Comparative Tests with Laminated Safety Glass Panes and Polycarbonate Panes at the Federal Highway Research Institute (BASt)

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- Final Report -

Subject of the test:
Adult head impactor according to Regulation (EC) 631/2009
Phantom head impactor according to UN Regulation No. 43

Type of test:
Drop tests and vehicle impact tests

Test site:
Federal Highway Research Institute (BASt)
Bergisch Gladbach, Germany

Test period:
January – November 2011

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0 Executive Summary

A series of drop tests and vehicle tests with the adult head impactor according to Regulation (EC) 631/2009 and drop tests with the phantom head impactor according to UN Regulation No. 43 have been carried out by the German Federal Highway Research Institute (BASt) on behalf of the German Federal Ministry of Transport, Building and Urban Development (BMVBS). Aim of the test series was to study the injury risk for vulnerable road users, especially pedestrians, in case of being impacted by a motor vehicle in a way described within the European Regulations (EC) 78/2009 and (EC) 631/2009. Furthermore, the applicability of the phantom head drop test described in UN Regulation No. 43 for plastic glazing should be investigated.

In total, 30 drop tests, thereof 18 with the adult head impactor and 12 with the phantom head impactor, and 49 vehicle tests with the adult head impactor were carried out on panes of laminated safety glass (VSG), polycarbonate (PC) and laminated polycarbonate (L-PC). The influence of parameters such as the particular material properties, test point locations, fixations, ambient conditions (temperature and impact angle) was investigated in detail.

In general, higher values of the Head Injury Criterion (HIC) were observed in tests on polycarbonate glazing. As the HIC is the current criterion for the assessment of head injury risk, polycarbonate glazing has to be seen as more injurious in terms of vulnerable road user protection.

In addition, the significantly higher rebound of the head observed in tests with polycarbonate glazing is suspected to lead to higher neck loads and may also cause higher injury risks in secondary impacts.

However, as in all tests with PC glazing no damage of the panes was observed, the risk of skin cut injuries may be expected to be reduced significantly.

The performed test series gives no indication for the test procedure prescribed in UN Regulation No. 43 as a methodology to approve glass windscreen not being feasible for polycarbonate glazing, as all PC panes tested fulfilled the UN R 43 requirements.

The performance of the windscreen area will not be relevant for vehicle type approval according to the upcoming UN Regulation for pedestrian protection. However, it is recommended that pedestrian protection being considered for plastic windscreens to ensure at least the same level of protection as glass windscreens.

1 Introduction

At the 99th session of GRSG[1] and the 152nd and 153rd session of WP.29[2] the installation of an Informal Group on Plastic Glazing (IGPG), as requested by the national representative of Germany, was approved.

The main tasks of this informal group are as follows:

1. Preparation of draft regulatory proposals for an introduction of plastic glazing for windscreens and laminated plastic panes other than windscreens.

2. Update of the test procedures to apply the proper tests and their combination(s) in order to ensure safety of plastic glazing focusing on performance requirements in Regulation No. 43 (addressing e.g. durability, abrasion, weathering, UV stability and chemical resistance).

3. The group will take full account of existing data and research (e.g. test specifications, test procedures) in developing its regulatory proposals. It should consider pre-existing standards and national legislations for motor vehicle glazing in developing its proposals.

As for the schedule of the informal group, the draft regulatory text should be submitted to the 104th session of GRSG (Apr./May 2013). Final decisions on regulatory proposals rest with GRSG, WP.29 and the Contracting Parties.

The German Federal Highway Research Institute (BASt) was tasked by the German Federal Ministry of Transport, Building and Urban Development (BMVBS) to investigate the possibility of introducing polycarbonate windscreens in passenger cars mainly with regard to effects for safety of vulnerable road users. Based on several extensive test series answers to the following questions were requested:

[1] GRSG: Working Party on General Safety Provisions of the UNECE WP.29
[2] WP.29: World Forum for Harmonisation of Vehicle Regulations of the UNECE

- Does the use of plastic windscreens in vehicles lead to a higher injury risk for vulnerable road users, especially for pedestrians?
- Can the current test procedure (Phantom head drop test) on the approval of glazing according to UN Regulation No. 43 be used for plastic glazing? Which modifications or extensions might be necessary?

The present report describes the test programme carried out at BASt, the different test setups, differences in material and variations of ambient conditions as well as the findings on the questions raised in terms of pedestrian injury risk and recommendations for a possible introduction of plastic windscreens within UN Regulation No. 43.

2 Investigated factors

In order to achieve the goals of this project listed in Chapter 1 as well as to get a better feeling of the effects of an introduction of plastic glazings for windscreens, the following factors were investigated.

- Material:
  The relevant properties of PC panes were compared with those of currently commonly used VSG (laminated glass) panes. This comparison was made with plane panes as well as with current vehicle windscreens.

- Fixation:
  At present, most of the windscreens are glued to the vehicle structure. As there may be an effect of the kind of fixation with plastic panes, drop tests were made with plane panes either glued on a structural frame or clamped onto the frame.

- Frame dimension:
  Drop tests were performed with PC panes fixed onto rectangular frames of two different sizes.

- Thickness of PC panes:
  As a significant influence of this parameter was expected, drop tests as well as vehicle tests were carried out with panes of different thicknesses.

- PC pane construction:
  Laminated polycarbonate panes were added to the test series to compare these with the monolithic polycarbonate panes.

- Temperature:
  As plastic panes are suspected to change their properties significantly if the temperature rises up to more than 100℃ or falls below 0° C, drop tests should be executed at corresponding temperatures.

- Test point position:
  Pedestrian protection head impact tests have shown repeatedly that the position of the impact point on the windscreen, especially the distance to the windscreen frame or other structures, is of major importance for the test result. Therefore, four different impact points had to be determined on the windscreen (Photo 9) .

- Impact angle:
  During the progress of this test series, some members of the IGPG raised concerns whether the impact angle specified in Regulation (EC) No 631/2009 together with the windscreen angle of the used vehicle can sufficiently reflect real-life-scenarios with the majority of passenger cars. Therefore, after an interim survey of windscreen angles of common passenger vehicles, a second impact angle was determined and comparatively used.

3 Test configurations

3.1 Overview

To investigate the influence of the factors listed in chapter 2, the following tests were performed for this project:

- Drop tests with adult headform
- Drop tests with phantom headform
- Vehicle impact tests with Laminated Safety Glass panes (VSG)
- Vehicle impact tests with Polycarbonate panes (PC)
- Vehicle impact tests with Laminated Polycarbonate panes (L-PC)

In total, 30 drop tests and 49 vehicle impact tests were executed in the laboratories of the Federal Highway Research Institute in Bergisch Gladbach, Germany.

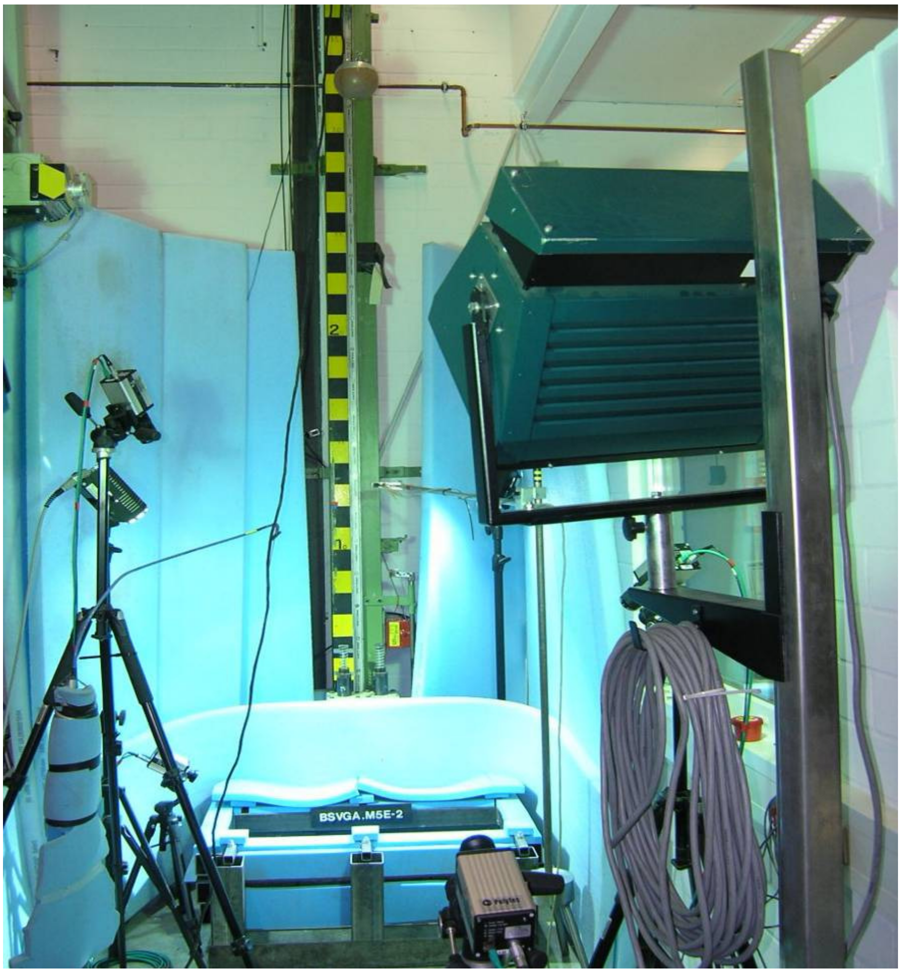

Photo 1: Drop tests with adult headform – test setup

3.2 Drop tests with adult headform

For these tests, a special universally usable drop test rig was used. With this test stand impactors up to approx. 30 kg can be used which may fall from a drop height of up to 7 m. The impactor is held by a permanent magnet system which can be immediately released by a remote control. This magnet is supported by an extension arm which is mounted to a vertical sled, equipped with smooth running ball bearings, and guided by a vertical rail, see Photo 1. Due to this unique equipment, guided and non-guided drop tests are possible to be executed. For the tests for this project, free fall could be chosen because the adult head impactor is rotationally symmetric. The drop height of 3 m refers to the procedure described in amendment ECE/TRANS/WP.29/GRSG/2009/8 to UN Regulation No. 43 (headform test).

The impactor used is the pedestrian protection adult head impactor prescribed in Regulation (EC) No 631/2009, having a total mass of 4.5 kg and a diameter of 165 mm. The headform which shall represent the head of an average human male, consists of an aluminium skull sphere covered by a vinyl skin, see Photo 2. Inside the two-piece sphere, in the centre of gravity of the headform which concomitantly is the geometrical centre of the impactor, three accelerometers are mounted to measure the decelaration of the headform in the three spatial directions when impacting the specimen (Figure 1).

Photo 2: Pedestrian headform

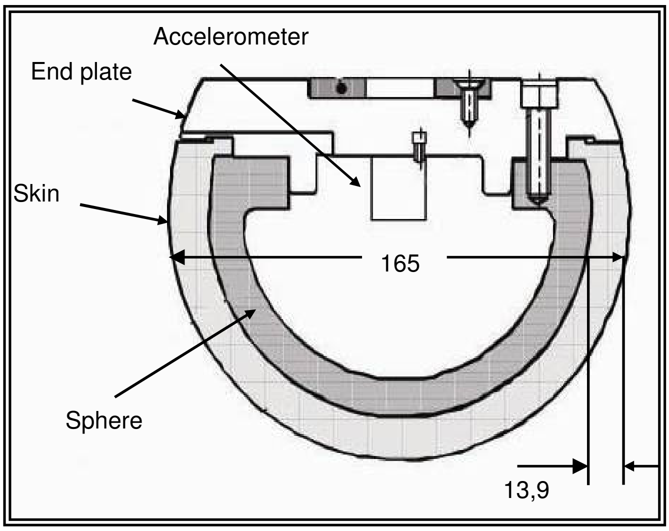

Figure 1: Pedestrian headform

With this test configuration, plane panes could be tested. For the positioning of the panes, two different test frames were used. The “base frame” with the outer dimensions of 500 x 1000 mm and the frame according to UN Regulation No. 43 with the dimensions 570 x 1170 mm, see Photos 3 and 4.

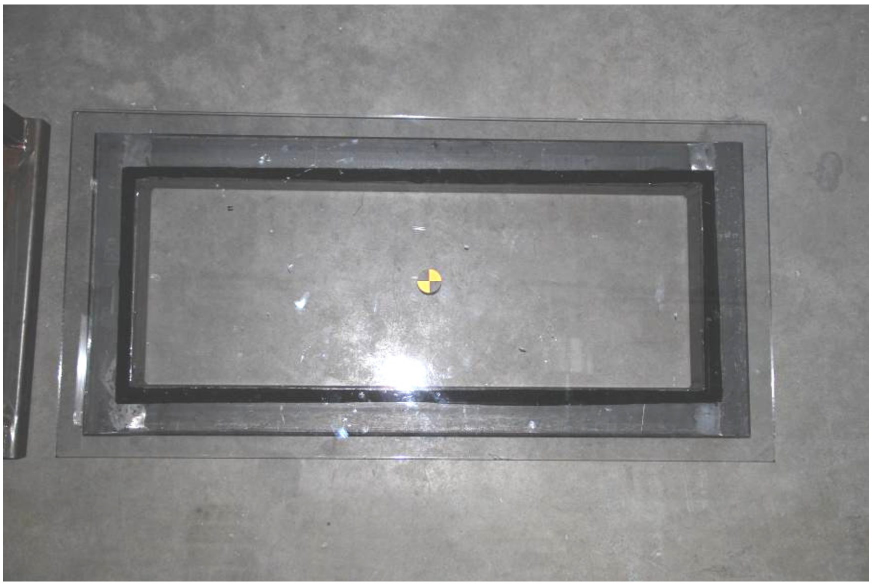

Photo 3: Base frame

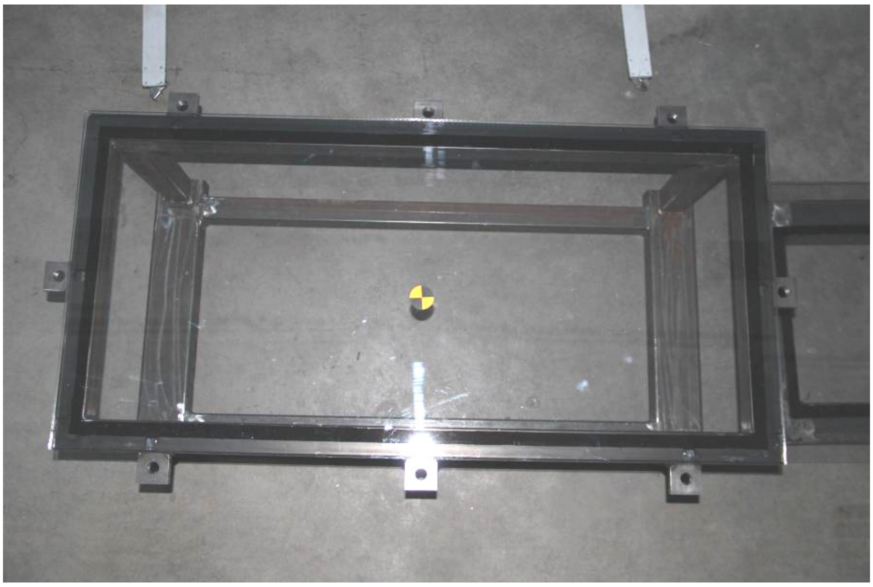

Photo 4: UN R 43 frame

The frames were positioned to allow an impact point exactly in the geometrical centre of the planes, see Photo 5.

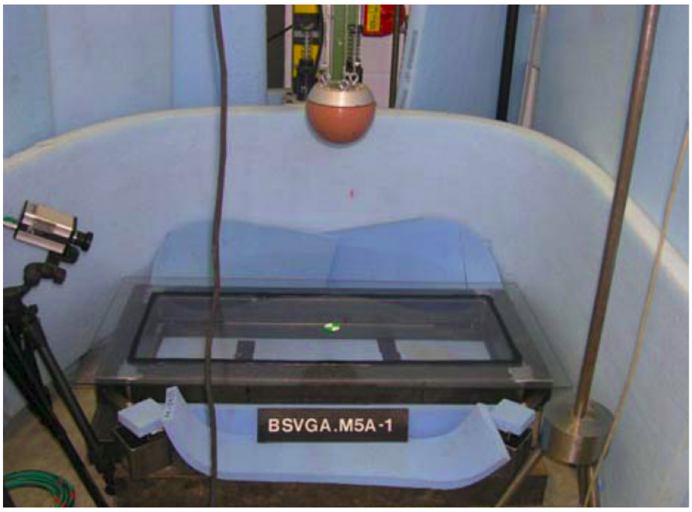

Photo 5: Adult headform drop test – impact point

3.3 Drop tests with phantom headform

In addition to the tests with the pedestrain protection adult head impactor, the phantom head impactor as prescribed in UN Regulation No. 43 was used for a series of drop tests.

