



**Department of Transport and Regional Services  
Australian Transport Safety Bureau**

# Further Development of a Protective Headband for Car Occupants

**Robert Anderson, Giulio Ponte and Jack McLean**  
Road Accident Research Unit  
Adelaide University

**Robert Tiller and Steve Hill**  
Tiller and Tiller

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**Authors**

Anderson RWG, Ponte G, McLean AJ, Tiller R and Hill S

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**Performing Organisations**

Road Accident Research Unit  
Adelaide University  
SOUTH AUSTRALIA 5005

Tiller and Tiller  
Suite 2, Level 2  
661 Darling Street  
ROZELLE NSW 2039

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Australian Transport Safety Bureau  
PO Box 967  
CIVIC SQUARE ACT 2608

Project Officer: John Goldsworthy

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**Abstract**

*In this report, we document a series of tests of different energy absorbing materials, to ascertain the potential benefit of a protective headband worn by car occupants. The testing reported on here extends the work reported in CR193 "The development of a protective headband for car occupants" (Anderson et al., 2000) by investigating the suitability of materials that, on the whole, are more efficient in absorbing energy than those tested in CR193. CR193 did not consider the form that the headband might take in a production version. This is also addressed in this report with a chapter on the development of a design concept that would be feasible to manufacture and deliver to market.*

**Keywords**

**Head protection, Helmet, Car occupant protection, Energy absorbing materials, Impact testing**

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- (1) This report is disseminated in the interests of information exchange.
  - (2) The views expressed are those of the author(s) and do not necessarily represent those of the Commonwealth.
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## Executive Summary

This publication is a sequel to the ATSB report CR193, “The development of a protective headband for car occupants” (Anderson et al., 2000). In that report, we documented a series of tests of different energy absorbing materials, to ascertain the potential benefit of a protective headband worn by car occupants. The project was initiated after McLean et al. (1997) demonstrated that energy absorbing headwear for car occupants might be effective in reducing the numbers of head injuries sustained by car occupants. McLean et al. estimated that the benefits were greater than the estimated benefits of padding of the upper interior of vehicles to the requirements of the US Federal Motor Vehicle Safety Standard 201.

The testing reported on here extends the work reported in CR193 by investigating the suitability of materials that, on the whole, are more efficient in absorbing energy than those tested in CR193. CR193 did not consider the form that the headband might take in a production version. This is also addressed in this report with a chapter on the development of a design concept that would be feasible to manufacture and deliver to market.

CR193 identified two energy absorbing materials for further investigation; polyurethane foam and a cardboard honeycomb liner encased in a hard shell. Both these materials significantly reduced the severity of impacts with a typical car structure. The characteristics of these materials were used as a guide in the further selection of materials for testing. As the durability of cardboard in such an application may render it unsuitable, a more durable substitute was identified that retained the characteristics of high energy absorbing efficiency. The material, STRANDFOAM\*™ (Dow Corporation) is an extruded expanded polypropylene (EPP), and has an intrinsic honeycomb structure, similar to the one in the cardboard honeycomb that gave it its exemplary energy absorbing characteristics. The third material tested was normal EPP, chosen because of its increasing use in impact energy management applications. The performance of the normal EPP also is a useful benchmark alongside which the performance of the STRANDFOAM\* can be compared.

As in the tests reported on in CR193, the new tests demonstrate that a headband for car occupants could significantly reduce the severity of certain head impacts in a crash. None of the new materials improved on the energy absorbing performance of the cardboard honeycomb, although the performance of the new materials, and STRANDFOAM\* in particular, certainly came close. Any of the materials tested for this report would be suitable as the energy absorbing component in the construction of the headband. The use of one or another of the materials would depend on cost, durability, ease of manufacture, and availability. While these factors have not been explicitly addressed in the report, the design development process has delivered a concept likely to be compatible with any of the materials examined herein. The design considers styling aspects relevant to its acceptability, without compromising the essential protective nature of the device.

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™ STRANDFOAM\* is a registered trademark of the Dow Chemical Company (U.S. patent 6,213,540)



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# 1 Introduction

The feasibility of a protective headband for car occupants was examined in a previous report for the Australian Transport Safety Bureau, CR193 (Anderson, White and McLean, 2000). In that report, the Road Accident Research Unit detailed the results of tests on materials that could be used for such a protective device. The conclusion of that study was that a protective headband constructed of an energy absorbing material could significantly reduce the severity of an impact to the head of a car occupant in a collision. The results included in this new report extend the work of CR193 testing materials suited to the design, production and use of the headband.

A design development process was completed in parallel to the material testing. This process helped to guide the selection of materials for testing. The design development process is an important part of the development of the headband, as its final appearance will have a bearing on its acceptability in the community. Importantly, the material used must be practical from a manufacturing perspective.

The tests reported herein follow the regime described in CR193. This has allowed direct comparisons to be made with the results of those earlier tests. The report combines the new results with those reported in CR193.

Section 7 of this report contains a description of the design development process, and includes sketches of candidate design concepts, renderings of a short list of final concepts and detailed renderings of the final design concept.

## 1.1 AIMS

The aims of the work reported herein were to:

1. Identify materials that would perform more effectively than those examined in CR193, while being practical from a design and manufacturing perspective, and
  2. To produce a design concept that illustrates the final form of the headband.
-

## 2 Methodology

The testing methods were designed to measure the energy absorbing performance of the candidate materials. The first two phases of testing examined the energy absorbing behaviour against a flat surface and against surfaces that concentrate the impact loads. On impact the headform had a similar energy to that required by FMVSS 201. The materials that performed well in these tests were subjected to a third phase of testing, in which the materials were interposed between the headform and a typical vehicle structure.

### 2.1 PHASE 1

A headform simulating the mass of a human head was dropped onto candidate materials at different velocities. The materials were placed on a rigid and massive steel slab, so the test measured the impact characteristics of the material only. The design of the test accounted for the temperature of the material, the thickness of the material and the durability of the material where appropriate.

### 2.2 PHASE 2

In this phase of testing, materials that performed well in Phase 1 were interposed between the headform and a standard hemispherical helmet testing anvil (AS2512.3.1: "Determination of impact energy attenuation - helmet drop test") to see how the material performed under a concentrated load. This test is somewhat analogous to a head impact with a structure that concentrates the force of the impact, such as an A-pillar or steering wheel hub.

### 2.3 PHASE 3

In CR193, the better performing prototype headbands were attached to a headform which was then fired at an internal structure of a vehicle and the impact severity was compared to tests in which no padding was attached to the headform. In this study, we designed an analogous test in which the internal structure was removed from the car and clamped at each end. The candidate materials were then interposed between the headform and the structure to measure their performance with a real vehicle structure.

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## 3 Phase 1

### 3.1 METHOD

The tool used for testing the performance of the materials in Phase 1 was the 'adult' headform proposed by Working Group 10 of the European Experimental Vehicles Committee for the assessment of pedestrian head protection<sup>1</sup>. This headform was also used in the tests reported in CR193. This headform consists of a sphere of phenolic resin with a diameter of 165 mm. The sphere is covered with a silicon rubber skin to simulate the compliance of the scalp and bone of a human head. A steel insert in the sphere is used to adjust the weight of the headform to 4.8 kg and to house a tri-axial accelerometer to measure the acceleration of the headform on impact. The headform is illustrated in Figure 3-1.

Each material was placed on a massive steel slab. Some materials were tested at elevated temperatures by heating for several minutes in a stream of hot air prior to the test. The temperature of the material was measured immediately following the test. The headform was suspended above the material and dropped from a predetermined height. The resulting impact acceleration was recorded using a high-speed data acquisition system (50 kHz) after being passed through a 10 kHz analogue filter. The resulting acceleration data was then filtered according to SAE CFC 1000. The test setup is illustrated in Figure 3-2.

The peak acceleration was noted and the Head Injury Criterion (HIC) was calculated for each test. The HIC is the criterion most commonly used for head injury risk assessment. It is calculated according to the formula

$$HIC = (t_2 - t_1) \left[ \frac{\int_{t_1}^{t_2} a dt}{t_2 - t_1} \right]^{2.5}$$

where  $t$  is measured in milliseconds and  $a$  is the acceleration measured in units of  $g$  (the acceleration due to gravity). The values of  $t_2$  and  $t_1$  are chosen so that the function is maximised. Impacts that produce HIC values of more than 1000 are considered to be unacceptably severe.

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<sup>1</sup> The headform will be referred hereafter as the EEVC WG10 headform

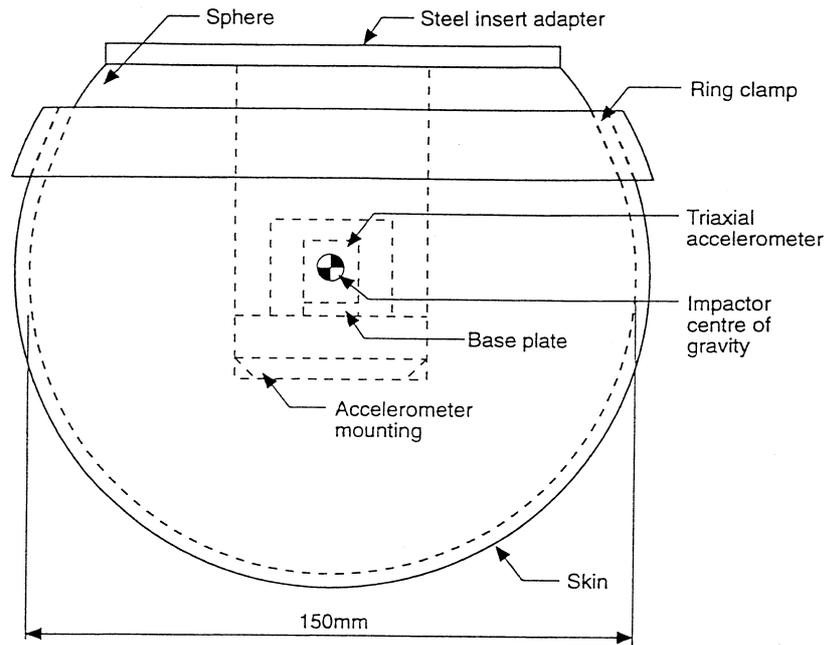


Figure 3-1 The EEVC WG10 headform used in the study

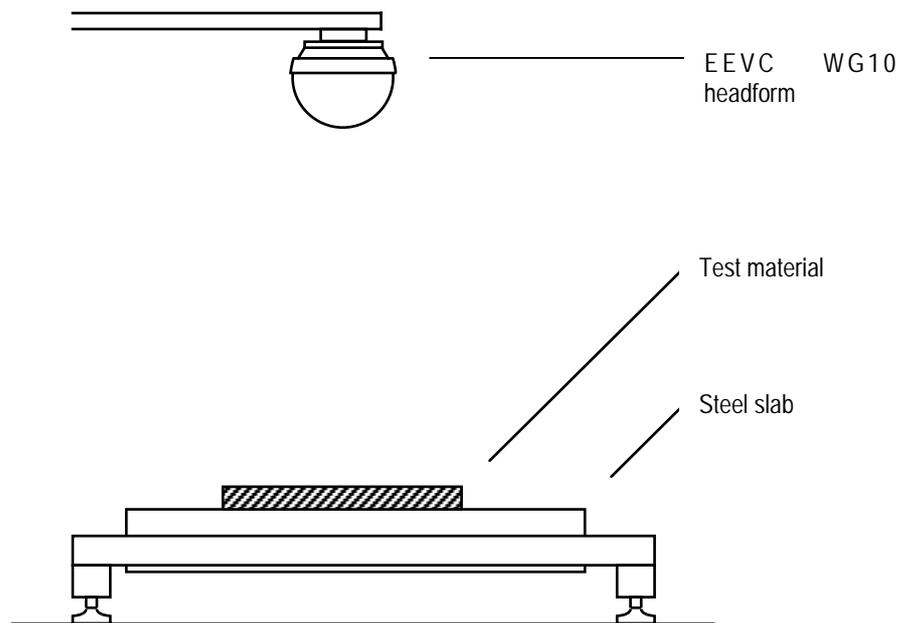


Figure 3-2 The test setup used in Phase 1

The force experienced by the headform was calculated by multiplying the acceleration experienced by the headform by its mass, and plotted against the displacement of the material in each test. The displacement was calculated by identifying the beginning and end of the acceleration and integrating the acceleration twice within those bounds.

## 3.2 RESULTS

### 3.2.1 Materials tested in CR193

Table 3-1 and Table 3-2 list the results of tests reported in CR193. Those tests showed that the best performing materials were certain grades of polystyrene, polyurethane and 30 mm thick sections of cardboard honeycomb. The force displacement curves produced from the tests are shown in Figure 3-3 and Figure 3-4. Unless otherwise stated, the samples listed in Table 3-1 and Table 3-2 were 25 mm thick.

