Evaluation of the Performance of New Laminated Composite Shells for Motorcycle Helmets

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Abstract — Motorcycles are considered a cost-effective and major means of transportation, particularly in the developing countries. However, motorcyclists are at higher risk of head and brain injuries in road crashes, which is the primarily cause of most of the fatalities occurred. Wearing a protective helmet is an efficient way for the safety of the motorcyclist, since it reduces the severity of head injuries through absorbing the impact energy during accidents. The main components of the helmet are the outer shell and the shock absorbing foam liner. The helmet performance depends to a great extent on the enhancement of the properties of the materials used to provide protection. This paper studied experimentally the protection performance of new laminated composite shells compared with that of an Acrylonitrile Butadiene Styrene (ABS) shell. The shell prototypes were fabricated in the form of an open face helmet, composed of a laminated composite structure reinforced with various fabric performs and materials. Expanded polystyrene foam was used for the shock absorbing liner and its compressive properties were examined. The shell prototypes including the foam liner were tested mechanically to investigate their damage behaviour under applying low velocity impacts and penetration loads. Non Destructive Inspection (NDI) methods were used, such as visual inspection and X-ray radiography to detect and evaluate the damages found in the prototypes. It was illustrated that, the laminated composite shell reinforced with the polyester/glass woven fabric and glass fiber mat achieved the best performance, can sustain impact loads and provide better protection to the head from penetration. When compared it with the ABS helmet, it approaches to its effectiveness in protection and the produced shell prototypes are promising for using in motorcycling.

Keyword- Motorcycle Helmet, Composite Shell, Low velocity Impact, Penetration Resistance, Non Destructive Inspection (NDI).

I. INTRODUCTION

Motorcycles are considered one of the main transport facilities, particularly in the developing countries with the increasing of gas price. Motorcyclists are less protected against road accidents compared with vehicles users who are protected by safety belts, airbags and the body structure of the car. It was reported that, motorcyclists are over 30 times more likely to die in traffic crashes than car occupants [1]. Head protection is of vital importance for the motorcyclist safety, where head injuries are common after motorcycle crashes and were estimated to be the main cause in over of 50% of the fatalities seen [2]. Usually, several types of head injury occur simultaneously in a traffic accident and may be divided into cranial injuries (skull fractures) and intracranial “soft tissue” injuries [3]. To improve motorcycle driving safety, many countries mandate the wearing of personal protective equipment such as protective clothing and helmets [4]. Helmets can provide effective protection for the motorcyclist through reducing the severity of head injuries by attenuating head acceleration and distributing the impact force over a larger area of the head. It decreases the risk of head and brain injury by 70 to 88% and facial injury to the upper and mid-face by 65% [5],[6].

Helmets are basically made from two principal components; a thin hard outer shell that provides the defense against the initial impact and spreads it over a large area of the helmet prevents the liner foam fracture and penetration by sharp objects. It holds all the components together and does not disintegrate upon abrasive contact with pavement. During a real accident, skull fracture may be caused by rigid object penetrating the skull such as road posts, tree branches, motorcycle parts, etc. Depending on the extent of the helmet coverage, the outer shell of the helmet may prevent such penetration [7]-[9].The inner foam liner; a soft, thick liner that crushes during an impact, thereby increasing the distance and period of time over which the head stops reducing its deceleration. Expanded Polystyrene (EPS) foams are often considered for the design of the helmet liners due to their capability of providing multidirectional resistance to impacts, combined with light weight and relatively low costs of production [7],[10]. Moreover, the helmet is composed of other parts such as the inner padding which is used for comfort and fitting purpose of different sizes of head .The visor is used to protect the rider's face from wind, dust and insects. The ventilation system which ensures fresh air is ducted into the helmet and exhaled air and humidity are vented out. The retention system serves to keep the helmet firmly on the rider's head [8],[10],[11]. Figure 1 shows the components of a full-face motorcycle helmet.

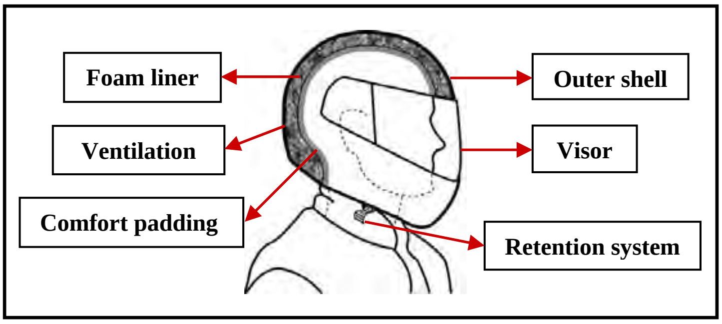

Fig.1. The components of a full-face motorcycle helmet.