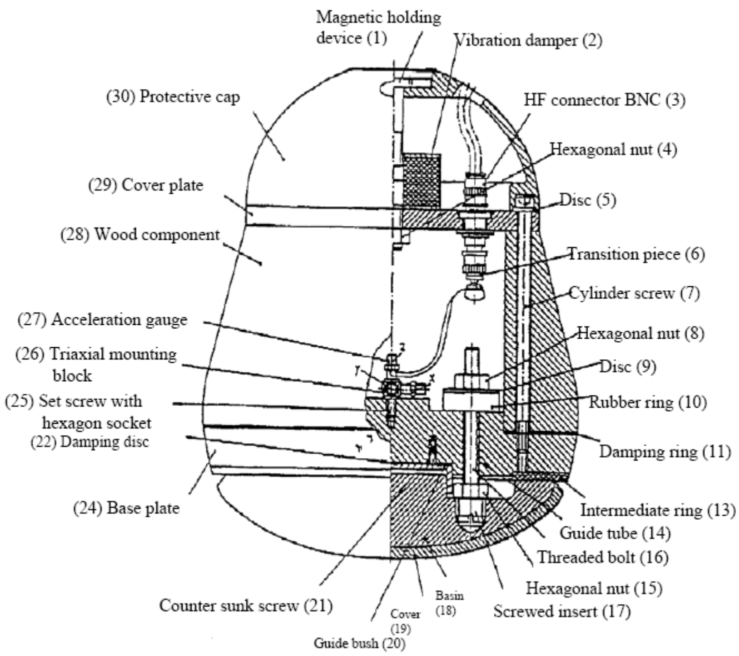

Figure 2: Phantom headform (source: UN R 43)

This headform consists of a wooden main body part with a rubber-covered basin at the impact side and a protective cap at the upper end. The headform is equipped with damping measures to reflect the elastic properties of a human skull. Within the wooden centre part, a triaxial accelerometer is installed and connected to an on-board data acquisition system that allows to perform tests without having cables coming out of the headform. The construction of the headform is illustrated in Figure 2.

Photo 6: Phantom head drop test – overview

Photo 7: Phantom head drop test – impact configuration

As, amongst others, the influence of high and low temperature was to be investigated, the corresponding panes had to be pre-conditioned in a climate chamber. As the available climate chamber could not provide a drop height of 3 m, the test setup had to be installed directly beneath the climate chamber to allow tests to be done immediately after the pane was taken out of the required ambient temperature. Therefore, a special test environment was built up with the ECE test frame being the central part. The support of the phantom head with its magnet release system was realized by a rigid bracket with a mounting device to hold the magnet.

This bracket was supported by a specially installed lifting system that could bring the phantom head in its pre-test position at the defined drop height exactly above the geometrical centre of the pane support frame. The lifting system was capable to move up the support bracket smoothly and steplessly to avoid an unintended detachment of the magnet release plate. An overview of the test setup is presented in photo 6 and the impact configuration in Photo 7.

3.4 Vehicle impact tests

Main focus of this project was to compare the characteristics of plastic glazing with those of laminated safety glass when used as windscreens in passenger cars with regard to pedestrian protection capabilities. Consequently, tests according to the European Regulation on pedestrian safety for vehicles had to be performed. The detailed procedure for the testing of windscreens is described in Regulation (EC) No 631/2009, Annex Part II, Chapter VI.

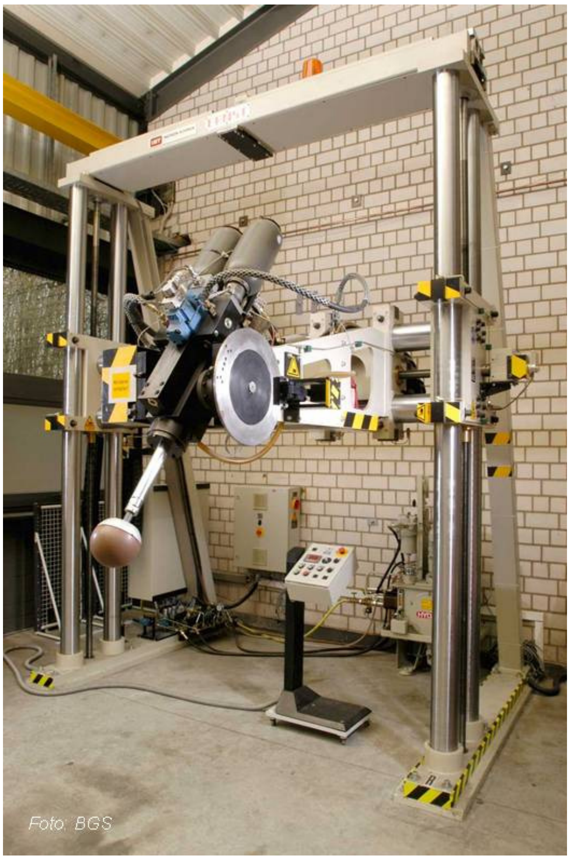

Photo 8: Pedestrian protection test rig at BASt

The vehicle used for this project was a Volkswagen T5 Transporter, mainly due to the availability of plastic windscreens. The reason for this particular situation is that this vehicle type is used by police departments for special operations, some of which require a windscreen that withstands violence better than glass.

The car was prepared to have the normal ride attitude for 40 km/h, as prescribed within Regulation (EC) No 631/2009. The tyre pressures were inflated for half load, all liquids such as petrol and oil were filled up to the maximum values, the driver and front passenger seat were equipped with loads of 75 kg each.

The vehicle was positioned in front of a pedestrian protection test rig, i.e. an accelerator capable of firing all pedestrian impactors agaist the vehicle's car front or roof. BASt's test rig is shown in photo 8. This accelerator was equipped with a launcher system to hold and support the pedestrian headform. The impact angle is adjustable between 0° (horizontal) and 90° (vertical). The headform used was the pedestrian protection adult head impactor already mentioned in chapter 3.2.

Four different impact points on the windscreen were chosen according to the prerequisites mentioned in chapter 2:

- 1 = Windscreen base

The point was chosen at the lowest possible position on the windscreen between the windscreen wipers in order to realize the highest influence of the windscreen base cross beam as a hard underlying structure. It was intended to get neither contact with wiper blades nor with the bonnet to avoid signal distortions due to damping effects or glancing blows.

- 2 = Glazing without structure within range

The geometrical centre of the windscreen was chosen because it is the point with the largest distance to any surrounding support or underlying structure.

- 3 = Glazing with underlying structure

The test point was defined on the centreline of the vehicle near the windscreen base but without direct contact to any underlying structure. The distance to the instrument panel ensured that during the test the panel was reached by the deforming windscreen.

- 4 = Next to A-pillar

The test point was determined midway between the front and rear end of the wind-screen to avoid any direct influence of the upper or lower windscreen frame cross bar. The lateral distance of 100 mm to the A-pillar ensured that its influence on the test measurements would be significant.

Photo 9 shows the impact positions on the test vehicle.

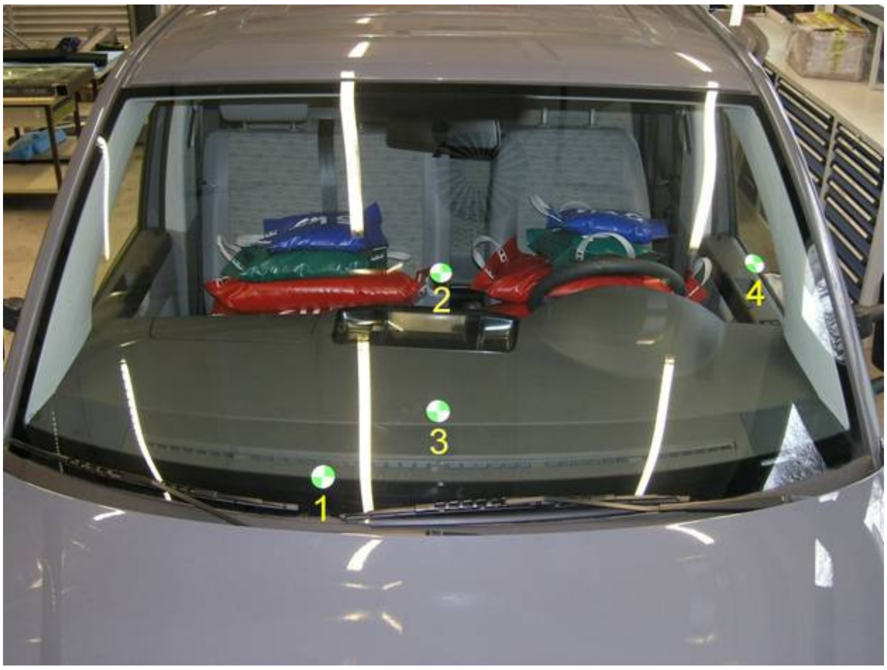

Photo 9: Windscreen impact locations

4 Test execution

4.1 General

All of the tests were carried out in accredited laboratories of the Federal Highway Research Institute (BASt) in Bergisch Gladbach, Germany. The audited quality management reflects the requirements of DIN EN ISO/IEC17025.

Before each test series the headform impactors were certified according to their individual provision: Regulation (EC) No 631/2009 for the adult pedestrian protection headform and DIN 52310 Part 2 for the phantom headform.

The adult pedestrian headform was equipped with three damped accelerometers type Kyowa ASE-A 500 according to the recommendations in the Euro NCAP technical bulletin TB003.

The filtering of the measurement channels, the calculation of the resultant accelerations and of the HIC values were executed according to Regulation (EC) No 631/2009.

The head injury criterion (HIC) is defined as follows:

$$HIC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,dt\right]^{2,5}(t_2 - t_1)$$

Each test was documented by pre-test and post-test photographs and at least two high-speed videos with different view angles.

The windscreens were always glued onto the vehicle. With these tests and in cases where adhesive was used to fix the plane panes to the test frames, at least 24 hours of drying time were allowed between the application and the pursuant test.

Unless otherwise stated, three tests were carried out with each test configuration. Even if no damage was seen on the pane, for each test on the same test point a new pane was used.

4.2 Drop tests

Altogether, 30 drop tests were performed: 18 tests with the pedestrian protection adult headform and 12 tests with the phantom headform.

Before the tests, a mass comparison of the different pane types was carried out. The results are presented in the following table. As the laminated safety glass panes had a slightly different size, the weight was also calculated for the size of the polycarbonat panes for comparison reasons. In Table 1, the calculated weight is presented in brackets.

Pane Type / Thickness	Dimension [mm]	Mass [kg]
VSG / 4,5 mm (2,1 mm outer pane, 1,6 mm inner pane)	1100 x 500 (1170 x 570)	5.5 (6.7)
PC / 5 mm	1170 x 570	4.1
PC / 6 mm	1170 x 570	4.8
PC / 8 mm	1170 x 570	6.3

Table 1: Mass comparison of plane panes

For the low and high temperature tests, +110° C and -18° C were chosen due to the laboratory capabilities. At temperatures of medium height (e.g. 40℃) no tests were performed because no significant influence was expected.

4.3 Vehicle tests

The overall number of performed tests with complete windscreens on a real test vehicle was 49.

15 tests were executed with windscreens made of laminated safety glass, 22 tests with monolithic polycarbonat panes and 12 tests with laminated polycarbonat panes.

The laminated safety glass consisted of a 1.6 mm inner pane, a foil of 0.8 mm and a 2.1 mm outer pane, thus having a total thickness of 4.5 mm.

The monolithic windscreens had thicknesses of 5 mm, 6 mm, and 8 mm.

The laminated polycarbonat windscreens consisted of an inner and an outer pane of 3.0 mm each, with a foil of 1.2 mm in between. Hence, the total thickness was 7.2 mm.

A mass comparison is given in Table 2:

Pane Type / Thickness	Mass [kg]
VSG / 5 mm	16.69
PC / 5 mm	approx. 9.4
PC / 6 mm	approx. 11.3
PC / 8 mm	approx. 15
L-PC / 7.2 mm	approx. 13.5

Table 2: Mass comparison of windscreens

As any pre-existing defect changes the windscreen tension and accordingly the test results, for each test with laminated saftey glass panes a new windscreen was mounted. The same procedure applied for the first tests with the polycarbonate windscreens. However, the results of the visual inspection, where no indication of any damage could be seen on the windscreens, led to the assumption that there should not be expected any influence of a previous impact on the same screen to the subsequent test at a different position.

As this assumption was proved by the following tests, the polycarbonate windscreens were always used for one test at each position.

Besides the impact angle of 35° to the horizontal according to Regulation (EC) No 631/2009, an alternative impact angle of 28° to the horizontal was used for reasons given in chapter 2. Photos 10 and 11 show the test setup with both impact angles.

Photo 10: Test setup with 35° impact angle


Photo 11: Test setup with 28° impact angle

Three tests were performed with each configuration, with the following two exceptions:

1. The first test with a polycarbonate windscreen on location 2 (centre of windscreen) showed an enormous rebound of the headform impactor together with a very low HIC value. As such a high rebound may cause damages to the headform or to other equipment of the test facility, no more tests on this impact location were performed.
2. The first series of tests on a 6 mm polycarbonat windscreen showed results that were to a high extent comparable to results obtained with polycarbonate windscreens of 5 mm and 8 mm thickness. Therefore, nofurther test on 6 mm panes were performed.

5 Test Results

5.1 Overview tables

The following tables provide an overview of all test setups, performed tests and the corresponding HIC results. The different shapes used within the subsequent diagrams (rectangular column, pyramid and round column) represent the different test setups (adult headform drop test, phantom headform drop test, vehicle test). Each test setup is then subdivided by the allocation to a particular colour code. Within the table, the following abbreviations are used:

VSG -	laminated safety glass
PC -	monolithic polycarbonate glazing
L-PC -	laminated polycarbonate glazing
RT -	ambient temperature
Mean -	mean value
CV -	coefficient of variation

	Cons. No.	Test No.	Repetition	Impactor	Support Structure	Impact Position	Material	Thickness	Fixation	Temperature	Imp. Angle	HIC	Mean	CV
Drop tests Adult Head (h= 3m)	1	BSVGA-V5A-1	1	Adult Head 4,5 kg	Base Frame	center	VSG	5 mm	Adhesive	RT	90°	473,7	339,6	47,8
	2	BSVGA-V5A-2	2	Adult Head 4,5 kg	Base Frame	center	VSG	5 mm	Adhesive	RT	90°	158,9		
	3	BSVGA-V5A-3	3	Adult Head 4,5 kg	Base Frame	center	VSG	5 mm	Adhesive	RT	90°	386,2		
	4	BSVGA-M5A-1	1	Adult Head 4,5 kg	Base Frame	center	PC	5 mm	Adhesive	RT	90°	672,8	666,5	1,9
	5	BSVGA-M5A-2	2	Adult Head 4,5 kg	Base Frame	center	PC	5 mm	Adhesive	RT	90°	651,6		
	6	BSVGA-M5A-3	3	Adult Head 4,5 kg	Base Frame	center	PC	5 mm	Adhesive	RT	90°	675,2		
	7	BSVGA-M5E-1	1	Adult Head 4,5 kg	Base Frame	center	PC	5 mm	Clamping	RT	90°	851,6	863,7	1,3
	8	BSVGA-M5E-2	2	Adult Head 4,5 kg	Base Frame	center	PC	5 mm	Clamping	RT	90°	867,0		
	9	BSVGA-M5E-3	3	Adult Head 4,5 kg	Base Frame	center	PC	5 mm	Clamping	RT	90°	872,6		
	10	BSVGA-M8A-1	1	Adult Head 4,5 kg	Base Frame	center	PC	8 mm	Adhesive	RT	90°	1081,2	1104,6	2,6
	11	BSVGA-M8A-2	2	Adult Head 4,5 kg	Base Frame	center	PC	8 mm	Adhesive	RT	90°	1095,6		
	12	BSVGA-M8A-3	3	Adult Head 4,5 kg	Base Frame	center	PC	8 mm	Adhesive	RT	90°	1137,0		
	13	BSVEA-M8E-1	1	Adult Head 4,5 kg	ECE Frame	center	PC	8 mm	Clamping	RT	90°	897,8	907,2	2,3
	14	BSVEA-M8E-2	2	Adult Head 4,5 kg	ECE Frame	center	PC	8 mm	Clamping	RT	90°	930,8		
	15	BSVEA-M8E-3	3	Adult Head 4,5 kg	ECE Frame	center	PC	8 mm	Clamping	RT	90°	892,9		
	16	BSVEA-M8A-1	1	Adult Head 4,5 kg	ECE Frame	center	PC	8 mm	Adhesive	RT	90°	776,8	806,6	3,4
	17	BSVEA-M8A-2	2	Adult Head 4,5 kg	ECE Frame	center	PC	8 mm	Adhesive	RT	90°	829,8		
	18	BSVEA-M8A-3	3	Adult Head 4,5 kg	ECE Frame	center	PC	8 mm	Adhesive	RT	90°	813,2		
Drop tests Phantom Head (h= 3m)	19	BSVEPM8E-LT1	1	Phantom Head	ECE Frame	center	PC	8 mm	Clamping	-18°	90°	851,1	883,5	10,8
	20	BSVEPM8E-LT2	2	Phantom Head	ECE Frame	center	PC	8 mm	Clamping	-18°	90°	990,8		
	21	BSVEPM8E-LT3	3	Phantom Head	ECE Frame	center	PC	8 mm	Clamping	-18°	90°	808,7		
	22	BSVEPM8E-NT1	1	Phantom Head	ECE Frame	center	PC	8 mm	Clamping	RT	90°	773,0	778,9	3,9
	23	BSVEPM8E-NT2	2	Phantom Head	ECE Frame	center	PC	8 mm	Clamping	RT	90°	751,7		
	24	BSVEPM8E-NT3	3	Phantom Head	ECE Frame	center	PC	8 mm	Clamping	RT	90°	811,9		
	25	BSVEPM8E-HT1	1	Phantom Head	ECE Frame	center	PC	8 mm	Clamping	110°	90°	919,8	857,6	7,2
	26	BSVEPM8E-HT2	2	Phantom Head	ECE Frame	center	PC	8 mm	Clamping	110°	90°	796,6		
	27	BSVEPM8E-HT3	3	Phantom Head	ECE Frame	center	PC	8 mm	Clamping	110°	90°	856,4		
	28	BSVEP-V5E-1	1	Phantom Head	ECE Frame	center	VSG	5 mm	Clamping	RT	90°	2624,2	1640,3	80,8
	29	BSVEP-V5E-2	2	Phantom Head	ECE Frame	center	VSG	5 mm	Clamping	RT	90°	132,5		
	30	BSVEP-V5E-3	3	Phantom Head	ECE Frame	center	VSG	5 mm	Clamping	RT	90°	2164,3		