**Table 3-1 Results of tests from a drop height 1.0 m, velocity 16.0 km/h, and material thickness 25 mm, reported in CR193**

Category	Material type	Supplier	Temp. (° C)	Peak acceleration (g)	HIC	Test number
Polystyrene	Polystyrene	Lactec Foam Products	20.5	127	440	27089805
Polyurethane	BB-38	Woodbridge Group	25	140	560	15129801
	E175		25	129	450	15129805
	E900, 5.6 pcf		25	129	460	15129809
	E900, 6.0 pcf		25	135	490	15129813
Cardboard honeycomb	15 mm thick small celled honeycomb cardboard <sup>1</sup>	Unknown	16	285	1190	26059905
Viscoelastic foam	CF-45100	E-A-R Specialty	42	262	1120	27089808
	CF-47100	Composites	41	270	1190	14099805

1. This material was only available in thicknesses of 15 mm and 30 mm

**Table 3-2 Results of tests from a drop height of 1.45 m, velocity 19.2 km/h, and material thickness 25 mm , reported in CR193**

Category	Material type	Temp. (° C)	Peak acceleration (g)	HIC	Test number
Polystyrene	Polystyrene	25.5	232	1090	17129802
Polyurethane	BB-38	25.5	208	1120	17129804
	E175	25.5	198	960	17129808
	E900, 5.6 pcf	25.5	260	1530	17129813
	E900, 6.0 pcf	25.5	227	1230	17129816
Cardboard honeycomb	30 mm thick small celled honeycomb cardboard <sup>1</sup>	25.5	104	440	17129816
Viscoelastic foam	CF-45100	25	282	1490	14089808

1. This material was only available in thicknesses of 15 mm and 30 mm

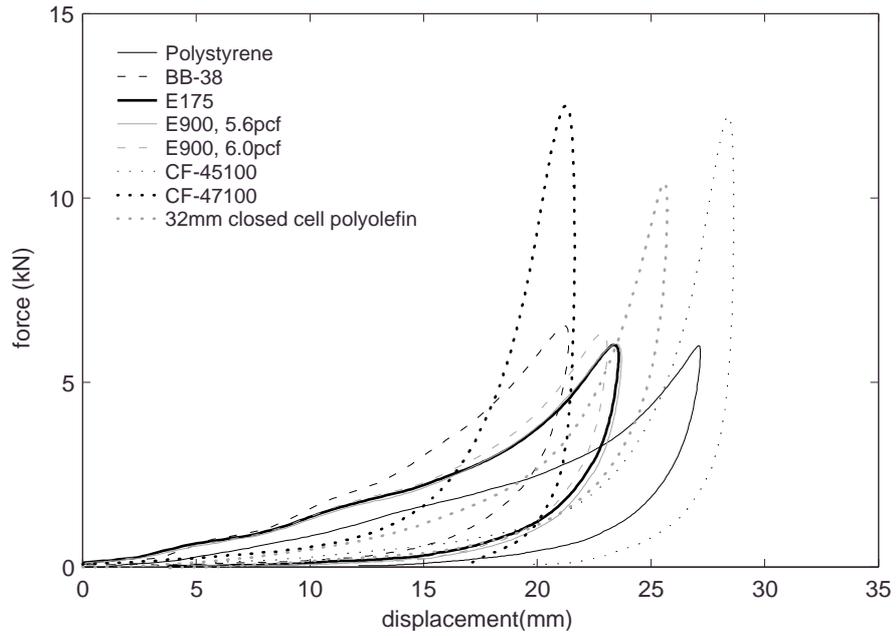


Figure 3-3 Force/deflection curves of various materials, 25 mm thick, drop height 1.0 m, reported in CR193

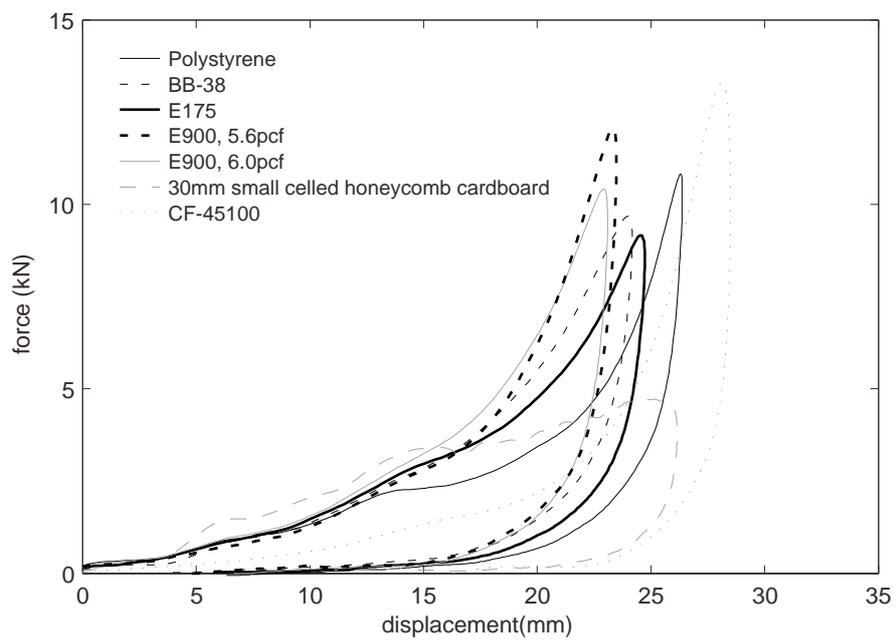


Figure 3-4 Force/deflection curves of various materials, 25 mm thick, drop height 1.45 m, reported in CR193

### 3.2.2 New materials tested

The results of the testing reported in CR193 showed that the materials that absorbed the most energy and limited the impact force, were those that were highly crushable. Furthermore, the cardboard honeycomb was able to absorb energy in a highly efficient way, by absorbing energy through columnar failure of its honeycomb structure.

These characteristics became the basis on which a set of new materials was selected for investigation. These materials are listed in Table 3-3. Each of these materials had been shown by their manufacturer to be efficient energy absorbers. Expanded polypropylene (EPP) is increasingly being used for impact protection and energy absorption in vehicles.

STRANDFOAM\*™ is manufactured by Dow Corporation. It is a modified polypropylene foam that has been passed through an extrusion process in which the foam is passed through adjacent orifices in a die, and then refused as they emerge. The interfaces of each column of foam form a higher density structure than the material in the centre of each column, and these interfaces form 'strands' and impart a columnar honeycomb structure, filled with a lower density foam. The manufacturer claims that this imparts outstanding material properties in the direction of the strand (von Diest et al., 2001). This foam is being promoted as a solution for meeting the requirements of FMVSS 201.

New grades of polyurethane were also explored in this study. Highly crushable formulations were obtained with the assistance of Schefenacker Research. These materials are supplied by Huntsman Urethanes, and the product codes for the formulations tested are listed in Table 3-3.

Table 3-3 Materials tested in Phase 1

Material Name	Nominal density (kg/m <sup>3</sup> )	Supplier	Thickness (mm)
Expanded Polypropylene 70	70	Rmax Industries	25.5
Expanded Polypropylene 90	90	Rmax Industries	25.5
STRANDFOAM* 2.5 pcf	40	Dow Industries	22.1
STRANDFOAM* 4 pcf	60	Dow Industries	22.5
Polyurethane ME 3453	60	Huntsman Urethanes	25
Polyurethane DR 929 V6 Suprasec 5005	60	Huntsman Urethanes	25
Polyurethane DR 929 V6 Suprasec 2050	60	Huntsman Urethanes	25.5

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\* STRANDFOAM\* is a registered trademark of the Dow Chemical Company (U.S. patent 6,213,540)

### 3.3 RESULTS

#### 3.3.1 Expanded Polypropylene Foam

Samples of material (nominal thickness of 25 mm) were tested in accordance with the procedure outlined in Section 3.1. The performance of EPP 70 (70 kg/m<sup>3</sup>) and EPP 90 (90 kg/m<sup>3</sup>) in this test is shown in Figure 3-5.

No residual deformation was observed in either of the samples. Repeat tests were performed on the same sample of EPP 70 (Test Numbers 27040103 & 27040104) to see whether the material structure had been changed by the impact. The results of tests subsequent to the first indicated that the material structural properties become poorer with repeated impacts, despite no observable residual deformation (Figure 3-6).

The EPP 70 was the better performing of the two materials. EPP 70 was also tested at a temperature of 37.5° C to examine how its impact properties change in hot environments. The result of this test (29050105) was almost identical to the room temperature test, indicating no degradation of performance.

If the headform were to contain EPP as its energy absorbing element, one method of manufacture could involve thermo-forming of the material. This would deform the structure of the material, possibly altering its properties. A 60mm wide sample of EPP was heated and formed into the shape of a headform to establish whether heating and forming would have adverse affects of the material properties. The result of this test (15060101) showed no such adverse affect in impact performance, and showed a slight improvement over the undeformed sample.

The performance of the EPP 90 was inferior to the EPP 70. It appeared to be too stiff in comparison to warrant further evaluation. Lower density grades of EPP (less than 70 kg/m<sup>3</sup>) were unobtainable at the time of writing.

Table 3-4 Expanded Polypropylene 1.45m drop test results

Material Type	Thickness (mm)	Temp. (° C)	Peak Acceleration (g)	HIC	Test Number
EPP 70 (1) <sup>1</sup>	25.5	16.5	169	984	27040102
EPP 70 (2)	25.5	16	196	1176	27040103
EPP 70 (3)	25.5	16.5	208	1220	27040104
EPP 90	25.5	17.5	194	1211	27040105
EPP 70	22.5	37.5	168	959	29050105
EPP 70 <sup>2</sup>	23.5	21	152	810	15060101

1. Numbers in parenthesis indicate repeated tests on the same sample of material
2. Thermo-formed material

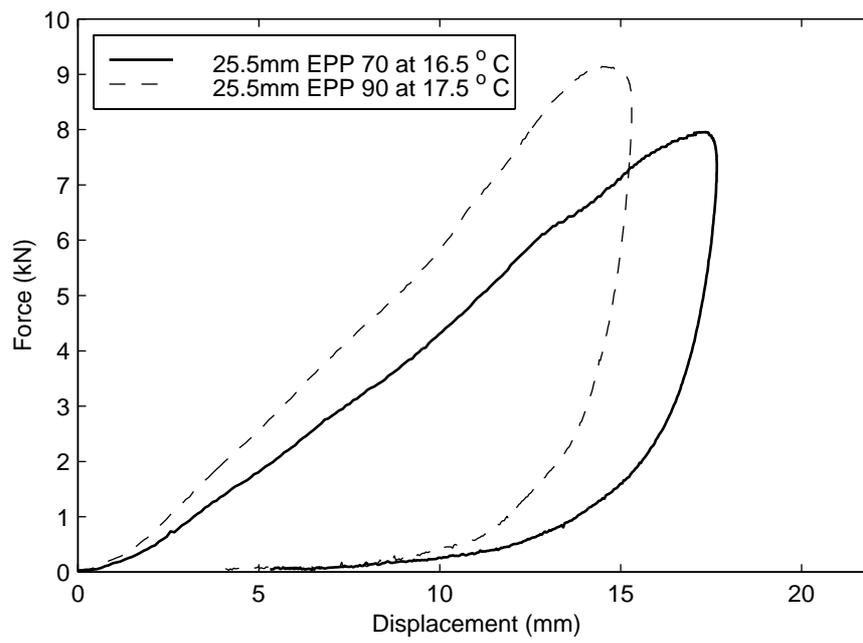


Figure 3-5 Force deflection curves of the two densities of EPP tested at room temperature

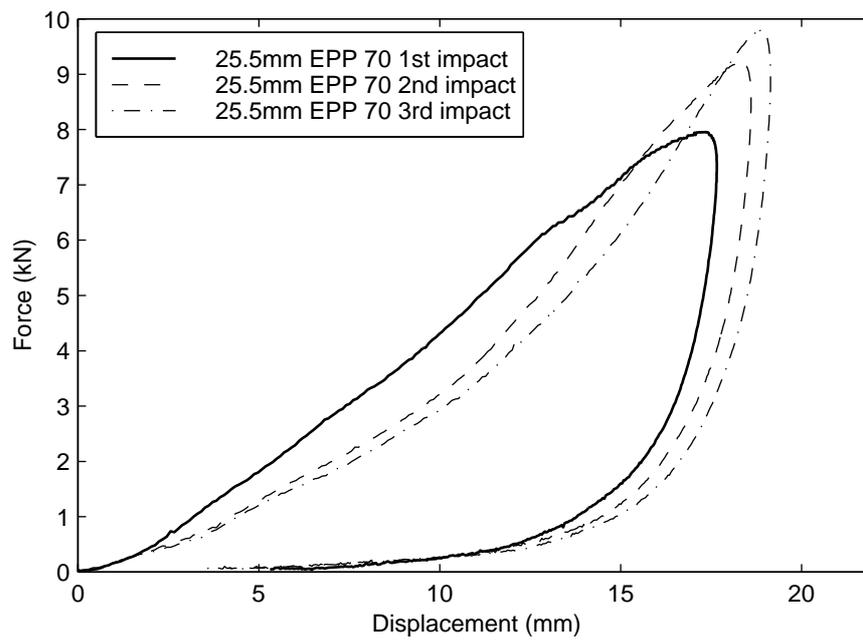


Figure 3-6 Force deflection curves of repeated tests on EPP 70

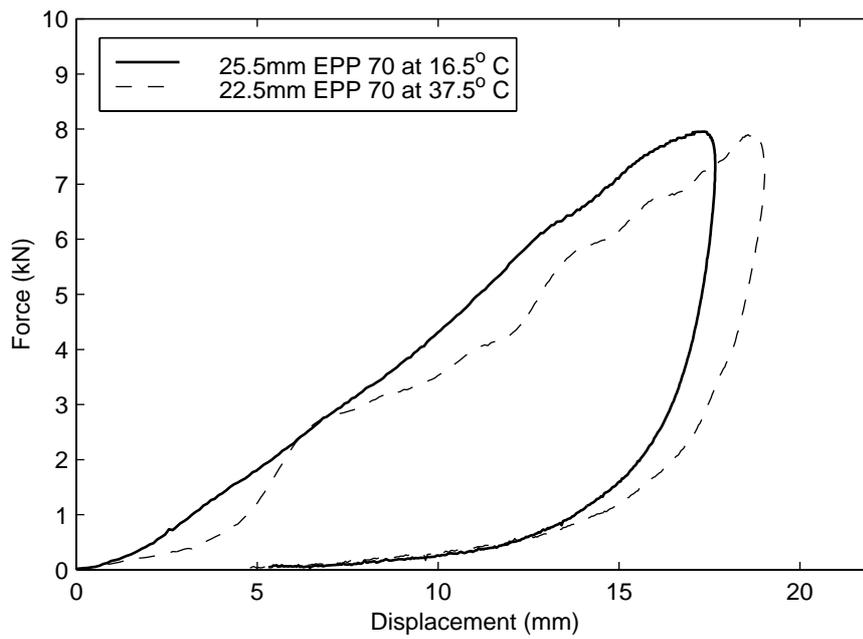


Figure 3-7 Influence of Temperature on the effectiveness of Expanded Polypropylene 70

