

Energy Absorption at Different Impact Locations of Riot Helmet Shells

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Abstract It has been already established that continuously textile reinforced helmet shells have shown its significance over discontinuous helmet shells. This paper is a part of research carried out for the evaluation of riot helmet shells having continuous textile reinforcement. ABAQUS, finite element software, has been used for simulation and model creation. Force transmitted and energy absorption at three different impact locations of the helmet shells were evaluated from the finite element model and validated by experimental testing. Significant correlation in between finite element results and physical impact testing results has been achieved. The finite element outcome displays the helmet top location is the least susceptible location against the impact as compared to the helmet side and helmet back location.

Keywords Helmet Shells, Continuous Textile Reinforcement, Finite Element, ABAQUS, Simulation, Energy Absorption, Force Transmitted

1. Research Background

Not much literature has been written on the continuously textile reinforced helmets[1]. An innovative, effective and modest method of making a single-piece continuous textile reinforced helmet shell using vacuum bagging has been established and discussed by Zahid and Chen[2]. A number of wrinkle-free single-piece composite helmet shells from angle-interlock fabric have been manufactured from the modified vacuum bagging technique. Furthermore, mechanical and physical properties of the developed composite structures from angle interlock fabric has been calculated and analysed[3]. These properties can be used in making a finite element simulation. A single-piece continuously Kevlar reinforced helmet shell can be viewed in Figure 1[2].

In order to evaluate an impact performance of produced helmet shells, an impact test rig was developed[4]. Sensors were mounted on side, back and top of the testing headform developed following the standard BS EN 960:2006[5]. The developed test rig can be seen in Figure 2. The experiments were also conducted and published[4].

In the drop weight system, potential energy of the system is converted into kinetic energy during an impact onto the sample. Energy absorption can be calculated by integrating the closed area of the load deflection curve[6]. Force

transmitted can be used for the evaluation of force attenuation factor which has been discussed by several authors[6-9]. A lesser value of attenuation factor corresponds to larger impact force being transmitted through the specimen (0% means all forces transferred and 100% means no force transferred).

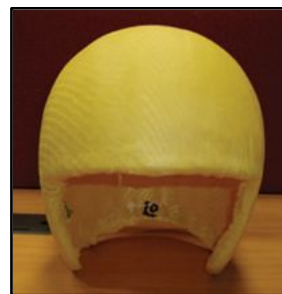


Figure 1. Single-piece helmet shell having continuously textile reinforcement

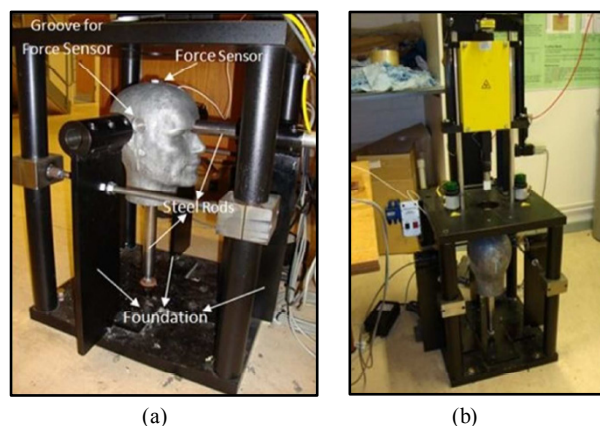


Figure 2. Helmet test rig (a) side view (b) front view

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2. Research Objectives

The literature review recommends that finite element analysis is a dynamic tool for the virtual investigation, since a validated FE model from experimental results will give a deeper understanding[10, 11]. Therefore, in current research paper, finite element (FE) method was used to model helmet shells, results of which are compared and validated by the published experimental results[4]. ABAQUS software was chosen for generating simulations due to its Microsoft windows interface and also due to availability in the University of Manchester.

For present study, the basic idea was to calculate the impact energy absorbed and force transmitted by the composite laminates through simulated models. Moreover, results have to be validated from the experimental data.

