Evaluation of Hot Press Forming Parts for Euro NCAP5 in P3-21A

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PROTON's first global car project, the P3-21A is required to meet the Euro NCAP 5 stars requirements and maintain the Body In White (BIW) light weight target of under 300kg. Current models use the Ultra High Strength Steel (UHSS) to meet the targeted safety requirements. However there are limitations of stamping UHSS which involves part accuracy problems.

Alternatively, the thickness of High Strength Steel (HSS) can be increased, but it would also add unnecessary BIW weight. Our objective here is to discuss the process of Hot Press Forming (HPF) and its impact on meeting the Euro NCAP 5 stars requirements in terms of weldability and crash worthiness as well as maintaining BIW weight target of individual parts. The implementation of HPF is based on the study of the HPF process and lab tests such as weldability and crash tests. The results of these tests prove that the P3-21A model can meet the Euro NCAP 5 stars requirements and the BIW weighs less than the target (298.8kg) with the adoption of HPF process. Further study should be conducted on the full utilisation of HPF process for all BIW parts without jeopardising the Built of Material (BOM) cost.

Key words: Euro NCAP, Body in White, Hot Press Forming, light weight.

INTRODUCTION

The P3-21A model is Proton's first global car project which aims to be marketable in Europe, Middle East & Australia. In order to do so, the P3-21A model must meet the regulations of these regions, including fulfilling the Euro NCAP 5 stars requirements. As an additional challenge, the model should also maintain its BIW light weight target of < 300kg. The light weight target is mainly to check off high fuel consumption of the car caused by excessive body weight.

The conventional stamping process uses the HSS or UHSS sheet metal and produces parts which may meet the required Tensile Strength but does not guarantee > 90% part accuracy. The main problem often encountered in stamping is spring back, caused mainly by high thickness or high Tensile Strength of the produced part.

Thus, HPF process is introduced to P3-21A project to increase the Tensile Strength of Manganese-Boron steel material (e.g. Usibor1500P) up to 1500MPa and still meet the required part accuracy percentage as well as maintain the light weight target. The HPF process is done by heating the sheet metal in the furnace, performing the part drawing and quenching it at the same time by using a hydraulic press machine.[1]

The advantages of adopting the HPF process in BIW parts are as follows:

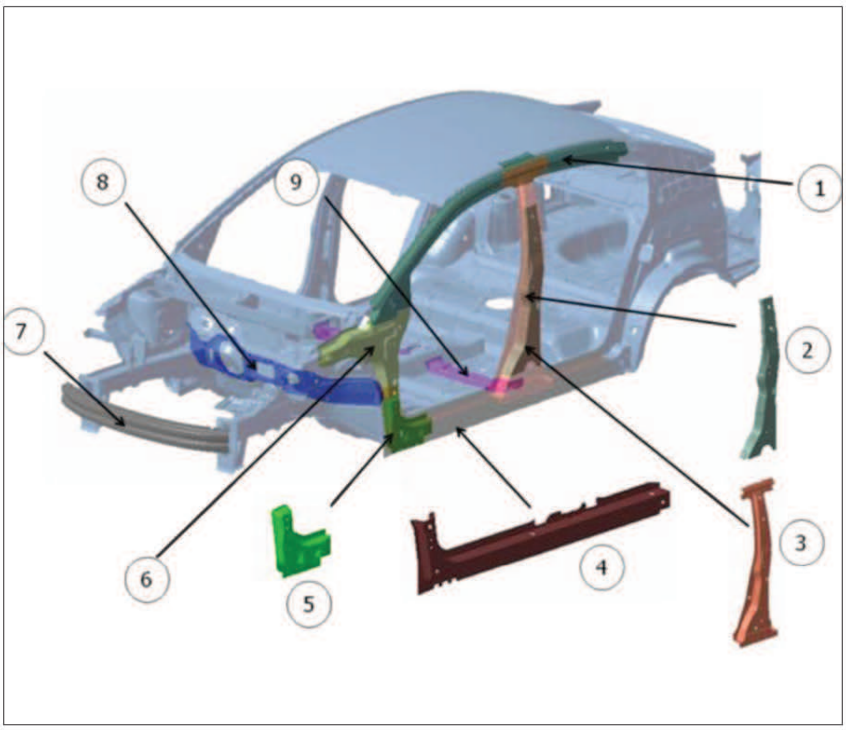

Figure 1: P3-21A Final release of HPF parts

1. Very high formability with very low built-in strain, good energy absorption qualities and low tooling force required (400-1200MPa)
2. Increase opportunities of complex designs
3. High Tensile Strength (up to 1500MPa)
4. Good repeatability without spring back
5. Good weldability - mild steel with low carbon
6. Well suited with crash requirements – good energy absorption with Ultra High Strength (UHS) mechanical properties

Figure 1 shows 12 BIW parts of P3-21A which adopts HPF process.

Legend:

NO.	PART NAME	THICKNESS (MM)
1	Reinforcement Front Pillar Upper LH/RH	1.75
2	Reinforcement Center Pillar Inner LH/RH	1.60
3	Reinforcement Center Pillar Outer LH/RH	1.75
4	Reinforcement Side Sill LH/RH	1.50
5	Reinforcement Front Pillar Inner Lower LH/RH	2.00
6	Panel Front Pillar Inner Upper LH/RH	1.75
7	Front Impact Beam	1.20
8	Reinforcement Cross-member Dash Lower RH	2.00
9	Cross-member Front Floor Rear LH/RH	1.20

BACKGROUND

a. HPF process

The process of HPF begins with heating the sheet metal (i.e. Usibor1500P; Tensile Strength 600 MPa) in the furnace at a temperature range of 9000C to 950 0C for 5 minutes. The heated sheet metal (Tensile Strength ≤100 MPa) is pressed (single stage) and quenched at the same time for at least 30 0C/s. Descaling is only needed for non-coated steel sheet, which is done right after the pressing and quenching process. There are two types of HPF process, which is the direct process and indirect process. The indirect process adds a pressing die before the heating process to form the complex profile of the part. The part is pressed again after the heating process to produce a perfect profile part. Figure 2(a) and 2(b) shows the direct and indirect HPF process layout.

The cold press forming produces large strain and rough shape to the part, whereas the hot press forming in the later stage of the process produces small strain part with accurate shape. The HPF product cools down quickly thus retain the shape accuracy of the part.

The formed product has an increased Tensile Strength of ±1500 MPa with Martensite structure. Figure 3 and Figure 4 shows the before and after quenching microstructure of the metal. Al-Si coated product can also be used as corrosion resistance to the sheet metal.(2)

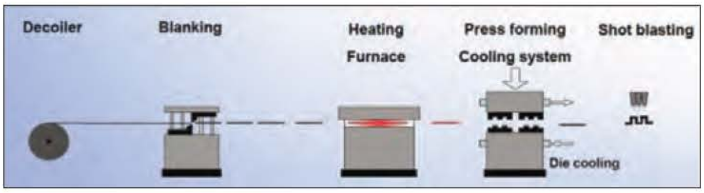

Figure 2(a): Direct HPF Process Layout[7]

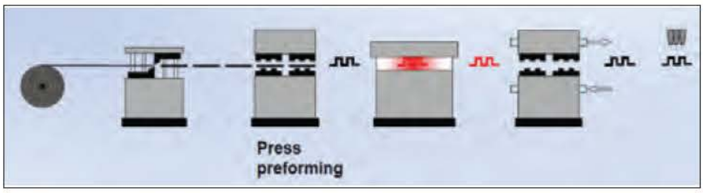

Figure 2(b): Indirect HPF Process Layout [7]