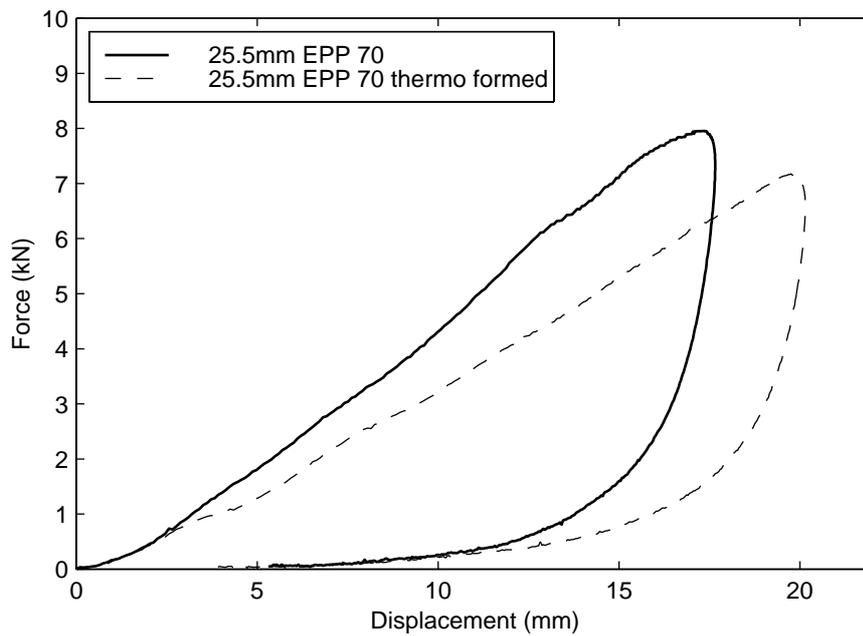


Figure 3-8 The effectiveness of heating and shaping of Expanded Polypropylene 70

### 3.3.2 STRANDFOAM\*

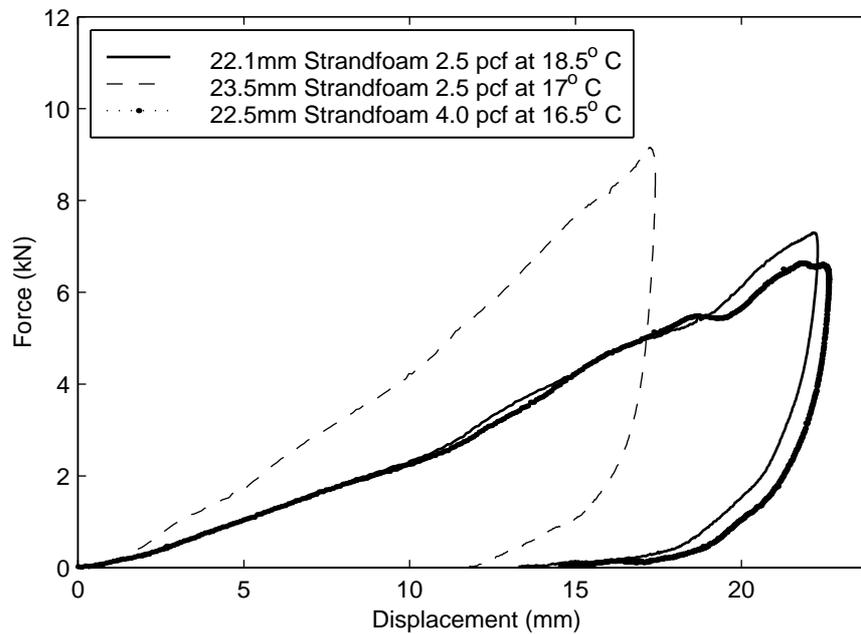
The two commercially available grades of STRANDFOAM\* were evaluated in this study; 2.5 pounds per cubic foot (pcf) and 4 pcf. The results of the tests are summarised in Table 3-5.

The STRANDFOAM\* 2.5 pcf bottomed out in each test, but absorbed energy in an efficient manner, and produced good results (Figure 3-9). The STRANDFOAM\* 2.5 pcf was also tested at an elevated temperature, and as was the case with the EPP samples, heat did not adversely affect the performance of the material (Figure 3-10)

The STRANDFOAM\* 4 pcf was stiffer than the STRANDFOAM\* 2.5 pcf, and as a consequence did not perform as well in the test. As STRANDFOAM\* 2.5 pcf appears to be more suited to this application, the STRANDFOAM\* 4 pcf was not tested any further.

Table 3-5 STRANDFOAM\* 1.45m drop test results

Material Type	Thickness (mm)	Temp. (° C)	Peak Acceleration (g)	HIC	Test Number
STRANDFOAM* 2.5 pcf	22.1	18.5	155	776	27040106
STRANDFOAM* 4 pcf	22.5	16.5	194	1069	27040107
STRANDFOAM* 2.5 pcf	23.5	17	141	705	27040108
STRANDFOAM* 2.5 pcf	23	38	150	728	29050106



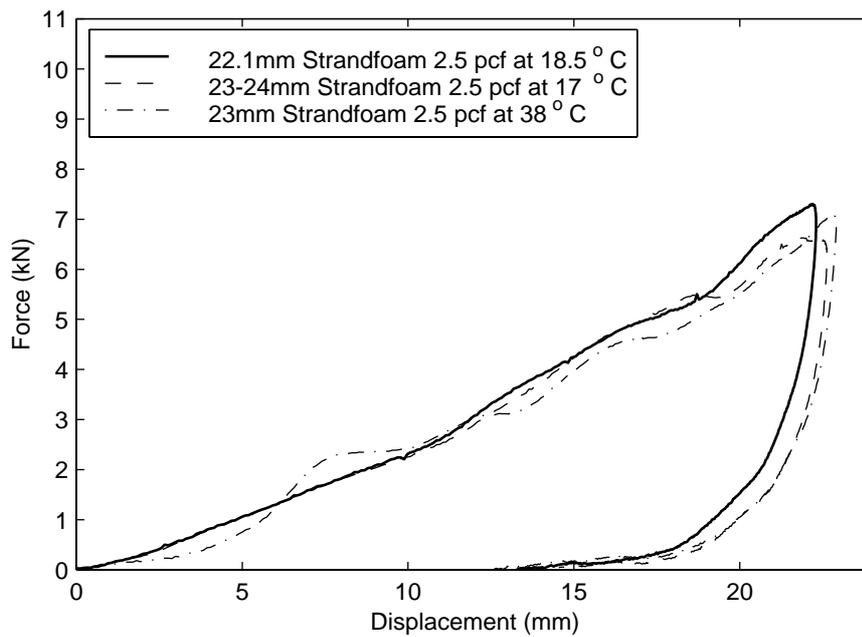


Figure 3-10 Influence of temperature on the effectiveness of STRANDFOAM\* 2.5 pcf

### 3.3.3 Polyurethane

Three types of polyurethane were tested. The first type tested was a free-rise moulded polyurethane (ME 3453) and performed poorly. The other polyurethanes (Huntsman Development Resin 929) were moulded and compressed to increase the density (and hence the stiffness). These polyurethanes have the same Polyolefin component (DR 929), but use a slightly different isocyanate compound. One uses Suprasec 5005 and the other Suprasec 2050. The polyurethane that was produced using the Suprasec 2050 isocyanate performed better. The force-deflection curves from these tests are shown in Figure 3-11.

Elevated temperature tests of the polyurethanes showed that heating the materials had negligible effect on their performance (Figure 3-12).

Table 3-6 Polyurethane 1.45m drop test results

Material Type	Thickness (mm)	Temp. (° C)	Peak Acceleration (g)	HIC	Test Number
Polyurethane ME 3453	25	18	329	2043	01050101
Polyurethane DR 929 V6/ Suprasec 5005	25	18.5	176	875	01050102
Polyurethane DR 929/Suprasec 2050	25.5	22	146	697	29050103
Polyurethane DR 929 V6/Suprasec 5005	24.5	40	176	878	15060102

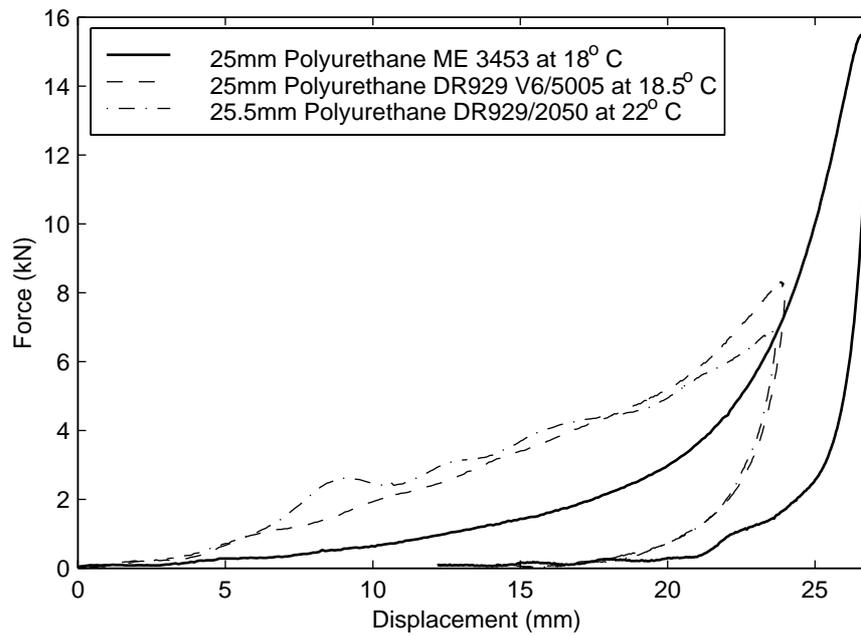


Figure 3-11 Force deflection curves comparing the three Polyurethane samples

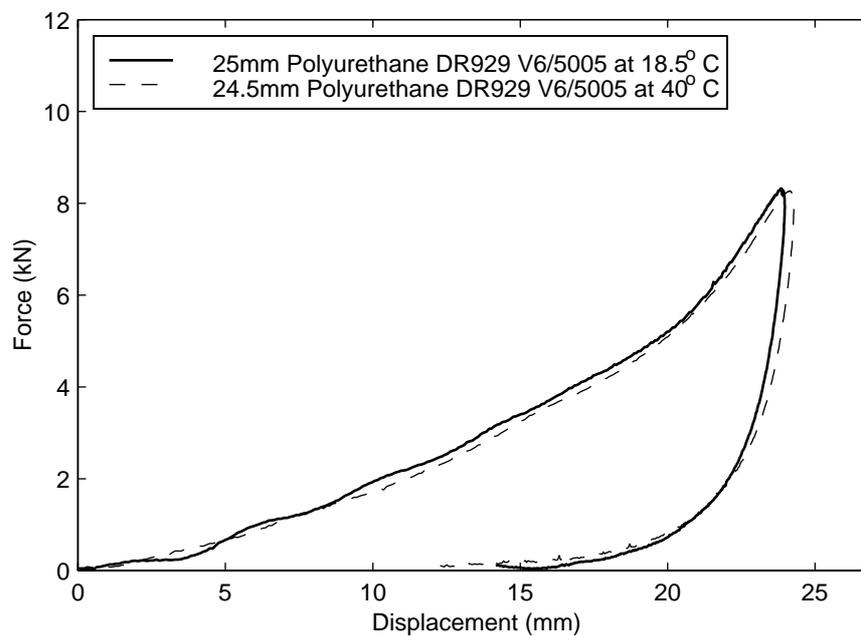


Figure 3-12 Influence of temperature on the effectiveness of Polyurethane

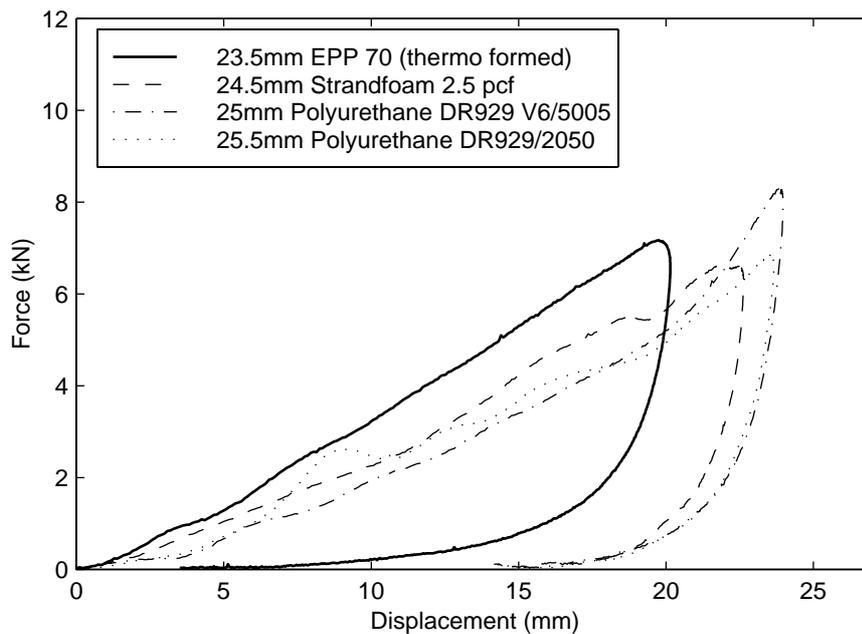
### 3.3.4 Summary of Phase 1 results

Table 3-7 summarises the results of the best performing materials. A comparison with Table 3-2 shows that these materials are, on the whole, much better at reducing the severity of the

impact than those tested in CR193. Only the 30 mm thick cardboard honeycomb did better, although it should be noted that the extra thickness of this material would have allowed extra energy absorption.

