Comparative Impact Tests on Helmets

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1. Abstract

ECE R22.05 regards to the motorcycle helmets and it prescribes Mg-alloy head forms for the drop tests which not adequately represents the correct dynamics of a human body.
The 50th percentile Hybrid III dummy is now the best and most sophisticated approach for simulation of an accident with head injury of a motorcyclist in the condition of a full-scale crash test. Instead of it we planned and suggested a comparative laboratory drop test series on helmets which were carried out with sitting type Hybrid III whole body, Hybrid III head-neck unit and Mg-alloy head form in research (COST 327) action.
Last part of this paper deals with development of energy absorbing capability of riding helmet's padding material.

2. Comparative motorcycle helmet tests

2.1. Basic regulation - ECE R22.05

The most important test requirement of this regulation, the impact absorption capacity of helmet is determined by recording against time the acceleration imparted to a head form fitted with helmet, when dropped in guided free fall at a specific impact velocity upon a fixed steel anvil. The drop height shall be such that the unit constituted by head form and helmet falls on test anvil at velocity:

- 7 m/s (+0. -0.15) for flat anvil, (height: 2.5 m)
- 6 m/s (+0. -0.15) hemispherical anvil, (height: 1.84 m)

(*Remark:* the acceleration measured in the head is higher when it dropped onto the flat anvil than dropping from the same height to the hemispherical anvil!)

2.2. Comparative laboratory tests

The freely falling dummy onto the same basement and anvil as used at helmet tests of ECE R22.05, gives good comparative data with detached HIII head+neck unit and Mg-alloy head form tests' results. The aim of this test series was to study the influence of body-neck unit on the linear acceleration comparing to the simple head form usage. (The rotational acceleration and neck force, moment would be also important, but our measuring line didn't give this possibility.)

Three different impact-absorbing (drop) tests' series were carried out with:

- a. a complete 50th percentile Hybrid III dummy (80 kg);
- b. Hybrid III head+neck unit (5,85 kg);
- c. Mg-alloy head (4,9 kg, "J" form).

Impact points (according to the ECE R22.05):

A.) B(*B1*) at the forehead area, in the vertical longitudinal plane of symmetry.
B.) P(*P1*) above the plane parallel to the base passing through point A, rearwards.

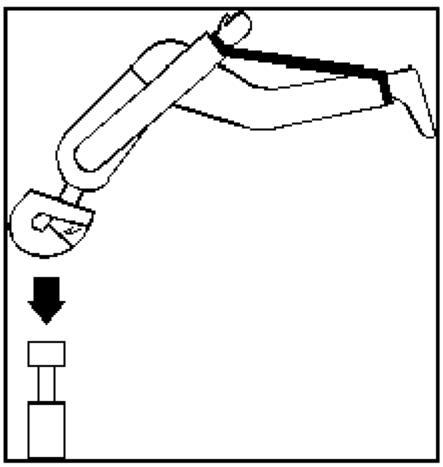
2.2.1. Test equipment

The heads at every drop were instrumented with a triaxial Endevco 7267A accelerometer and the acceleration together with the impact force vs. time functions (ISO 6487) were measured at each drop test. (Data recording of accelerations happened with 5000 samples/s, data recording of force occurred with 10000 samples/s.)
The height of the helmet impact point from the anvil surface was constant at every drop test: 2000 +/- 3 mm. The anvil surface was flat.
Additionally between the flat surface and the 550 kg mass of base was placed a special force transducer, designed with strain gauges, calibrated for 0-25 kN.
The motorcycle helmets, used at drop test series, were made by AGV Italy.

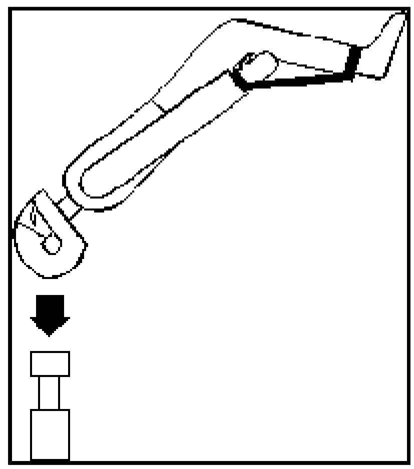
2.2.2. Dummy tests

A standard 50th percentile Hybrid III sitting male dummy was used. The dummy was hanged up with an automatic release mechanism. The dummy's legs and hands were tied together for the better installation and better repeatability. The test configuration were selected that the first contact occurred at the marked impact point on the helmet without any contact effect of other parts of the body.

Five drop tests, two in frontal direction [A) situation] and three rearwards [B) situation] were carried out.



a) Forehead drop arrangement (neck angle: 60^0)



b) Rear-head drop arrangement (neck angle: 45^0)

Figure 1.
Dummy drop test arrangement (from height of 2 m)

2.2.3. Hybrid III head+neck unit test

Impact points and positions were same as at the whole dummy tests. Together six drop tests (three forwards and three rearwards) were carried out.

2.2.4. Mg-alloy head test

Using the "J" head form of ECE R22.05, six drop tests (three forwards and three rearwards) were performed.

3. Test results of motorcycle helmets

We had 11 pieces original helmets and we have carried out 17 drop tests.
The next Table I. shows the helmet's numbering at each test:

	Front (neck 60^0)			Rear (neck 45^0)		
H III dummy	01	02	-	22	03	04
H III head+neck	05	06	23	07	08	25
Hg-alloy head	09	10	24	11	29	26

Table I.
Numbering of tested helmets

[Number between 01 - 11 signs unattached helmets for carrying out the first drop test. Numbers 22, 23, 24, 25, 26, 29 mean second drop test on the previously tested 02, 03, 04, 05, 06, 09 helmets. E.g. the second test of helmet 06 is signed: 26.]

	Front impact (helmet point *B*, neck 60^0) [Helmet No. / max. res. acceleration / impact force]								
Type of drop test	No.	max. acceleration [g]	impact force [kN]	No.	max. acceleration [g]	impact force [kN]	No.	max. acceleration [g]	impact force [kN]
H III dummy	01	103	11,9	02	128	8,7			
H III head+neck	05	168	10,3	06	159	10,2	23	182	11,4
Mg-alloy head	09	222	12,4	10	220	12,9	24	218	13,7

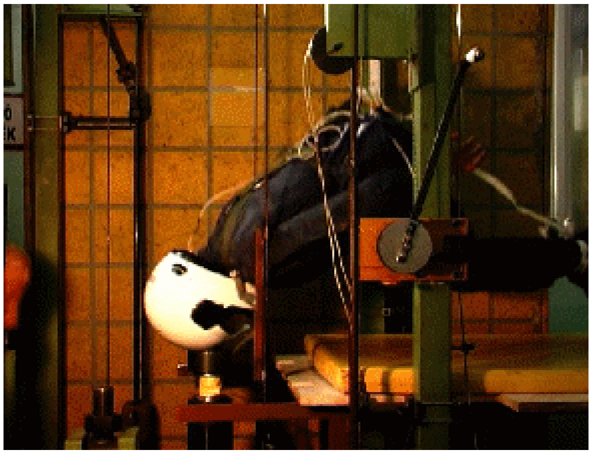
Table II.
Helmet drop tests forwards (forehead impact)

	Rear impact (helmet point *P*, neck 45^0) [Helmet No. / max. res. acceleration / impact force]								
Type of drop test	No.	max. acceleration [g]	impact force [kN]	No.	max. acceleration [g]	impact force [kN]	No.	max. acceleration [g]	impact force [kN]
H III dummy	22	157	8,3	03	136	9,2	04	128	8,2
H III head+neck	07	180	12,2	08	139	10,9	25	223	13,5
Mg-alloy head	11	198	12,1	29	254	16,1	26	232	12,8

Table III.
Helmet drop tests rearwards (rearhead impact)

4. Conclusions

According to the measured values and functions we can make the next conclusions:
In the case of Mg-alloy head higher acceleration values were measured than at the HIII head+neck unit. The whole-body arrangement gives less peak acceleration. During a real accident the impact force acting onto the head is transmitted by the neck to the body. The resulting linear acceleration to the head will therefore be reduced for the same impact force compared to head form tests, due to an increase in the effective mass of the dummy head form. Measuring with used helmets (second drop tests) the registered peak values are higher than at the previous test (using untouched helmet). [The helmet shall be changed after any accident resulting severe impact onto any surface in daily usage!]
At the Mg-head tests and HIII head-neck tests two-wave form signals were measured at rear head impacts and one-wave forms were registered at forehead impacts. The reason is the different interaction of the three-parts (shell-padding-head unit). It was observed that the linear acceleration signal form is qualitatively similar at dummy and head form experiments. Between the measured peak accelerations and forces related to the B (forehead) or P (reread) points there were no significant differences.



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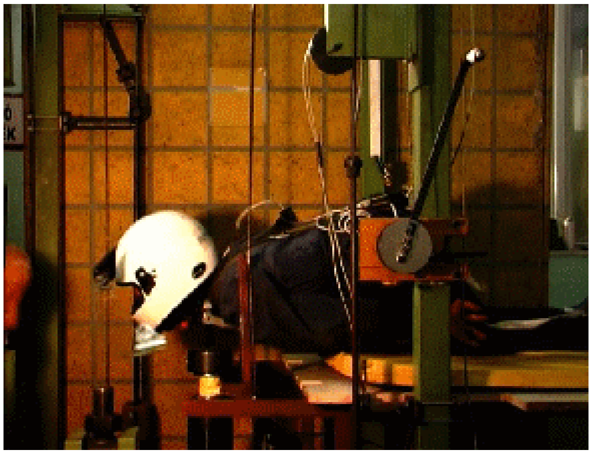

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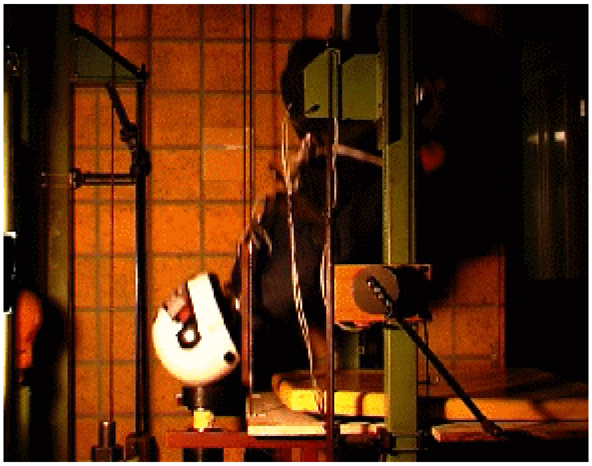

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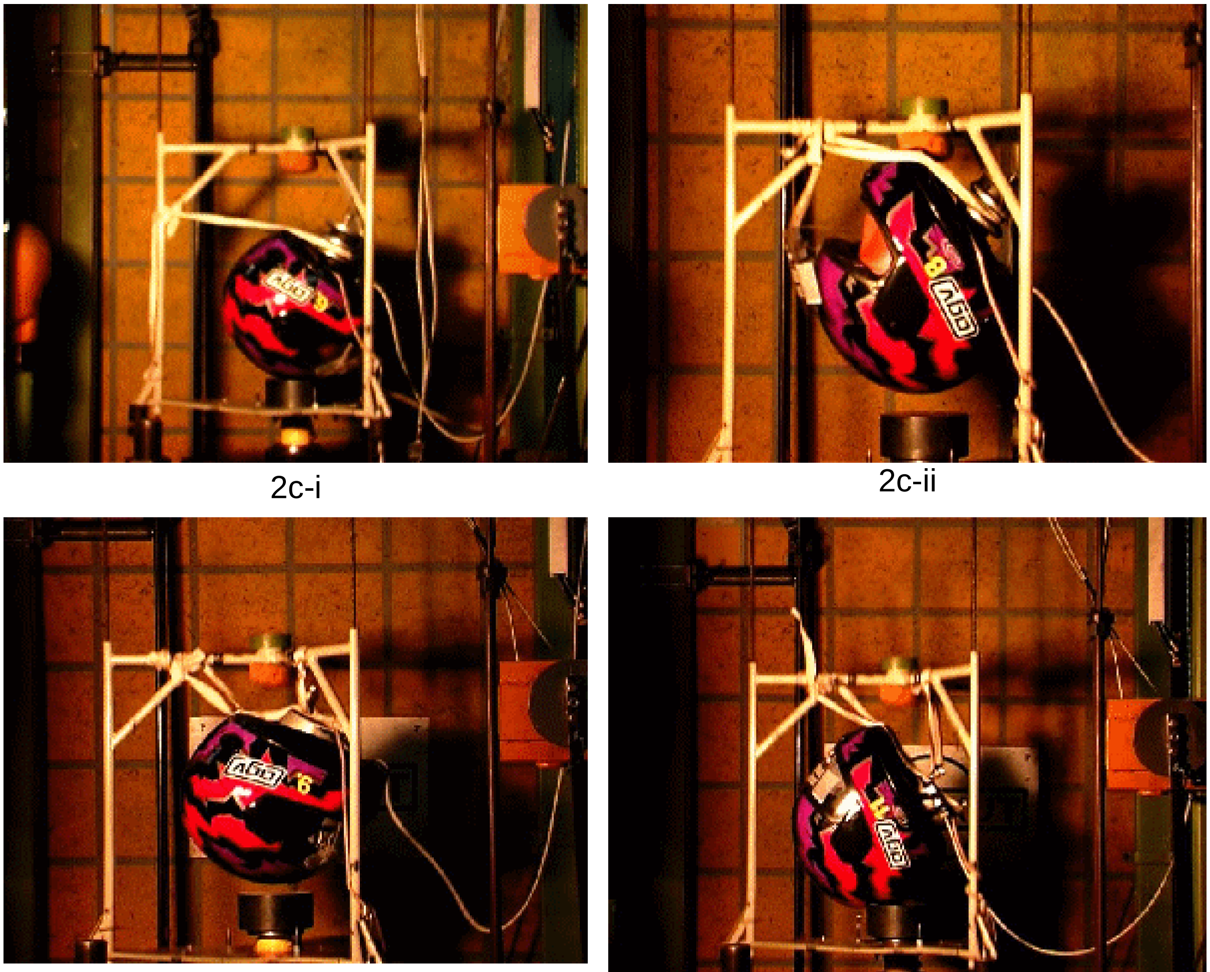

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2d-i 2d-ii

Figure 2.
Pictures on helmet dropping tests

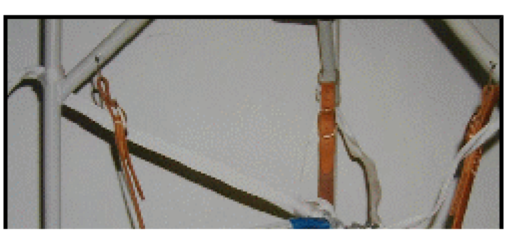
The Figure 2. shows couple pictures from the tests. At Mg-alloy-head or at HIII neck+head unit tests the helmets rebound as plastic ball from the anvil. At dummy tests the helmets rebound after the first peak force then begin to rotate backward with slight forward sliding, oppositely with the body. The linear peak acceleration happens at the first impact and the non-measured rotational peak acceleration belonging to the second phase of the impact process, occurs after the rebound.
After this back to the force-time signals, the duration between the maximum peak linear and peak rotational acceleration can be calculated from the force process without measuring it: 3-5 ms.

5. Riding helmet energy absorbing capability

(The influence of density of padding foam onto the impact acceleration)
The riding helmets, used by equestrians, have to be tested related to the regulation of DIN EN 1384:1996. (Paragraph 6.4 of this regulation requires same drop test arrangement as at motorcycle helmet.)

5.1 The goal and the requirements of the tests

(Figure 3.: A moment after the drop test of riding helmet)



Before the complete test process first had to be checked the effectiveness of the mitigation of the used padding materials of helmet at impact test and had to be chosen the more suitable bed material. The material of the padding was polystyrene with different density.
The size of 60 of Mg-alloy head was chosen for the tests, because it is

made with the thinnest padding material. (The size 54 helmet is manufactured with the same outer shell, so the padding material is thicker in it and the thicker padding means less acceleration, bigger mitigation.)
The resultant of the measured triaxial acceleration in the Mg-alloy head shall be less than 250 g and not over 150 g for more than 5 ms duration.

5.2 Test results

Measured resultant acceleration [g] and duration [ms] over 150 g							
Test No.	Helmet padding layout	Crown (top of head)		Occipital (rear-head)		Lateral (side-head)	
1	basic arrangement (density of polystyrene: 25 g/cm^3)	**119**	0	*708*	1,2	*512*	1,6
2	plus (3 mm) polyfoam bed between the shell and the polystyrene padding	**102**	0	*326*	1,3	*406*	1,5
3	double polystyrene padding (with size of 54 head form)	**78**	0	**132**	0	**115**	0
4	basic thickness of polystyrene (density of polystyrene: 35 g/cm^3)	**116**	0	*654*	1,4	*456*	1,3
5	basic thickness of polystyrene (density of polystyrene: 50 g/cm^3) *1st*	**132**	0	**237**	2,4	**228**	2,6
6	basic thickness of polystyrene (density of polystyrene: 50 g/cm^3) *2nd*	**128**	0	**225**	2,2	**242**	2,3

Table IV.
Riding helmet's padding development drop tests

Table IV. shows the results of drop tests of 5 different types of padding materials with unchanged helmet shell. (New helmet was used at each test.) There is a decorative hemispherical-shape foam button (diameter: 4 cm, height: 1,5 cm) on the top of helmet, which explains the low values of the central drop arrangement at any padding layout.
Lateral impact was the worst situation and as comes from the table, increasing the density of the padding foam, the helmet could fulfil the acceleration-requirements.
After this development test series, chosen the best performance (test No.:5,6) of padding for the riding helmet, the complete test process related to regulation of DIN EN 1384:1996 can be carried out probably with good results.

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