Table 3: Drop tests

	Cons. No.	Test No.	Repetition	Impactor	Support Structure	Impact Position	Material	Thickness	Fixation	Temperature	Imp. Angle	HIC	Mean	CV
Vehicle Tests (v= 9,7 m/s)	31	BSVFA-V1-1	1	Adult Head 4,5 kg	T5	1	VSG	5 mm	Adhesive	RT	35°	1196,9	1089,2	13,6
	32	BSVFA-V1-2	2	Adult Head 4,5 kg	T5	1	VSG	5 mm	Adhesive	RT	35°	1150,1		
	33	BSVFA-V1-3	3	Adult Head 4,5 kg	T5	1	VSG	5 mm	Adhesive	RT	35°	920,5		
	34	BSVFA-V2-1	1	Adult Head 4,5 kg	T5	2	VSG	5 mm	Adhesive	RT	35°	600,0	550,7	21,4
	35	BSVFA-V2-2	2	Adult Head 4,5 kg	T5	2	VSG	5 mm	Adhesive	RT	35°	635,7		
	36	BSVFA-V2-3	3	Adult Head 4,5 kg	T5	2	VSG	5 mm	Adhesive	RT	35°	416,4		
	37	BSVFA-V3-1	1	Adult Head 4,5 kg	T5	3	VSG	5 mm	Adhesive	RT	35°	642,4	611,6	7,6
	38	BSVFA-V3-2	2	Adult Head 4,5 kg	T5	3	VSG	5 mm	Adhesive	RT	35°	558,0		
	39	BSVFA-V3-3	3	Adult Head 4,5 kg	T5	3	VSG	5 mm	Adhesive	RT	35°	634,5		
	40	BSVFA-V4-1	1	Adult Head 4,5 kg	T5	4	VSG	5 mm	Adhesive	RT	35°	407,6	398,9	34,0
	41	BSVFA-V4-2	2	Adult Head 4,5 kg	T5	4	VSG	5 mm	Adhesive	RT	35°	259,0		
	42	BSVFA-V4-3	3	Adult Head 4,5 kg	T5	4	VSG	5 mm	Adhesive	RT	35°	530,1		
	43	BSVFA-V4-28-1	1	Adult Head 4,5 kg	T5	4	VSG	5 mm	Adhesive	RT	28°	187,0	195,8	4,0
	44	BSVFA-V4-28-2	2	Adult Head 4,5 kg	T5	4	VSG	5 mm	Adhesive	RT	28°	202,3		
	45	BSVFA-V4-28-3	3	Adult Head 4,5 kg	T5	4	VSG	5 mm	Adhesive	RT	28°	198,1		
	46	BSVFA-M1-1	1	Adult Head 4,5 kg	T5	1	PC	5 mm	Adhesive	RT	35°	1667,1	1545,2	7,7
	47	BSVFA-M1-2	2	Adult Head 4,5 kg	T5	1	PC	5 mm	Adhesive	RT	35°	1537,8		
	48	BSVFA-M1-3	3	Adult Head 4,5 kg	T5	1	PC	5 mm	Adhesive	RT	35°	1430,6		
	49	BSVFA-M2-1	1	Adult Head 4,5 kg	T5	2	PC	5 mm	Adhesive	RT	35°	196,9	196,9	
	50			Adult Head 4,5 kg	T5	2	PC	5 mm	Adhesive	RT	35°			
	51			Adult Head 4,5 kg	T5	2	PC	5 mm	Adhesive	RT	35°			
	52	BSVFA-M3-1	1	Adult Head 4,5 kg	T5	3	PC	5 mm	Adhesive	RT	35°	835,1	726,2	13,4
	53	BSVFA-M3-2	2	Adult Head 4,5 kg	T5	3	PC	5 mm	Adhesive	RT	35°	695,4		
	54	BSVFA-M3-3	3	Adult Head 4,5 kg	T5	3	PC	5 mm	Adhesive	RT	35°	648,0		
	55	BSVFA-M4-1	1	Adult Head 4,5 kg	T5	4	PC	5 mm	Adhesive	RT	35°	909,5	840,1	11,0
	56	BSVFA-M4-2	2	Adult Head 4,5 kg	T5	4	PC	5 mm	Adhesive	RT	35°	735,3		
	57	BSVFA-M4-3	3	Adult Head 4,5 kg	T5	4	PC	5 mm	Adhesive	RT	35°	875,6		

Table 4: Vehicle tests (1)

	Cons. No.	Test No.	Repetition	Impactor	Support Structure	Impact Position	Material	Thickness	Fixation	Temperature	Imp. Angle	HIC	Mean	CV
Vehicle Tests (v= 9,7 m/s)	58	BSVFA-M1-6-1	1	Adult Head 4,5 kg	T5	1	PC	6 mm	Adhesive	RT	35°	1315,1	1315,1	
	59			Adult Head 4,5 kg	T5	1	PC	6 mm	Adhesive	RT	35°			
	60			Adult Head 4,5 kg	T5	1	PC	6 mm	Adhesive	RT	35°			
	61	BSVFA-M3-6-1	1	Adult Head 4,5 kg	T5	3	PC	6 mm	Adhesive	RT	35°	645,8	645,8	
	62			Adult Head 4,5 kg	T5	3	PC	6 mm	Adhesive	RT	35°			
	63			Adult Head 4,5 kg	T5	3	PC	6 mm	Adhesive	RT	35°			
	64	BSVFA-M4-6-1	1	Adult Head 4,5 kg	T5	4	PC	6 mm	Adhesive	RT	35°	731,4	731,4	
	65			Adult Head 4,5 kg	T5	4	PC	6 mm	Adhesive	RT	35°			
	66			Adult Head 4,5 kg	T5	4	PC	6 mm	Adhesive	RT	35°			
	67	BSVFA-M1-8-1	1	Adult Head 4,5 kg	T5	1	PC	8 mm	Adhesive	RT	35°	1289,1	1222,9	5,0
	68	BSVFA-M1-8-2	2	Adult Head 4,5 kg	T5	1	PC	8 mm	Adhesive	RT	35°	1168,2		
	69	BSVFA-M1-8-3	3	Adult Head 4,5 kg	T5	1	PC	8 mm	Adhesive	RT	35°	1211,5		
	70	BSVFA-M3-8-1	1	Adult Head 4,5 kg	T5	3	PC	8 mm	Adhesive	RT	35°	659,9	676,2	2,2
	71	BSVFA-M3-8-2	2	Adult Head 4,5 kg	T5	3	PC	8 mm	Adhesive	RT	35°	687,9		
	72	BSVFA-M3-8-3	3	Adult Head 4,5 kg	T5	3	PC	8 mm	Adhesive	RT	35°	680,9		
	73	BSVFA-M4-8-1	1	Adult Head 4,5 kg	T5	4	PC	8 mm	Adhesive	RT	35°	794,6	750,0	7,6
	74	BSVFA-M4-8-2	2	Adult Head 4,5 kg	T5	4	PC	8 mm	Adhesive	RT	35°	685,5		
	75	BSVFA-M4-8-3	3	Adult Head 4,5 kg	T5	4	PC	8 mm	Adhesive	RT	35°	770,0		
	76	BSVFA-MV1-7-1	1	Adult Head 4,5 kg	T5	1	L-PC	7,2 mm	Adhesive	RT	35°	1089,5	1124,0	3,0
	77	BSVFA-MV1-7-2	2	Adult Head 4,5 kg	T5	1	L-PC	7,2 mm	Adhesive	RT	35°	1156,5		
	78	BSVFA-MV1-7-3	3	Adult Head 4,5 kg	T5	1	L-PC	7,2 mm	Adhesive	RT	35°	1126,1		
	79	BSVFA-MV3-7-1	1	Adult Head 4,5 kg	T5	3	L-PC	7,2 mm	Adhesive	RT	35°	777,1	846,1	8,7
	80	BSVFA-MV3-7-2	2	Adult Head 4,5 kg	T5	3	L-PC	7,2 mm	Adhesive	RT	35°	837,5		
	81	BSVFA-MV3-7-3	3	Adult Head 4,5 kg	T5	3	L-PC	7,2 mm	Adhesive	RT	35°	923,7		
	82	BSVFA-MV4-7-1	1	Adult Head 4,5 kg	T5	4	L-PC	7,2 mm	Adhesive	RT	35°	892,4	883,6	1,6
	83	BSVFA-MV4-7-2	2	Adult Head 4,5 kg	T5	4	L-PC	7,2 mm	Adhesive	RT	35°	866,8		
	84	BSVFA-MV4-7-3	3	Adult Head 4,5 kg	T5	4	L-PC	7,2 mm	Adhesive	RT	35°	891,6		
	85	BSVFA-MV4-28-1	1	Adult Head 4,5 kg	T5	4	L-PC	7,2 mm	Adhesive	RT	28°	855,4	848,9	0,7
	86	BSVFA-MV4-28-2	2	Adult Head 4,5 kg	T5	4	L-PC	7,2 mm	Adhesive	RT	28°	844,1		
	87	BSVFA-MV4-28-3	3	Adult Head 4,5 kg	T5	4	L-PC	7,2 mm	Adhesive	RT	28°	847,2		

Table 5: Vehicle tests (2)

5.2 Drop tests with adult headform

As a first observation, no visible damage of the PC panes could be detected after the tests.

Figure 3 provides an overview of all test results obtained with the adult head impactor within the drop tests:

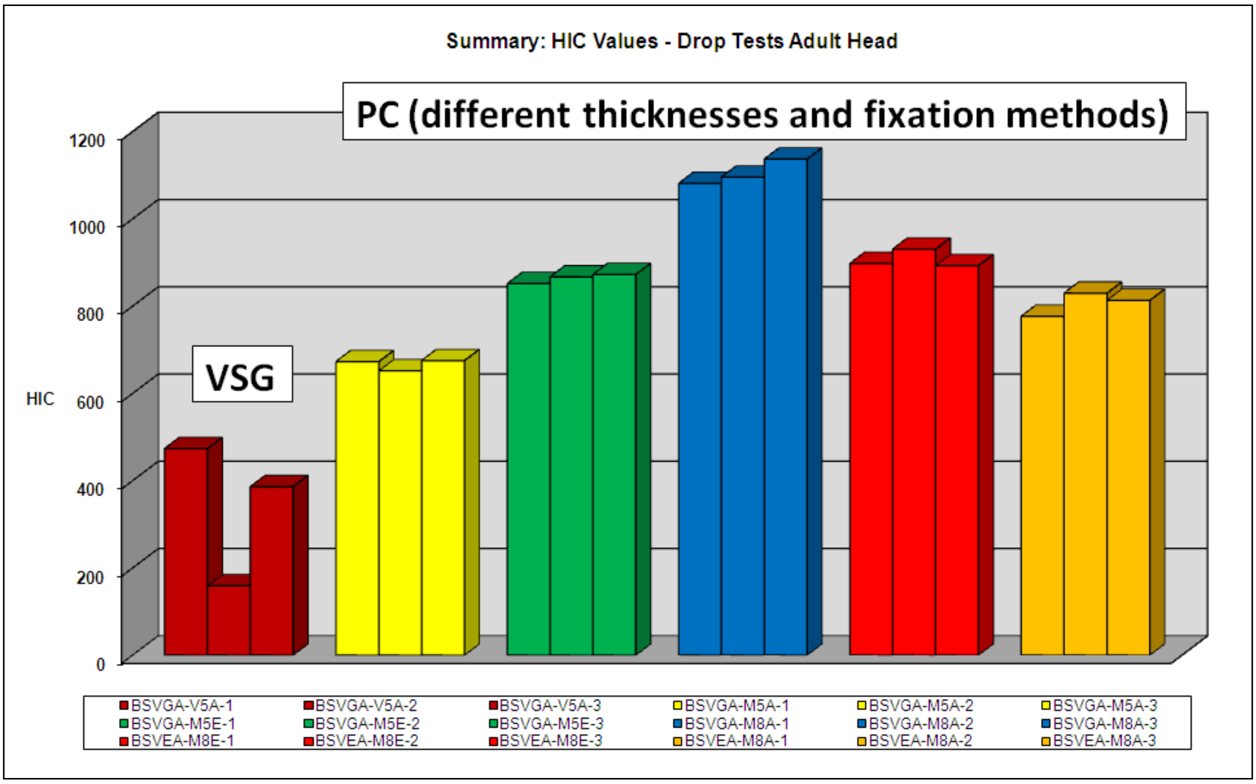

Figure 3: Overview of test results – Drop tests with adult head

The test performed on glass panes produced significant lower test results than those on polycarbonate panes. The panes with adhesive fixation on the test frame loaded the head impactor less than those that were clamped within the frame. The mean HIC values of the test results produced with the different setups are given in Figure 4:

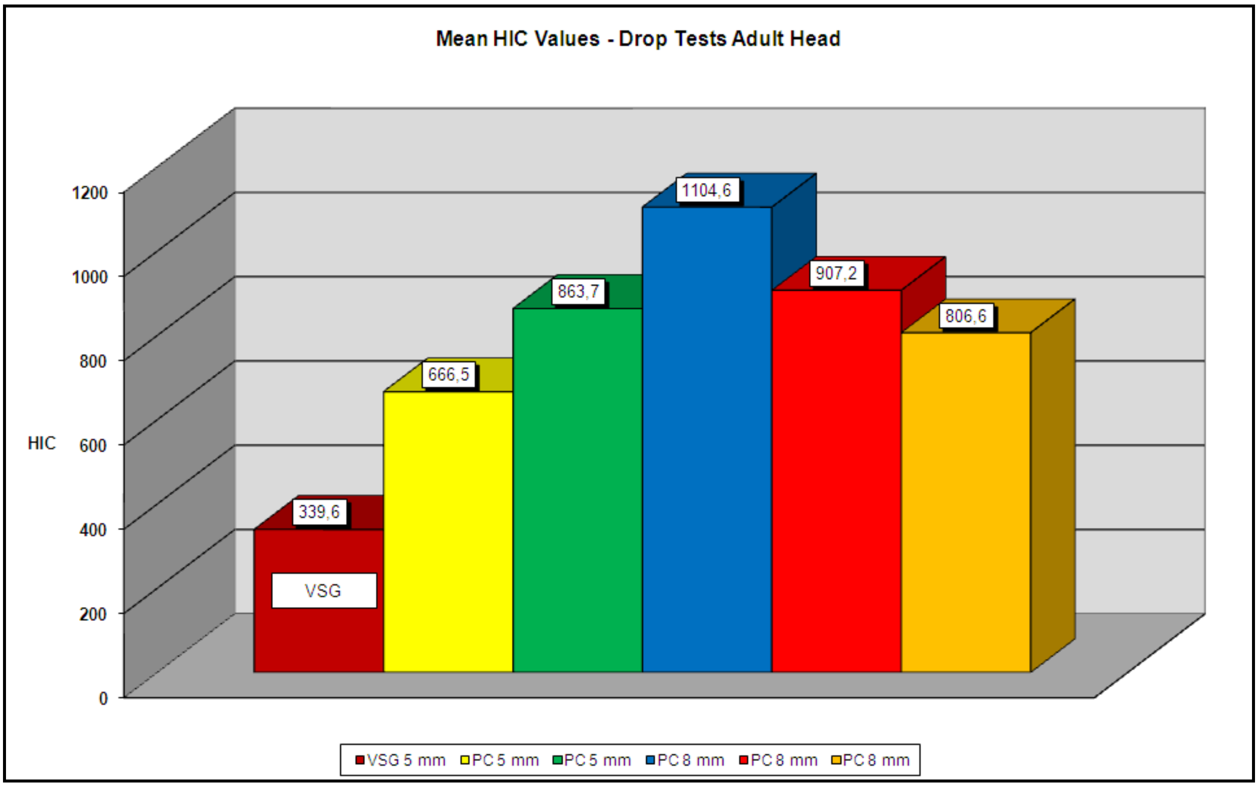

Figure 4: Mean test results - Drop tests with adult head

While the loads on the headform were the lowest ones in tests against the glass panes, this test setup produced the highest scatter in test results.

As shown in Figure 5, most results using the remaining test setups had a good repeatability according to the best practice guidelines for dummies (see Figure 6) with coefficients of variation below 3%. Only the repeatability of the test setup with the 8 mm polycarbonate panes and adhesive fixation to the ECE frame was acceptable only.