Helmet design can be divided into functional like (shock-absorbing capability, penetration resistance, retention and reliability) and non-functional like (low cost, good aesthetics, comfort, light weight and good thermal characteristics) categories [12]. Helmet testing standards were established to evaluate the helmets effectiveness during accidents and almost all the standards follow the same concepts which are; helmet ability to absorb enough impact energy, its retention on the head during accident and its penetration resistance [1]. In helmet market, the dominant outer shell is made of thermoplastics (either Acrylonitrile Butadiene Styrene or Polycarbonate) or composites of epoxy with fibers of glass, carbon or Kevlar. The helmet shells made from composite materials are generally more expensive than the conventional thermoplastic material and have low weight and thickness. When subjected to impact loading, the dominant failure mechanisms taking place in composite laminates are a complex combination of various interlaminar and intralaminar damage mechanisms such as fiber breakage, matrix cracking and delamination. Besides absorbing energy by deformation, the composite shell of helmet also absorbs energy through these damage mechanisms [8]. Gilchrist and Mills [13] studied the structural behaviour and deformation mechanism of thermoplastic and composite motorcycle helmet shells. The composite shell absorbed significantly more energy than the thermoplastic shell and its rebound velocity was smaller due to delamination. Thermoplastics shells can also absorb energy by both buckling and permanent plastic deformation [14]. Kostopoulos et al. [15] have investigated the effect of composite shell stiffness and the damage development during impact on the dynamic response of a composite motorcycle helmet. The composite shells exhibited lower shear performance provided additional absorbing mechanisms and resulted in better helmet behaviour in crashes.

In helmet design, the impact absorption capabilities provided by polystyrene foams can be adjusted by varying the thickness and the density of the material, which are considered the most contributing factors in preventing head injury [16],[17]. The liner should be soft and thick so the head decelerates at a gentle rate as it sinks into it. If the liner is too soft, the head will crush it completely upon impact without coming to a stop. Therefore, an ideal helmet liner is stiff enough to decelerate the impacting head from an abrupt stop into a smooth uniform manner just before it completely crushes [7]. Landro et al. [16] performed compression tests on EPS and obtained detailed deformation mechanisms for each regime of the stress–strain curve. SEM showed that, at 25% strain the cells within the beads did not show evidence of permanent deformation. At a higher compression stage, once densification occurred, complete, permanent cell wall buckling was observed. Some studies focused on investigating the penetration resistance of motorcycle helmets. Yuhazri et al.[18] studied the penetration resistance of bio-composite motorcycle helmet shell reinforced with coconut fibers in epoxy resin matrix . It was found that, the mechanical performance increased as the coconut fibers inside epoxy resin are increased. Because of the increasing utilization of composites in structural applications, Non destructive Inspection (NDI) techniques are widely used to detect and evaluate the internal damages and delamination propagation in fiber reinforced composites subjected to various loads. These techniques include visual inspection, tap testing, ultrasonic testing, thermography, x-ray radiography, etc. [19].

In this paper, an experimental study was performed to investigate the performance of new laminated composite shells proposed for motorcycle helmet compared with an ABS helmet towards low velocity impacts and penetration loads. The shell prototypes were fabricated using laminated composites reinforced with woven fabric and glass fiber mat impregnated in a polyester resin matrix. Expanded Polystyrene foam with different densities was examined for its compressive strength, and used as the liner in the helmet prototypes to enhance the energy absorption properties. The damage behaviour of the laminated composite shells was characterized and evaluated using NDI methods such as visual inspection and X-rays radiography.

II. EXPERIMENTAL

A. Materials

The laminated composite shells were fabricated using woven fabrics weaved with satin 4 structure produced from polyester warp yarns and different weft yarn materials (Polyester, glass and polyamide fibers) and E-glass fiber mat of weight 144 g/m^2. Polyester resin was used as the polymer matrix with Methyl Ethyl Ketone Peroxide as catalyst and Cobalt Napthanate as accelerator. Expanded polystyrene foam was used with various densities (17, 20, 25) kg/m^3.

B. Preparation of the Shock Absorbing Liner

In this study, Expanded Polystyrene (EPS) foam with different densities was examined for its compression properties. The foam density that achieved the best properties was chosen to be molded as the helmet liner. EPS foam is produced from polystyrene beads which expand under the effect of heat and steam. The helmet EPS liner is formed by injection molding process. It was manufactured separately from the helmet prototypes and then was pressed into the shells manually. The produced liner thickness ranges from (25-30) mm throughout the sides to the crown region and weights 70 g. Figure 2 shows the produced EPS foam liner sample.

Fig.2. EPS foam liner sample.

C. Fabrication of the Helmet Shell Prototypes

The helmet shells were prepared in the form of three-layer laminated composite structure, consisted of an upper layer of woven fabric and two layers of glass fiber mat. First, the fabrics were molded in the form of flat panels for the preliminary impact test. After that, the fabric samples were prepared and molded in the form of an open face helmet. The helmet outer shell mold was manufactured as two parts, a positive and a negative type molds as shown in figure 3.The shell mold was designed to be larger to some extent than the foam liner, so the liner can easily fit into the cavity of the shell, which also corresponds to the anatomy of the wearer's head. Polyester resin was used as the polymer matrix mixed with the catalyst and the accelerator. The fabric samples were impregnated with the resin layer after layer, placed in the negative type mold and pressed into the mold by means of the positive mold to achieve the desired shape. The laminated composite shells were left to cure at room temperature for 24 hours.