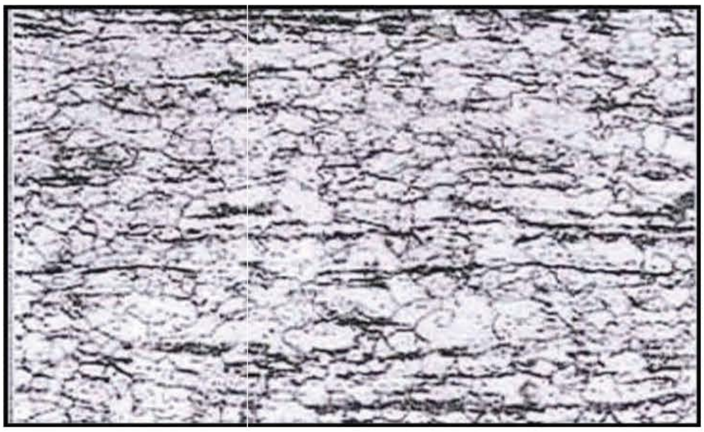

Figure 3: Metal microstructure before quenching ferrite-pearlite

Figure 4: Metal microstructure after quenching martensite

b. Sample test of HPF Steel (Boron Alloyed Steel)

A sample data was taken from Nippon Steel Corporation (NSC) showing the Tensile Strength of the sample material (NHPB-1500) after quenching. Two sample pieces were tested and the results are shown in Figure 5(a) and Figure 5(b).

Sample 1 gives a maximum Tensile Strength of 1590 MPa and Sample 2 gives a maximum Tensile Strength of 1651 MPa. The Chemical Composition and Mechanical Properties of the sample material (NHPB-1500) can be seen in Table 1 and Table 2.

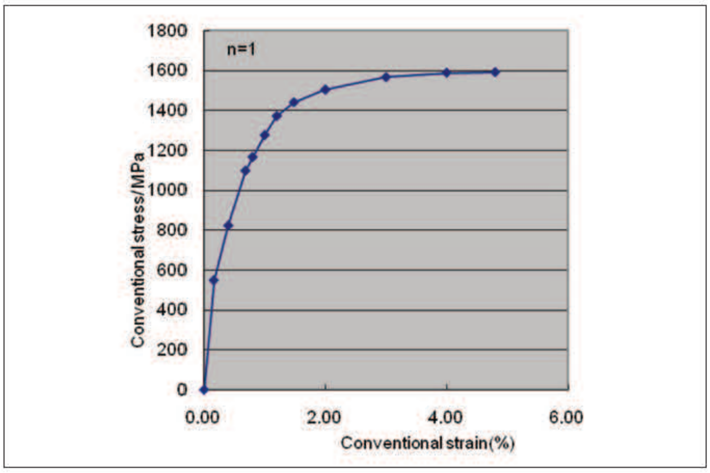

Figure 5(a): Strain curve data for sample 1 after quenching[3]

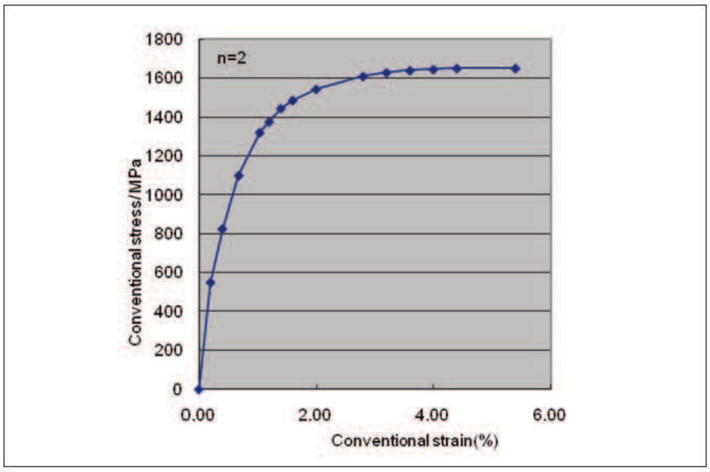

Figure 5(b): Strain curve data for sample 2 after quenching [3]

Table 1: Chemical Composition of NHPB-1500 [3]

	C	Si	Mn	P	S
min	0.20	0.20	1.10	-	-
Max	0.25	0.35	1.30	0.025	0.005

Table 2: Mechanical properties of NHPB-1500 [3]

1.6mm	Mechanical Properties		
	YP (M_{pa})	TS (M_{pa})	EL (%)
Before quenching	374	513	32
After quenching	1286	1609	8

(JIS No. 5 tensile test piece, 1.6mm thick)

C. HPF material properties

The change in the metal microstructure of the HPF steel (i.e. boron alloyed steel) is affected by the heat transformation throughout the HPF process. Refer to Figure 6 for the heat transformation chart.