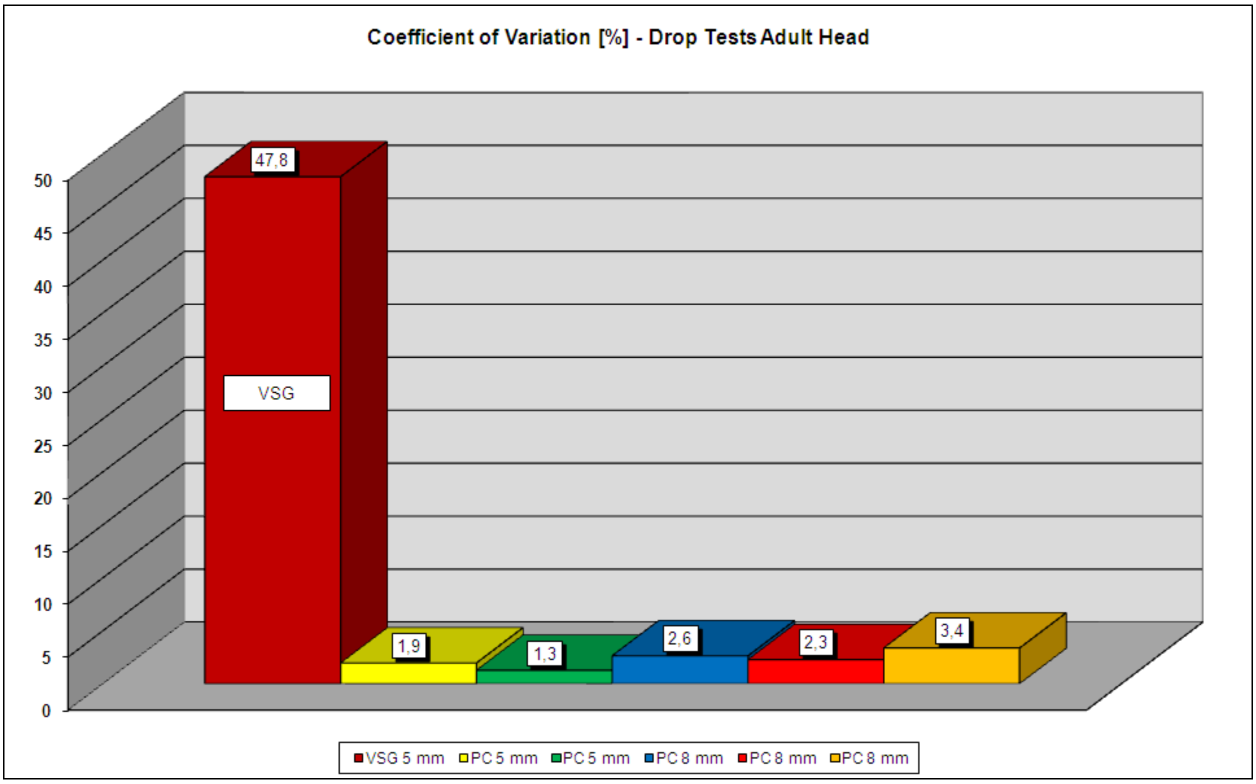

Figure 5: Coefficients of variation – Drop tests with adult head

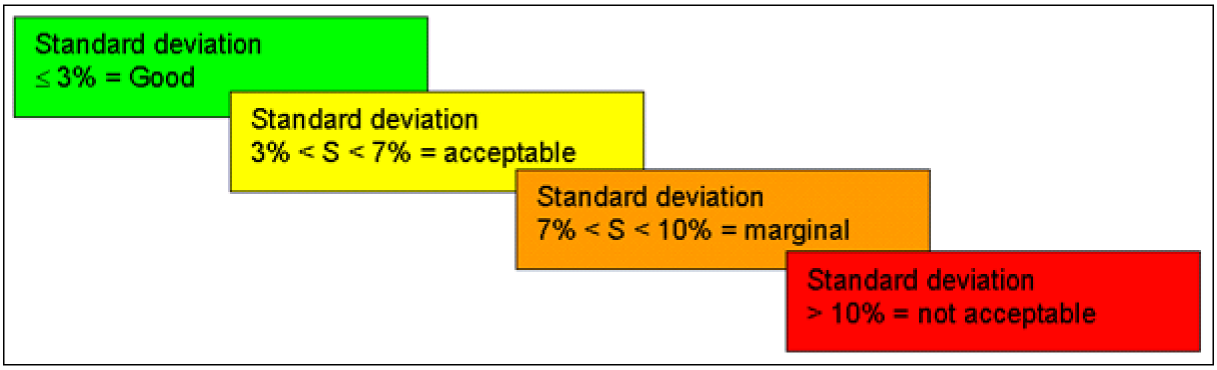

Figure 6: Repeatability assessment according to best practice guidelines for dummies [7]

Figure 7 provides the mean drop test results with adult head against polycarbonate panes only. The lowest results were produced with the base frame test setup and 5 mm polycarbonate pane secured with adhesive on the base frame. The highest results were obtained using the same test setup but 8 mm polycarbonate panes.

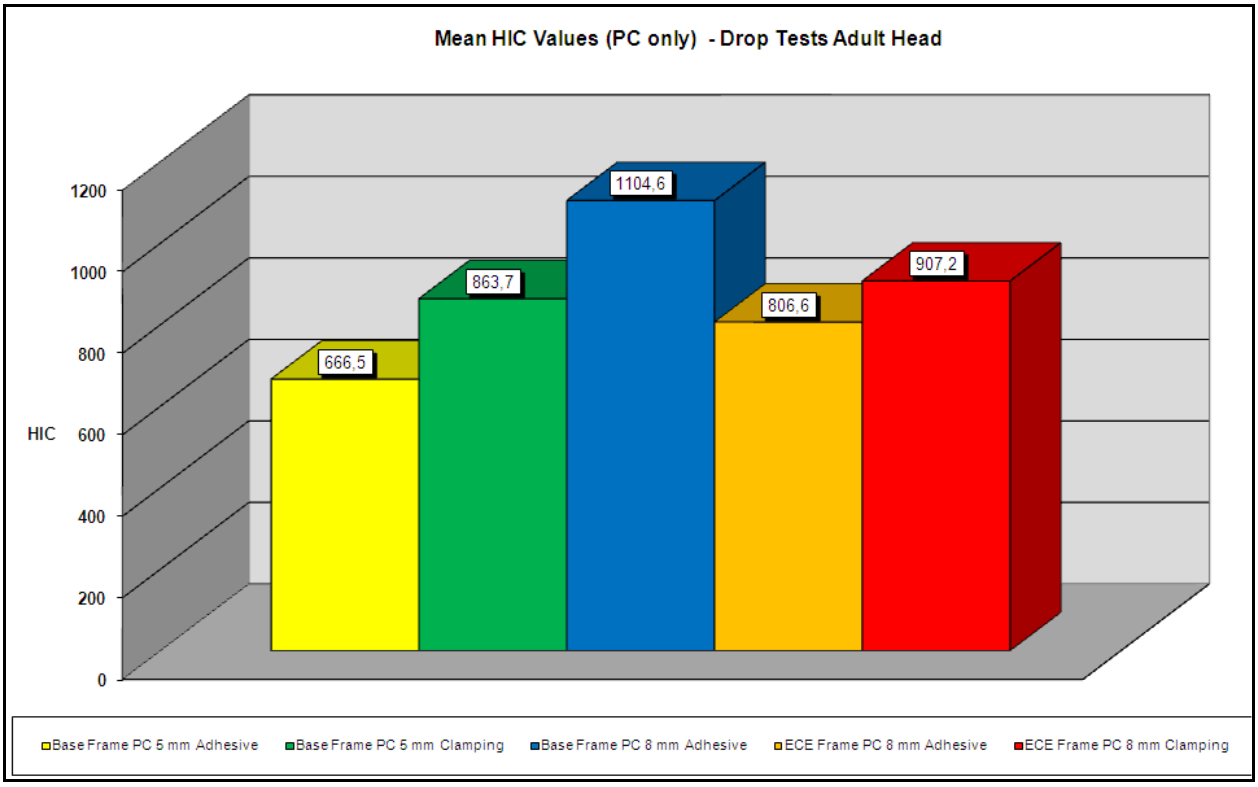

Figure 7: Mean test results with polycarbonate panes - Drop tests with adult head

The influence of the fixation method of the probe to the test frame is illustrated in Figure 8. When all other factors were identical, the clamping method produced higher test results than the bonding method:

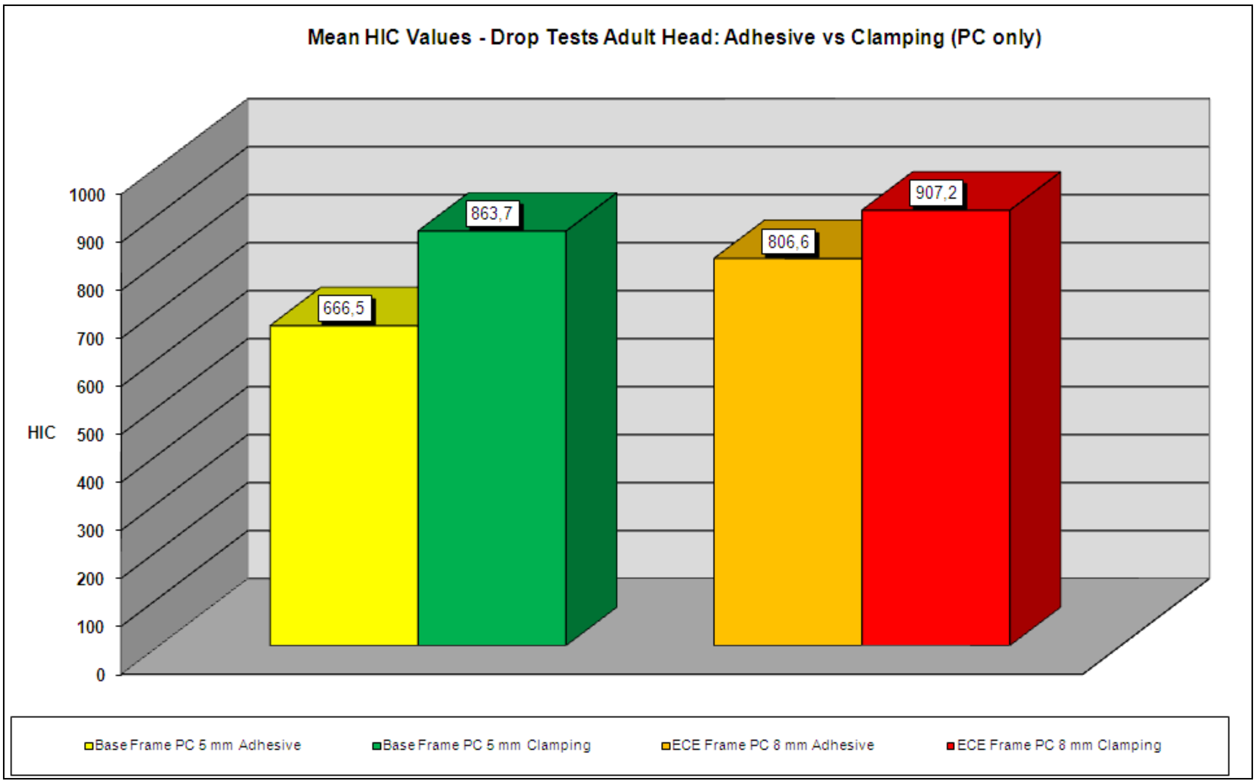

Figure 8: Influence of fixation on test results - Drop tests with adult head

Another parameter that had a significant influence on the test results was the thickness of the polycarbonate panes. Under otherwise identical test conditions the test specimen with 8 mm thickness caused higher loadings on the adult headform than the 5 mm panes, as shown in Figure 9. Thus, it can be assumed that the head loadings increase with an increasing thickness of the polycarbonate panes.

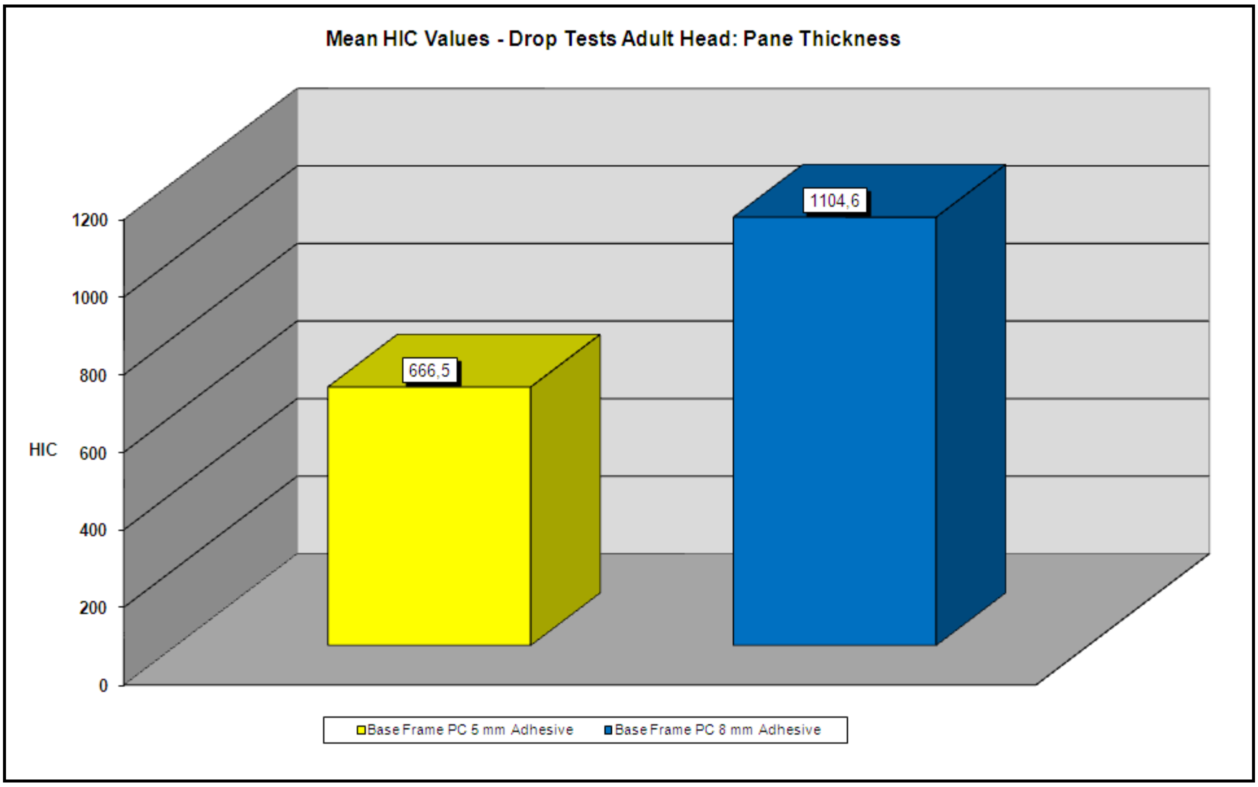

Figure 9: Influence of pane thickness on test results - Drop tests with adult head

Besides, the type of test frame used was of a certain significance (see Figure 10). Under otherwise identical test conditions the tests with polycarbonate panes fixed to the base frame resulted in higher loadings than those under the use of the ECE frame according to UN R 43.

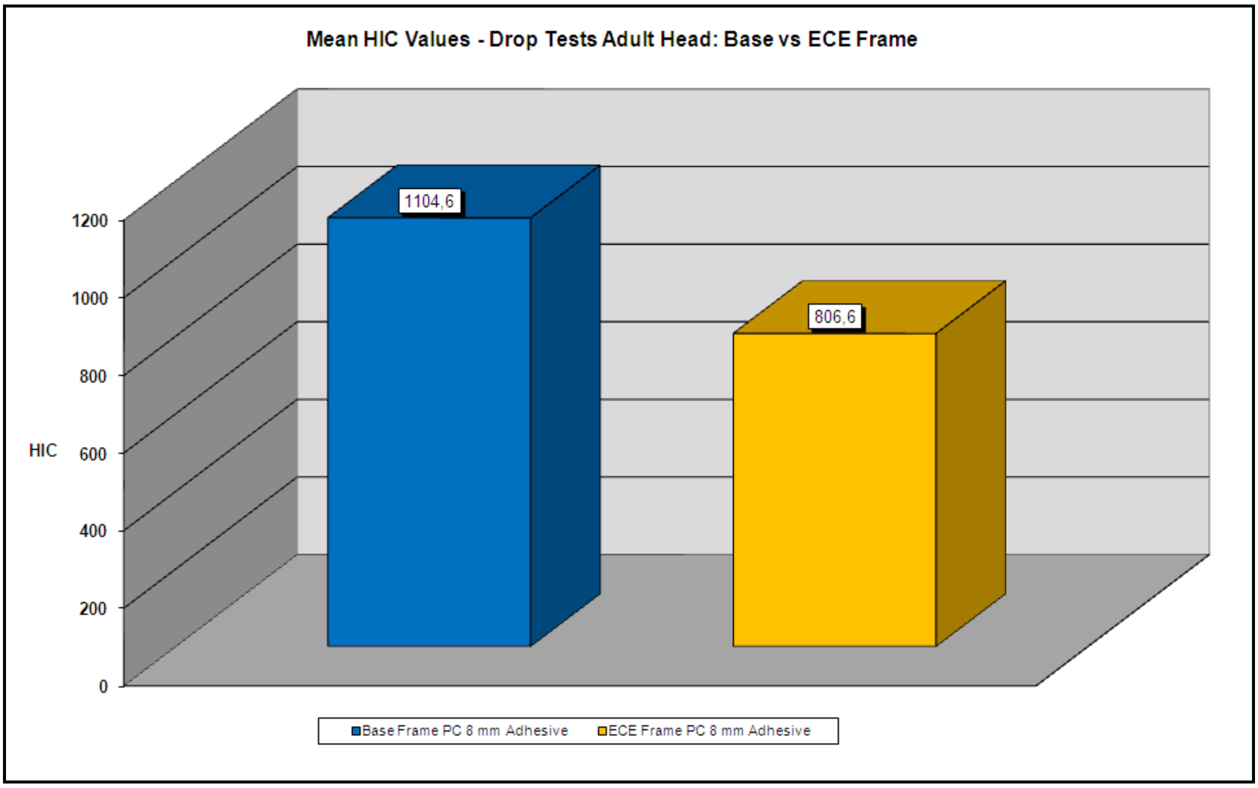

Figure 10: Influence of frame type on test results - Drop tests with adult head

5.3 Drop Tests with phantom headform

Again during the drop tests with the phantom headform, no visible damage of the polycarbonate panes was noted.