Fig.3. The helmet shell two pieces mold.

When applying the first attempts for molding the fabric samples to produce the shell prototypes, there were some wrinkles appeared on the upper woven fabric layer of the laminated structure. It caused deformations on the shell surface after molding which will affect on the shells behaviour during applying tests. So in order to reduce these wrinkles, a common style "pinwheel" perform was used, it had proven its efficiency in reducing wrinkles in ballistic helmet performs [20]-[22]. The pinwheel perform used in the study for the helmet shell was consisted of a single continuous piece of the woven fabric divided into nine vanes vary in size, cut up from the center point leaving an uncut area across each direction as shown in figure 4(a). During forming the woven fabric layer, the vanes came close from each other, so their edges almost joined together. Figure 4(b) shows the composite shell prototype after molding and curing. Surface finishing was applied to the shell prototypes to have a smooth colorful surface and clean edges, see figure 5. The shell prototypes were identified with respect to the type of the woven fabric material used in the laminated composite structure. Acrylonitrile Butadiene Styrene (ABS) thermoplastic helmet is used in the comparison with the produced helmet prototypes. Its liner is made from EPS foam with thickness ranges from (10-30) mm throughout the sides to the crown region. Table 1 presents the specifications of the helmet prototypes produced and the ABS helmet used in the study.

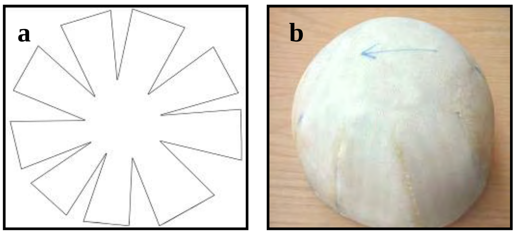

Fig.4. a) The Pinwheel perform used in the helmet shell and b) the shell after curing.

Fig.5. The helmet shell prototypes after finishing.

TABLE 1
Specifications of the Helmets Used in the Study

Helmet material	Thickness (mm)	Weight (g)
100% polyester laminated composite shell + EPS foam liner	(5-6) + (25-30)	920
(Polyester/Glass) laminated composite shell + EPS foam liner	(4-5) + (25-30)	920
(Polyester/Polyamide) laminated composite shell + EPS foam liner	(5-6) + (25-30)	965
ABS helmet shell +EPS foam liner	(6) + (10-30)	1340

C. Mechanical Testing:

1) Compression Test:

The compression test was performed on Expanded Polystyrene foam specimens with different densities according to ASTM D1621-73 [23]. EPS foam cube specimens with (50 x 50 x 50 mm) dimensions were used for testing. The experiments were performed using an Instron type 5500R device. The compressive strength properties were evaluated as a function of the foam density.

2) Low Velocity Impact Test:

Low velocity impact test was carried out on two stages to investigate and characterize the damage behaviour of the produced shells. The influence of the shell material and the foam liner on their ability to absorb impact energy was discussed. The impact tests were performed using a drop-weight impact tester, with an impactor of constant mass 5kg with a hemispherical striker with a tip diameter of 20 mm.

3) Flat Shells Impact Resistance Test:

The impact test was firstly carried out according to ASTM-D7136 [24]. It was performed on flat panels of the laminated composite structures in order to have a preliminary evaluation about their performances. The impact resistance of the specimen was observed and identified in terms of the type and size of the resulting damage. The specimens were clamped at edges to ensure that the imapactor will strike the specimens at the center. The impact energy needed to produce fracture within the specimen (**E**) was calculated from the Eq.; $E = C_E \times h$,

Where; E is the potential energy of impactor prior to drop (J), $C_E = 6.7$ (J/mm) is the specified ratio of impact energy to specimen thickness, and h is the specimen thickness (mm).

The potential energy of the drop-weight is defined by the mass and drop height of the impactor, so the drop height required for the test can be calculated from the equation; $H=E/mg$,

Where; H is the drop height (m), m is the mass of imapactor (kg) and g is the acceleration of gravity (9.81 m/s^2).

The Impact velocity can be calculated from the equation; $V=\sqrt{2gH}$,

Where; V is the velocity of the impactor (m/s).

The energy absorbed by the test specimen is the impact energy and can be calculated from the Eq.; $E_i = 1/2\ mv^2$,

Where; E_i is the impact energy (J).

So the energy level of (16-20) J was chosen for the test and it corresponds to an impact velocity ranges from (2.6-2.8) m/s. After performing the impact tests, the fractured specimens were evaluated via visual inspection to characterize the damages and their extent on the face and back sides of the specimens.

4) Helmets Impact Absorption Test:

In the second stage of the test, after fabricating the helmet laminated composite shells and the addition of the EPS foam liner, their impact resistance was investigated. The shock absorbing test was conducted using drop-weight impact tester on five different impact sites on the helmet shell (crown, front, rear, right and left sides) to assist in having a broad evaluation about the prototypes protection performance as it is followed in most of the international standards. Similar studies were performed to evaluate motorcycle helmets impact resistance [25]. The helmet prototypes were clamped to ensure stability before applying test. The mass was dropped vertically through a freefall of 2m on the helmet prototype positioned onto a headform to give a constant impact velocity of 6.26 m/s. The helmet prototypes performance was compared with that of an ABS helmet. Visual inspection and X-rays radiography were used to detect and characterize the damages observed on the helmet prototypes.

5) Penetration Resistance Test:

Penetration resistance test was carried out on the helmet prototypes according to Snell standards to evaluate their performance [26]. In this test, a striker with sharp pointed head of constant mass is dropped in a guided fall from drop height onto the outer shell of the helmet positioned on a rigid mounted head form. The test striker must not penetrate or achieve a contact with the head form.

All of the pervious tests were carried out in the Material testing laboratory at the Central unit for analysis and scientifically services at National Research Centre.

6) X-Ray Radiography:

X-ray radiography is used for the observation of the interior of materials and detecting cracks and overall delamination propagation after applying loads. It relies on the absorption capabilities of the materials during penetration of radiations through the examined part. The x-ray radiographic image shows areas with various shades of gray between black and white representing different densities of the materials. The helmet shells were radiographed in a Siemens-Heliophos 4E 500ma X-ray machine.

III. RESULTS AND DISCUSSION

A. Compressive Strength:

Figures 6 and 7 present the results of compressive strength test applied on EPS foam specimens of different densities and their percentage of deformation after applying load. It was clear from the results that, the compressive strength of the EPS foam specimens is related to their density, which is a ratio of the foam density to the density of the solid from which it is made. The compressive strength of the foam specimens increased with increasing density, and the EPS specimen with density 25 kg/m^3 recorded the highest compressive strength and the lowest percentage of deformation. This may be interpreted to that, increasing density leads to decreasing cells size, which means more of the solid is contributing to the foam mechanical properties rather than the air gaps within the cells. The EPS foam deformation behavior is related to its linear elasticity that arises from bending in the cell walls [27].

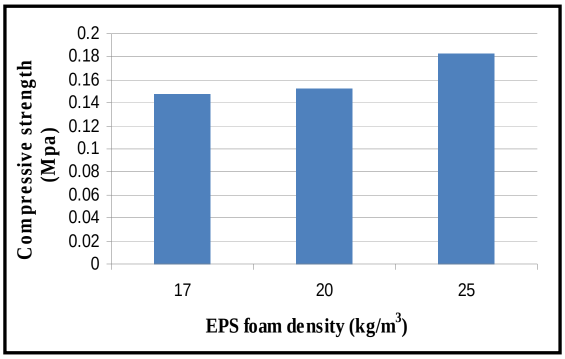

Fig. 6. Compressive strength of the EPS foam specimens.

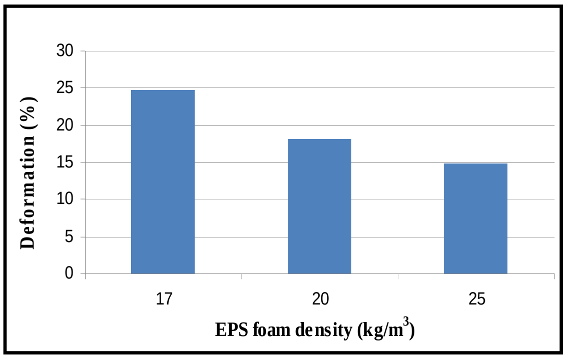

Fig.7. Deformation percentage of the EPS foam specimens after applying load.

B. Impact Resistance Test Results on Flat Shells:

Low velocity impact test was performed to investigate the impact behaviour of the laminated composite specimens used for the helmet shells. Damage was detected for all specimens by using visual inspection and measuring the damage diameter and the dent depth. The damage diameter is the mean value of damage lengths in two main perpendicular directions and the dent depth is measured from the deepest part of the dent to the surface plane. Figures 8-10 show the damaged areas in the front and the back views of the laminated composite specimens after applying the test. Figures 11 and 12 present the damage diameter in the front and back faces of the specimens and the dent depth respectively. The impact energy absorbed by the specimens is equivalent to the incident energy taken up in the formation of damage. The damage resistance of the laminated composite structure depends on the effectiveness of the interface between the fibers and the matrix. It was observed that, the impact loads caused matrix cracking, delamination and fibers breakage in the specimens due to absorbing impact energy. However, the damage resulting from the striker mass has a different effect on the front and the back faces of the specimens due to the laminated composite structures capability of bearing loads. Using woven fabric in the upper layer of the laminated composite structure enhanced in resisting cracks propagation, and the glass fiber mat porous structure assist in good wetting with the matrix and improved the fiber/matrix interfacial bonding. In figure 8, the 100% polyester composite specimen suffered from matrix cracking and delamination in the front and back faces in addition to depression. In figure 9, the polyester/glass composite specimen suffered matrix cracks in both faces, delamination and fibers breakage in the back face and there is no penetration observed in the specimen. It had the smallest damage diameter in the front face area, while in the back face it had the biggest one, although it had the smallest dent depth. This may be related to glass fiber ability to absorb impact energy and the high stiffness of the composite structure produced due to the good fiber/matrix interfacial bonding. In figure 10, the polyester/polyamide composite specimen exhibited damage through matrix cracking, delamination, indentation and fibers breakage in both faces. It has the biggest dent depth compared to the other composites. Also, it was cleared that the extension of damage at the back faces of the specimens is larger than that of the front faces for all the shells specimens, and the dent depth varied due to the reinforcement materials properties, see figures 11 and 12.