The initial material structure of the HPF steel is Ferrite + Pearlite. The heating effect of the steel changes the material structure into Austenite which makes it easy to form in the pressing die. Then the quenching process cools the steel and hardens it. The hardening process changes the material structure to Martensite with maximum Tensile Strength of ≥ 1500 MPa.

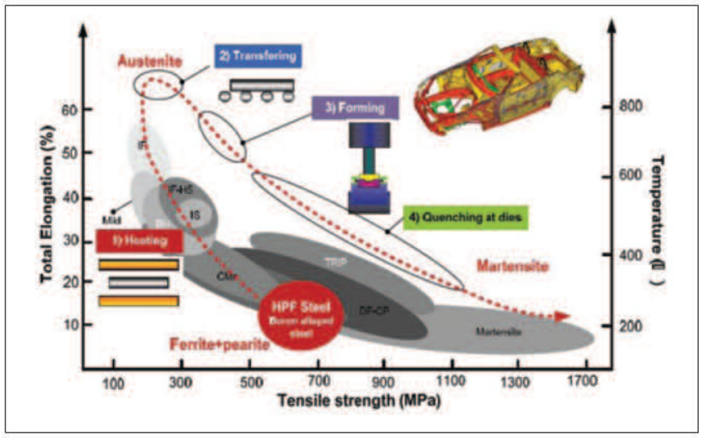

Figure 6: Changing in material property throughout the HPF process [2]

THEORY

There are three main factors taken into account and study before the HPF process is implemented and utilised in the P3-21A project. The HPF steel must meet the production workability (i.e. steel weldability), meet the crash effectiveness (in requirement of Euro-NCAP 5 stars) and, most importantly, maintain the BIW light weight target of < 300 kg.

a) Weldability

Weldibility is defined by the American Welding Society as "the capacity of a metal to be welded under the fabrication conditions imposed into a specific suitability designed structure and to perform satisfactorily in service". One of the factors affecting the quality of steel welding is the carbon content. Carbon is a strengthening element in iron, which increases the metal Tensile Strength but reduces the ductility. High carbon content promotes the formation of hard, brittle microstructures upon cooling. For HPF process, high carbon content is not necessary since the process itself is sufficient to increase the Tensile Strength of the steel. The chemical composition of the boron alloy steel used for HPF (refer Figure 6) shows low carbon content makes it favourable for welding.

b) Crashworthiness

Crashworthiness is defined as the ability of a structure to protect its occupants during an impact and this is rated through various vehicle assessments such as the Euro-NCAP. As the P3-21A project aims to achieve the Euro-NCAP 5 stars rating in terms of safety, vehicle crashworthiness status is a high priority. The implementation of HPF process is believed to be the ultimate option to pass the Euro-NCAP 5 stars rating requirement, considering the guarantee of high Tensile Strength of the product material. With the implementation of HPF process to the selected parts (refer Figure 1), the P3-21A model is believed to sustain high impact crash.

c) BIW Light Weight Target

The motoring industry has adopted Green Technology and is moving towards the mass reduction of CO2 gas emission. Therefore, the fuel consumption of a unit vehicle should be minimised by first eliminating unnecessary weight on the car body at the development stage. In previous projects, the stiffness of the frontal and side impact areas is increased by adding patches of steel metal or by increasing the thickness of the steel metal.

However such conventional methods add unnecessary weight to the car body. The metal patches and extra thickness are now replaced by adopting the HPF process, where similar stiffness of the frontal and side impact areas is achievable with a single piece metal.