3. Model Creation and Simulation

In this research, impact performance with respect to force transmission and energy absorption, at different impact locations on the helmet shells are investigated. Physically riot helmet shells were tested on the developed helmet testing instrument and virtually by means of FE simulation at ABAQUS software. Focus of current research is the energy absorption instead of damage mechanism. Abaqus / Explicit method was used in order to develop simulation.

In this study the ABAQUS/Explicit product was used which has three stages, which includes; pre-processing, simulation and post processing. One of the advantages of ABAQUS/Explicit as used is that it can convert or import geometries in to the ABAQUS/CAE environment. Further, ABAQUS/Explicit is used for simulating impact problems [12]. In current study, the simulated different parts have been developed in Rhinoceros software and then imported to Abaqus.

The helmet shell created in Rhinoceros software can be seen in Figure 3.

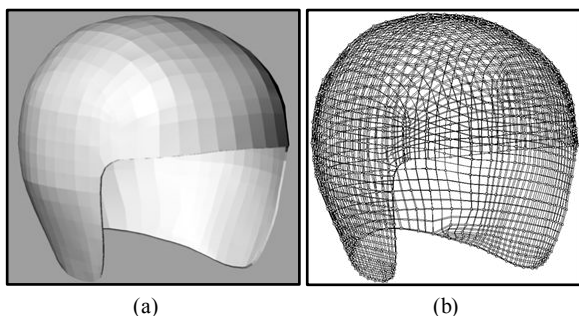


Figure 3. Developed riot helmet shell in Rhinoceros Software (a) with render (b) without render

Similarly, the headform coordinates were sourced from EN 960:2006 standard[5] and generated via Rhinoceros. The headform was given details of a solid material having aluminium properties. Aluminium headforms are normally used by several authors[13-15]. Developed headform can be viewed in in Figure 4.

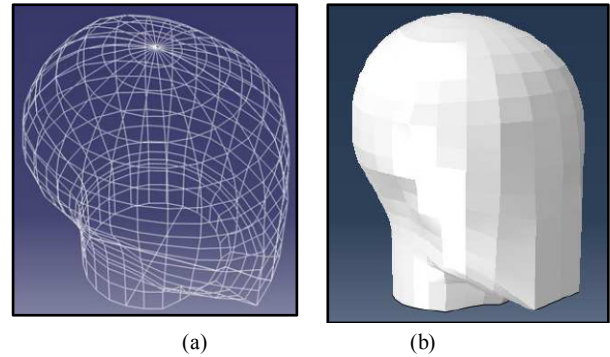


Figure 4. Development stages of Headform(a) Wire structure headform (b) Solid headform

The impactor was generate and designed in ABAQUS as in Figure 5, as a flat rigid cylindrical impactor of mass 4.66 kg. The dimensions of the impactor were 25 mm diameter and 67.5 mm height, similar to the impactor used in experimental tests.

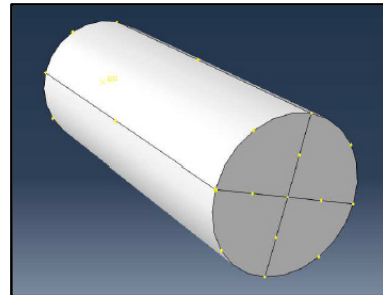


Figure 5. Flat impactor

A small part was created and attached on the top of the headform by means of a tied command in ABAQUS, similar to the force sensor used in experimental analysis.

The properties for the helmet shell were obtained from the research work by Zahid and Chen[3] and calculated according to the method considered by several authors[12, 16, 17].