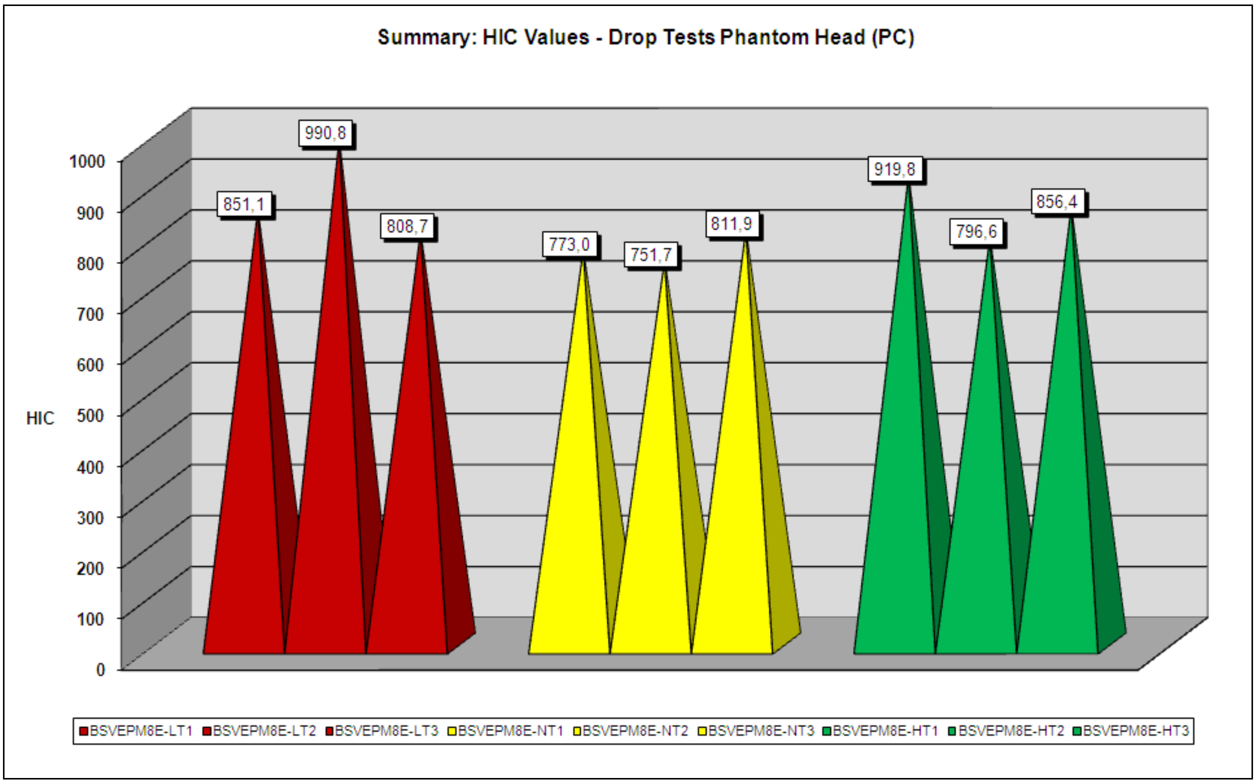

Figure 11 gives on overview of all drop test results with the phantom head, while Figure 12 illustrates the mean values of the results obtained with the three different setups. The diagrams underline the trend of tests performed at room temperature giving lower results than those at low (-18 °C) or high temperature (110 °C). When comparing the tests at low and high temperature, no clear trend in terms of influence of the temperature on the test results can be stated.

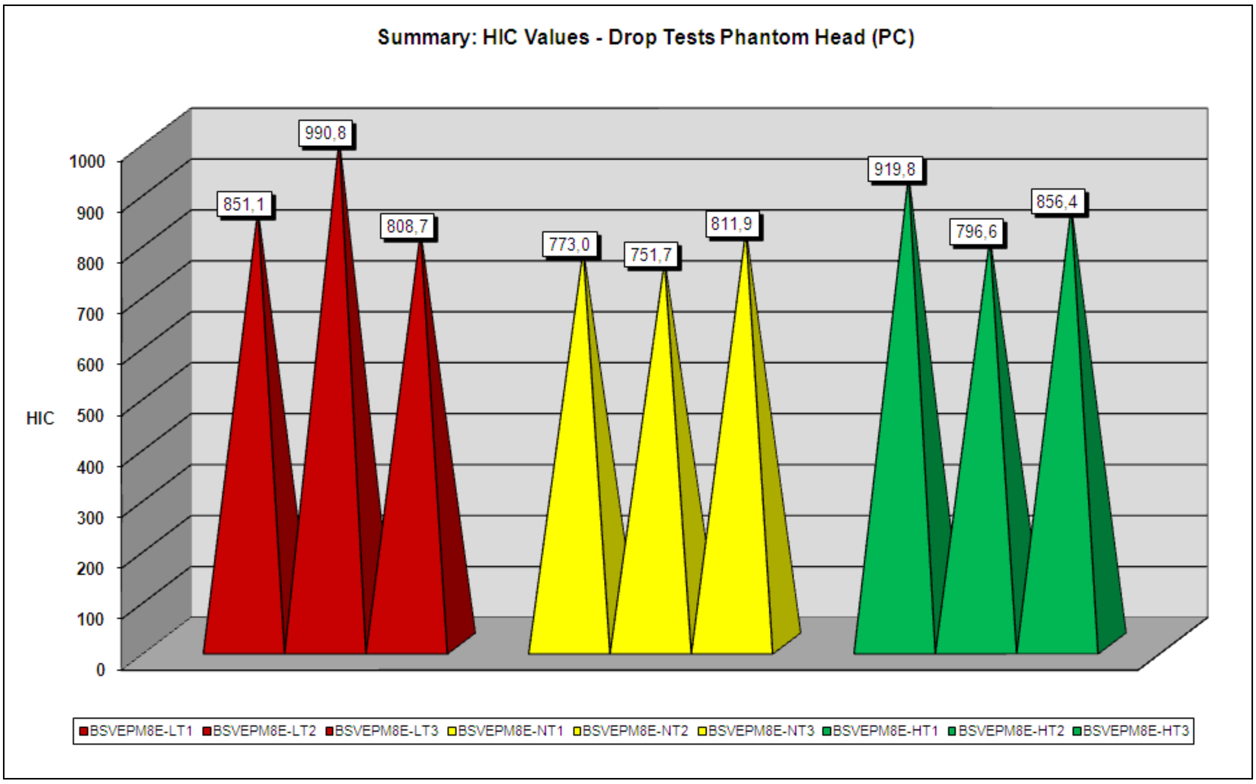

Figure 11: Overview of test results – Drop tests with phantom head

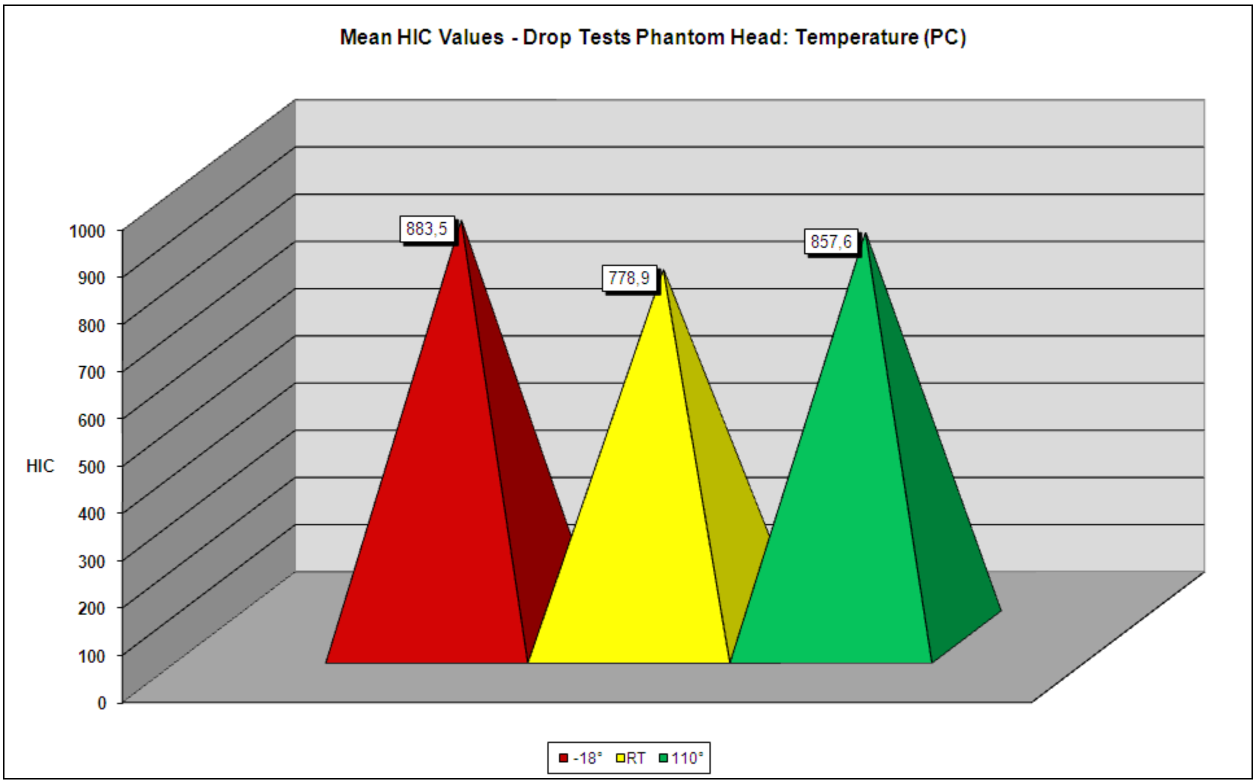

Figure 12: Mean test results – Drop tests with phantom head

As it can be seen in Figure 13, the scatter of test results is the highest in the tests at low temperature, followed by the ones at high temperature. On the other hand, the range within all of those tests was too high to rely on a certain tendency. The tests at room temperature produced the lowest scatter with an acceptable repeatability according to the best practice guidelines for dummies, see Figure 6.

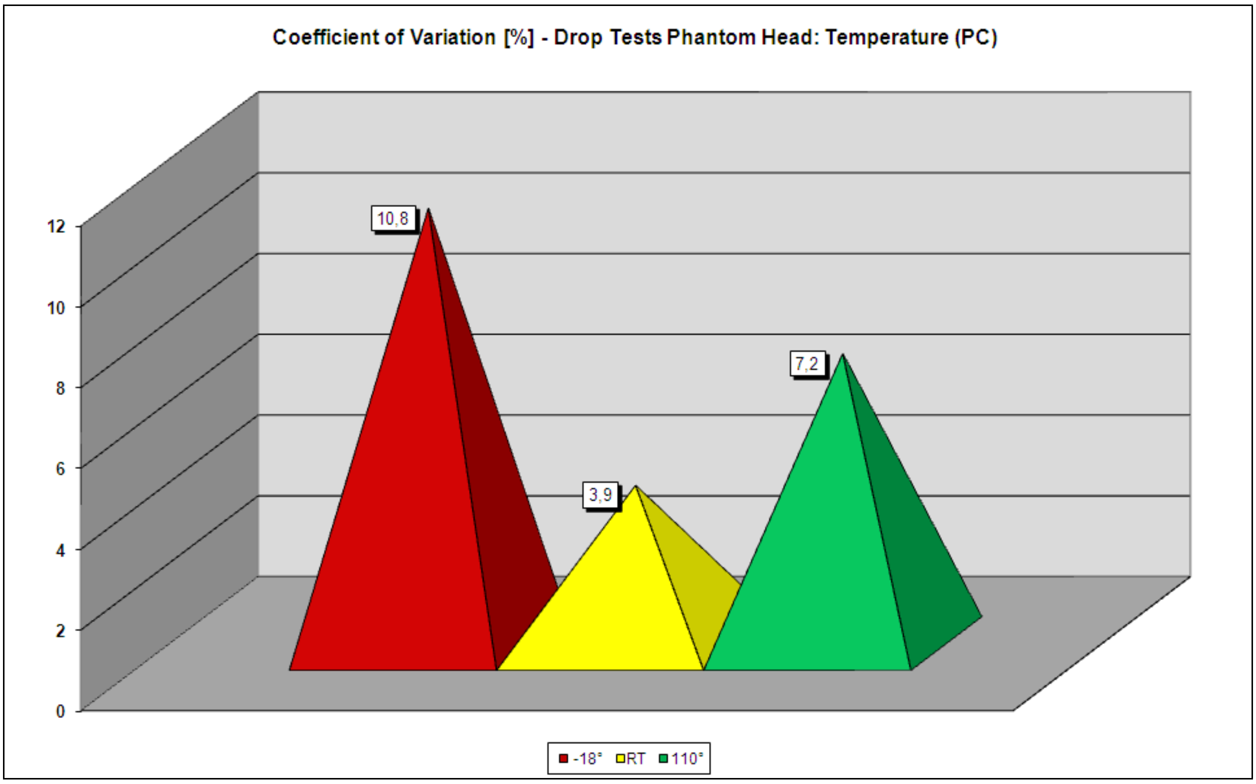

Figure 13: Coefficients of variation – Drop tests with phantom head

The stated observations may also result from the properties of the rubber strips that were used to clamp the panes in the frame, because the whole test setup was preconditioned (except the headform). This was found to represent more realistic situations, rather than laboratory conditions.

Figure 14 demonstrates the influence of the chosen impactor on the drop test results. Under otherwise identical impact conditions the tests with phantom head produced lower results than those with the adult headform:

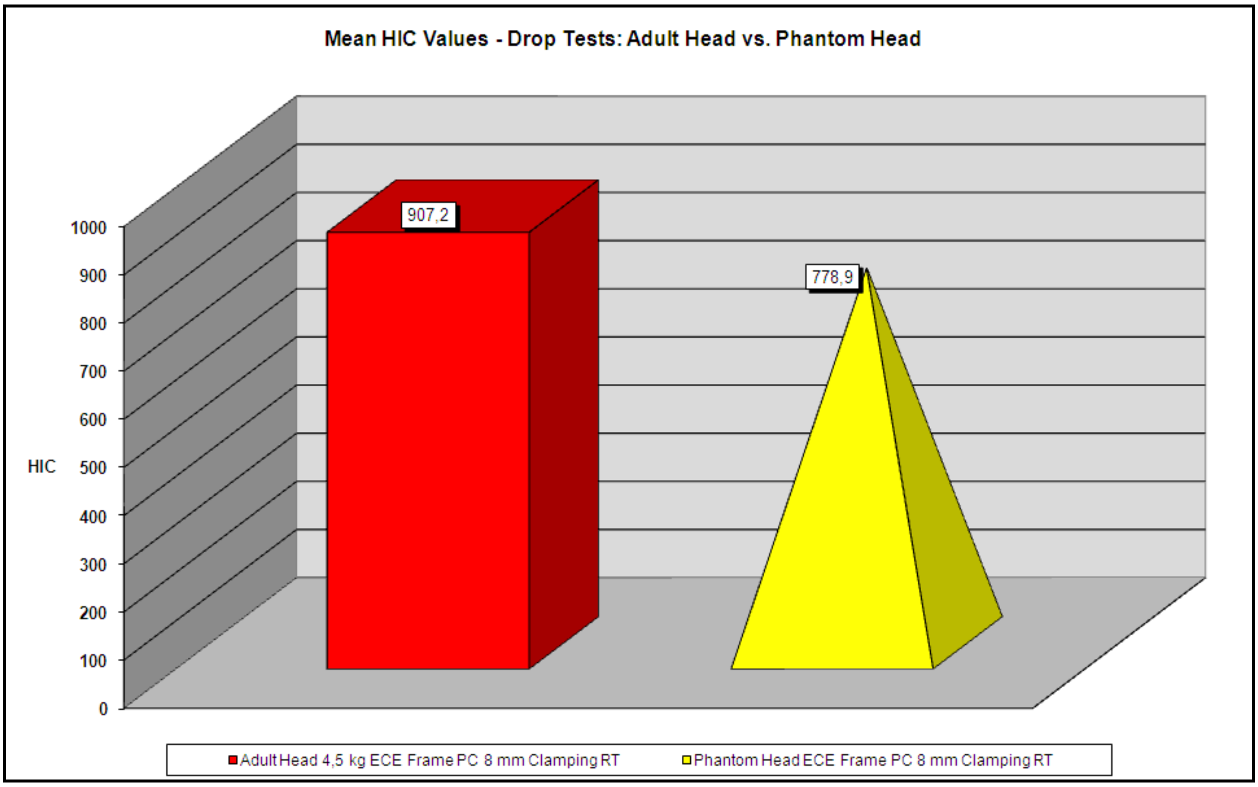

Figure 14: Influence of impactor type on test results - Drop tests w/ adult and phantom head

5.4 Vehicle Tests (Adult Headform)

Comparable to the observations in the drop tests and in contrary to the destructive tests with laminated safety glass, there was again no visible damage noted in tests with the polycarbonate windscreens.