Table 3-7 Summary of the best performing materials in Phase 1 tests

Material Type	Thickness (mm)	Temp. (° C)	Peak Acceleration (g)	HIC	Test Number
EPP 70	23.5	21	152	810	15060101
STRANDFOAM* 2.5 pcf	23.5	17	141	705	27040108
Polyurethane DR 929/Suprasec 2050	25.5	22	146	697	29050103
Polyurethane DR 929 V6/Suprasec 5005	24.5	40	176	878	15060102



## 4 Phase 2 Testing

### 4.1 METHOD

Anvils are commonly stipulated by standards that govern the performance requirements of protective helmets. The helmets, attached to a standard headform, are dropped onto the anvils to test for the effects of concentrated loading. Under this type of loading, the energy absorption of the helmet will differ from that in an impact with a flat surface.

The Phase 2 testing of this study used a standard hemispherical anvil. The anvil was constructed according to the Australian Standard AS2512.3.1: "Determination of impact energy attenuation - helmet drop test". The anvil was mounted to the steel slab that was used for the Phase 1 tests. A prototype headband was interposed between the headform and the anvil, using light supports. The drop height was 1.385 m, as specified in AS2512.3.1.

The purpose of this test was to examine the effects of concentrated loading on the performance of the various materials, rather than to test its effectiveness as a helmet according to AS2512.3.1. Rather than use the criteria AS2512.3.1, we have used the peak acceleration, the HIC value and the force/displacement curve as assessments of performance, to maintain consistency with other results in this report. All data acquisition and signal processing was the same as in Phase 1 of this study. The drop testing setup is shown in Figure 4-1.

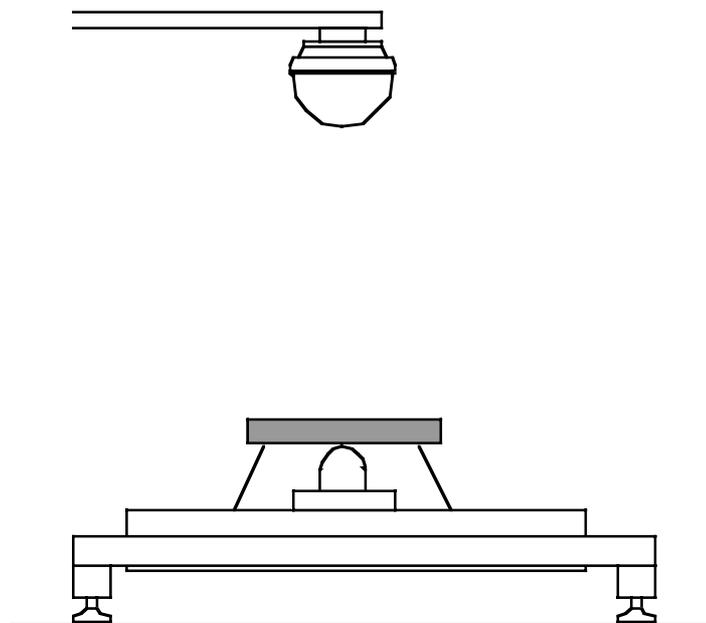


Figure 4-1 Phase 2 drop testing setup

4.2 RESULTS FROM CR193

For comparison, the results of tests reported in CR193 are given in Table 4-1. In this test the concentrated loading compromised the performance of the cardboard honeycomb. A hard shell was used in another test to distribute the load over the honeycomb surface, and a very low HIC number was obtained in that test. The other promising material from this testing was the Woodbridge polyurethane with the code BB-38. The force deflection curves from these tests are shown in Figure 4-2.

Table 4-1 Results of headband tests on the hemispherical anvil from CR193 (drop height 1.385 m, velocity 18.8 km/h)

Prototype description	Peak acceleration (g)	HIC	Test number	Damage to prototype
30 mm honeycomb cardboard	241	970	02069901	none
15 mm honeycomb cardboard in 4 mm PVC shell	290	1410	02069903	none
25 mm E175, polyurethane foam	286	1470	02069904	none
25 mm E900, 5.6 pcf, polyurethane foam	289	1520	02069905	none
25 mm E900, 6.0 pcf, polyurethane foam	320	1740	02069906	none
25 mm BB-38, polyurethane foam	185	860	02069907	none
25 mm polystyrene foam	348	1650	02069908	shattered
30 mm honeycomb cardboard in 4 mm PVC shell	87	260	09069910	none

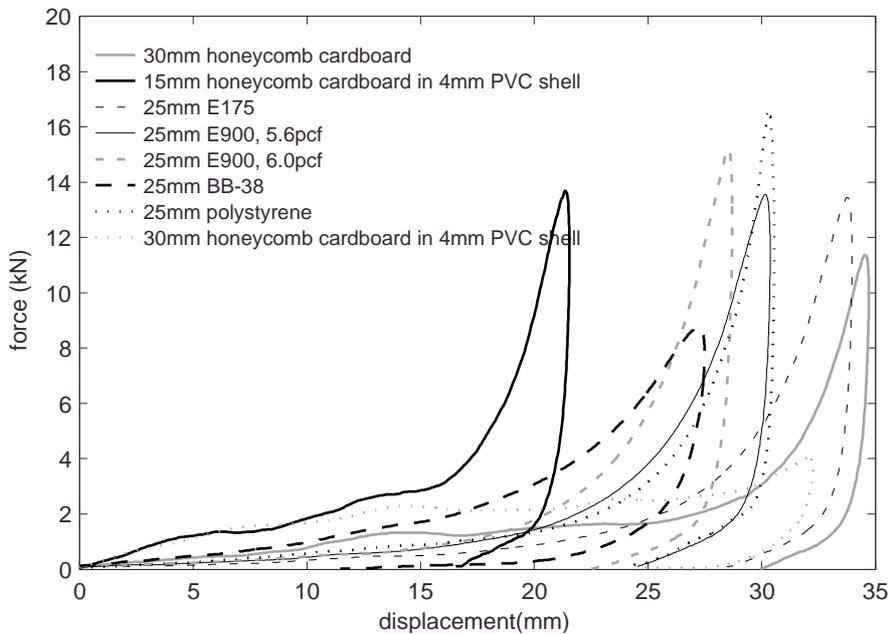


Figure 4-2 Hemispherical anvil drop test results from CR193

#### 4.3 RESULTS OF ANVIL TESTS USING NEW MATERIALS

This test caused the STRANDFOAM\* 2.5 pcf to delaminate along the strand lines, and disintegrate. Consequently, the material performed poorly. This effect was similar to that seen in the cardboard honeycomb in earlier tests. STRANDFOAM\* 2.5 pcf was tested again, with plastic film adhered to the bottom and top surface of the sample. The film was 500  $\mu\text{m}$  thick, and made of layers of polyester and polyethylene bonded with an adhesive ethylene vinyl acetate copolymer (Ibico GmbH, Germany). The performance of the material improved in this configuration, but it appeared the plastic layers may have stiffened the material and slightly degraded its energy absorbing properties. Interestingly both polyurethanes performed well in the anvil tests, even though they too disintegrated on impact.

With the exception of the first STRANDFOAM\* test, the HIC results for these materials were better or comparable with those obtained in CR193 (Table 4-1).

Table 4-2 Hemispherical Anvil drop test results

Material Type	Drop Height (m)	Thickness (mm)	Temp. (° C)	Peak Acceleration (g)	HIC	Test Number
Expanded Polypropylene 70	1.383	27	21	128	580	31050100
STRANDFOAM* 2.5 pcf	1.383	22	21	386	1993	31050101
STRANDFOAM* 2.5 pcf sandwiched with plastic	1.378	25	20	194	854	01060100
Polyurethane DR 929 V6/Suprasec 5005	1.383	24.5	21	160	685	15060103
Polyurethane DR929/Suprasec 2050	1.381	26.5	21	136	550	15060104

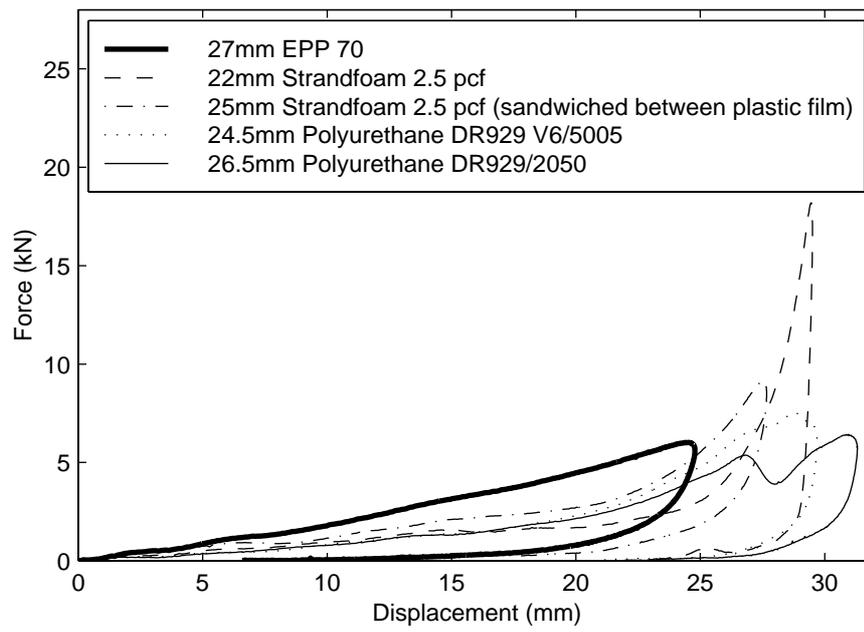


Figure 4-3 Hemispherical anvil drop test results

## 5 Phase 3 Testing

### 5.1 METHOD

In CR193, prototype headbands were constructed from the most promising materials identified in phase 2 of that study. These headbands were attached to an aluminium headform. The headform was fired at an internal structure of a vehicle to see how the headband reduced the severity of the impact. The test setup used in CR193 is illustrated in Figure 5-1.

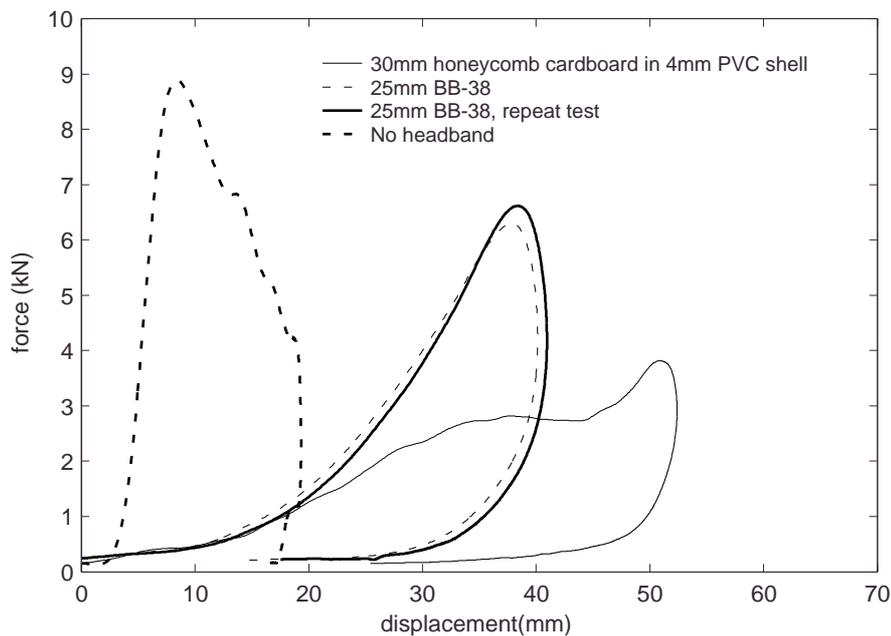


Figure 5-1 Test setup used in CR193. The photo was taken immediately after a test (Note that the RARU headform was used in the tests reported on in this report, not the EEVC WG10 headform as shown).

A summary of results for the Phase 3 tests of CR193 is given in Table 5-1. The force/displacement characteristics for these four tests are presented in Figure 5-2.

**Table 5-1 Results from Phase 3 - Tests at 23 km/h horizontally against the B-pillar of a 1977 Toyota Corolla station wagon**

Prototype description	Velocity (km/hr)	Peak acceleration (g)	HIC	Test number
30 mm honeycomb cardboard in a 4 mm PVC shell	22.8	78	280	17069901
25 mm BB-38 polyurethane	22.5	130	600	17069902
25 mm BB-38, repeat test	22.7	137	640	17069903
No headband	23.0	193	850	17069905



**Figure 5-2 Phase 3, B-pillar Test Results**

In Phase 3 of this study, it was decided that it would be adequate to test the samples as a rectangular block placed between the head form and the test surface. Although the EPP-based materials could be thermoformed, the polyurethanes could not, and it was not practicable to manufacture the shapes required with the small amounts of material made available to us for testing.