Kevlar Composite Material, density $\rho = 1.229 \text{ gm/cm}^3$
 Modulus, weft direction, $E_1 = 36938.301 \text{ MPa}$
 Modulus, warp direction, $E_2 = E_3 = 7793.701 \text{ MPa}$
 Poisson Ratio (weft to warp), $\nu_{12} = \nu_{13} = 0.356$
 Poisson Ratio (warp to weft), $\nu_{21} = 0.075$
 Poisson Ratio (warp to thickness), $\nu_{23} = 0.108$
 Inplane Shear Modulus, $G_{21} = G_{12} = G_{13} = 1379.255 \text{ MPa}$

Inplane shear, warp to thickness, $G_{23} = 3516.808 \text{ MPa}$
 Where,

$$\nu_{12} = (\nu_f \times \nu_r) + (\nu_r \times \nu_r)$$

$$\nu_{21} = (E_2 / E_1) \times \nu_{12}$$

$$\nu_{23} = \nu_{12} \times ((1 - \nu_{21}) / (1 - \nu_{12}))$$

$$G_{23} = [(E_2) / \{2 \times (1 + \nu_{21})\}]$$

ν_f is Poisson ratio, Kevlar 49[18] = 0.36

ν_r is Poisson ratio, Aradur 5052 and Araldite LY5052[19] = 0.35

In this model a tetrahedral shape mesh is used because it is the appropriate mesh shape for three dimensional parts[12]. Encastre boundary conditions were given at the neck and

helmet shell edge as shown in Figure 6. A cross sectional view of the simulated model in Abaqus CAE environment can be viewed in Figure 7.

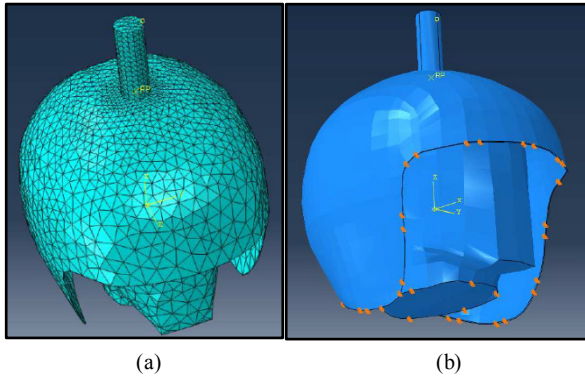


Figure 6. Simulated pictures (a) Meshed parts (b) Boundary conditions

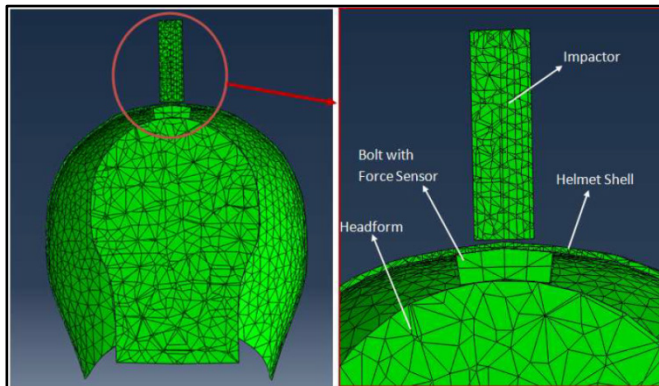


Figure 7. Cross-sectional view of the simulated model

A simulated model can be seen in Figure 8.

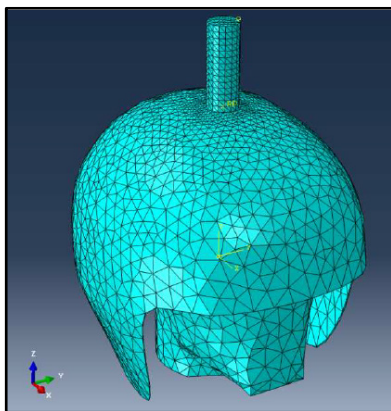


Figure 8. Top impact helmet location

4. Simulated Results and Validation with Experimental Results

Finite element (FE) simulation has been executed with three different impact energies 5.5J, 15.5J and 25.5J. Impact was conducted at three different locations on the developed helmet shells namely, the top location, the back location and the side location. The results generated from the simulated models were put together with the corresponding

experimental results to look for similarities between them. In this way 9 models have been simulated and the results for the percentage energy absorption are illustrated in Table 1.