However, large differences were observed between the individual test results. This becomes very clear in Figure 15, where an overview of all test results is presented. For a first possibility of comparison, Figure 16 shows an overview of all mean HIC values of the different test configurations, whereas Figure 17 is confined to the mean values of tests at locations 1, 3 and 4 and of tests with an impact angle of 35°. In this diagram it becomes obvious that at those three impact locations the HIC values of tests with polycarbonate panes are always significantly higher than HIC values obtained with laminated safety glass.

Comparing the coefficients of variation as shown in Figure 18, it can be noted that the scatter in tests with 8 mm polycarbonate panes and with 7.2 mm laminated polycarbonate panes is significantly lower than in tests with laminated safety glass but also than in those with 5 mm polycarbonate panes.

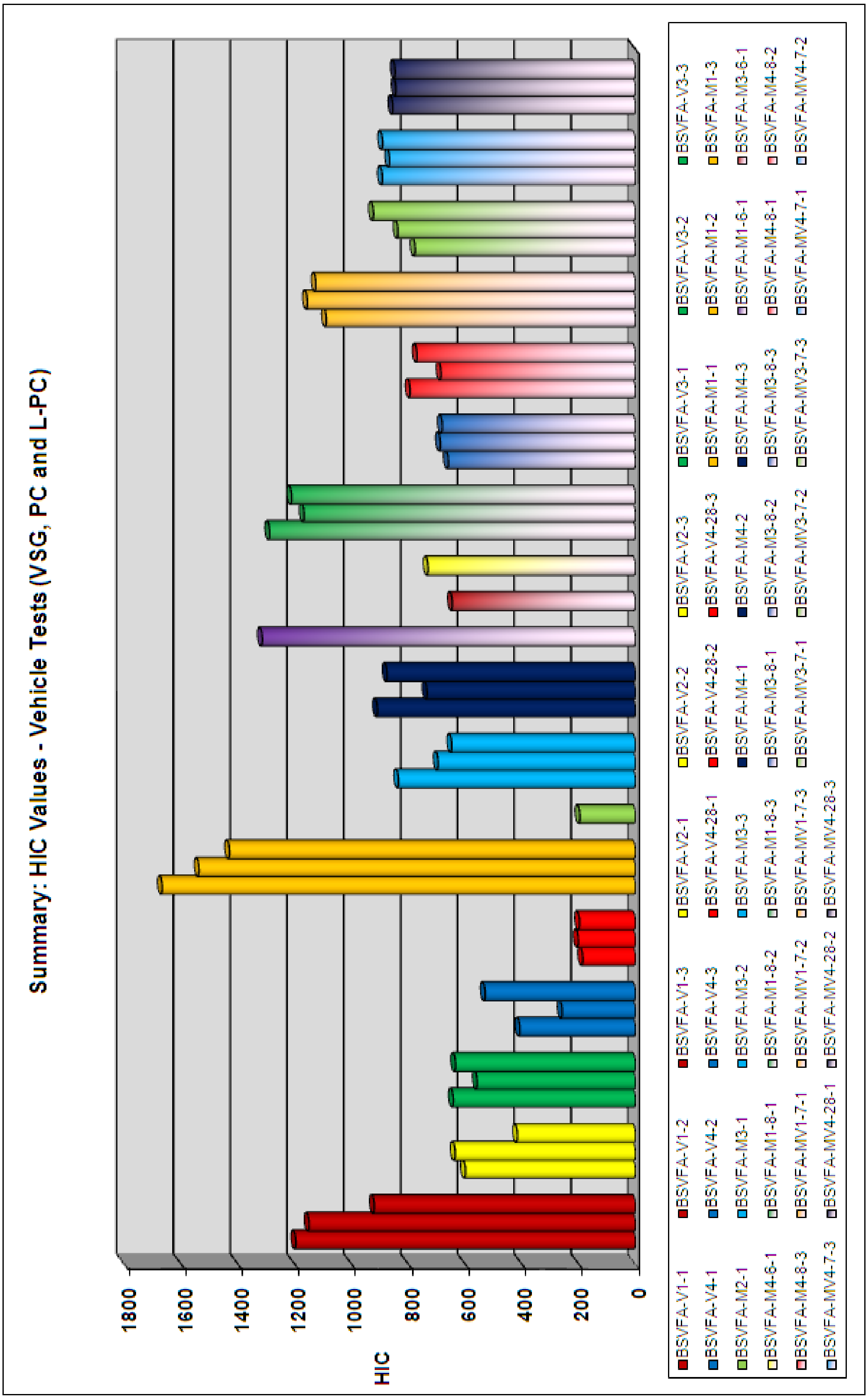

Figure 15: Overview of test results – Vehicle tests

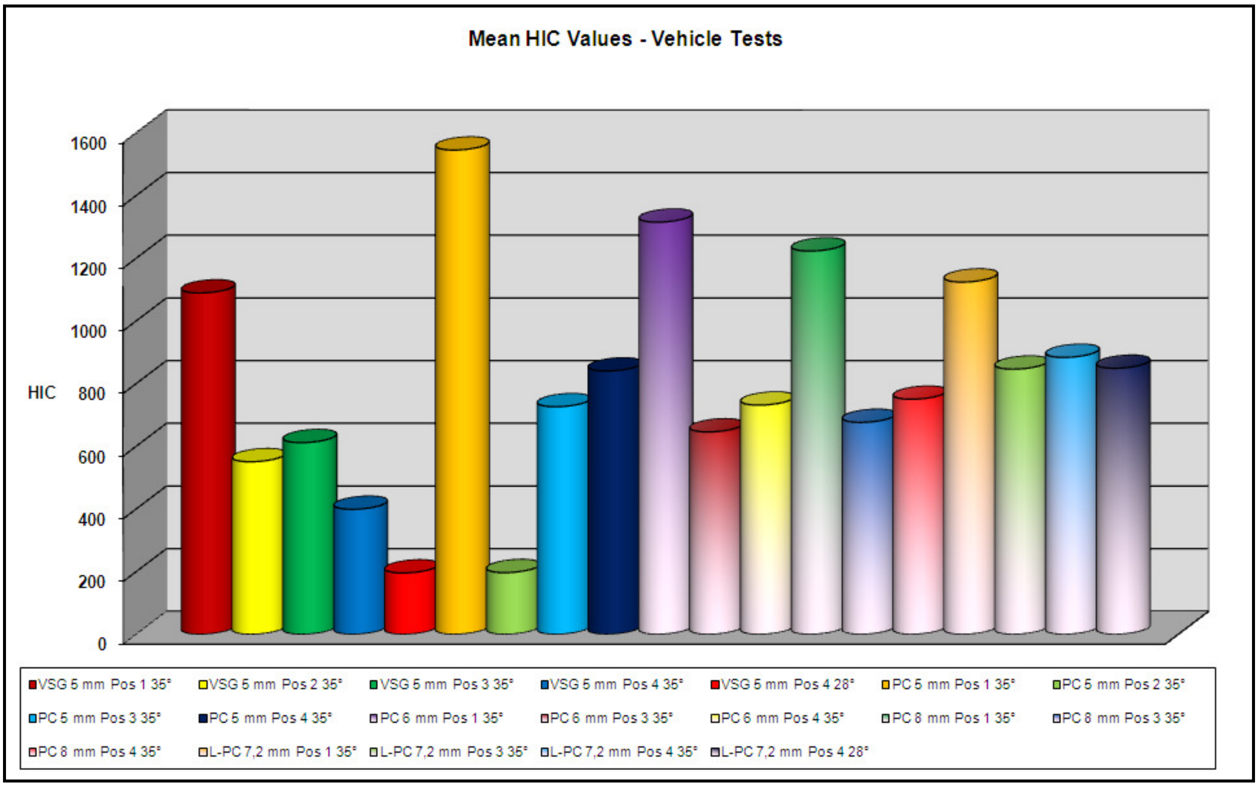

Figure 16: Mean test results – Vehicle tests

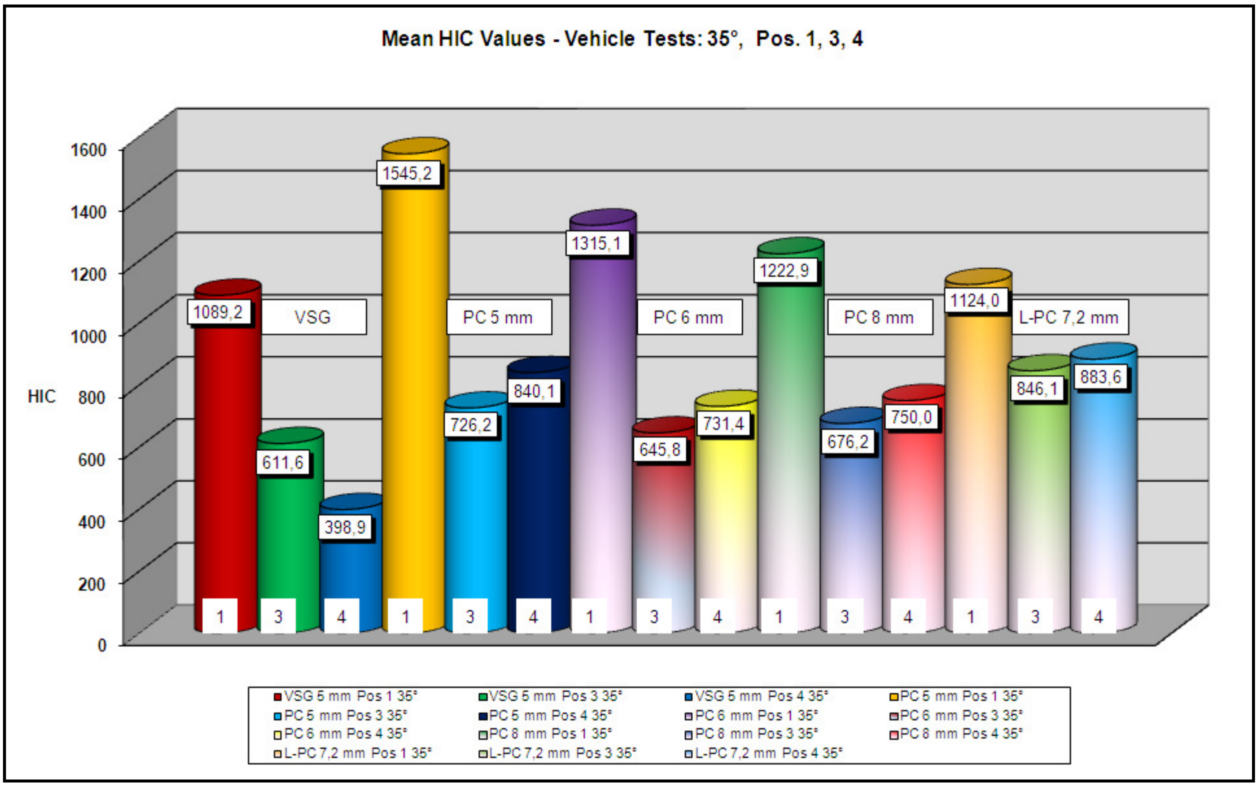

Figure 17: Mean test results at 35° impact angle on impact locations 1, 3 & 4 - Vehicle tests

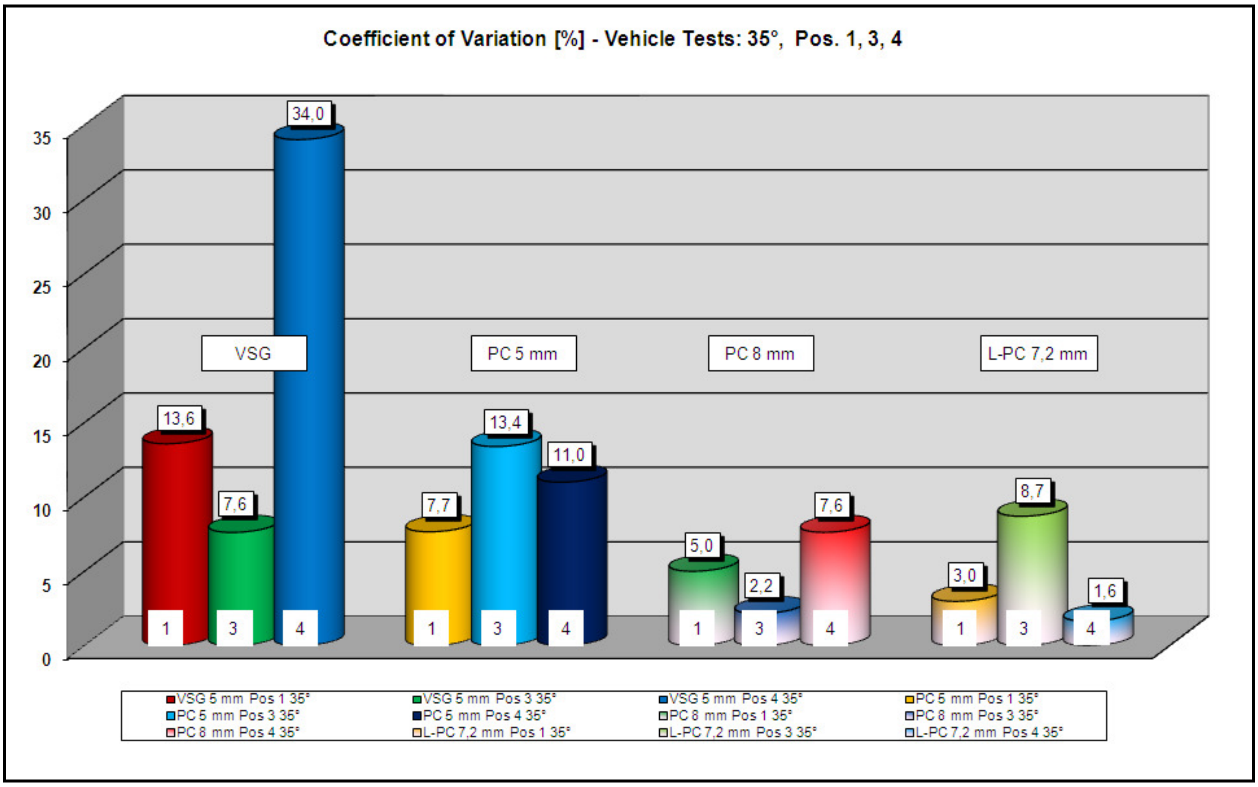

Figure 18: Coefficients of variation – Vehicle tests

In the following diagrams, the mean HIC values of the tests on one single impact location are compared.

At impact position 1 (windscreen base) shown in Figure 19, the HIC results of the tests with polycarbonate panes decrease with increasing pane thickness whereas the mean HIC value from tests with 7.2 mm laminated PC glazing is even lower than the mean result of tests with 8 mm monolithic PC glazing . At impact positions 3 (see Figure 21) and 4 (see Figure 22) the influence of the different pane thicknesses on the results is not significant.

At the only impact position on the windscreen where an influence of any hard structure is excluded, i.e. impact position no. 2 (center of windscreen), the single test performed on 5 mm polycarbonate glazing shows a significantly lower result than all three tests with laminated safety glass. Figure 20 illustrates this issue.