METHODOLOGY

The main evaluations of HPF parts for P3-21A project are implemented through several in-house and outsourced testings as the following:

a) Weldability Test

The weldability test was conducted by the Proton Homologation and Testing Department to analyse spot welding condition of HPF parts combination. The facilities used for this activity are the Medium Frequency Direct Current (MFDC) with adaptive control welding gun and the Universal Instron Tensile Strength machine. Figure 7 shows the layout of the test specimen[4].

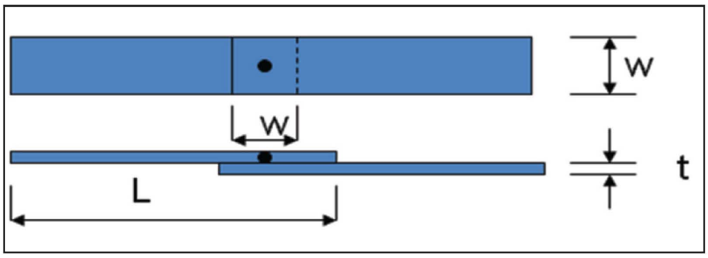

Figure 7: Weldability test layout [4]

The width and length of the test pieces vary with thickness. Table 3 shows the width and length of the test pieces according to the specified metal thickness to be tested.

Table 3: Test piece dimensions [4]

Nominal Thickness, t	Width, w	Length, L
< 0.8	20	75
0.8 - 1.3	30	100
1.3 - 2.5	40	125
2.5 - 3.5	50	150

There were 6 samples tested for weldability using the Tensile Strength Machine, with specified welding pressure variables (320 kgf, 400 kgf, 450 kgf, 500 kgf). The test was basically done for 2 and 3 metal pieces with different thicknesses. Refer Table 4 for the sample pieces combinations.

Table 4: Test Piece Dimensions [4]

Sample Piece	Welding Layers	Thickness Combination (mm)
A	2	1.5 x 1.75
B	2	1.75 x 1.75
C	2	1.5 x 2.0
D	3	1.6 x 2.0 x 1.5
E	3	0.7 x 1.75 x 1.75
F	2	1.6 x 1.6

The load application direction is indicated in Figure 8.

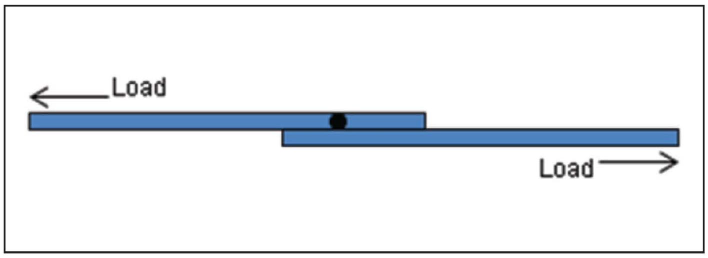

Figure 8: Weldability test load direction

Test speed: 200 mm/min.

b) Frontal crash & side impact test

The F-Proto Crash Program was conducted in Idiada, Spain on the 21 February to 9 March 2011. The main objective was to assess whether the body structure of P3-21A met the Euro-NCAP 5 stars requirements. The test set-ups are shown in Table 5.

Table 5: Frontal crash & side impact test set-ups

Sample Piece	Setups
Frontal Crash (64 kph)	
Side Impact Mobile Deformable Barrier , MDB (50 kph)	
Side Impact Pole (29 kph)	

The main parts measure for the Frontal Crash offset is shown in Figure 9.

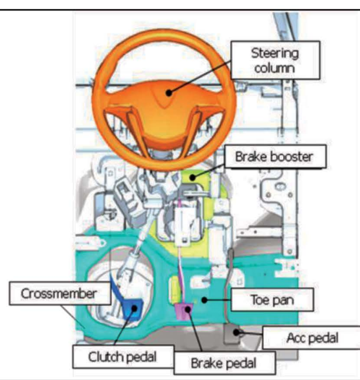

Figure 9: Main Parts measured for 64 km/h Euro-NCAP Frontal Offset [5]

c) BIW Light Weight Assessment

A study was conducted in the early stage where 4 types of materials were benchmarked for use to meet the requirements of Euro-NCAP 5 stars. The BIW weight and kerb weight were measured by conceptually designing the BIW with the selection of materials in requirements of the Euro-NCAP 5 stars requirement. The fixed BIW weight target for P3-21A is under 300 kg.