Table 1. Simulated results of helmet shells for energy absorption

Impact Location	Energy of Impactor (J)	Absorbed Energy by the helmet (J)	Energy Absorption
Helmet Top	25.5	21.038	82.502%
Helmet Back	25.5	19.485	76.411%
Helmet Side	25.5	19.108	74.932%
Helmet Top	15.5	12.270	79.161%
Helmet Back	15.5	11.941	77.039%
Helmet Side	15.5	11.826	76.296%
Helmet Top	5.5	4.613	83.871%
Helmet Back	5.5	4.389	79.791%
Helmet Side	5.5	4.305	78.266%

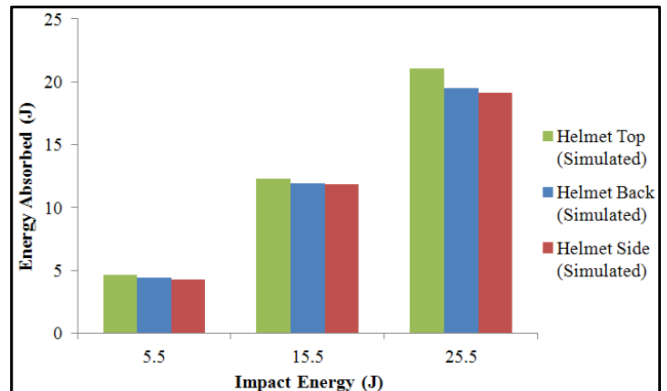


Figure 9. Energy absorbed by the helmet shell at different locations

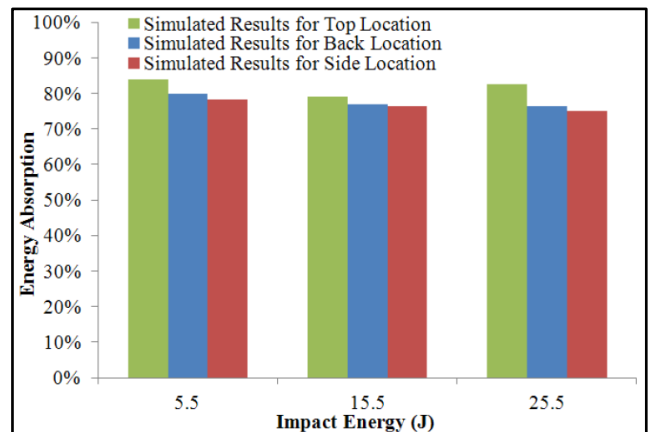


Figure 10. Percent energy absorption for helmet shell

Figure 9 and Table 1 shows that with higher energy impacts, helmet top surface absorbs more impact energy. The helmet shell side absorbs the least amount of energy. At every location energy absorption is increased with the increase of impact energy. Moreover, the percentage energy absorption in Figure 10 also shows similar trends at each energy level. These results show that the helmet top location is the least vulnerable position against impact. More

importantly, these results are very similar to the results obtained from the experimental test data and are compared in Figure 11.

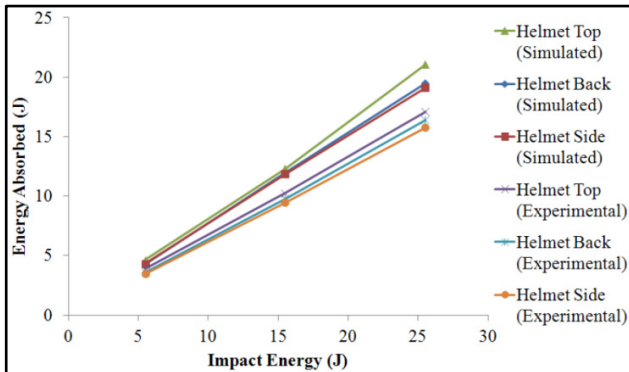


Figure 11. Comparison of energy absorption results for helmet shells at different helmet locations

experimental results, and simulated trends are near and similar to the experimental results.

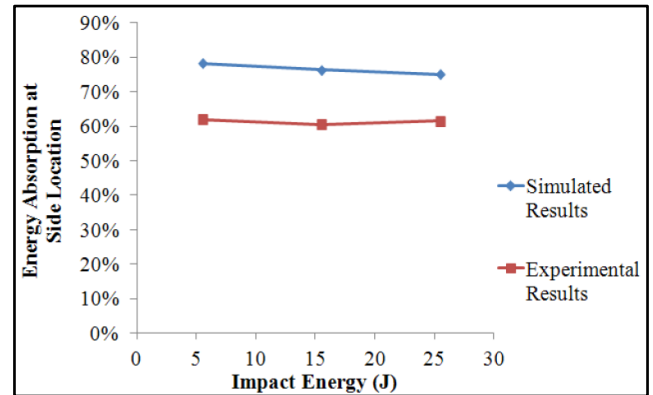


Figure 14. Percent energy absorption at Side location on helmet shells

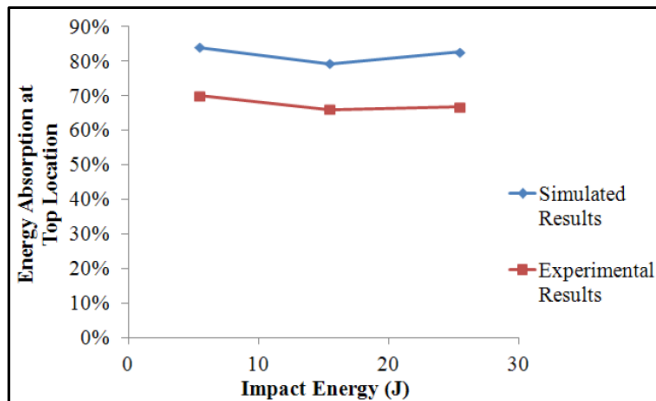


Figure 12. Percent energy absorption at Top location of helmet shells

The force transmitted at different helmet locations has been obtained and compared with the experimental results. Force transmitted has been obtained from the top surface of the force sensor which touches the inside surface of the helmet shell. In Figure 15, Figure 16 and Figure 17, it can be observed that the force transmitted also has a similar trend. However, there is difference in the magnitude of the peak force transmitted. This seems to be true being due to the fact that in simulations the helmet shell has been taken as one composite entity with a solid surface whereas, in reality the composite structure is made-up from AI-fabric which transfers the load throughout its inherent weave structure. Moreover, the reason to explain this kind of difference could be that FE simulation is a much simpler approach to the real situation.

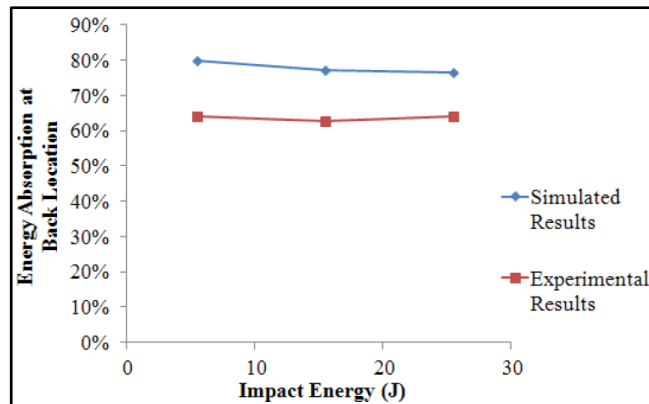


Figure 13. Percent energy absorption at Back location on helmet shells

Figure 11 show that the simulated energy absorption has similar trends as compared to the average experimental results. The top location seems to absorb more impact energy as compared to the other two locations. This may be due to the fact that the top impact location is at greater distance from the shell edge as in comparison to other locations.

It can be observed that simulated and experimental percentage energy absorption shares similarities. The results for percentage energy absorption in Table 1 are compared with the experimental testing and shown in Figure 12, Figure 13 and Figure 14. Simulated results have greater values than

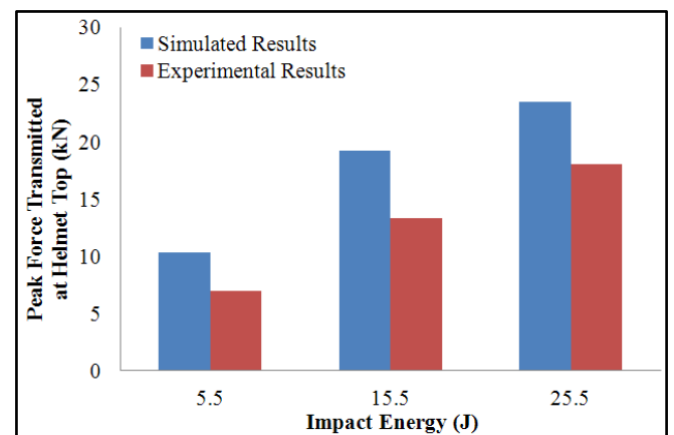


Figure 15. Force transmitted results at Top location on helmet shells

Impact performance of the helmet shells having continuous textile reinforcement can be characterised by the impact location. From the experiments both virtual and physical, the helmet top position appears to be the least susceptible impact position on the helmet shell.

It should be noted that the distance of the impact top location from the shell edges is larger than the side and back impact locations. Due to fact the impact at the top impact location is dispersed to a wider area and causes better impact performance. Due to this reason, to bend the helmet top

surface, more impact force is required and due to this reason usually less force will be transmitted to the head. Moreover, due to the advantage of single-piece continuously textile reinforcement and no discontinuity till the shell edges, makes the helmet top impact position to be least threatening impact position. The helmet side and back impact locations attract more attention compared to the top location for better impact performance. Improving the helmet shell stiffness could result in better impact performance.

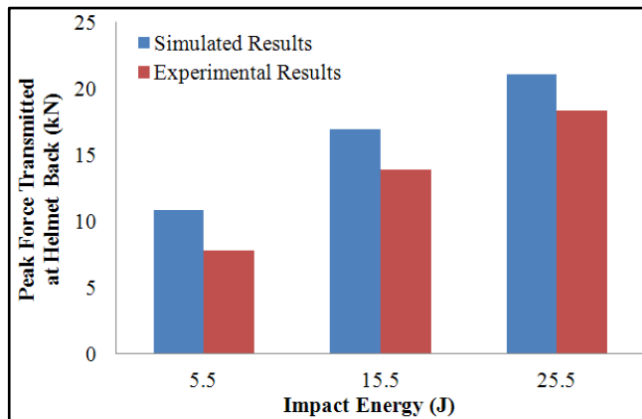


Figure 16. Force transmitted results at Back location on helmet shells

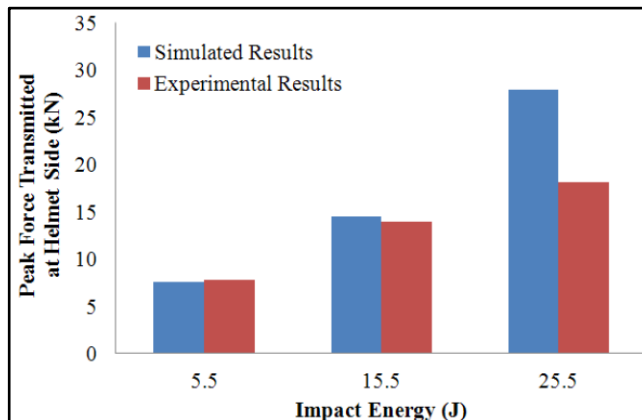


Figure 17. Force transmitted results at Side location on helmet shells

5. Conclusions

The research was carried out to develop an impact simulation and its validation through practical testing. The simulated models were validated by the experimental data. The results revealed that the simulation generally correspond and shows the similar trends as the experimental results although there are some imprecisions due to the simplification of the simulated model compared to the real impact on the developed helmet shells.

Impact simulation shows similar energy absorption trends as compared to the experimental results. The helmet top impact has been to be the safest position in respect of low energy impact if compared to the helmet back and the helmet side locations. Creation of models in ABAQUS has shown an effective way of analysing the impact properties of a riot helmet shell in terms of energy absorption and force

transmission.

In this paper successful riot helmet shell models have been generated and developed impact simulations were successfully validated by experimental results.

6. Funding

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