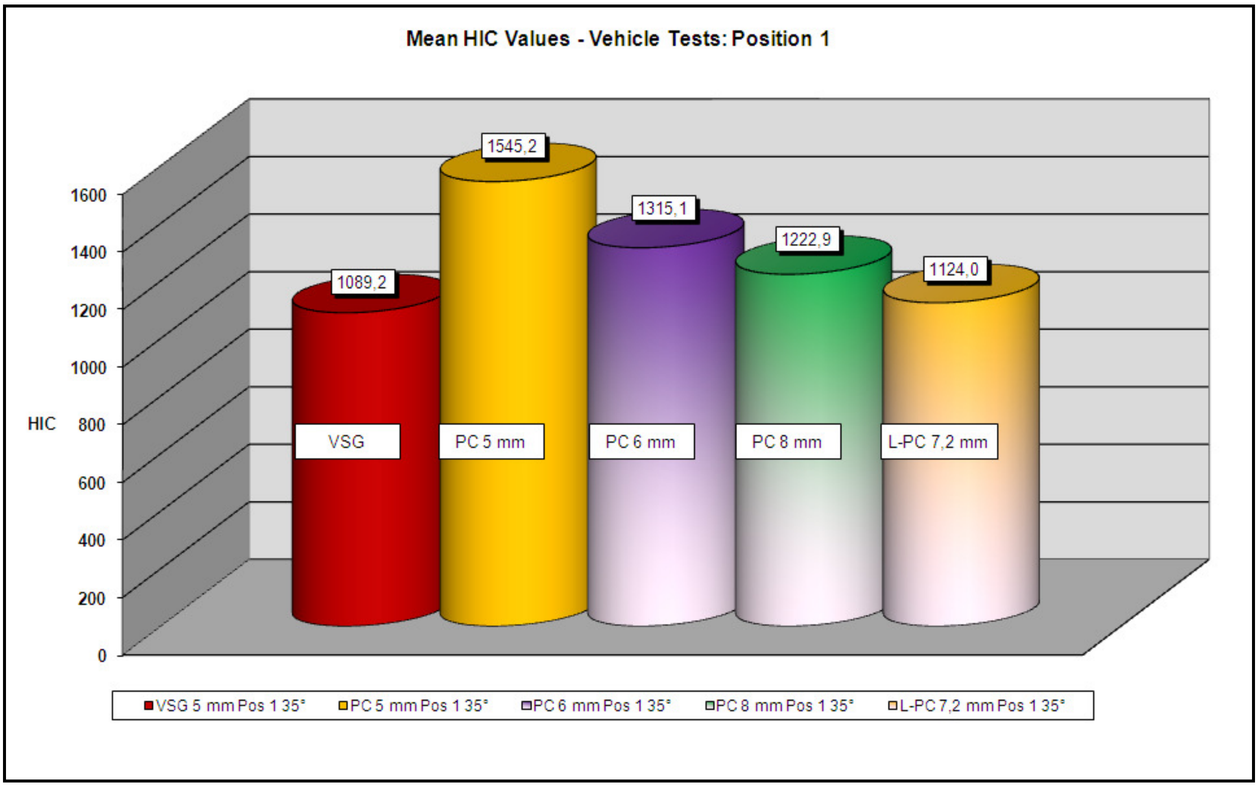

Figure 19: Mean test results on impact location 1 – Vehicle tests

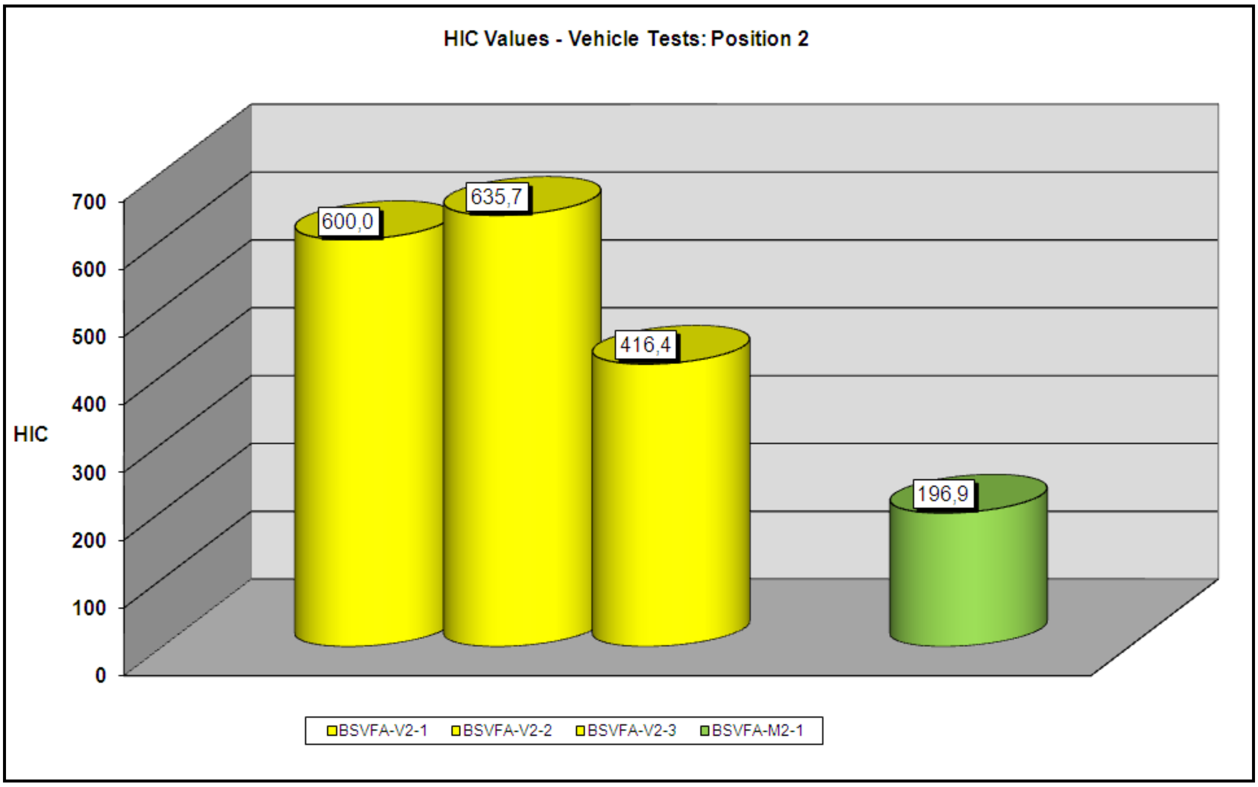

Figure 20: Test results on impact location 2 – Vehicle tests

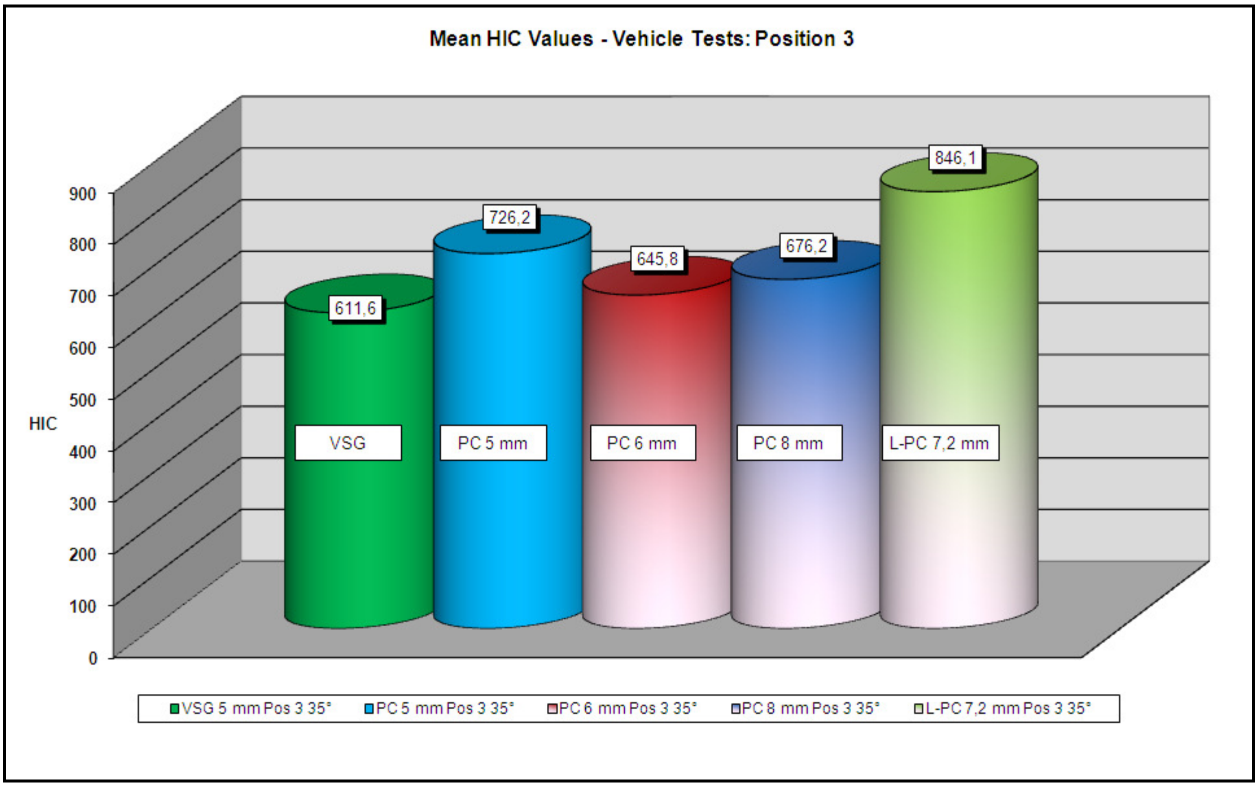

Figure 21: Mean test results on impact location 3 – Vehicle tests

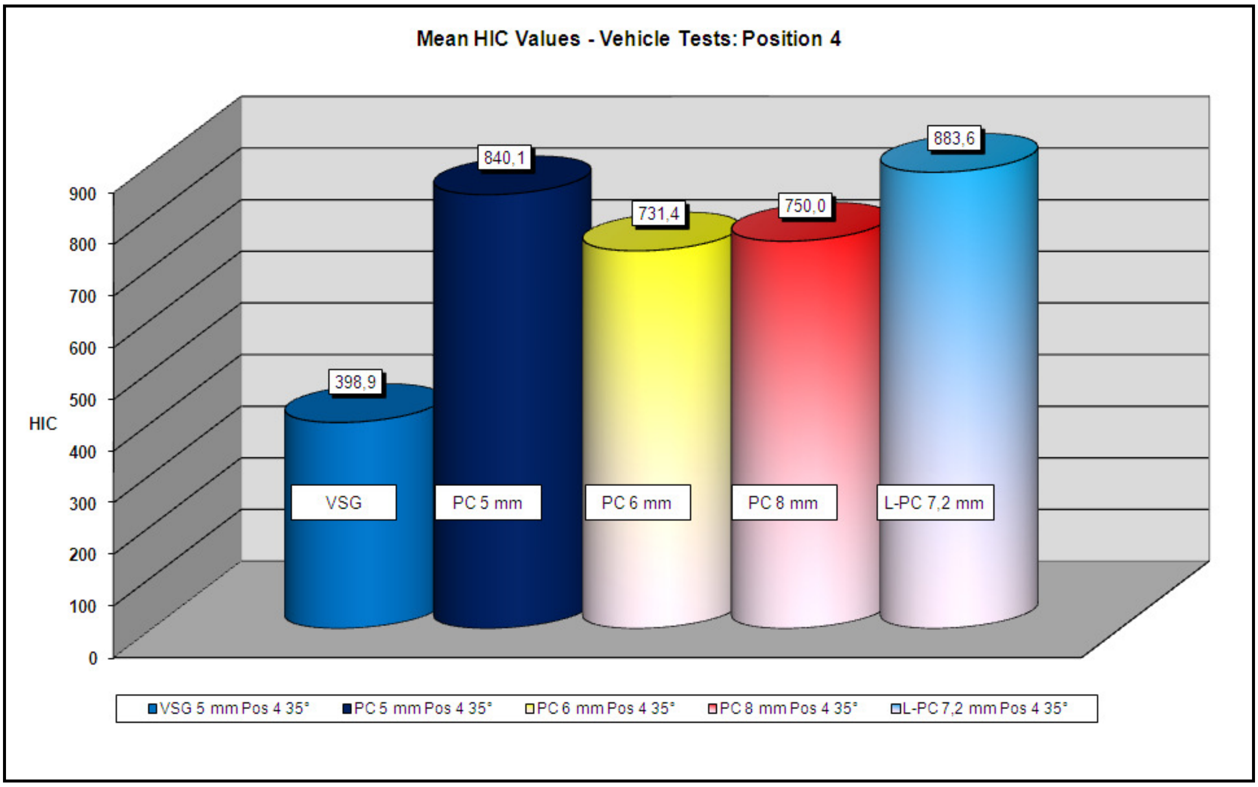

Figure 22: Mean test results on impact location 4 – Vehicle tests

To further investigate and understand the differences between the test results with different windscreen materials, it seemed necessary to closely look at the individual acceleration curves. As an example, Figure 23 to Figure 26 show the acceleration curves of one test each to impact point no. 3 located on four different materials: Laminated safety glass (Figure 23), 5 mm monolithic polycarbonate (Figure 24), 8 mm monolithic polycarbonate (Figure 25) and 7.2 mm laminated polycarbonate (Figure 26). Actually, significant differences of the shapes of the curves can be observed.

The main difference is the first short peak that only occurs with glass panes. This peak is resulting from the initial resistance of the glass. The decrease of the peak starts when the glass breaks. As there is no breakage of the polycarbonate material, there is no such first peak.

Another remarkable observation is the difference of the curve shapes of the different polycarbonate windscreens. E.g. the curve obtained with laminated polycarbonate seems to rest a long time on a certain level which can be of advantage when considering maximum values.

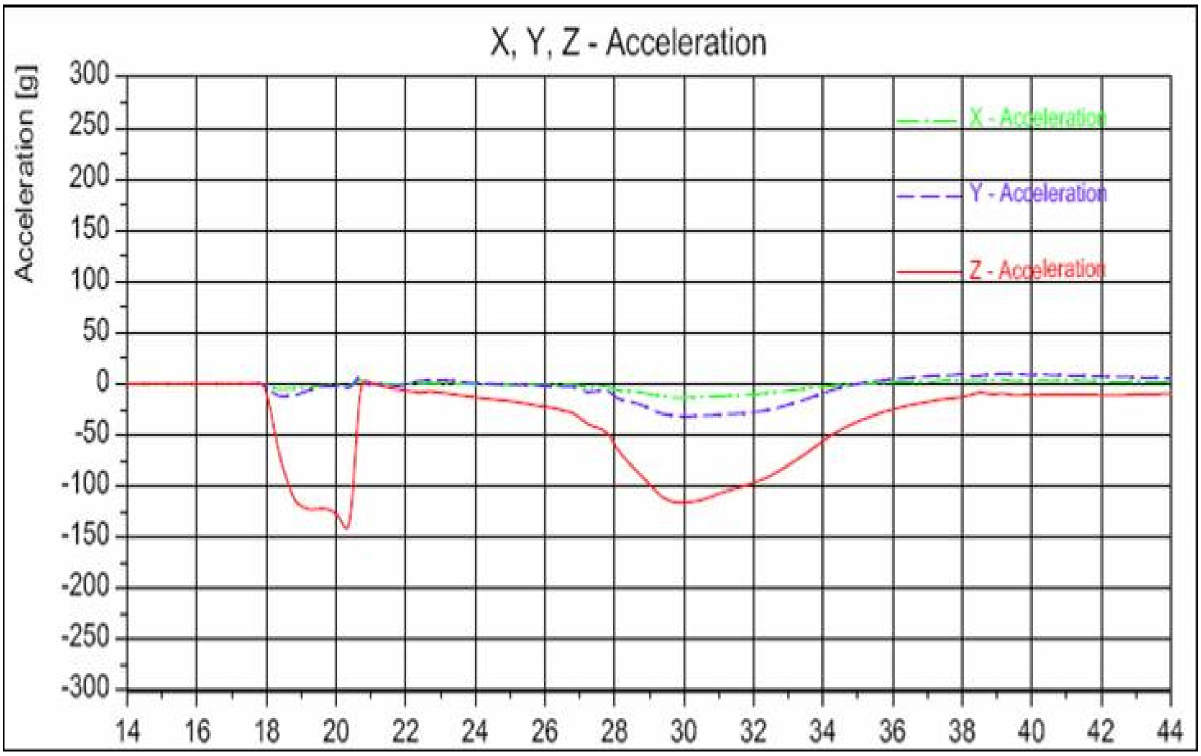

Figure 23: Acceleration curve – Laminated safety glass - Impact location 3 - Vehicle tests

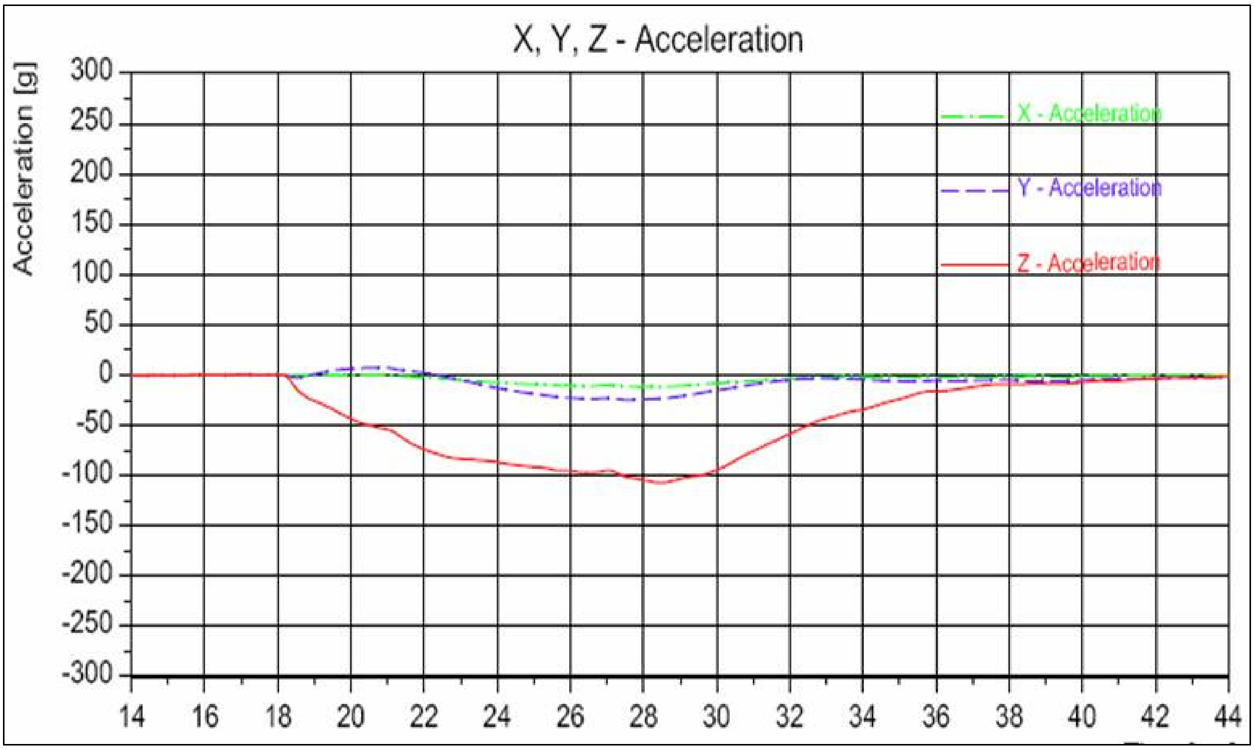

Figure 24: Acceleration curve – 5 mm polycarbonate - Impact location 3 - Vehicle tests

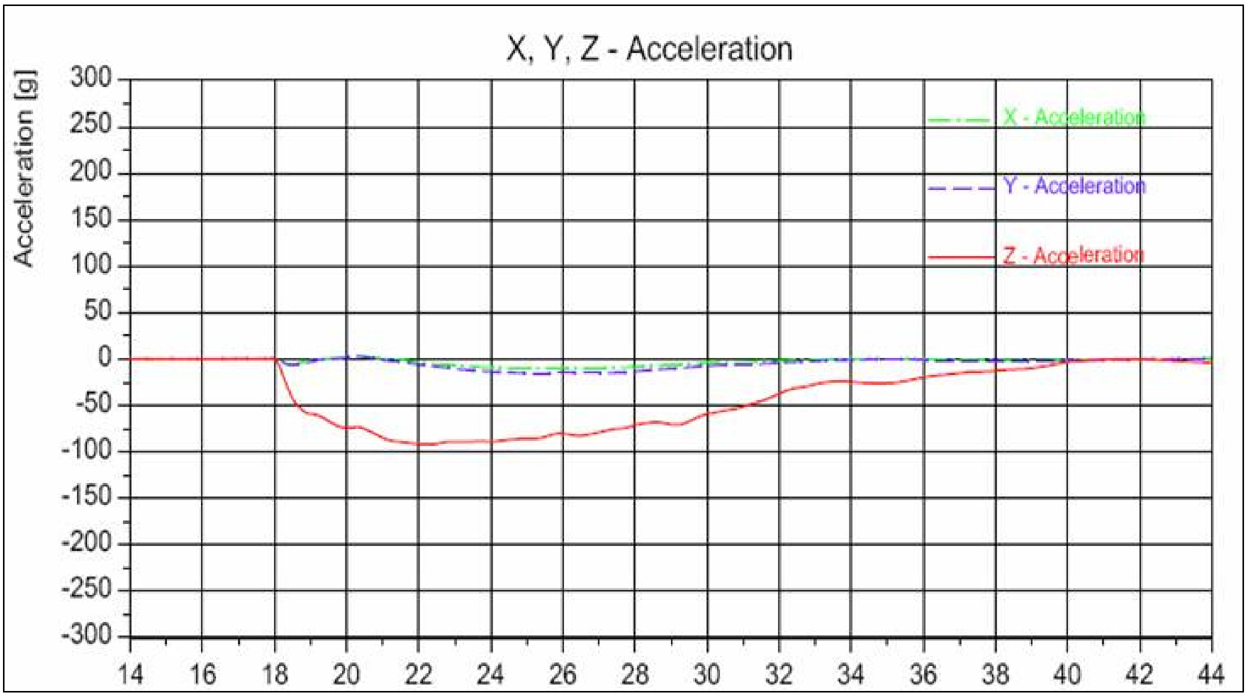

Figure 25: Acceleration curve – 8 mm polycarbonate - Impact location 3 - Vehicle tests

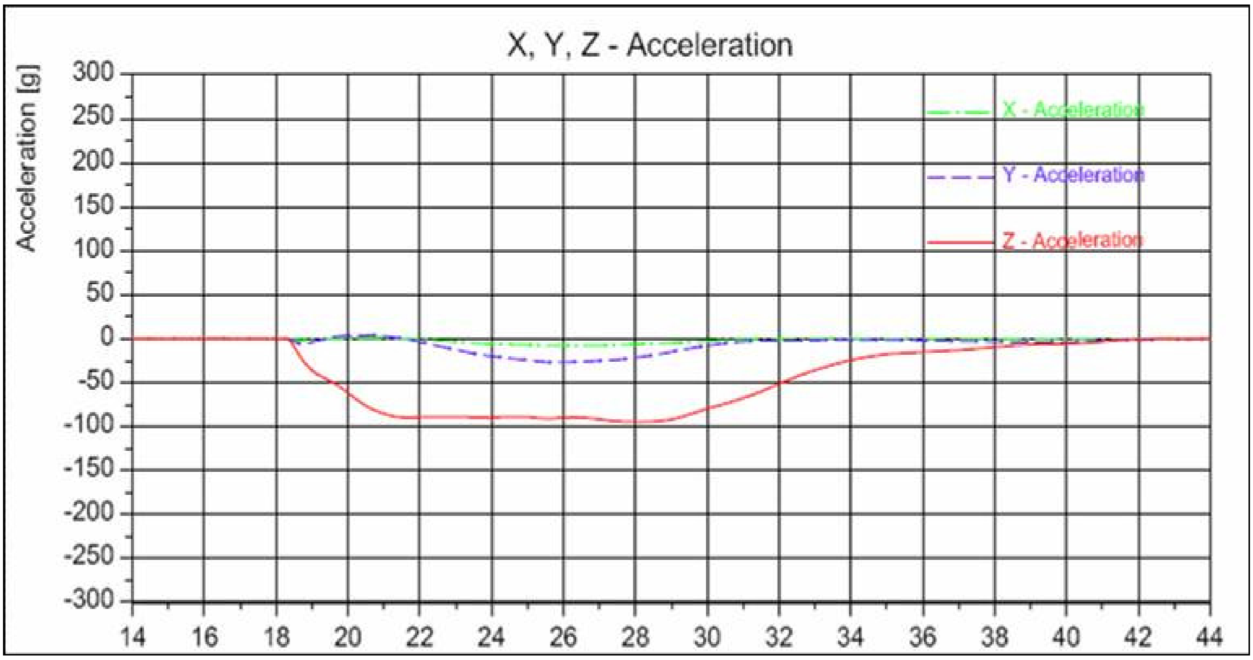

Figure 26: Acceleration curve – Laminated polycarbonate - Impact location 3 - Vehicle tests

Looking at the test results with different impact angles, it becomes obvious, and is presented in Figure 27 and Figure 28, that the influence of the impact angle is significant in tests with laminated safety glass: A lower impact angle to the horizontal results in lower HIC values and lower scatter. On the other hand, both figures show also that the influence of the impact angle on polycarbonate glazing seems to be rather marginal with respect to HIC results and scatter.

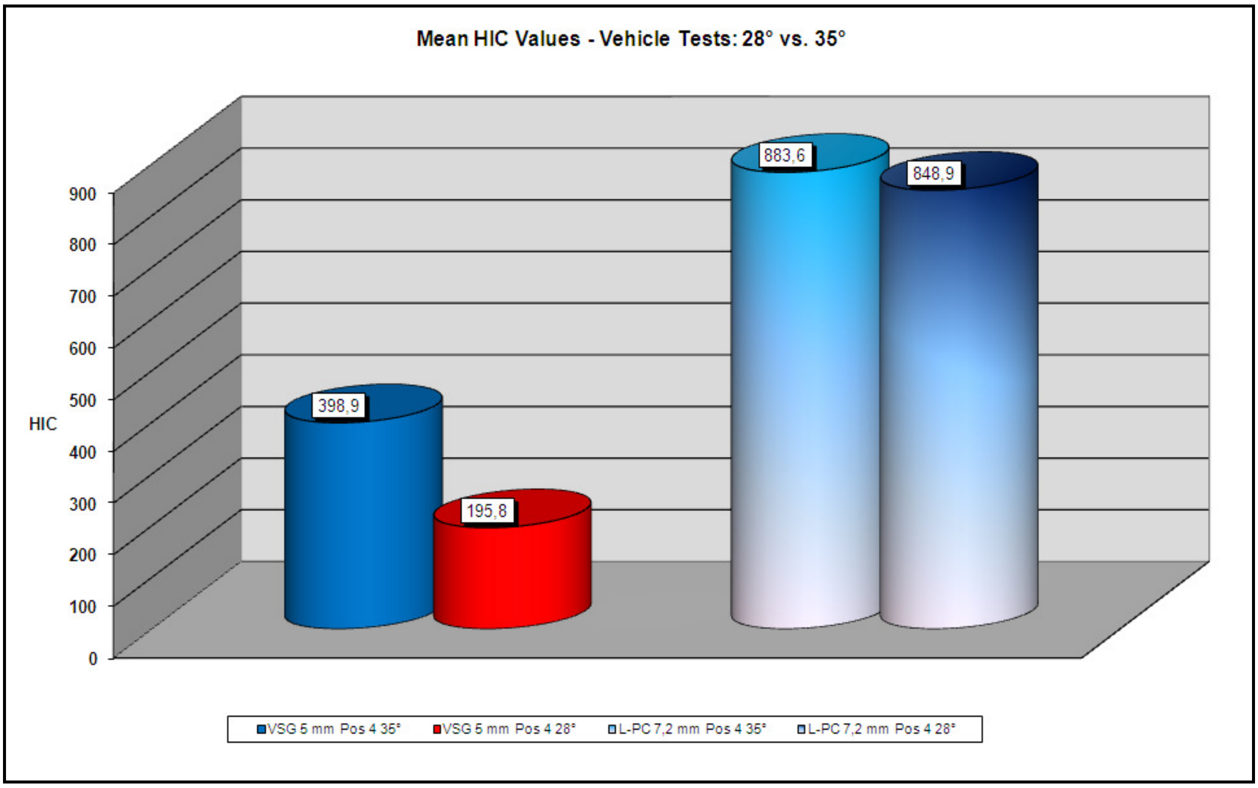

Figure 27: Influence of impact angle on test results – Vehicle tests

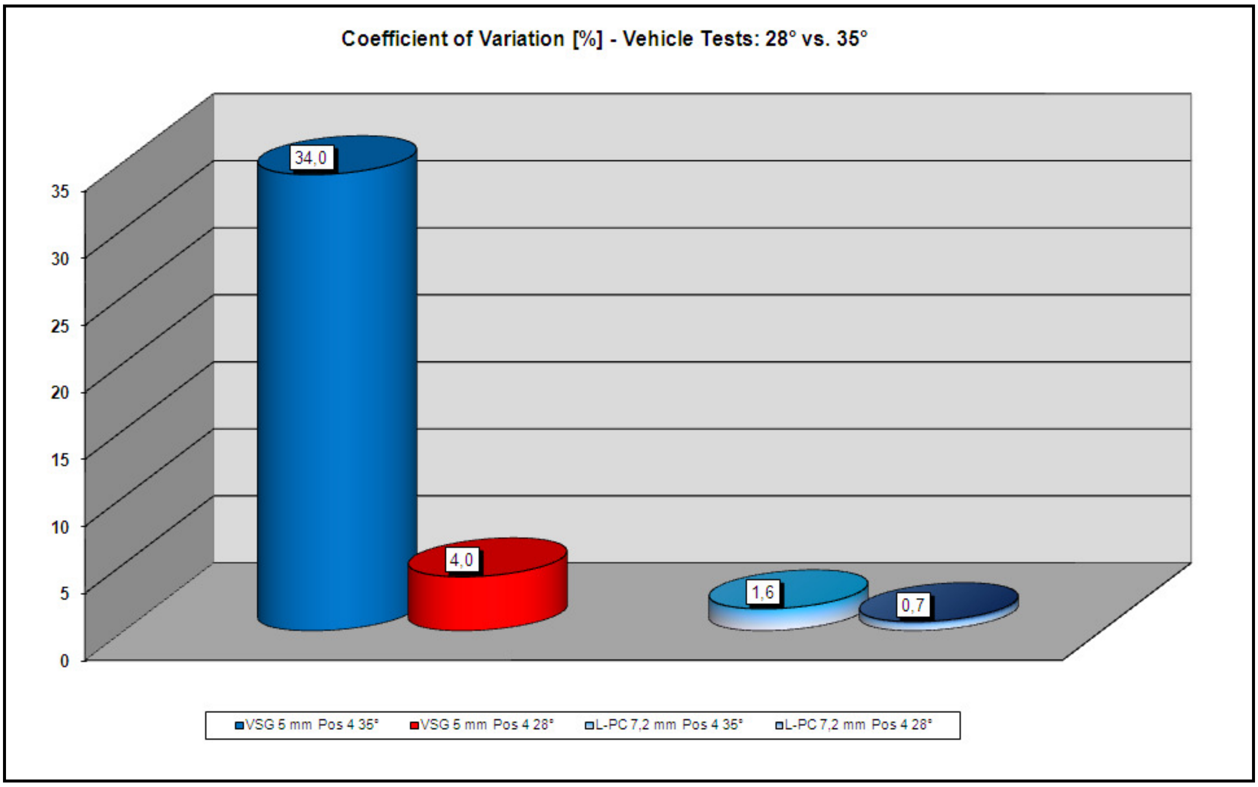

Figure 28: Influence of impact angle on scatter of test results – Vehicle tests

6 Conclusions

The evaluation of this test series led to fundamental answers to the questions this project is focused on:

1. Does the use of plastic windscreens in vehicles lead to a higher injury risk for vulnerable road users, especially for pedestrians?

Compared to tests with laminated safety glass, higher HIC values were generally observed in tests with monolithic as well as laminated polycarbonate glazing. As the HIC is the current criterion for head injury severity assessment, polycarbonate glazing has to be seen as more injurious in terms of vulnerable road user protection.

In addition, the significantly higher rebound of the head in tests with polycarbonate glazing is suspected to lead to higher neck injury risks during the windscreen impact and may also cause higher injury risks in secondary impacts, e.g. due to a higher drop height of the head before impacting the ground.

However, as in contrary to the tests on glass panes, in all tests with polycarbonate glazing no damage of the panes was observed, the risk of skin cut injuries might be significantly reduced.

2. Can the current test procedure (Phantom head drop test) on the approval of glazing according to UN Regulation No. 43 be used for plastic glazing? Which modifications or extensions might be necessary?

The test procedure prescribed in UN Regulation No. 43 is generally accepted as a methodology to approve glass windscreens. This performed test series gives no indication that that procedure is not feasible for polycarbonate glazing, especially because UN R 43 does not reflect any pedestrian protection aspects.

The testing of windscreens according to Phase 1 of the current European Regulation (EC) No 78/2009 is executed only for monitoring purposes. The performance of the windscreen area will not be relevant for vehicle type approval according to the upcoming UN Regulation for pedestrian protection. However, pedestrian protection should be considered also for windscreens made of materials other than glass to ensure at least the same level of protection for vulnerable road users as glass windscreens.

7 Acknowledgements

The project partners thank the following companies for their kind support to this project:

- Bayer MaterialScience AG
- KRD-Gruppe GmbH
- Volkswagen AG
- Saint Gobain

8 References

[1] Regulation (EC) No 78/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 January 2009 on the type-approval of motor vehicles with regard to the protection of pedestrians and other vulnerable road users, amending Directive 2007/46/EC and repealing Directives 2003/102/EC and 2005/66/EC

[2] COMMISSION Regulation (EC) No 631/2009 of 22 July 2009 laying down detailed rules for the implementation of Annex I to Regulation (EC) No 78/2009 of the European Parliament and of the Council on the type-approval of motor vehicles with regard to the protection of pedestrians and other vulnerable road users, amending Directive 2007/46/EC and repealing Directives 2003/102/EC and 2005/66/EC

[3] DIN 52310: Phantomfallversuch an Sicherheitsscheiben für Fahrzeugverglasung. 1986.

[4] European New Car Assessment Programme (Euro NCAP): Technical bulletin TB003 – Damped accelerometers in pedestrian protection testing. Version 2.0. February 2012.

[5] UN Regulation No. 43: UNIFORM PROVISIONS CONCERNING THE APPROVAL OF SAFETY GLAZING MATERIALS AND THEIR INSTALLATION ON VEHICLES

[6] UN Regulation No. 43: Proposal for draft amendments to Regulation No. 43. ECE/TRANS/WP.29/GRSG/2009/8

[7] Zander, O., Lorenz, B., Leßmann, P., Gehring, D.: The pedestrian legform impactor according to EEVC WG 17 - results of an actual research and possibilities for the implementation within regulations on pedestrian protection. IRCOBI conference proceedings 2005

9 Appendix

9.1 Register of photographs

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9.5 Photo Documentation (on DVD only)

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