RESULTS & DISCUSSION

a) Weldability

The minimum target Tensile Shear Strength is 23 kN and the minimum target for the welding nugget diameter is 6.3 mm. Table 6 shows the test results based on the minimum targets of the TSS and Nugget Diameter respectively.

Table 6: Weldability test results [4]

Sample Piece	Test Item	Welding Pressure (kgf)			
		320	400	450	500
A	TSS (kN)	28.52	26.36	24.70	17.76
	Nugget dia. (mm)	6.05	6.06	6.00	4.20
B	TSS (kN)	29.84	29.24	26.62	26.27
	Nugget dia. (mm)	6.71	6.30	6.04	5.97
C	TSS (kN)	28.84	25.86	24.13	25.01
	Nugget dia. (mm)	6.60	6.30	6.14	5.84
D	TSS (kN)	30.83	25.17	28.72	26.24
	Nugget dia. (mm)	6.60	6.50	6.23	6.11
E	TSS (kN)	25.80	26.77	28.31	26.75
	Nugget dia. (mm)	6.20	5.35	6.10	6.43
F	TSS (kN)	28.43	27.92	26.54	29.18
	Nugget dia. (mm)	6.40	6.36	6.16	6.01

Legend: OK Acceptable NG

b) Frontal Crash & Side Impact Test

The intrusion results of the Frontal Crash Test is shown in Table 7.

Table 7: Result of 64 km/h Euro-NCAP frontal crash test [5]

Item	Intrusion Target (mm)	F-PROTO (mm)
Toe pan x-direction	<80	88.1
Steering column x-direction	<100	45.3
Brake booster x-direction	<120	152
Brake pedal x-direction	<100	15.6
Acc pedal x-direction	<100	71.1
A-B pillar shortening	<15	11.1
Cross-member (HPF)	<80	95.4
Acceleration (Peak) {B-Pillar upper RH}	< 50g	32.4g

From the frontal impact test, the passenger cabin structure shows good integrity. The dummy injuries status is 11.5 (severity rating scale), less than the targeted value (13). The displacement in the cross-member (HPF part) is caused mainly by the assembly connection.

The results of the side impact tests (MDB and Pole) are shown in Table 8(a) and Table 8(a) respectively.

Table 8(a): Result of 50 km/h Euro-NCAP side impact mobile deformable barrier (MDB) [5]

Item	Intrusion Target (mm)	Test (B Pillar - HPF)
Door Lower	< 145	22
R Point	< 145	33.2
Door Medium	< 145	39.3
Beltline	< 145	42

Table 8(b): Result of 29 km/h side impact pole [5]

Item	Intrusion Target (mm)	Test (B Pillar - HPF)
Door Lower	< 350	152.2
R Point	< 350	155.6
Door Medium	<350	154.4
Beltline	< 350	145.5

The results of the side impact tests show that the passenger cabin structure is in very good condition. The B-pillar (HPF part) shows minimal displacement during the crash test, compared to previous model test. Figure 10 shows the difference of side impact results between P3-21A (HPF B-pillar) and Exora (without HPF B-pillar).

P3-21A: Maximum B-pillar intrusion 42mm

P6-20A: Maximum B-pillar intrusion 168mm

Figure 10: Maximum B-pillar intrusion comparison between HPF and Non-HPF Part [5]

c) BIW Light Weight Target Assessment

The result of the BIW weight assessment based on selected materials is shown in Table 9.

