viewed under SEM. Figure-9 to Figure-11 show the scanning electron micrograph of the failure surface at loading speed of 50 mm/min of conical, hemispherical and blunt nosed impactor respectively. Glass fiber debonding and pull-out occur as seen from figures. Decreased adhesion between the glass fiber and the matrix is evident from the surface morphology of the pulled out glass fibers. The work of debonding and pull out needs more energy and thus the energy required increases.

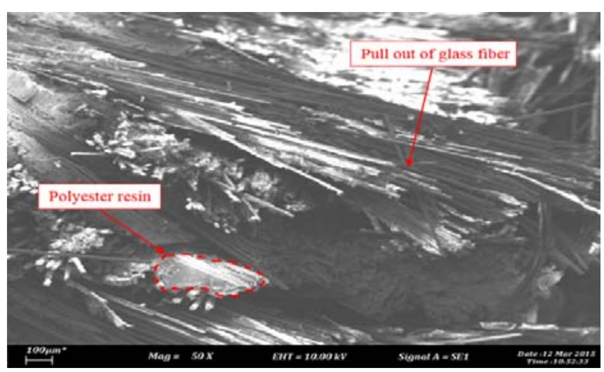

Figure-9. Scanning electron micrographs of impact fractured surfaces for conical nosed impactor.

As the loading speed increased, the adhesive bonding between the glass fiber and matrix become weaker. The work of debonding and pull out of glass fiber needs more energy and thus more force is needed to penetrate the composite plate. The fiber leads to easy debond as the higher loading speed which at higher loading the impact resistance also increased. The brittle of fiber can be seen in Figure-10. In general, the failure characteristic changed from fiber pull-out to fiber breakage. Low bond strength between matrix and fibers and this makes the fibers that fractured away from the crack interface will be pulled out from the matrix at different sections, which may involve more energy dissipation. As force increased, this bond enhancement results in fibers breakage.

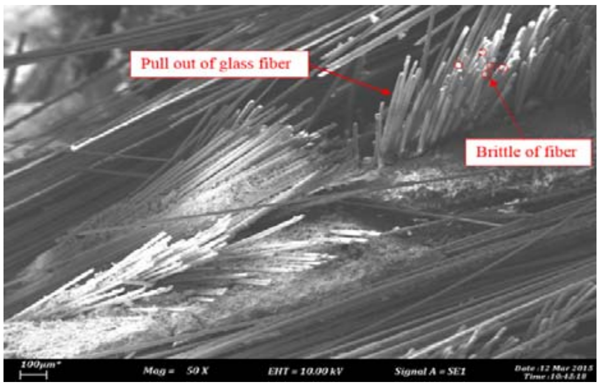

Figure-10. Scanning electron micrographs of impact fractured surfaces for hemispherical nosed impactor.

The fibers which are embedded in the matrix were breakage and pull out occur on the application of the force can be seen from Figure-11. The inter fiber interaction decreases the effective stress transfer between fiber and matrix, this contributes to a decrease in impact properties. Interfacial failure between fiber and matrix and the force which transfer from the broken fiber to surrounded fiber until breakage of fiber occured at the maximum of DoP caused the fiber sustain higher force compared to others.

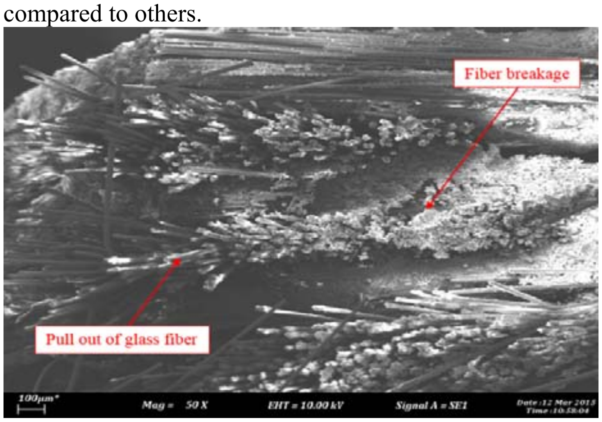

Figure-11. Scanning electron micrographs of impact fractured surfaces for blunt nosed impactor.

The maximum force required to penetrate the target material is found for conical, hemispherical and blunt nosed impactor where blunt nosed impactor required higher force to achieve the penetration followed by hemispherical and conical nosed impactor. The different head of these three impactors results in different surface area in contact with the composite plate. Higher resistance force is found for blunt nosed impactor and it required more energy to cause the fiber breakage. However, at loading speed of 10 to 50 mm/min, the maximum force need for impactors are slightly increased either in conical, hemispherical or blunt shape. This shows the different loading speed did not give much effect to the behavior of fiber breakage.

CONCLUSIONS

In this work, a few points can be concluded as follows;

(a) The conical and hemispherical nosed impactor have penetrated through the target material while blunt nosed impactor do not achieved the complete penetration.

(b) The force required for conical nosed impactor to penetrate the laminated composite is the lowest followed by hemispherical and blunt nosed impactor where the effectiveness of impactor to penetrate the target material is the highest for conical head whereas hemispherical head and blunt head is 15% and 74 % less respectively in comparison. This means that conical nosed impactor required least energy to perforate the target plates. In other words, the penetration resisting force for blunt nosed impactor is the highest.

(c) The different forces needed for each impactor is due the nose area of the impactor. A greater impactor nose area induces a larger plastic zone on the target material. As the impactor nose area increases, the impactor nose surface area in contact with the composite plate during penetration increase. Hence, the resistance of the composite plate to perforate will be increase.

(d) The different energy absorption caused by three different impactors show that conical nosed impactor produced smallest range of plastic zone where hemispherical nosed impactor and blunt impactor create 1.8 % and 11.6 % higher range in plastic zone on the target material.

(e) The first contact of frontal area to the target material is directly affect to the penetration capability. Blunt nosed impactor which has higher frontal area compare to conical and hemispherical nosed impactor lost more energy as the resistance force is highest. Conical nosed impactor which has smallest frontal area incite the force concentration on one area, the specific energy absorption increases with the decreasing in angle.

(f) The trend of finding shows that loading speed of 30 mm/min is the best speed for quasi-static to respond due to the average force required to penetrate the target material is closed to that in speed of 30 mm/min.

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