Impact properties of continuously textile reinforced double fabric layered riot-police-helmet-shells

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ABSTRACT – REZUMAT

Impact properties of continuously textile reinforced double fabric layered riot-police-helmet-shells

The manuscript is a section of research completed for the overall impact performance of riot-police-helmet-shells having continuously textile reinforcement. In this research paper, manufacturing of double fabric layered helmet and its impact analysis has been discussed. Moreover, energy contained and blocking forces at various zones at the police-head protector shells were assessed. Results are also compared with the previous work for the impact evaluation of single piece riot-police-helmet-shell. The comparative results show significant difference in values in comparison with single layered riot-police-helmet-shell. These results can lead to the development of Riot-police-helmet-shells that can resist high velocity impact.

Keywords: *impact, force blocking effectiveness, energy absorption, textile reinforcement, continuous, helmet*

Proprietățile de impact ale căștilor polițiștilor de la ordinea publică fabricate din țesătură întărită continuă, dublu stratificată

Lucrarea este o cercetare finalizată asupra performanței generale de impact a căștilor polițiștilor de la ordinea publică, care sunt fabricate din țesătură întărită continuă. În această lucrare de cercetare, s-a discutat despre fabricarea căștii cu strat dublu de țesătură și analiza impactului acesteia. Mai mult, a fost evaluată energia conținută și forțele de blocare în diferite zone ale căștilor de protecție. De asemenea, rezultatele sunt comparate cu lucrările anterioare pentru evaluarea impactului căștilor de protecție cu un singur strat. Rezultatele arată o diferență semnificativă de valori în comparație cu casca cu un singur strat. Aceste rezultate pot duce la dezvoltarea de căști pentru polițiștii de la ordinea publică care pot rezista impactului la viteze mari.

Cuvinte-cheie*: impact, eficiență de blocare a forței, absorbție de energie, armare textilă, continuu, cască*

INTRODUCTION

The purposes of riot-police-helmets are to shield the police officers from head damage. Harm to a person's head can cause indications, for example, cerebrum injuries and skull misshaping [1]. Problems like cerebra-concussion are the main reason due to the inertial effects in which due to movement of the brain and can lead to injury in brain tissues. These impacts can prompt loss of human body capacities or physical issue of neural tissues and the casualty can have unpleasant impacts. For police officers, brain protection has supreme importance due to vulnerable to thrown objects.

Riot is a violent disturbance of the peace by a crowd. Disturbances caused by disorganised rioters are normally destructive and continuously have created an intense situation. The nature of riots varies all from one place to another in the world. However, police officers have to control the situation. Frequently, while comforting depressed rioters, usually police officers have physical contact with the rioters.

The police use different techniques and tactics to control the crowd. These techniques for handling or calming down people may be also different for different regions depending on culture, environment and laws of that particular country or region. The dressing of police officers includes limb protectors, face shield, helmets and body armour. A huge number of mob protective helmets are required for cops in the United Kingdom. Each officer who is a member of riot squad must have a helmet for head protection. Demand for riot helmets is also increasing in other countries. Cost effectiveness, wearer comfort, light weight and impact protection are the basic requirements for helmet qualities.

HELMET SHELL MANUFACRTUIRNG

Current study was a phase onward for the manufacturing of continuous reinforced textile riot-police-helmet-shells. Angle interlock (AI) fabric (5-layer) was prepared on conventional shuttle loom – "Arbon 100W" made by Adolf Saurer^{TM}. Para-aramid Kevlar roving type 49 supplied by DuPont^{TM} is used for warp and weft yarns. Moreover, single-fabric layered (continuous reinforced) textile reinforced composite riot-police-helmet-shells were successfully established by modified vacuum bagging setup [2]. Additionally, mechanical and physical characteristics of the established composite flat-panels from Al-fabric (5-layer) has been examined [3]. In figure 1 [2], single-fabric layered riot-police-helmet-shell can be seen. Riot-police-helmet-shells were tested in University of Manchester's Instron Dynatup on modified drop weight impact testing device [4]. Moreover, the main aim of this paper is to compare the already developed single-fabric layered riot-helmet shells [5] with newly developed double-layered riot helmet shells.

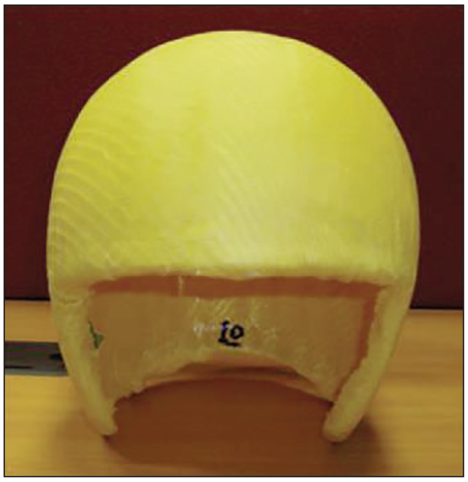


Fig. 1. Developed textile reinforced riot-police-helmet-shell

Double-layered composite riot helmet shells have been developed by conforming two fabric layers on a collapsible mould, followed by vacuum assisted draping and resin infusion. This technique was similar to the technique developed for manufacturing single-piece riot helmet shells [2]. The only difference was the draping of two layers of 5-8-28 angle-interlock fabric on the mould before vacuum bagging for composite manufacturing. Araldite LY5052 and Aradur HY5052 was used as epoxy and hardener respectively. To enhance the shell stiffness, helmet shells were further cured in the drying oven at 100°C for 4 hours.

REQUIREMENT OF DATA HANDLING

Essentials of drop weight impact test

Drop weight instrument works on the energy conversation principle. Impact velocity and dropweight head impact energy when initially it drops onto the specimen can be evaluated from equations 1 and 2:

$$E = \frac{1}{2} \cdot m \cdot v^2 \qquad (1)$$

$$v = \sqrt{2gh} \qquad (2)$$

At the point of impact onto the specimen, all the potential energy is converted into kinetic energy in a drop weight impact machine. Since, the motion of impactor is free fall, friction is taken as zero. The ratio of energy absorbed by the specimen to the impact energy gives energy contained in the specimen.

Force blocking effectiveness (Force Attenuation Factor, FAF)

Transmitted force F_t can be obtained from implanted sensor in the headform installed in the modified machine and impact force F_i was obtained by the load-cell installed on impactor assembly. Force-blocking effectiveness or attenuation factor, f_{att}, and can be determined from the equation 3:

$$f_{att} = \left(1 - \frac{F_t}{F}\right) \cdot 100 \qquad (3)$$

where F_t is transmitted force thru the specimen, F – force collected on the anvil without any specimen.

Several scientists used force attenuation [6–9]. A higher number of FAF corresponds to less force being transmitted through the sample, and a smaller number of FAF indicates plentiful of the impact force has been transferred through the sample (0% equals all forces transferred and 100% equals no force transferred).

Calculation for energy absorption

Contact force or load commonly known as impact force is calculated from:

$$F_i = m \cdot a \qquad (4)$$

where a is acceleration of free fall impactor and m – mass of impactor.

Load deflection curve gives the energy absorption [9]. Absorbed energy is calculated from the zone beneath the load-displacement chart as can be seen in figure 2.

$$E = \sum S_i = \frac{1}{2} \sum_{i=0}^{n} (F_i + F_{i+1})(y_{i+1} - y_i) \qquad (5)$$

where, F_i is contact force applied on the sample, S_i – trapezoidal zone, E – absorbed energy and Y_i – displacement increment.