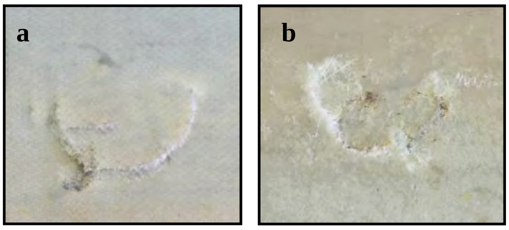

Fig.8. 100% polyester laminated composite specimen; a) front face and b) back face.

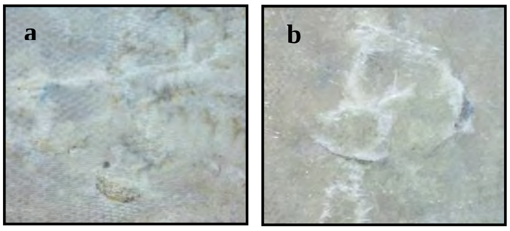

Fig.9. Polyester/Glass laminated composite specimen; a) front face and b) back face.

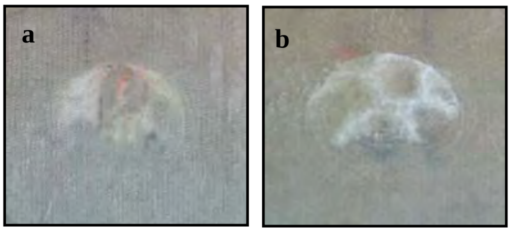

Fig.10. Polyester/Polyamide laminated composite specimen; a) front face and b) back face.

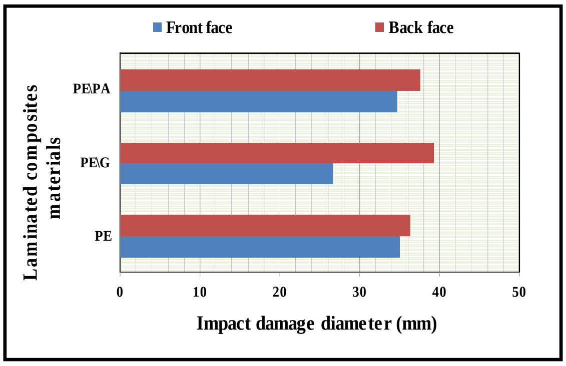

Fig.11. Damage diameter in the front and back faces of the specimens.

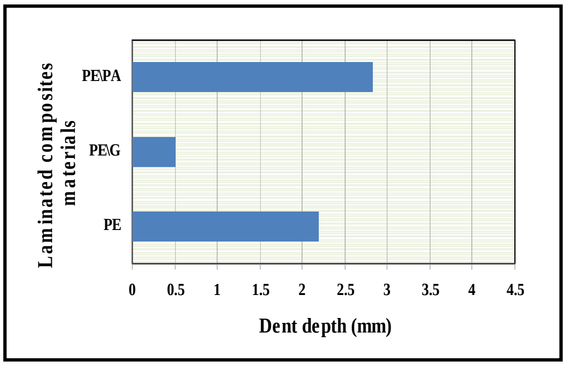

Fig.12. Dent depth of the specimens.

C. Impact Absorbing Test Results on Helmets:

The produced laminated composite helmet prototypes and the ABS thermoplastic helmet were subjected to low velocity impacts, and their damage behaviour was detected by using visual inspection of the damage zone and X-ray radiography. The laminated composite shells absorbed the impact energy through damage mechanisms as clarified in figures 13-21. Figure 13 shows the damages that occurred on different impact sites of the 100% polyester laminated composite shell. At the crown, right side, back and front sites of the shell, the impact load caused matrix cracks and scratches in the painted layer on the shell surface. At the left side of the shell, there are matrix cracks and breakage, delamination and fibers pullout in the lower glass fiber mat layer of the composite structure as observed from the internal view of the shell in figure 14-a. This may be related to the interlaminar shear stress that makes the cracks initiate delamination to the lower glass fiber mat layer and to the fiber/matrix interfacial bonding in this impact point. The EPS foam liner suffered plastic deformation and absorbed a lot of the impact energy on the shell left side, which leads to crushing of the foam cells in this area, and also it was cleared that there is no penetration occurred, see figure 14-b. Figure 15(a-c) shows the X-ray radiograph images of the internal view of the 100% polyester composite shell at the crown, front and right side impact sites to detect the overall damage inside the shell body. It was found that, the dark areas in the X-ray radiograph images presents the impact damages occurred due to matrix cracks and delamination in the left side of the shell. The cracks didn't propagate in the shell body because of the good interlaminar fracture resistance and there is no penetration occurred and this appeared clearly from the different views of the shell.

Fig.13. The impact damages occurred on the 100% polyester helmet composite shell on different impact sites.

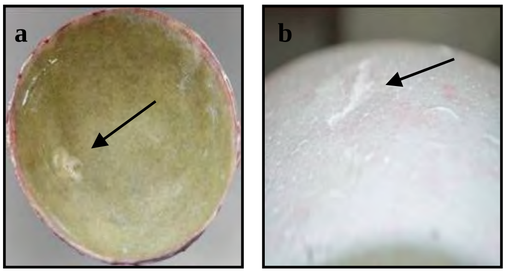

Fig.14. a) The impact damages occurred on the internal overall view of the 100% polyester composite shell and b) the EPS foam liner.

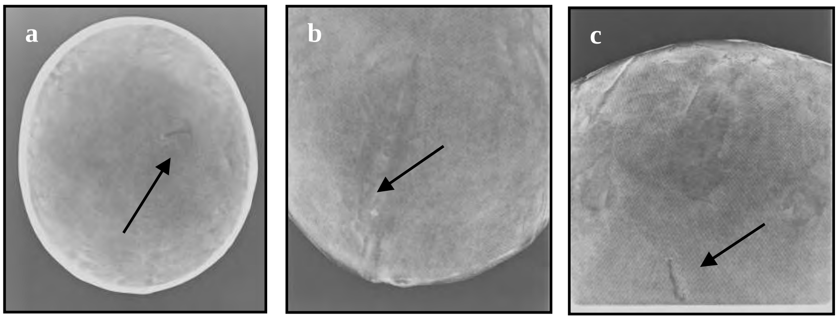

Fig.15. X-ray radiograph for the damages in the internal view of the 100% polyester shell ; a) crown , b) front side and c) right side.

Figure 16 shows the damages that found in different impact sites of the polyester/glass laminated composite shell. At the crown, front, left and right sides of the shell, the impact load caused matrix cracks and scratches in the painted layer on the shell surface. At the back of the helmet, delamination and fiber breakage took place in the lower glass fiber mat layer of the laminated composite structure and the cracks didn't propagate as observed from the shell internal view in figure 17-a. The extent of damage is lower compared with the other shell prototypes and this may be related to the stiffness of glass fiber composites and their ability to absorb impact energy. As mentioned before, using woven fabric in the upper layer of the structure resist penetration and delays cracks propagation. The EPS foam liner absorbed a lot of the energy, and there is no fracture in the liner and no penetration occurred, see figure 17-b. Figure 18(a-c) shows the X-ray radiograph images of the internal view of the polyester/glass composite shell at the crown, front and right side impact sites. The dark areas in the X-ray radiograph images show the impact damages occurred and it was observed that, the cracks didn't propagate in the shell body.

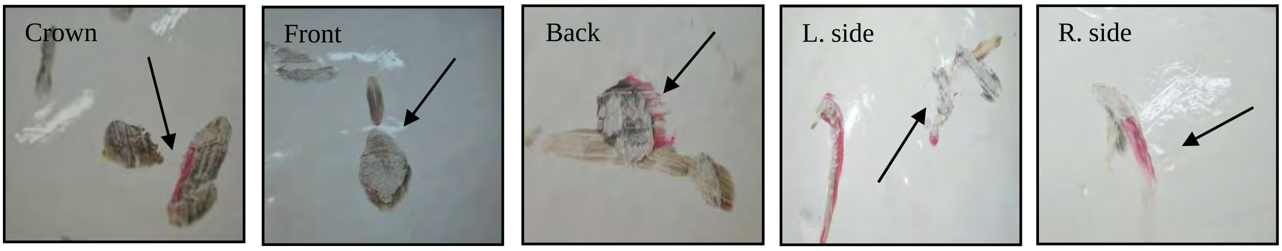

Fig.16. The damages occurred on the polyester /glass helmet composite shell on different impact sites.

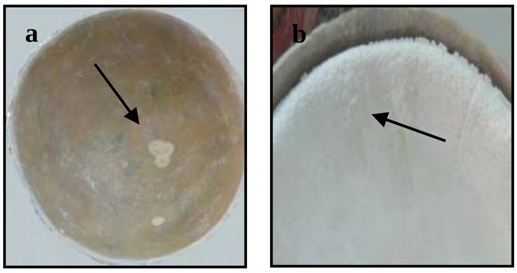

Fig. 17. a) The impact damages occurred on the internal overall view of the polyester/glass composite shell and b) the EPS foam liner.

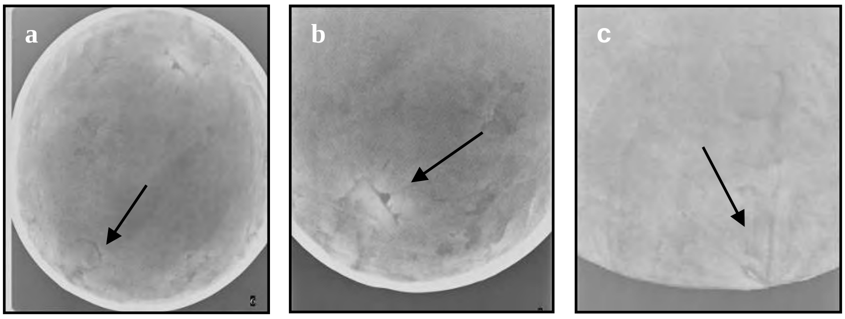

Fig.18. X-ray radiograph for the damages in the internal view of the polyester/glass shell; a) crown, b) front side and c) right side.

Figures 19 shows the damages that occurred on different impact sites of the polyester/polyamide laminated composite shell. At the crown, front, left side and back sites of the shell, the impact load caused matrix cracks and scratches on the shell surface. Polyamide fibers have high elongation to fracture and excellent adhesion to resin which enhance the fiber/matrix interfacial bonding. At the crown and the right side of the helmet shell, there are matrix cracks and breakage, delamination and fibers pull out in the lower layer of glass fiber mat in the composite structure and it was cleared in the shell internal view as shown in figure 20-a.The EPS foam liner absorbed a lot of the impact energy and there is no fracture in the liner body, see figure 20-b. Figure 21(a-c) shows the X-ray radiograph images of the internal view of the polyester/polyamide laminated composite shell at the crown, front and right side sites. The dark areas in the X-ray radiograph images show the impact damages occurred. It was obvious from the different views of the shell that, the cracks didn’t propagate in the shell body and no penetration occurred.

Fig.19. The damages occurred on the polyester/pol

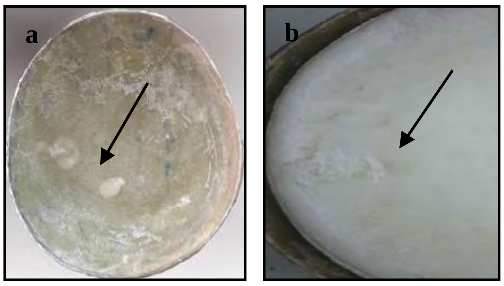

Fig.20. a) The impact damages occurred on the internal overall view of the polyester/polyamide composite shell and b) the EPS foam liner.

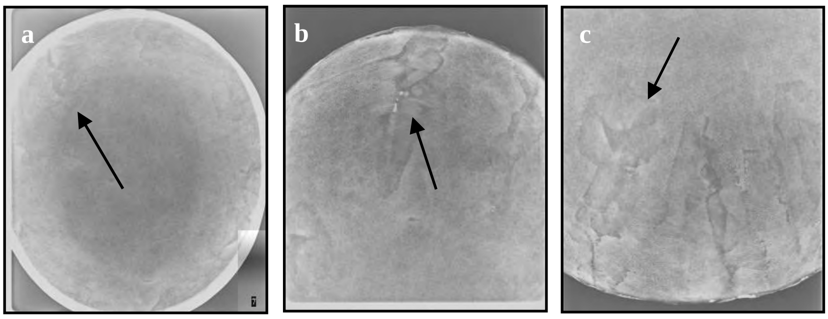

Fig.21. X-ray radiograph for the damages in the internal view of the polyester/polyamide composite shell; a) crown, b) front and c) right side.

Figures 22 and 23 show the impact response of the ABS helmet after applying the test. It was observed from figure 22 that, there are cracks and scratches on the shell surface on the impact sites of the helmet. At the crown and the right side of the helmet, there was plastic deformations appeared. The shell absorbs a lot of the impact energy due to its elasto-plastic nature. The EPS foam liner absorbed the impact energy that leads to crushing of the foam cells in these areas, and there is no fracture observed in the liner body. Figure 23 shows the X-ray radiograph images for the internal view of the ABS shell at the crown and the right side impact sites. It was clarified from the shell views the deformations areas in the shell body and there is no penetration occurred.

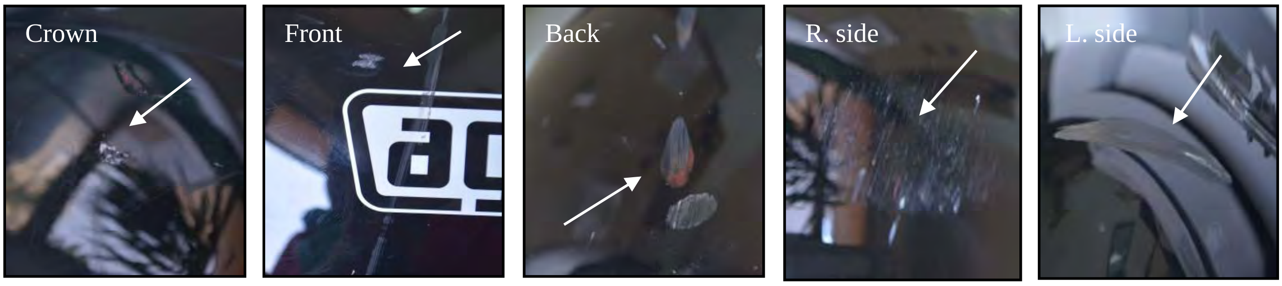

Fig.22. The damages occurred on the ABS helmet at different impact sites.

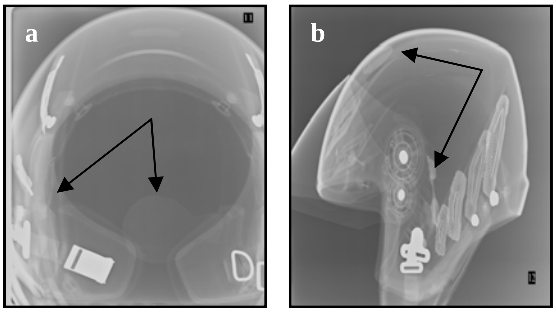

Fig.23. X-ray radiograph for the damages in the internal view of ABS shell; a) crown and b) right side.

C. Penetration Resistance of Helmets:

Figure 24(a-d) shows the damage happened to the helmet prototypes after applying the penetration resistance test. The penetration resistance of the shell prototypes varied depending on the properties of the laminated composite structure. During applying load, penetration took place when the impact energy applied by the striker is absorbed by the composite laminates and its resistance to penetration came in the forms of damage or delamination in the laminated composite layers. It was revealed from figure 24(a-c) that, the penetration load caused matrix cracks , delamination and fibers breakage in the composite shells with various degrees of deformation as a result of absorbing the impact energy, but it stopped at the EPS foam liner with no fracture. It varied from one shell to another depending on the reinforcement materials which differs in thickness due to the hybrid woven fabrics used. Also, the addition of woven fabric with stain weaves in the upper layer of the composite structure had worked on resisting penetration, delaying cracks propagation and preventing the splitting of the damage due to the tightness of the weaves. The EPS foam liner absorbed the impact energy causing crushes in the cells without penetration in the liner body, and this is related to the foam density and thickness. The polyester/polyamide composite shell showed more penetration resistance followed by the polyester/glass composite shell. The ABS helmet shell resisted penetration and the striker caused cracks on the shell surface without penetration, see figure 24-d.

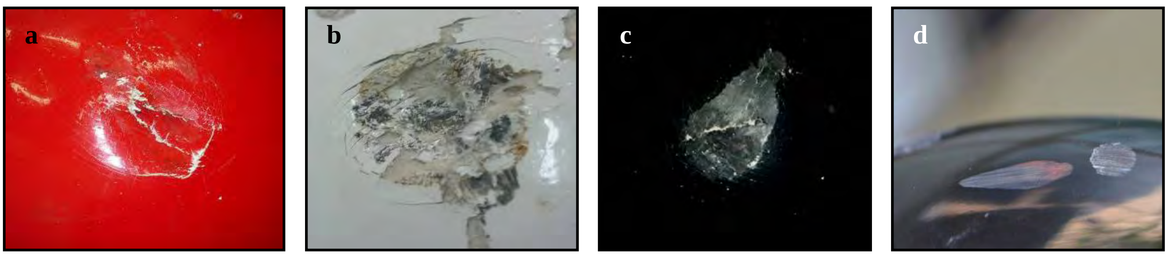

Fig.24. The damages occurred on the helmet prototypes after applying penetration test; (a) 100% polyester helmet, (b) Polyester/glass helmet,(c) Polyester/polyamide helmet and (d) ABS helmet.

In comparing the proposed laminated composite helmet prototypes with the ABS helmet, it was found that the weight and the thickness of the produced laminated composite shells with the addition of the EPS foam liner is lower than the ABS helmet with the foam liner. The composite shell prototypes are stiffer than the ABS shell; they spread the loads and absorb the impact energy through the damage mechanisms occurred. The EPS foam liner absorbs the remaining of the impact energy without occurrence of penetration. So it was revealed that, the produced helmet prototypes succeeded in their functional performance in terms of providing protection. On the other hand, the ABS helmet was better in penetration resistance.

IV. CONCLUSION

Motorcycle helmets are found to be effective in reducing the risk of death and the severity of head injuries resulting from road crashes. The helmet protection performance is relying on its ability to resist impact and penetration loads, which directly related to the motorcyclist safety. The study aimed to investigate the performance of new laminated composite shells for motorcycle helmets towards low velocity impacts and penetration loads. The tests were carried out using drop weight impact tester. EPS foam with different densities was examined for its compressive strength to be used as the helmet shock absorbing liner. The shell specimens were studied and evaluated using visual inspection and X-ray radiography. The study illustrated that, the woven fabric materials used in the reinforcement and the fiber/matrix interfacial bonding greatly affect on improving the shell prototypes performance. It was clarified that, the laminated composite shell produced from the polyester/glass woven fabric and glass fiber mat provided better protection to the head from impacts compared with the other prototypes, and it offers better protection from penetration load followed by the polyester/polyamide shell. Hence, the helmet prototype was effective in providing protection and approaches to the ABS helmet protection performance, in addition to its low weight and thickness.

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