A B-pillar was removed from a 1978 Toyota Corolla (the same model vehicle used in CR 193) and rigidly fixed to two mounts such that only elastic bending of the entire B-pillar structure and localised deformation of the impacted area could occur (Figure 5-3). Testing in this orientation made the ballistics of the test simple and more accurate, and allowed the samples to be easily mounted to the structure of the B-pillar.

An aluminium headform was fired at the sample and B-Pillar with a vertical velocity. The aluminium headform was designed by the Road Accident Research Unit for use in the reconstruction of pedestrian/car collisions. The headform has a spherical contact surface of 165 mm diameter, but is cylindrical about its long axis (Figure 5-4). The headform has a mass

of 4.8 kg. The launch height was such that the combined kinetic energy imparted to the headform from the release of the spring and from the force of gravity produced the required impact speed. All tests were conducted at a room temperature of 21° C.

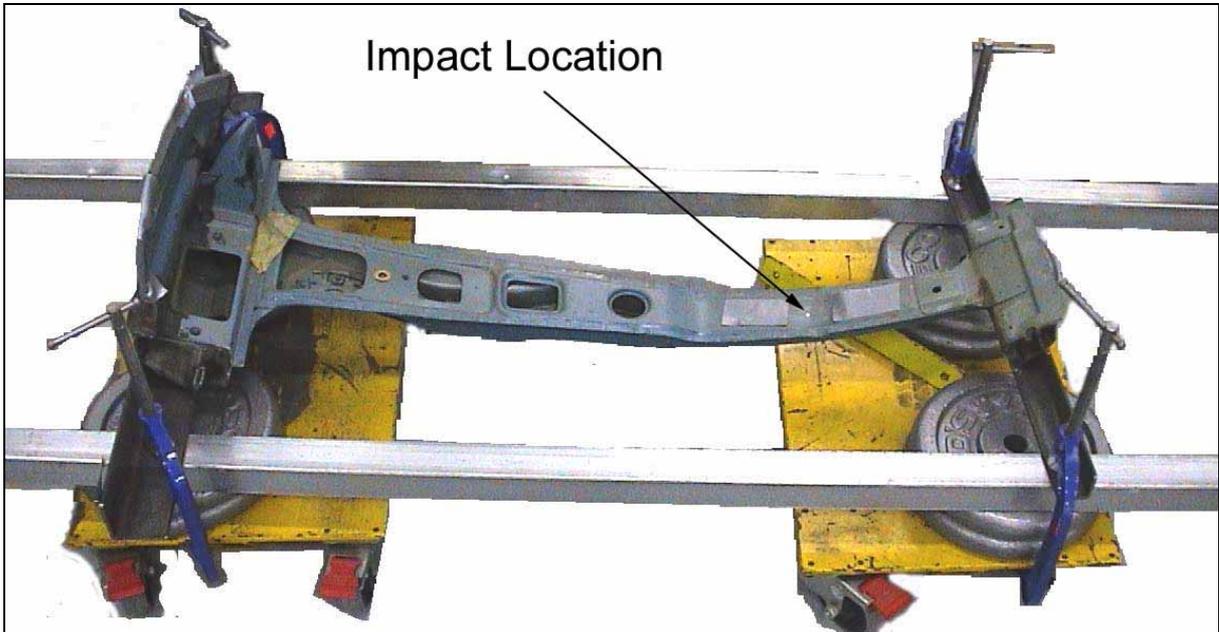


Figure 5-3 B-Pillar Set-up.

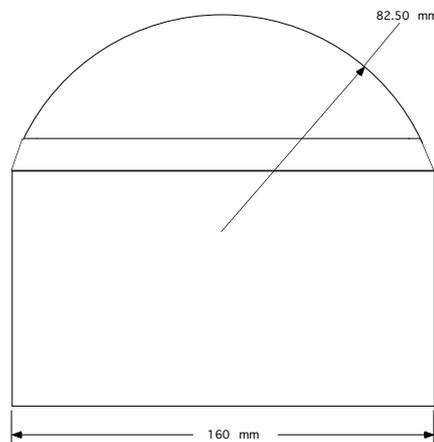


Figure 5-4 The aluminium headform used in Phase 3 tests

As in CR193, the tests were performed at a nominal speed of 24 km/h (15 mph), which is the speed stipulated by FMVSS 201. The criterion in FMVSS 201 is that the maximum acceleration in the impact should not exceed 80 g for more than 3 ms. However, the peak acceleration, the HIC value and the force deflection curves were used to assess each impact, to remain consistent with earlier phases of this study.

The unprotected B-pillar was also tested to ensure that the structure was comparable to that used in CR193. This was done at the outset, and again after the samples had been tested, to ensure that its response had not significantly changed throughout the tests. The results of these tests indicate that the structure did not change significantly (Figure 5-5).

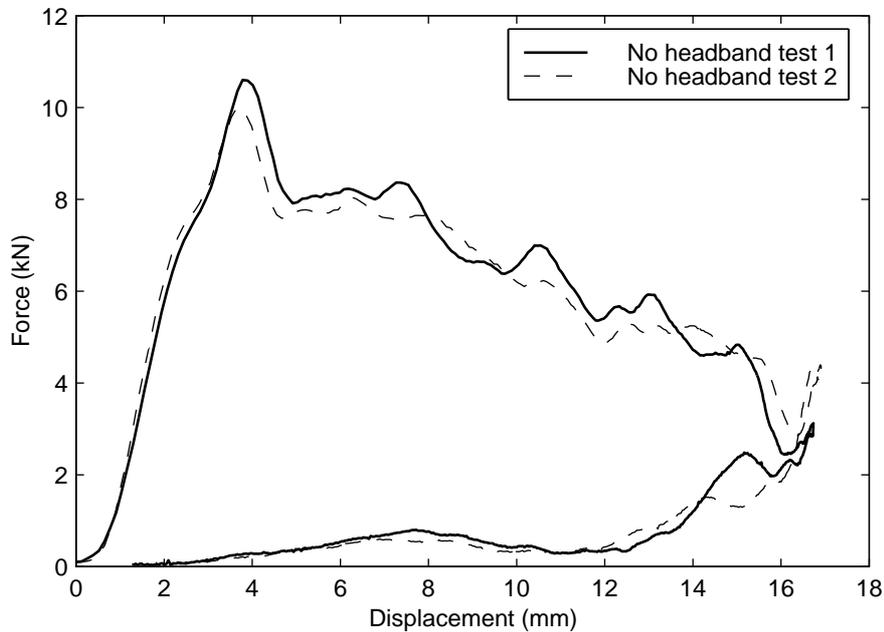


Figure 5-5 Force displacement curves measured from impacts with the unprotected B pillar. Test 1 (28060100) was performed before the tests of the headband materials and Test 2 (28060104) was performed after the materials tests had been completed.

As an additional experiment, the EPP 70 was cored to reduce its density. This method was loosely based on 'An area of future development' described in Everitt et al. (1998). In that publication, the authors recommended, '... testing "creative" foam designs (i.e. foam coring - punching holes in foam)'. Initially holes were made in an EPP 70 block, and the block was tested (29060100). Subsequently, additional holes were made in the sample and the sample was then re-tested (29060103).

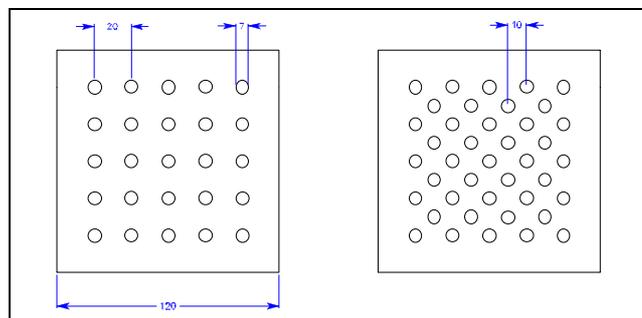


Figure 5-6 Two cored foams used in test 29060100 and then test 29060103 respectively.

Modifications were also made to the STRANDFOAM\* 2.5 pcf to prevent delamination of the structure. In one test, the sample's impact surface was laminated with a 250 µm thick layer of

plastic sheet (Test 29060101). Another sample was heated and formed into the shape of the head form and also laminated with a 250  $\mu\text{m}$  plastic sheet on its impact surface (Test 29060101; see Section 4.3 for details of the plastic film).

## 5.2 RESULTS

While reducing the impact severity, EPP 70 was inferior to all other materials tested using the Phase 3 test, including those in CR193. Coring the material to reduce its density improved its performance only marginally. The Polyurethane DR929 V6/Suprasec 5005 and the STRANDFOAM\* 2.5 pcf were able to reduce the severity of the impact significantly. Table 5-2 summarises the results of the testing done in Phase 3.

Table 5-2 Results of the Phase 3 testing

Material	Thickness	Impact Speed (km/h)	Peak Acceleration (g)	HIC	Test No.
No headband	-	23.4	225	822	28060100
Expanded Polypropylene 70	24	23.5	124	679	28060101
STRANDFOAM* 2.5	23.5	23.4	98	457	28060102
Polyurethane DR 929 V6/Suprasec 5005	25	23.4	103	583	28060103
No headband	-	23.3	212	858	28060104
Cored Expanded Polypropylene 70	24	23.5	120	654	29060100
STRANDFOAM* 2.5 with exterior laminated	23.5	23.5	96	532	29060101
STRANDFOAM* 2.5 heated and formed with exterior laminated	23.5	23.2	108	501	29060102
Further Cored Expanded Polypropylene 70	24	23.6	120	648	29060103

The performance of materials in the present study and those tested in CR193 is summarised in Figure 5-7. This bar-graph shows that the better materials in this study significantly reduced HIC levels. The peak acceleration experienced by the headform was more than halved by the STRANDFOAM\* (Table 5-2).

Figure 5-8 shows the force deflection curves of the tests of the unmodified materials in Phase 3. All materials reduced the stiffness of the impact. STRANDFOAM\* shows a flat section in its force displacement characteristic, which is indicative of its propensity to crush at a more or less constant load before bottoming out. It may be observed that the curves for STRANDFOAM\* and the polyurethane DR929/5005 were very similar.

Figure 5-9 and Figure 5-10 show the force displacement curves for materials that have been modified in some way. Figure 5-9 shows the effect of coring the EPP 70. The coring appears to soften the material on first contact. However, the efficiency of its energy absorption seems to be unaffected by the modification. Figure 5-10 shows the effect of forming and laminating STRANDFOAM\*. It may be seen that the lamination tends to degrade its performance. These results show that if delamination needed to be prevented in the use of the headband, some alternative method of prevention that will not stiffen the material may be preferable.

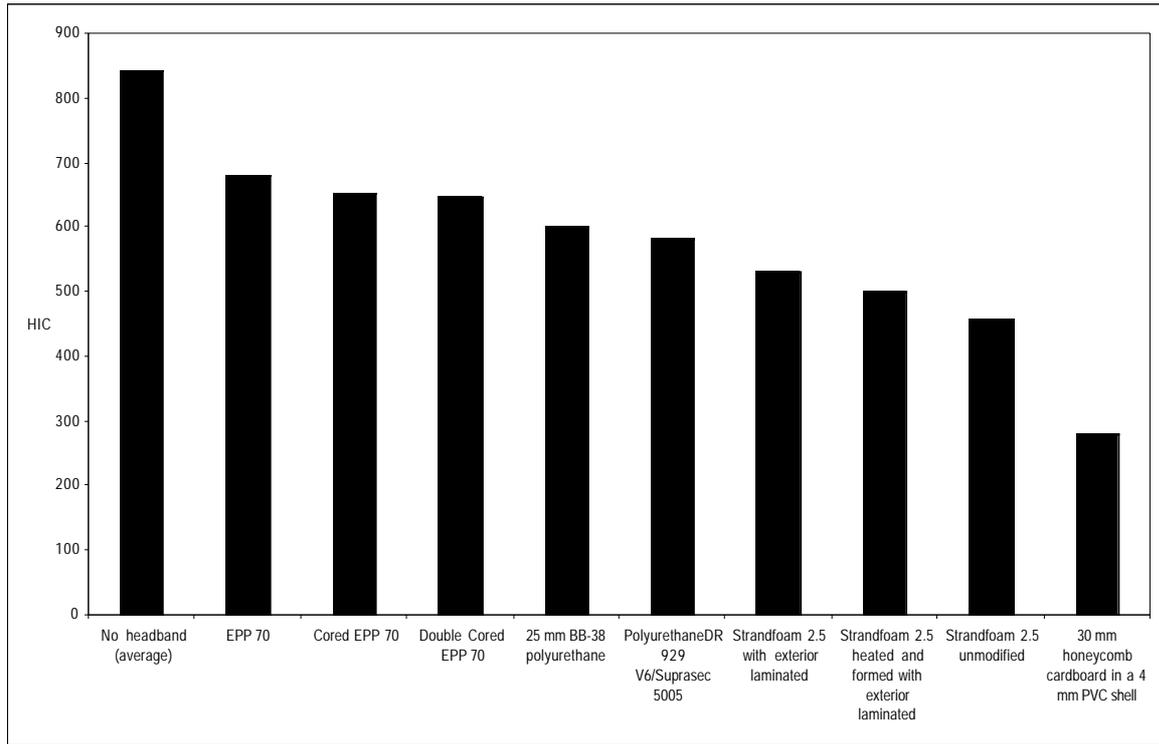


Figure 5-7 A comparison of HIC values across the range of materials examined in CR193 and in this study