Table 9: Results of BIW material benchmarking[6]

Variant	1	2	3	4
Steel UTS (MPa)	590	780	980	1450
Material	TRIP60, DP60	TRIP780, DP80	TRIP980, DP980	(HPF Part)
BIW Weight (kg)	352 (+53)	323 (+24)	319 (+20)	309 (+10)
Kerb Weight (kg)	1369	1340	1335	1326

The results clearly show the HPF is the best process to be implemented in the P3-21A project to meet the Euro-NCAP 5 stars requirements. This is because the HPF material gives the highest possible Tensile Strength, with maximum of 10kg additional weight (for optimum BIW stiffness case) and the minimum kerb weight of 1326kg.

CONCLUSION & RECOMMENDATIONS

The implementation of HPF technology in P3-21A model has been proven to improve the body structure stiffness towards meeting the requirements of Euro-NCAP 5 stars. This is shown by various test results conducted on the P3-21A CBU throughout the project development phase. The BIW weight target is also met with the actual figure of 298.8kg (BIW & sealant) for P0-1 phase.

a) Weldability

The weldability test results show that it is possible to weld HPF parts in the normal production conditions, with up to 3 layers of welding. Table 10 shows the recommended welding pressure for the HPF parts at the assembly line.

Table 10: Recommended welding pressure

Combination	Thickness Combination (mm)	Recommended Welding Pressure (kgf)
A	1.5 x 1.75	320, 400
B	1.75 x 1.75	320, 400
C	1.5 x 2.0	320, 400
D	1.6 x 2.0 x 1.5	320, 400
E	0.7 x 1.75 x 1.75	500
F	1.6 x 1.6	320, 400

b) Crashworthiness

The stiffness of the HPF part is proven by the retained shape of the cross-member after the crash. This is clearly shown in Figure 11.

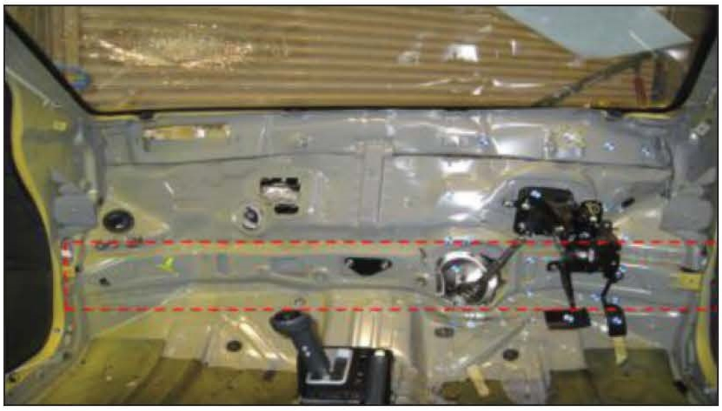

Figure 11: Main Parts measured for 64 km/h Euro-NCAP Frontal Offset [5]

The results of the side impact tests highly recommend the optimisation of the B-pillar as a major part of the restrain system. Hence, the adoption of high-end restrain system such as side air-bag can be minimised.

c) BIW Light Weight Target

During the P0-1 phase, the BIW weight is measured in different finish conditions (additional weight variables) and the results (refer Table 11) prove that the light weight target is achievable.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contribution and assistance from the following persons:

1. QETS Coordinator – En. Meor Mohd. Rizal bin Ismail
2. Internal Panels – Dr Mohd. Azman bin Zainal Abidin, En. Fauzy bin Ahmad and En. Fuad bin Alias
3. External Panels – Dr Hairi (UTM), Dr Mohd. Fadlee (NEST), Dr Rahizar (UM), Dr Shuhaimi (UTM), and Dr Salmiah (UTM)

Table 11: BIW weight during the P0-1 phase

BIW Condition	Weight (kg)
BIW with melting sheet, sealant, hinges	313.92
BIW with melting sheet, sealant	307.0
BIW with sealant only	298.8

4. Head of Dept, Body Design - En. Azrifin Bin Amin, Head of Dept, Body Design. ■

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Editor's Note: *The P3-21 A was launched in 2012 with model name as Preve and the same architecture is also used for Suprima model. