DEVELOPMENT OF A THORAX PROTECTOR FOR MOTORCYCLISTS

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ABSTRACT

This paper describes the development of a new thorax protector as part of the personal protective equipment for motorcyclists. The function of the protector is the mitigation of injuries in impacts to the frontal or lateral parts of the thorax. A sandwich structure was selected. The outer shell of polypropylene was designed to spread concentrated impact forces, a shock absorbing aluminium honeycomb material was coupled with a comfort layer for the inner part of the protector.

The materials were characterized and an FE model was created for impact simulations with the HUMOS2 model. Frontal and lateral impact tests against which the HUMOS2 model had previously been validated were simulated. The simulations highlighted that the main benefit of such a device is derived from the force distribution and that the shock absorbing material provides smaller contribution to the protector's performance.

After a pre-selection of the design variants by means of simulation, a series of thorax protector prototypes were manufactured and tested in terms of comfort (ergonomic tests) and impact protection. Ergonomic tests confirmed the quality of the design, showing that the protector does not interfere with the normal rider's movements. A series of frontal impact tests using the Hybrid III Dummy was carried out. It was concluded that the protector reduces the compression of the thorax and the probability of sustaining rib fractures in the analysed impact conditions and thus reduces the potential injury risk.

INTRODUCTION

The APROSYS project aims, within Sub-Project 4 "Motorcycle Accidents", at reducing the number and severity of powered two wheelers (motorcycle and moped) user injuries for the most relevant accident scenarios.

In order to accomplish this result, an in-depth analysis based on four accident databases (COST 327, MAIDS, GIDAS and DEKRA) and a literature review have been carried out at the beginning of APROSYS for investigate in the injuries mechanisms and in the most frequent injuries that motorcyclists sustain during accidents [Manzardo 2006].

THE IMPACT TEST CONDITIONS

From these analyses it has been pointed out that, even though, thorax is not the most frequently injured body region, injuries in the thorax area often have a high severity index. In the light of these results, the development of a device able to protect from and reduce the severity of injury to the thorax region has been addressed within APROSYS project.

The development process has been started defining a validation plan, able to check the impact safety performance of a thorax protective device. The test plan included four impact conditions, frontal and lateral at 5 and 10 m/s carried out with a cylindrical impactor with a diameter of 15.2 cm and weight 23.4 kg, impact locations are shown in Figures 1 and 2.

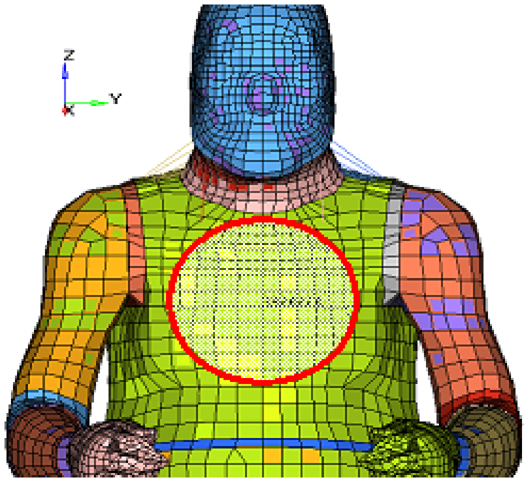

Figure 1. Frontal impact location.

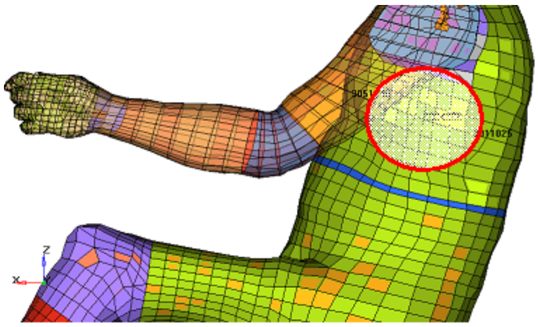

Figure 2. Lateral impact location.

The simulation and test analysis were carried out considering the following injury criteria associated with ECE-R94 (frontal) and ECE-R95 (lateral):

- for the frontal impact the thorax compression and the peak viscous response VCmax
- for the lateral impact the compression of the impacted half of the thorax was evaluated

Simulations and real tests data coming from the validation had then to be analysed comparing measurements with and without protector. No absolute limits have been set for measurements: the evaluation criterion was the maximization of the difference between the values with and without protector.

DESIGN OF THE PROTECTOR

The design concept activity has been driven by the necessity to achieve a good impact energy distribution and, at the same time, the capability to shift the forces from the central to the lateral area of the thorax reducing the flexural moment, thus fracture risk, on ribs.

Furthermore, these safety requirements should be accomplished taking into account also ergonomic and comfort issues. An integral solution has been preferred, with a one piece semi-rigid external shell, connected to lateral rigid plates. The shell's internal side has been provided with a reticular structure.

The honeycomb absorbing structure has been selected to grant, besides impact absorption, a proper breathability on the chest zone.
Once the structural and ergonomic design issues have been defined, also the aesthetic aspect has been taken into account.

The final step for the design process had been the elaboration of the thorax protector CAD model. Figure 3 shows the design of the protector.

NUMERICAL STUDY

Brick elements have been used to mesh the protector. The interior face of the rigid shell is constituted of reinforcements which had to be taken

Figure 3 Thorax protector draft design

into account during the simulation. To model these surfaces, a series of brick elements, with a size equal to the reinforcement's width (2 mm) have been used.

The thorax protector final mesh had 100238 nodes and 54972 elements. 9056 bricks defined the honeycomb structure, 45306 bricks the rigid shell and 610 shells were included to represent the zip parts (see figures 4 and 5).

Figure 4. Rear-lateral view of FE model of the thorax protector

Figure 5. Frontal-lateral view of FE model of the thorax protector

In order to simulate impacts, thorax protector mesh has been placed on HUMOS 2 model (see figures 8 and 9).

Thorax compression and VCmax have been calculated for each frontal impact. Half thorax compression and VCmax have been calculated for each lateral impact.

Figure 6. Set-up for simulation of lateral impact including the thorax protector.

Figure 7. Set-up for simulation of frontal impact including the thorax protector.

Referring to the injury criteria table (table 1), the main benefits of the thorax protector had been expected in frontal impacts. The simulations highlighted that honeycomb did not records any deformation and for that reasons its behaviour has been further investigated in the optimization phases, firstly changing impactor's shape then modifying the honeycomb mechanical properties in order to simulate stiffness behaviour.

Simulations then demonstrated that honeycomb compression was similar for cylindrical and for kerbstone impactors, but that it was varying with its stiffness. Taking into account injuries criteria, the honeycomb stiffness changes in combinations with impactor changes, which have been carried out during optimization phase, did not cause a remarkable effect on the thorax protection performance.

PROTOTYPE AND CRASH TESTING

After the numerical optimization phase, the prototype manufacturing has been started with the mould construction (figure 8).

Figure 8. Mould for the protector shell.

Then, a series of prototypes for the validation tests have been prepared. In order to further investigate the honeycomb behavior, protectors have been prepared in different configurations, one without honeycomb, one with honeycomb between the rigid shell and the thorax and one with honeycomb outside (see figures 9 to 11).

Figure 9. Protector without honeycomb

Figure 10. Protector with honeycomb outside.

Table 1.
Impact simulations: Parameters measured for the assessment of protection level.

IMPACT CONFIGURATION	FRONTAL			LATERAL
	Chest compression	*Vcmax*	*Chest deflection*	*Half thorax compression*
5 m/s – without protector	27 %	0.66	46.5 mm	27 %
5 m/s – with protector	20 %	0.41	34.5 mm	29 %
10 m/s – without protector	71 %	3.21	120 mm	61 %
10 m/s – with protector	51 %	2.53	85.8 mm	56 %

Figure 11. Protector with honeycomb inside.

Tests have been carried out with an instrumented HYBRID III test dummy seated in a plane and an octofilar pendulum that guide a cylinder probe with the impactor mounted on one its side, to hit the dummy in the sternum area (see figures 12 and 13).

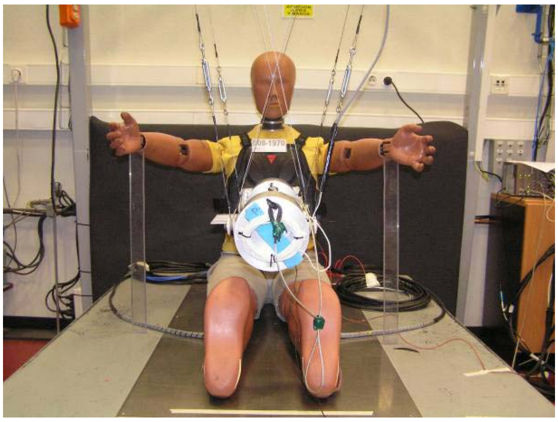

Figure 12. Impact test with Hybrid III – frontal view.