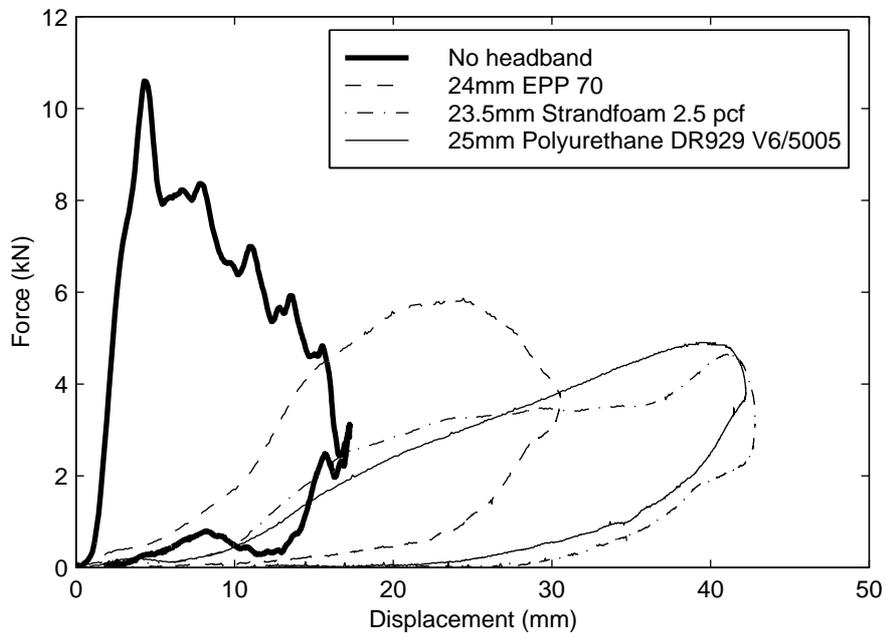


Figure 5-8 Force/deflection curves measured during tests of the unmodified materials

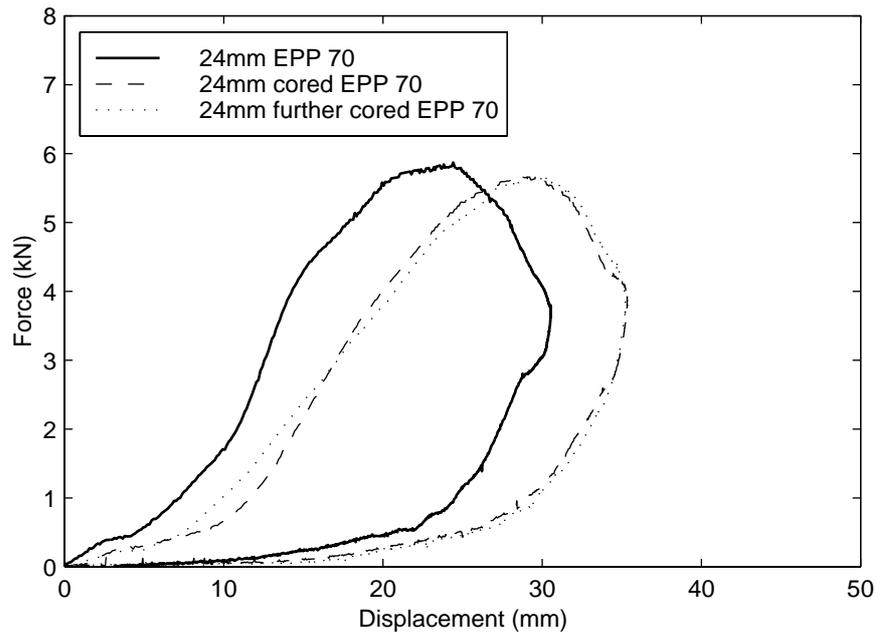


Figure 5-9 B-Pillar test results a comparison of EPP 70 with coring

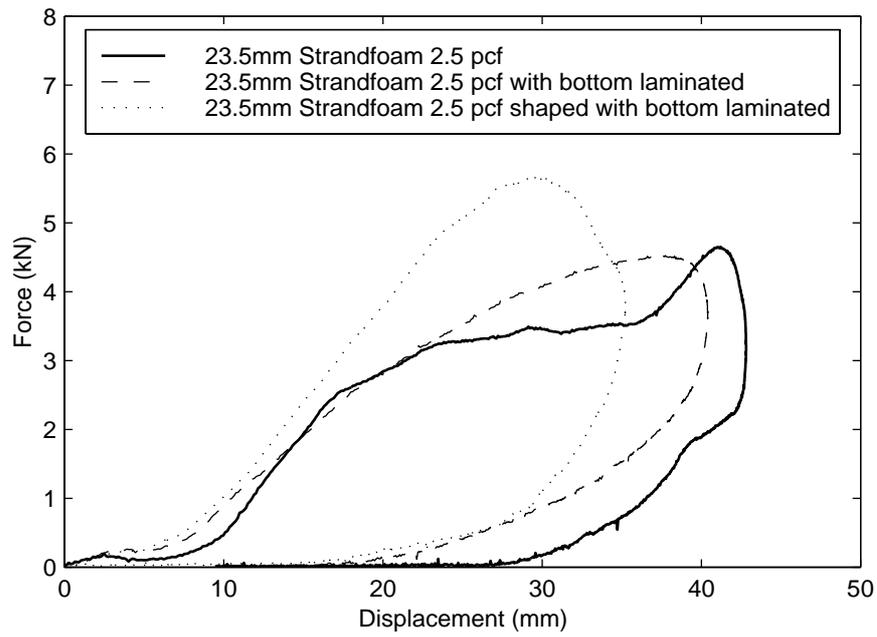


Figure 5-10 B-Pillar test results a comparison of STRANDFOAM\* 2.5 pcf variations

## 6 Discussion of test results

The criteria for choosing a material for the headband would be ultimately ones based on performance, ease of manufacture, durability and cost. While 30 mm of cardboard honeycomb with a rigid outer shell is the best structure tested to date, it seems unlikely that this material would satisfy the durability criteria, and possibly the ease of manufacture criteria.

Of the materials tested for this report, all three categories seem to have their advantages and disadvantages. Expanded polypropylene appears to be a very durable material. Its performance was good through the first two phases of testing. Its performance in Phase 3, however, was poorer than might have been expected after its performance in the previous tests. STRANDFOAM\*, which is a modified EPP, proved to be the best performing material in Phase 3. This suggests that EPP may be a good choice of material, but probably in some variant of the EPP 70 tested here. This could be EPP of an alternative grade or geometry, or EPP produced as STRANDFOAM\*.

STRANDFOAM\* has excellent energy absorbing characteristics. Its delamination failure in Phase 2 was the reason for its poor result in this test. The test is probably very severe, however, and may unfairly represent the performance of the material. Its performance may improve markedly with even a soft shell covering.

The grades of polyurethane tested here were also excellent energy absorbers. As with the other materials, their performance comes from crushing of the foam structure. The material is eminently suitable from a manufacturing and a price perspective, but it has an almost friable characteristic, which may present some durability problems. These may be overcome by incorporating a cover that protects the material from wear and tear.

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## 7 Design development

To date, the only formal evaluation of the concept of wearing a protective headband inside a motor vehicle has been through a marketing focus group study, undertaken for the ATSB. In that study, a mock-up of a headband was produced for discussion within the focus group. The focus group's attitude to the design was not positive overall. The results of the focus group study demonstrated that the success of the headband will depend largely on its acceptability in the community. This will involve overcoming the misgivings of people who currently do not see the headband as a safety device that they would wish to use.

To allow the public to fairly determine their attitudes to a protective headband, it is sensible to produce a design that realistically represents one that the public would encounter should the device become commercially available. To this end, this study has included the development of such a design. This process was a collaboration between Tiller and Tiller Design and the Road Accident Research Unit.

The following pages illustrate the three phases of the design development. The first was some brief concepts that Tiller and Tiller produced in response to design requirements laid down by RARU. These provided the basis of further discussion and development, which led to three final concepts being put forward for consideration. Finally, the design that both Tiller and Tiller and RARU considered best satisfied the requirements of form, function and acceptability was identified and further detailed.

### 7.1 FIRST ROUND CONCEPTS

The design concepts produced in the first round considered various means of overcoming user resistance. This could be by a mechanism such as disguise, adding extra features, making the unit easy to wear, and/or making a bold statement. Table 7-1 provides a legend to the illustrations of these concepts which can be found in the following pages.

Following the production of the concepts by Tiller and Tiller, the designers and members of the Road Accident Research Unit considered the advantages and disadvantages of each concept. Disguise was discounted as a suitable mechanism for overcoming consumer resistance, as it might not send an appropriate message to potential consumers. Rather, it was felt that the function of the device should be clear, and the design should have a familiar feel that suggested safety, and that this would be a preferable mechanism for overcoming resistance to the product. For similar reasons, the bold-statement concepts were also discounted.

Providing extra features with the headband may enhance the appeal for some consumers. Some of these concepts would produce the familiar feel that was identified as an important feature of the design. However, there are some conceivable problems with this approach. For example, a visor may become hazardous in a crash, should it become damaged on impact, and a built-in headphone could become a distraction when driving. Extra features would also add cost and may inhibit consumer uptake of the product.

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In summary, this round of conceptualising produced clearer design requirements beyond the need to meet certain protection criteria, such as coverage and material thickness specifications. In particular, the headband's function should be obvious from its appearance and it should have a familiar aesthetic to help overcome resistance to the product.

Table 7-1 Legend to first-round concept development

Group	Page	Sketch	Description
Disguised appearance	1	A, B	Tennis style sun visor with integrated padding.
		C, D	'Baggy' baseball cap, with protection front and back.
	2	A, B	Baseball cap, sun hat with peak integrated padding.
Headband visor	3	A, B, C, D	Sun visor style protection, placement on forehead and stabilised like spectacles, tinted visor can be used instead of sunglasses.
	4	A	Head band style
		B	Similar to 3, but is a complete ring with integrated headphone.
		C	Sun-glasses style
		D	Visor style with 'neck-cushion' integration
Hood	5		Worn around the neck and is ready to be used like a hood for protection.
Alternative – bold statement	6	A, B	Alternative style head protection gear, with added protection.
		C	Added protection with integrated visor.
	7	A, B	Alternative 'skeleton' style full protection head gear with headphone.
		C	Cyclist helmet style with headband like fitting.
		D	Minimalist headphone style forehead protection.

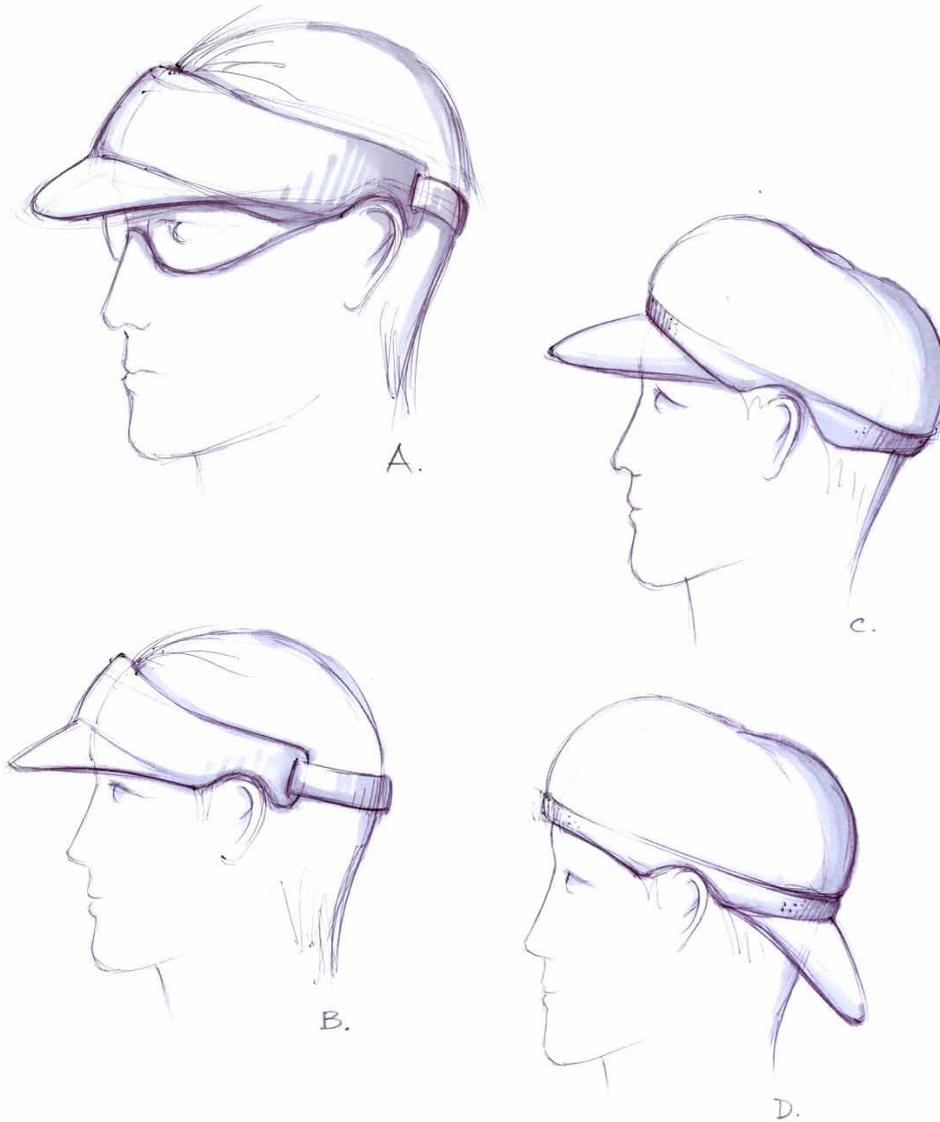
## 7.2 SECOND ROUND CONCEPTS

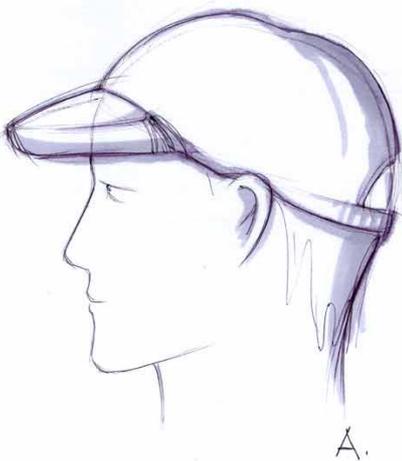
Three concepts were developed using the preferred elements from the first round of concepts. The concepts all use a headband style construction and a small integral visor. The visor provides the design with a familiar feel of head apparel. The variations between the concepts centre on the appearance, the fastening of the headband and one option has a larger soft sun visor. The preferred concept to emerge from the second round of concept development was concept 2, which provides for an adequate thickness of material, while maintaining a simple form which recalls the shape of a bicycle helmet, reinforcing the protective aspect of the design.

