# THE FRACTURING OF HELMET SHELLS

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ABSTRACT.-

The analysis of accidents involving two-wheeled motorized vehicles reveals the high incidence of fracturing of helmet shells.
The severity of injuries increases because of the following two phenomena :

The loss of the helmet during the occurrence of collision and the very poor distribution of impact forces against the shock-absorbent material.

The occurrence of fractures is closely dependant upon the two following factors :

The type of material of the shell and the violence of collisions.

The present investigation therefore aims primarily to define a performance criterion in accordance with real-world collisions. This criterion could be required for future certification tests and should enable the selection of the most efficient materials.

## DESCRIPTION OF THE SAMPLE.-

The sample of accidents was constituted thanks to joint financing provided by the French Ministry of Transport and The Peugeot/Renault Association. It included collisions which occurred in the Paris area during the 1979-1981 period.

The 111 victims were wearing helmets designed in accordance with French standard NF S 72 302.

The sample included 26 moped riders and 85 motorcyclists. The cases studied mainly concerned severe crashes : the fatality rate here was for moped riders from four times and for motorcyclists more than six times greater than what is found at the national level. Each file includes :

- Medical data concerning the victims,
- An objective description of the data for each collision: marks of braking on the road, characteristics and deformation of obstacle(s) struck, etc...
- A careful examination of the helmet : after dismantling, each deformation (crack, etc...)was measured and photographs were taken.

RESULTS.-

1 - OCCURRENCE OF HELMET-SHELL FRACTURING was observed in 32 % (35/111) of cases (25 % in the cases involving moped riders and 33 % in those involving motocyclists). Two main reasons can explain these proportions. The first of these reasons is the great severity of the crashes analysed. The second reason is that all the helmet shell fractures observed were taken into consideration including those which, principally because of their smallness, might be thought to have no influence on the total head injuries sustained. However, some kinds of deterioration were not taken into account. This was true in the cases of delamination of the fibre-base materials whenever there had been no rupture in the continuity of the material. SNIVELY (1)* lists a proportion of up to 50 % of fracturing ; CESARI et al (2)* note major shell fractures in 9 % of cases. Such differences are especially to be ascribed to the particular definition of the helmet shell fracturing which is used by different teams. In any case, such fractures are certainly of major importance.

2 - GRAVITY AND TYPE OF HEAD INJURIES

Among other things, the shell's role consists of distributing impact energy over as wide an area of the shock-absorbent material as possible. Besides this it must also act as a resistance to penetration of the obstacle into the helmet. The fractures were observed in 8 cases out of 10 at a point very close to that of helmet impact (figure 1)

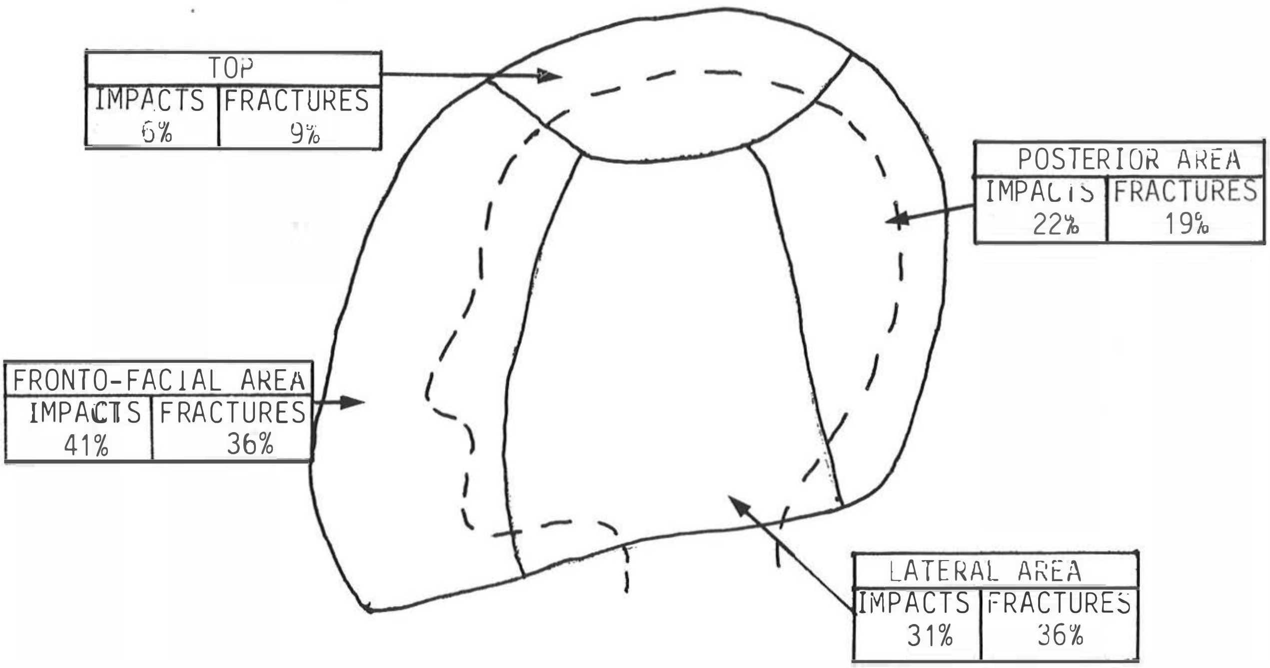



Figure 1 : Distribution (in %) of sites of impact and sites of helmet shell fractures

* The number between brackets refers to the reference at the end of the paper.

In cases where fractures occur, the helmet has clearly not been able to play either of the roles just mentioned : the very poor distribution of impact energy involves high and localized stresses against the head.

Thus, the fractures of helmet shells were more often related to severe head injuries : 38 % (12/32) of AIS $\geq$3. When helmet shells were not fractured only 21 % (15/73) of AIS $\geq$3 injuries were observed (Table I).

| Head AIS | Helmet shell fractured | Helmet shell non-fractured |
|---|---|---|
| 0 | 7 | 32 |
| 1 | 5 | 12 |
| 2 | 8 | 14 |
| 3 | 2 | 4 |
| 4 | 2 | 1 |
| 5/6 | 8 | 10 |
| Total | 32 | 73 |
| (Head AIS unknown | 3 | 3) |

Table I : Gravity of head injuries according to occurrence or non-occurrence of shell fractures.

The efficiency of the shell helmet became obvious when we noticed the type of head injuries that were or were not combined with fractures of the shell. When such fractures took place, the risk of a fracture of the skull occurring was three times greater than when there was no fracture of the shell : the association between shell fracture and skull fracture was observed in 47 % (15/32) of the cases, whereas when there was non-occurrence of shell fracture, the proportion of bone injuries was only 15 % (11/73). (Table II).

| Type of injuries | helmet shell fractured | helmet shell non-fractured |
|---|---|---|
| Uninjured or minor (AIS $\leq$1) | 12 | 42 |
| Brain only | 5 | 20 |
| Brain and skull | 14 | 8 |
| Skull only | 1 | 3 |
| Total | 32 | 73 |
| (Head AIS unknown | 3 | 3) |

Table II : Type of head injuries according to occurrence or non-occurrence of shell fractures

## 3 - FRACTURING OF HELMET SHELLS AND LOSS OF HELMETS

Loss of helmets occurred in 15 % of the collisions. One-third of these losses were caused by technological failure of the helmet. All the retention systems currently used are directly fixed on the helmet shell. When helmet fractures occur, the grip of the helmet on the head can be seen not to have been satisfactory and we notice helmets being lost in spite of the fact than the retention system remains undamaged. Helmet losses were in three cases only attributable to the fragmentation of the shell. In three other cases a shell fracture contributed, among other causes, to the loss of the helmet. Assuming that the protection afforded by the helmet was sufficient, non-occurrence of helmet loss, a loss attributable to shell fracturing, would quite probably have made it possible to prevent the death of one of the eighteen fatalities in the survey. There was a close link between the risk of helmet loss and the size of the shell fracture (table III) : all such fractures in cases of helmet loss were 25 centimetres or more in length (photograph N°1).

| Case N° | Helmet loss | Severest impact | First impact | Second impact | Head AIS | Length of the fracture of the shell(in cm) |
|---|---|---|---|---|---|---|
| 461-1 | After 1st impact | First | Wall | - | 1 | 4,10 and 25 cm |
| 486 | After 1st impact | First | Car roof side rail | Ground | 6 | 40 cm |
| 609 | After 1st impact | Second | Lamp post | Edge of Sidewalk | 6 | 40 cm |

Table III - Characteristics of collisions with occurrence of helmet loss attributable to fragmentation of the shell.

## 4 - HELMET SHELL FRACTURES AND DISTRIBUTION OF IMPACT ENERGY

Some of the shock-absorbent materials used for helmets still showed a trace of the stress undergone during impact. This was true for polystyrene, the recovery of elasticity of which was only partial. The crushing which was evenly spread over a wide area of this shock-absorbent material gave evidence of good behaviour of the helmet shell. In some cases where fractures occur, we observed irregular stresses of this shock-absorbent material . This phenomenon involved an increasing of the stresses against the head. Thus, as we have seen above, an increase of injury severity. In the case of 11 out of the 21 helmets lined with polystyrene shock-absorbent material, an irregular residual crushing was found just underneath the shell fracture line. This irregular crushing of the shock-absorbent material and fracture of the shell occurred during the same impact for 10 out of the 11 cases mentioned above.

The occurrence of irregular crushing of the shock-absorbent material is linked to the size of the shell fractures : irregular crushing was observed in one-third (2/6) of cases with small fractures of the shell. This proportion rose to three quarters (9/12) of the cases with fractures longer than 10 centimetres (Table IV).

| Fracture Length (in cm) | Absorbent material: Without residual crush | With crush regular | With crush irregular |
|---|---|---|---|
| Under 5 | 2 | 1 | - |
| 6 to 10 | - | 1 | 2 |
| 11 to 15 | 1 | 1 | 5 |
| 16 to 20 | - | - | - |
| 21 to 25 | - | - | 1 |
| > 25 | 1 (*) | - | 3 |

(*) In this case,fracturing occurred at some distance from the site of impact.

Table IV : Sizes of shell fractures and interaction between shells and shock-absorbent material.

## 5 - HELMET SHELL FRACTURES AND INFLUENCE OF THE MATERIAL

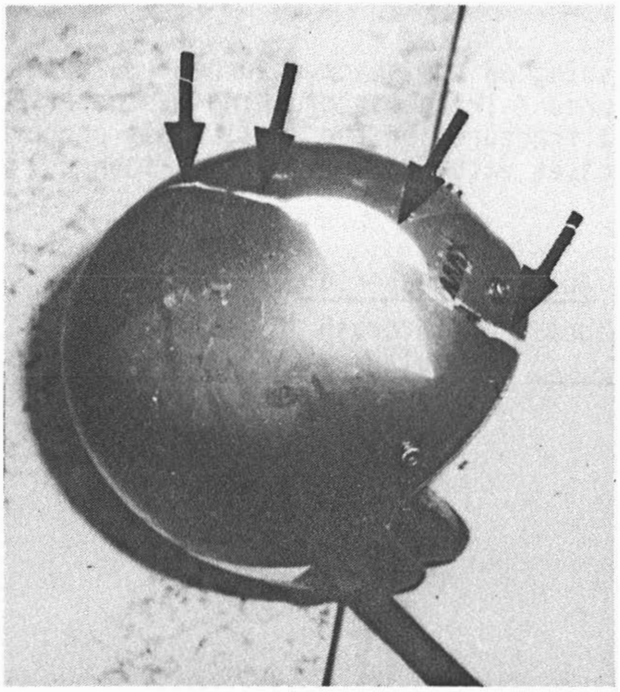
The materials used for manufacturing helmet shells are classified into two groups as follow :

- Thermoplastics including mainly the A.B.S. (acrylonitrile butadiene styrene) and the polycarbonates.

- Duroplastics. The duroplastics are stratified material made from a base of resins and glass or Kevlar fibres.

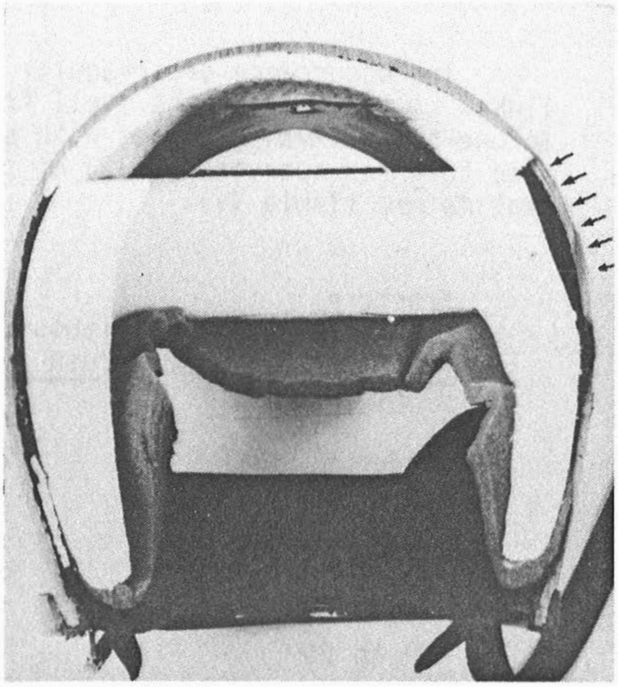
Helmet shell fracturing was observed to a different extent depending on the type of material used (table V). However, in our opinion, the comparison between materials must be made in accordance with the real injury risk involved as a result of different fracture sizes.

Thus, if some materials seemed to have a low resistance to fragmentation their design incorporates a certain resistance to the extension of the fracture. This was true for the fibre base material (duroplastics) : only 1 out of 6 fractures was longer than 10 centimetres. In decreasing order of performance, following fibre base material came polycarbonates and then the A.B.S. material.



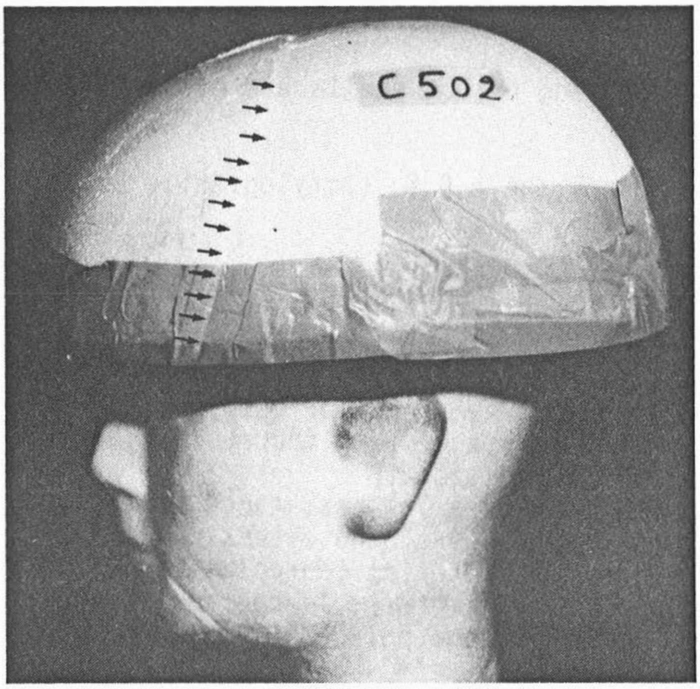
Photograph N° 1 :

A fracture of 42 cm in length was responsible of the loss of this helmet. A second obstacle was struck by the unhelmeted head. This latter impact involved a fatal head injury.



Photograph N° 2 :

We can see a residual crushing (arrow) of the shock-absorbent material beneath the impact point.




Photograph N° 3 :

On this shock-absorbent material, made of polystyrene, we observe an impression just underneath each of the two sides of the fracture of the shell. We notice irregular crushing about 2 to 4 millimetres thick.

With the A.B.S. material, we observed that 50 % of the fractures were longer than 10 centimetres and 1 cut of 5 were longer than 25 centimetres.

| Fracture length (in cm) | A.B.S. | Polycarbonate | Fibres |
|---|---|---|---|
| Under 11 | 11 | 3 | 5 |
| From 11 to 25 | 7 | 2 | 1 |
| Over 25 | 5 | 1 | - |
| Total | 23 | 6 | 6 |
| All cases (with or without shell fractures) | 65 | 30 | 16 |

Table V : Sizes of fractures according to shell materials

Among the various factors that can degrade the behaviour of material during impact two studies have noted the factor of ageing (3 and 4). Our sample, which was made up of helmets all of which were of recent manufacture - less than three years old - did not therefore lend itself to analysis of this phenomenon. One of these studies conducted by U.T.A.C. (3) performed all the tests used for the standard design certification in France upon a sample of helmets actually in use amongst a group of moped riders and motorcyclists. After showing up several cases of nonconformity due on the one hand, to poor maintenance by their owners and, on the other hand, to the fragility of certain materials due to the influence of ageing. Concerning the helmet shells, the main findings were as follows :

- Shell fracturing was observed only in the case of one type of material, namely A.B.S. and, according to test conditions, in the case of from 14 % to 58 % of such helmet shells.

- The ageing of this A.B.S. material was accompanied by increased fragility : from 46 % to 61 % of fractures of the helmet shell according to their age (3-6 years).

Another study (4) measured the influence of the natural and artificial ageing of construction workers' safety helmets made of five different materials . Its author recommended a maximum duration of use of two years in the case of high-performing materials. A.B.S. material seemed a little better than fibre base material but such variation in the results is, in our opinion, attributable to the specific tests conditions used for each study (temperature, hygrometry, and the violence of shocks to which helmets were subjected).
Some complementary studies are needed to corroborate the relative influence of each ageing factor such as :

- The exposure to atmospheric agents
- The inherent ageing process of materials

A second current study is being performed by a U.T.A.C. team, on the basis of tests performed upon helmets not recently manufactured and never worn. The main results, concerning shell material, are the same as those in the first study mentioned above.

## 6 - HELMET SHELL FRACTURES AND VIOLENCE OF COLLISIONS

To estimate the supplementary risk for the victim attributable to fracture of the helmet shell, it would be necessary to compare the injury level observed in two groups matched in terms of proportion of collision violence--with or without shell fractures. This method is the classic one used in car accidentology to evaluate the supplementary risk related to some aspect of a car's structural behaviour (steering wheel rearward displacement, intrusion, etc...). The same method is used to evaluate the efficiency of protective devices such as seat belts. The photographic library of experimental car-crashes gives references which are needed for rigorous evaluation of collision speeds.

Concerning two-wheelers, the innumerable range of collision configurations, linked to the lack of experimental references* in this field prevents the adopting of a strict approach to obtaining knowledge of collision speeds between the two-wheelers and the obstacles they strike : the head impact speed against the obstacle is different - ranging from 0.4 to 1.6 - of the closing speed (5).

Various approaches were proposed to remedy this difficulty. certain were based on the kinematics of the victim (6) : with or without escape against the obstacle, side-swipe, run over... Some other approaches were based on the kind of obstacles struck (7) : vehicles, trees, the ground, ... etc. Our classification takes into account the characteristics that are specific to the obstacle, i.e. its geometry and its estimated stiffness (Figure 2).

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* The results of an experimental study (5) showed the limits of the method : it was not possible to evaluate the collision speed according to the final relative position of the victim, the two-wheel vehicle and the car struck : for instance, the kinematics of the victim are different according to the occurrence or non-occurrence of arm impact against the hood of the car.

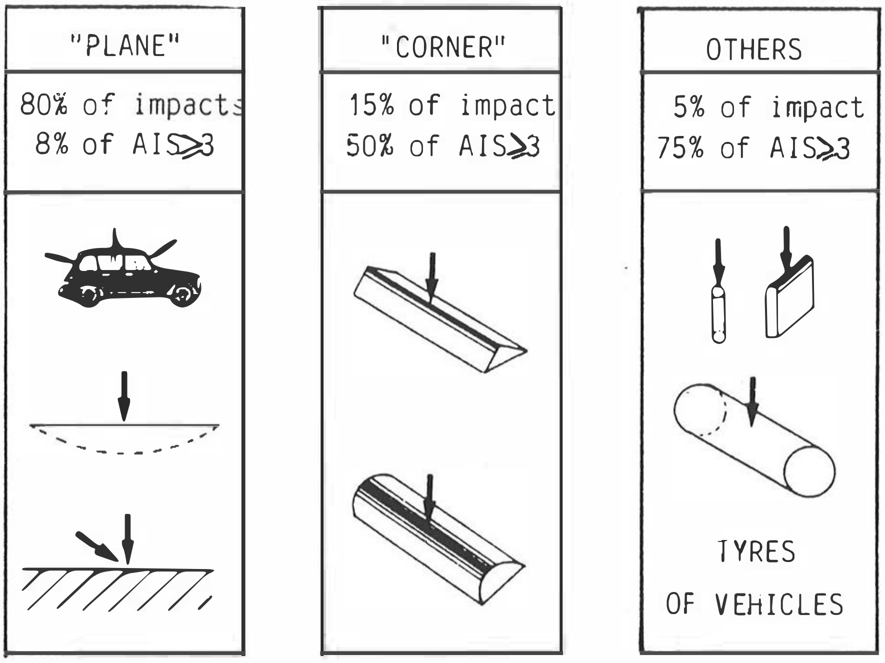


Figure 2 : Frequency and severity of head injuries according to types of obstacles struck.

(reference 8)

The aggressivity of the obstacle was also verified with respect to the helmet shells : the proportion of shell fractures was twice as high in accidents involving impacts against "CORNER" obstacles as they were in those against "PLANE" obstacles. As far as the materials are concerned, their behaviour with regard to either of these types of obstacles showed a lesser impact resistance in the care of the fibre-base and of the A.B.S. materials (Table VI).

| | | Shells materials | | |
|---|---|---|---|---|
| | Impact | A.B.S. | Polycarbonate | Fibres |
| Against "PLANE" | - with fracture | 11 | 2 | 3 |
| | - with and without fracture | 46 | 20 | 10 |
| Against "CORNER" | - With fracture | 3 | 1 | 1 |
| | - with and without fracture | 7 | 4 | 1 |

Table VI : Incidence of shell fractures according to obstacle struck and shell material.

## PROPOSALS.-

The analysis of real-world accidents showed that it is important to avoid the occurrence of fracture to the helmet shell.

With a view to proposing a future certification test for helmet shells, we propose a criterion based on fracture dimensions.

To reduce the risk of loss of helmet, all helmets with fractures longer than 25 centimetres would be rejected. In lowering this threshold to 10 centimetres, we significantly reduce the risk of a poor distribution of impact energy over the shock-absorbent material.

The study has showed that certain materials used for manufacturing helmet shells have a poor resistance to fragmentation. Since the proportions of the basic components can be modified, and consequently their mechanical behaviour, it seems more efficient to define realistic test conditions, rather than to prohibit the use of certain materials. In this latter case we should risk ending up with a result completely contrary to our real wish.

We have observed the influence of some factors in the occurrence of fracture of helmet shells, but the relative influence of each of these factors is still not well understood. That is also true of the energy dissipation resulting from a fracture of the shell. In our opinion, these are interesting new fields for future research.

## CONCLUSIONS.-

- The fracturing of helmet shells was observed in one third of the collisions.

- The risk of severe or fatal injury was doubled when a fracture of the shell occurred : 38 % of head AIS $\geqslant$3 with fracture compared with 21 % of such injuries where no fracture was observed.

- The efficiency of the helmet shell was obvious : the risk of skull fracture is three times greater when fracture of the helmet shell occurred.

- Fractures of the helmet shell produced the two following mechanisms :
  - . Loss of helmet, when fractures of the shell are longer than 25 centimetres
  - . Poor distribution of impact energy over the shock-absorbent material when fractures are longer than 10 centimetres.

- Helmet shell fracturing was observed to a different extent according to the type of material used : the best performances were obtained by the fibre-base material. Their design provides good resistance to the extension of the fractures. Long fractures are often noticed in the case of A.B.S. material.

- The influence of the violence of collision on the occurrence of helmet shell fracture is obvious : more than 40 % of the shells were fractured against "CORNER" type obstacles compared with only 20 % for the "PLANE" type.

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