In table 2 the matrix of tests shows the test results. From the data it can be easily observed that comparing data on the chest compression, viscous criterion recorded in the test, with and without protector, for each type of prototype a reduction on the recorded values in case of use of the protector have been achieved. Taking into account sternum accelerations only the thorax protector without honeycomb demonstrate to be able, in all the test conditions, to reduce or at least maintains the accelerations values without any degrade on the data.

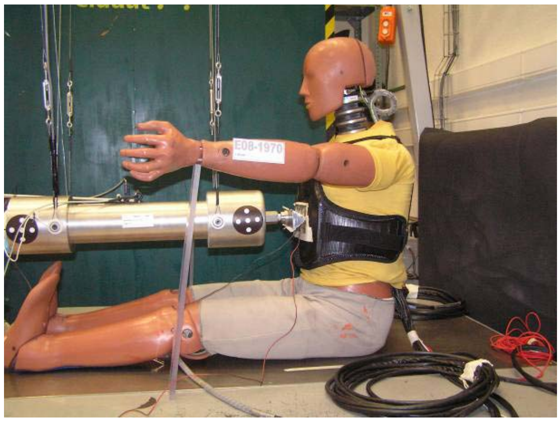

Figure 13. Impact test with Hybrid III – lateral view.

CONCLUSIONS

From the simulations results as well as from the physical impact tests it can be concluded that the presented thorax protector reduces the compression of the thorax and the probability of sustaining rib fractures in the analysed impact conditions and thus reduces the potential injury risk.

Apart from offering an additional protection to the thoracic area of a motorcyclist, ergonomic tests confirmed the quality of the design, showing that the protector does not interfere with the rider's normal movements.

This study highlights the importance of the distribution of the impact forces on the human body in case of an impact. This is an important fact that should be taken into account for the future development of motorcyclists protective equipment and for any draft or revision of standards for the testing of such eqipment.

ACKOWLEDGEMENTS

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REFERENCES

Manzardo, D., 2006. "APROSYS SP4.1: Analysis on protective clothing for motorcyclists ". Deliverable 4.1.4. AP-SP41-0004

Table 2.
Impact tests: Parameters measured for the assessment of protection level.

IMPACTOR	PROTECTIVE CLOTHING	Target probe velocity (m/s)	Measured probe velocity (m/s)	Chest_S (mm)	Chest VC (m/s)	Sternum_ax (g)
FLAT	NO	5,00	4,88	49,8	0,51	93,11
FLAT	YES, WITHOUT HONEYCOMB	5,00	4,88	43,8	0,50	84,52
FLAT	YES, WITH HONEYCOMB INSIDE	5,00	4,92	42,6	0,49	78,78
FLAT	YES, WITH HONEYCOMB OUTSIDE	5,00	4,92	42,5	0,47	101,88
FLAT	NO	6,70	6,68	72,2	1,07	135,44
FLAT	YES, WITHOUT HONEYCOMB	6,70	6,74	63,9	0,99	136,21
FLAT	YES, WITH HONEYCOMB INSIDE	6,70	6,75	62,1	0,96	146,15
FLAT	YES, WITH HONEYCOMB OUTSIDE	6,70	6,74	62,0	0,93	130,31
KERB	NO	5,00	4,92	50,5	0,61	70,02
KERB	YES, WITHOUT HONEYCOMB	5,00	4,95	43,4	0,45	69,78
KERB	YES, WITH HONEYCOMB INSIDE	5,00	4,95	43,1	0,47	92,10
KERB	YES, WITH HONEYCOMB OUTSIDE	5,00	4,95	42,2	0,34	81,04
KERB	NO	6,70	6,74	73,6	1,20	203,29
KERB	YES, WITHOUT HONEYCOMB	6,70	6,8	65,7	0,87	112,16
KERB	YES, WITH HONEYCOMB INSIDE	6,70	6,74	59,6	0,84	109,40
KERB	YES, WITH HONEYCOMB OUTSIDE	6,70	6,80	62,3	0,89	102,61