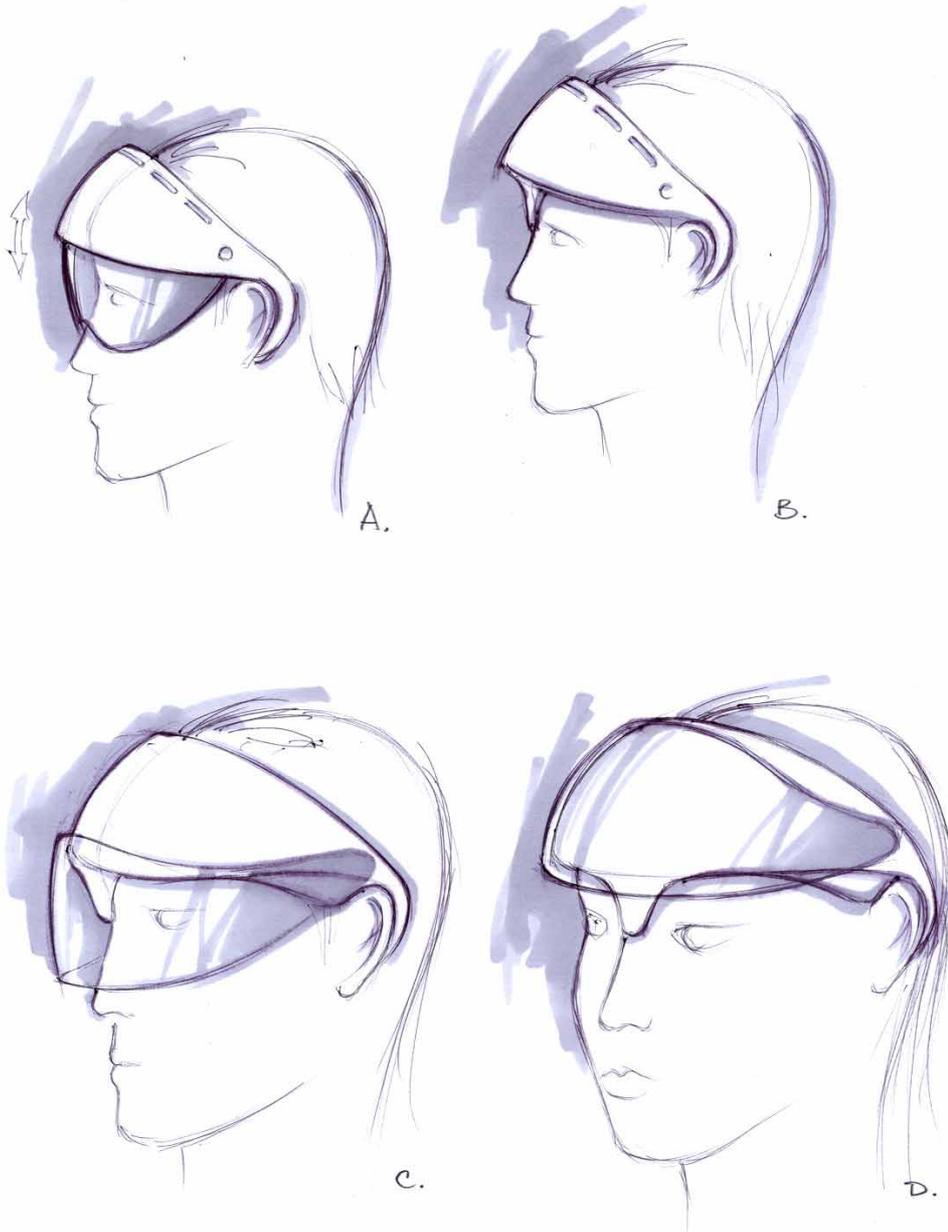
## 7.3 FINAL CONCEPT

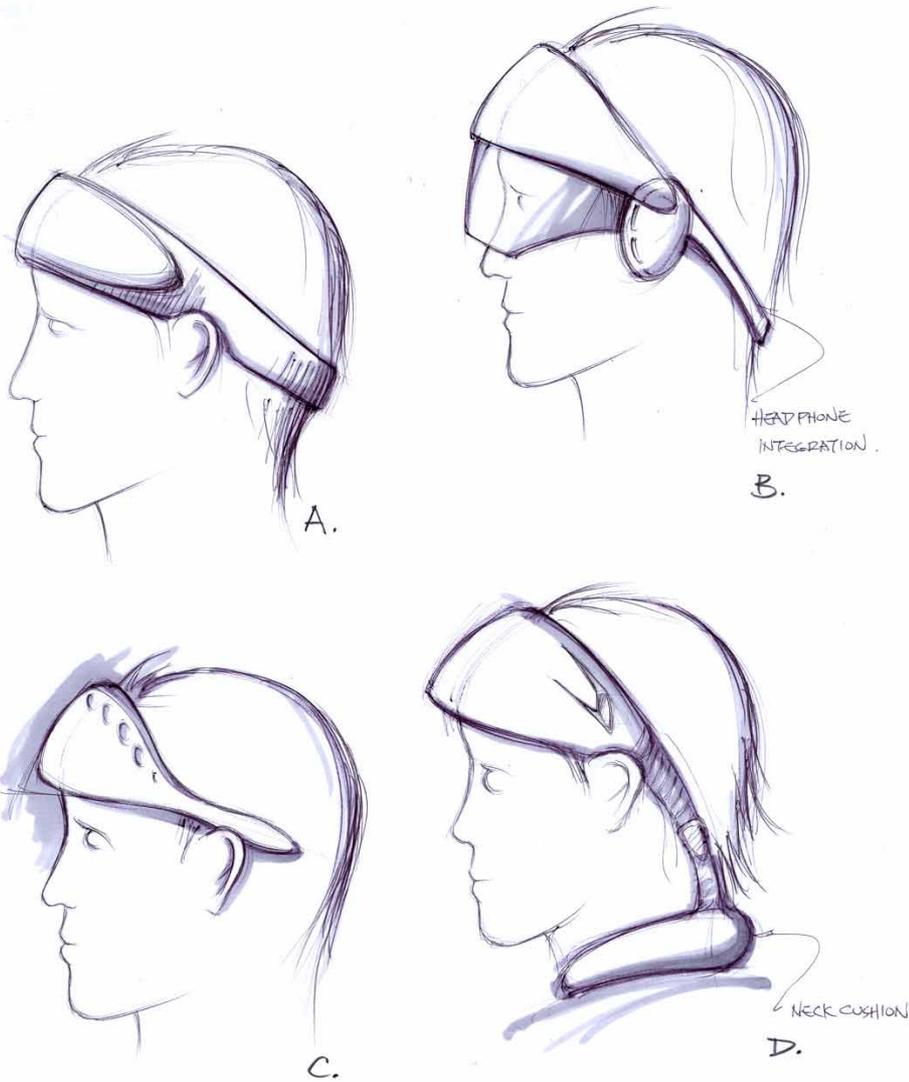
The final concept is a refinement of concept 2 from the second round of concept development. It maintains the form of the energy absorbing material and the minimal and familiar aesthetic. The main development in the concept was an easy to use comfortable mounting strap and clip, integrally mounted into the main body of the headband.

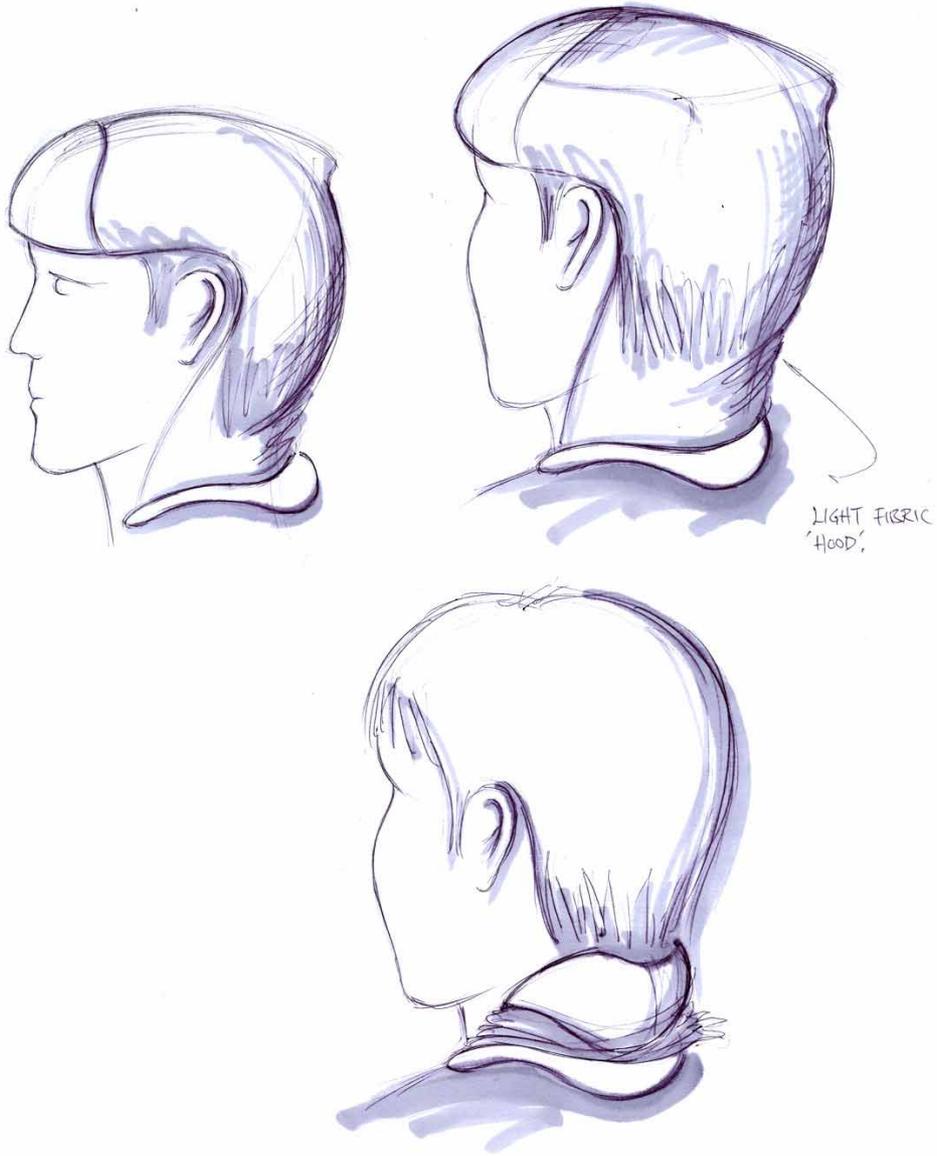
7.4 FIRST ROUND CONCEPT DEVELOPMENT: PRODUCT RENDERINGS

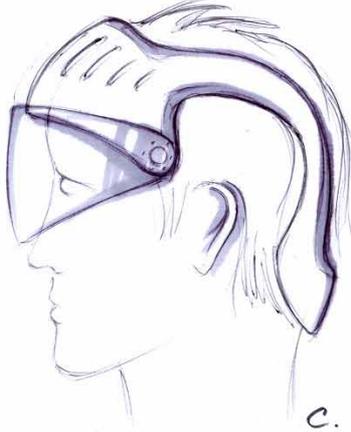












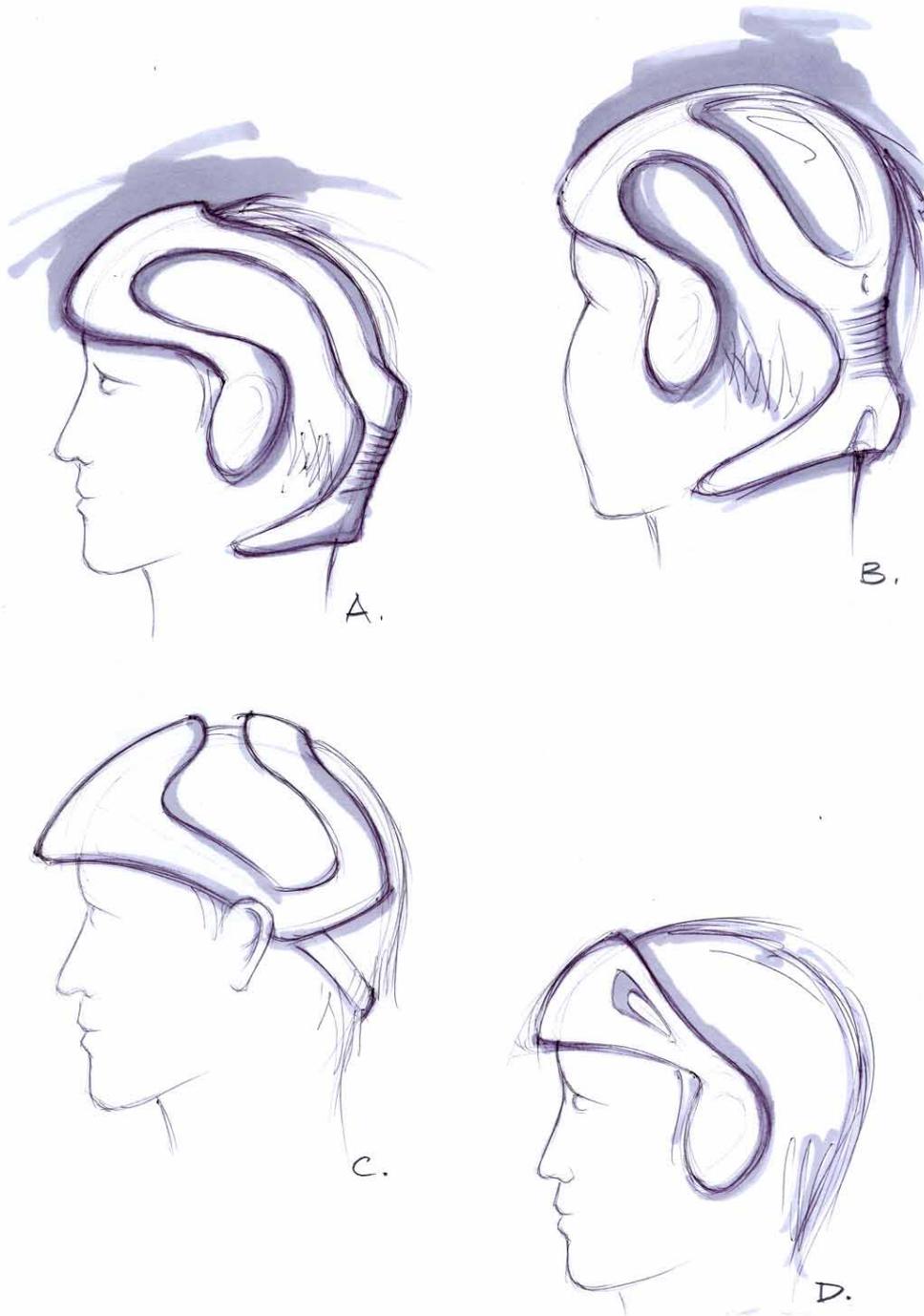
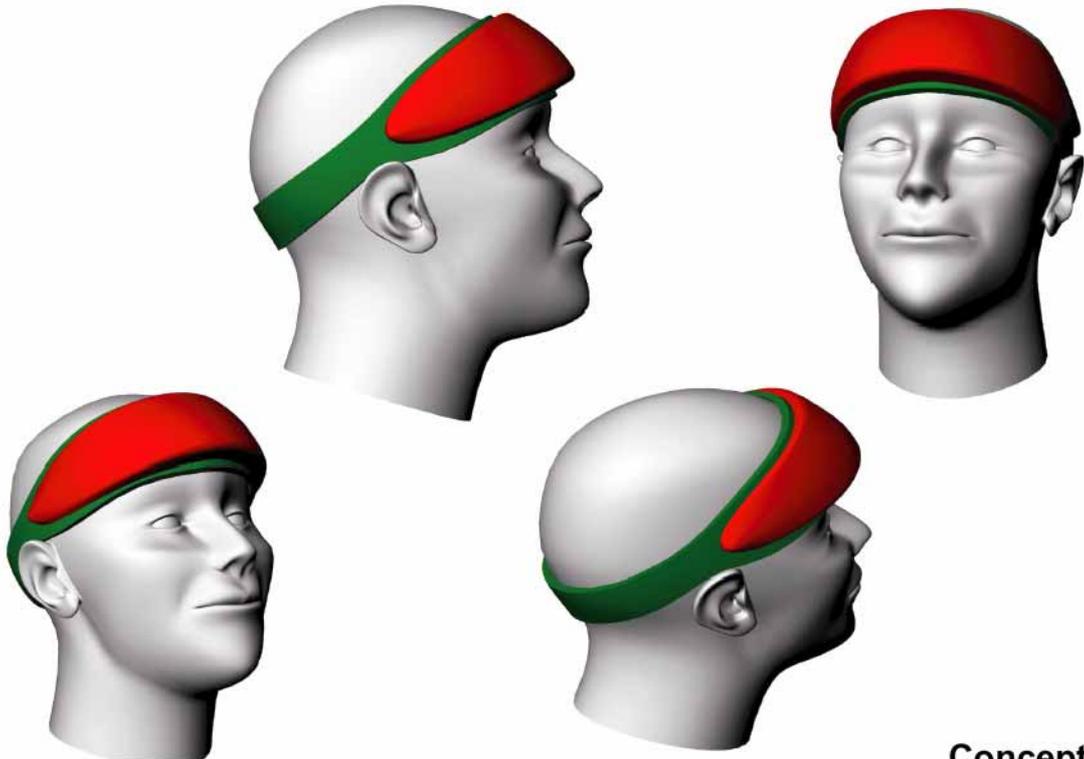
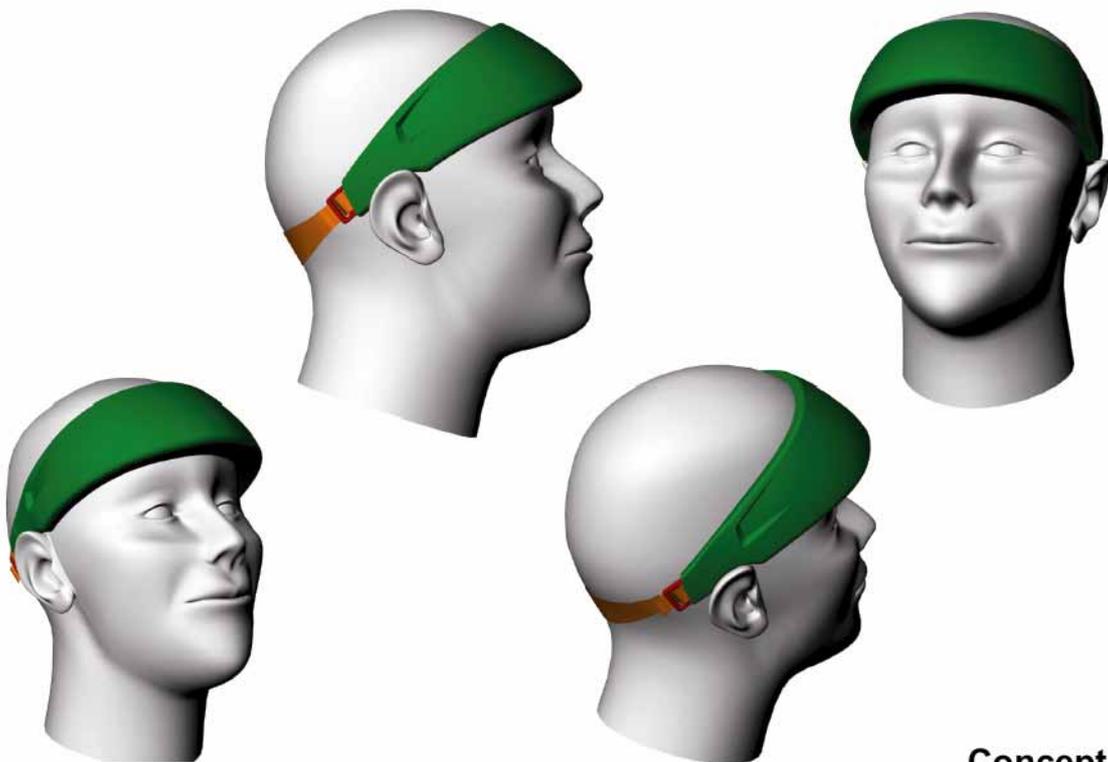


Figure 7-1

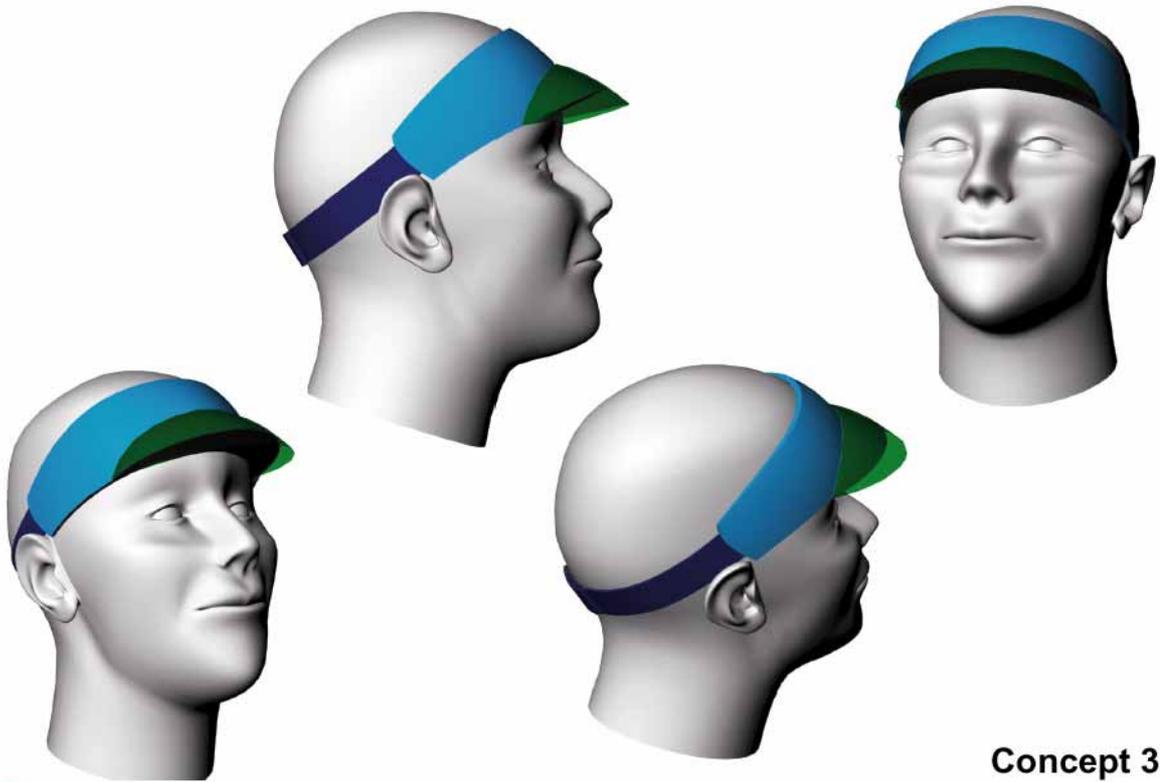
7.5 SECOND ROUND CONCEPT DEVELOPMENT: PRODUCT RENDERINGS



**Concept 1**

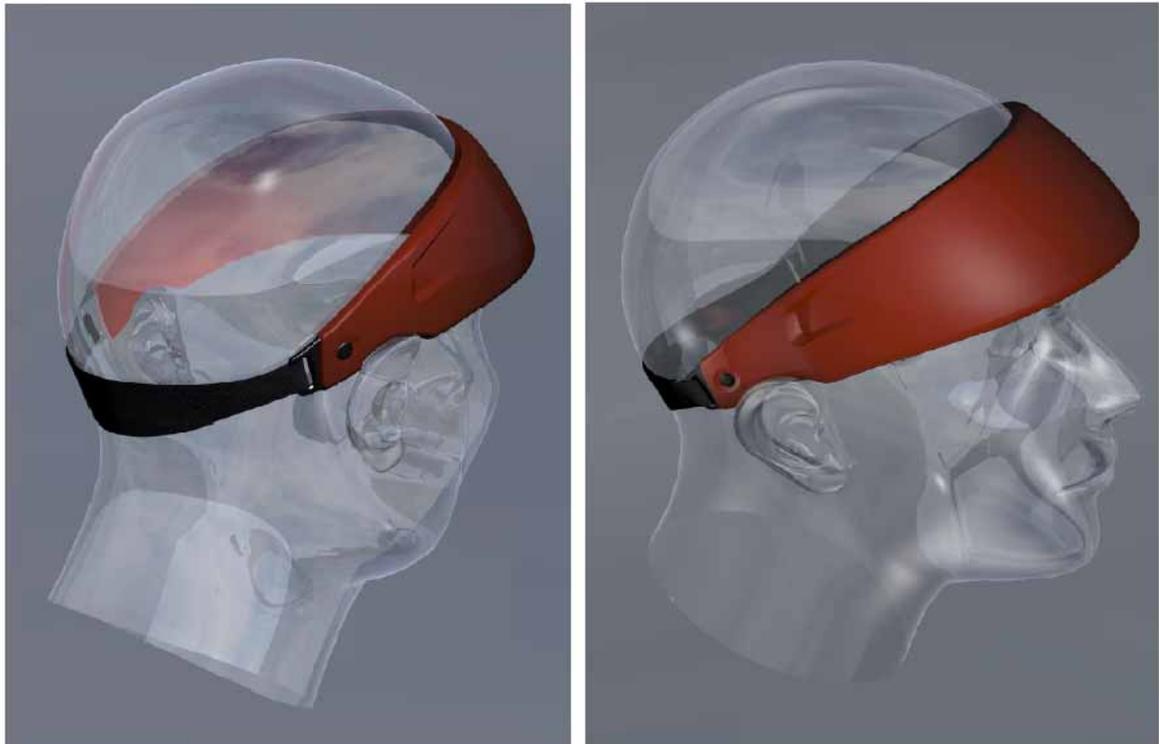


**Concept 2**



**Concept 3**

## 7.6 FINAL CONCEPT RENDERING



## 8 References

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