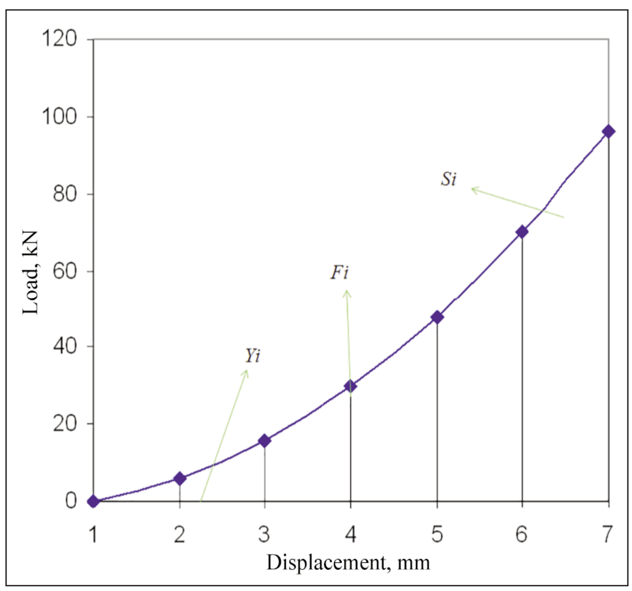


Fig. 2. Energy absorption graph for trapezoidal method

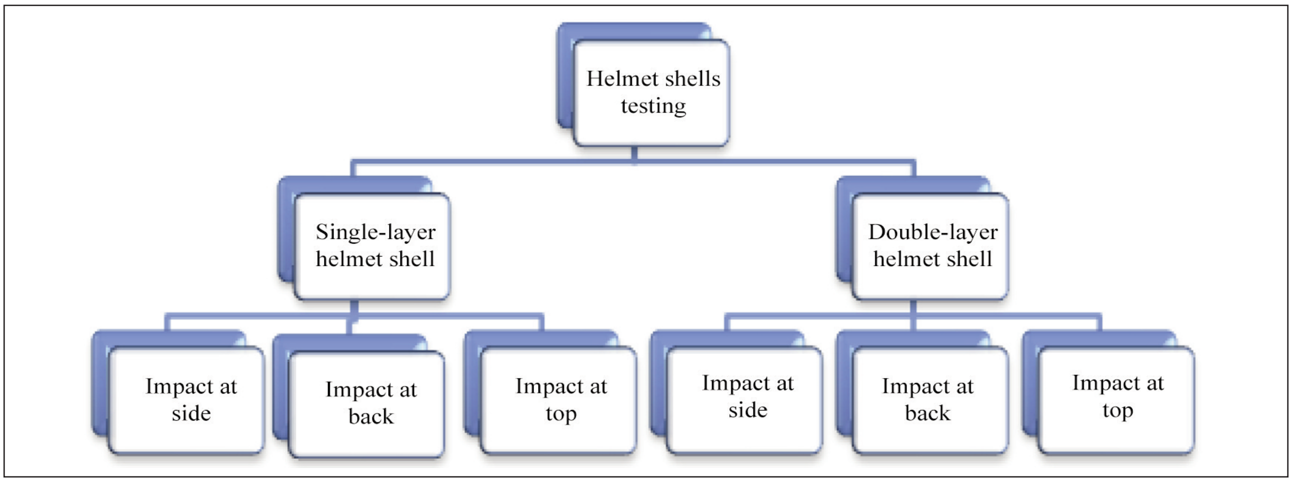


Fig. 3. Categories of developed riot-police-helmet-shells and zone for impact testing

EXPERIMENTAL RESULTS OF HELMET SHELL TESTING

The developed riot-police-helmet-shells were impacted at three different zones namely; helmet top, helmet side and helmet back with impact energies of 25.6 J approximately. Testing conditions were kept similar to the flat composite panel testing. Two different categories of composite riot-police-helmet-shell were developed. One was the single-layer riot-police-helmet-shell developed from a single-layer of 5-8-28 angle-interlock woven fabric. The second variety of riot-police-helmet-shell was developed from two layered of 5-8-28 angle-interlock woven fabric and double-fabric layered riot-police-helmet-shell. This variety was produced by overlapping two 5-8-28 layered fabric in the vacuum assisted draping technique.

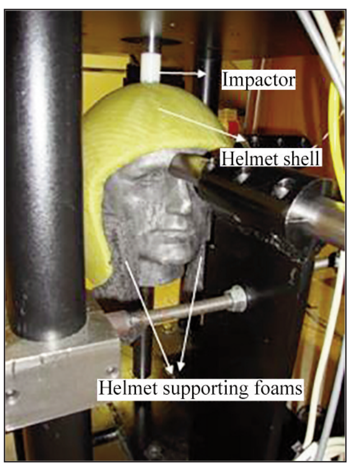


Fig. 4. Testing of riot-police-helmet-shell

Impact energy of 25.6 J was used to test helmets shells and impact tests were conducted at three different zones. The riot-police-helmet-shell categories along with the impact zones can be seen in figure 3.

ENERGY ABSORPTION

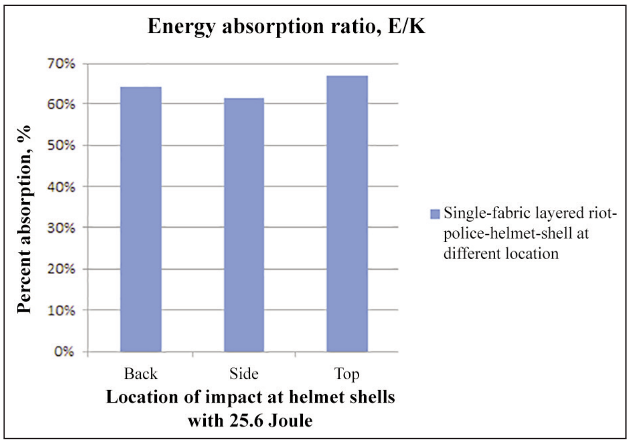
The testing of Riot-police-helmet-shells were carried out on the modified Instron testing machine in the University of Manchester. The riot-police-helmet-shells were impacted with approx. 25.6 J of impact energy at different impact zones. The Low impedance voltage mode system and Impulse data acquisition system were used to extract results. The average results for energy absorption for various experiments are listed in table 1.

Figure 5 and table 1 show the energy absorption performance (average values) at different impact zones on riot-police-helmet-shells in which greater energy absorption performance at the upper helmet zone as related to the side and back zones. However, in both varieties of riot-police-helmet-shell, the side zone of helmets absorbs lesser impact energy with respect helmet top and helmet back zones. It should be noted, the helmet top zone has the maximum curvature intensity. It seems that curvature intensity is also influencing in energy absorption at the riot-police-helmet-shell top (upper) zone. In general riot-police-helmet-shell is a dome-shape structure. Dome-shape

Table 1

EXPERIMENTAL DATA FOR ENERGY ABSORPTION RATIO

Type of riot-police-helmet-shell	Zone	Impact energy (J)	Energy absorbed (J)	Energy absorption ratio (%)
		K	E	E/K
Single-layer riot-police-helmet-shell	Back	25.64	16.40	63.96
Double-fabric layered riot-police-helmet-shell	Back	25.62	18.19	70.97
Single-layer riot-police-helmet-shell	Side	25.64	15.77	61.49
Double-fabric layered riot-police-helmet-shell	Side	25.63	16.04	62.57
Single-layer riot-police-helmet-shell	Top	25.61	17.07	66.65
Double-fabric layered riot-police-helmet-shell	Top	25.58	18.36	71.76



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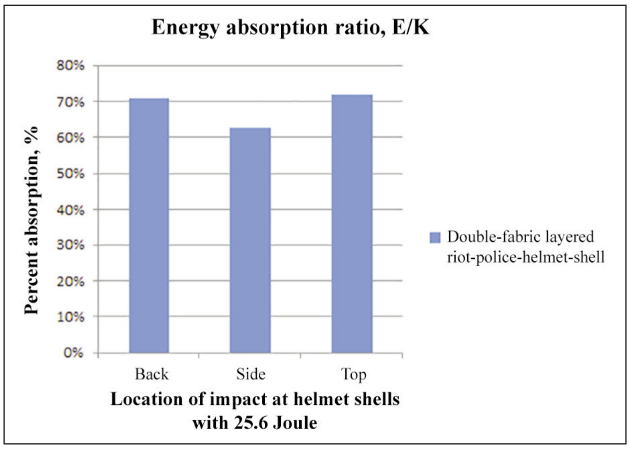

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Fig. 5. Graphs of energy absorption of riot-police-helmet-shells at various zones on: *a* – single-fabric-layered riot-police-helmet-shells for 25.6 J energy; *b* – double-fabric-layered riot-police-helmet-shells for 25.6 J energy

structures are normally used in construction due to their inherent characteristics of supporting both in tensile as well as in compressive loads. The double-fabric layered riot-police-helmet-shells more or less behaves like the same as single-fabric layered riot-police-helmet-shells.

This can also be noted that in both the varieties of helmets (single and double fabric layered) shows, top impact zone as the better one as related to the other two back and side zone. One more reason for this phenomenon can be due to the fact that the top area is at the farthest position from the shell edges and also it has more fabric area to dissipate the energy till the edges.

Double-fabric layered riot-police-helmet-shells follows the same track of results as in single-fabric layered riot-police-helmet-shells i.e. helmet top impact location is much better than the other two locations.

PEAK TRANSMITTED FORCE

In table 2 it can be observed that peak transmitted force is proportionate to the energy impacted. Low impedance voltage mode system was used for measurement of peak transmitted force.

The above table shows that the top zone of riot-police-helmet-shell transmits singinificantly less peak force. For double-fabric layered helmets, the top of riot-police-helmet-shell also transmits significantly less force as compared to the other two zones. In table 2, double-fabric layered helmets at a similar impact energy of 25.6 Joules transmits less force to the headform than the single-fabric layered riot-police-helmet-shells. Moreover, the double riot-police-helmet-shells have more material at the impacted sites as compared to the single-layer riot-police-helmet-shells. If these results are normalised with respect to the thickness, the double-riot-police-helmet-shells will show less force is transmitted compared with the single-fabric layered hemet shells.

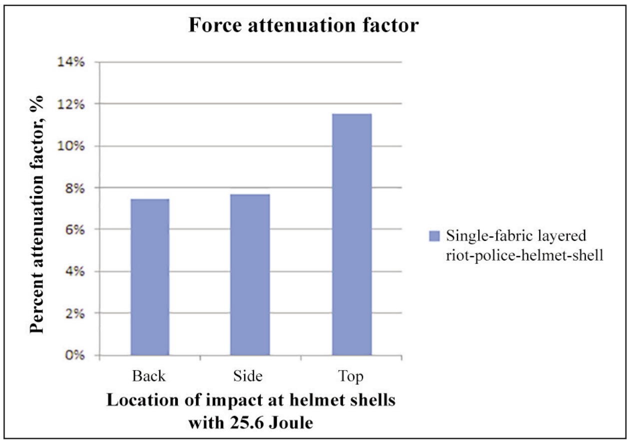
Force attenuated factor (FAF)

Force attenuation factor for various impact zones on riot-police-helmet-shells can be analysed in table 2 in which shows no substantial difference in the FAF at the side zone and back zone of helmets. However, force blocking effectiveness upper zone of riot-police-helmet-shell is always greater than at the counter

Table 2

EXPERIMENTAL DATA FOR FAF AT VARIOUS RIOT-POLICE-HELMET-SHELL'S ZONES

Type of riot-police-helmet-shell	Zone	Impact energy	Force on headform without specimen	Transmitted force	Attenuation factor
		E (J)	F_{trans} (kN)	F (kN)	f_{att} (%)
Single-layer riot-police-helmet-shell	Back	25.64	19.843	18.354	7.503
Double-fabric layered riot-police-helmet-shell	Back	25.62	19.843	17.956	9.510
Single-layer riot-police-helmet-shell	Side	25.64	19.666	18.148	7.720
Double-fabric layered riot-police-helmet-shell	Side	25.63	19.666	17.915	8.905
Single-layer riot-police-helmet-shell	Top	25.61	20.381	18.028	11.544
Double-fabric layered riot-police-helmet-shell	Top	25.58	20.381	17.431	14.473



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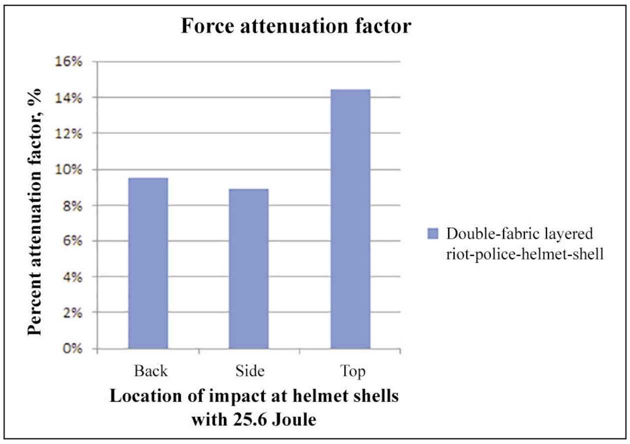

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Fig. 6. Force attenuation factor at different zones on riot-police-helmet-shells: *a* – single-fabric layered riot-police-helmet-shells; *b* – double-fabric layered riot-police-helmet-shells

parts as can be seen in figure 6. The reason behind this phenomenon is the greater distance from the riot-police-helmet-shell edges and also due to the continuous fibre reinforcement. Further, the highest curvature intensity of the helmet top impact zone seems to have an influence on the force attenuation factor and less force is transmitted in the high curvature region of riot-police-helmet-shell.

The double-fabric layered riot-police-helmet-shell also behaves in the same way as the single-fabric layered riot-police-helmet-shells with a higher force percentage attenuation factor due to the greater amount of fabric in these riot-police-helmet-shells as can be seen in figure 6. Moreover, double-fabric layered riot-police-helmet-shells show a greater force attenuation factor as compared to the single-layer riot-police-helmet-shells with similar 25.5 J impacts.

CONCLUSION

In this manuscript experimental result has been described. Developed single and double fabric layered (continuously textile reinforced) riot-police-helmet-shells were impacted at various zones with 25.5 J energy; force blocking effectiveness at various zones were calculated and analysed. Furthermore, energy absorption and force blocking effectiveness of double fabric layered riot helmet shell has been compared for different impact locations.

Impact performance of the produced riot-police-helmet-shells has an influence on the impact zone. Least vulnerable position among the three zones was found out to be the helmet upper zone. This seems to be due to the fact that continuously fibre reinforced riot helmet shell's upper area is at the greater distance from the shell edges and has more chance to distribute the impact force and impact energy to a greater distance as compared to the side and back impacted areas. Moreover, the upper helmet zone needs higher impact energy to collapse and for this purpose less force will be communicated to the brain. It can be concluded that in double-fabric layered riot-police-helmet-shells, top/upper position is also the least threatening impact position as compared to the side and back area of the helmet shells.

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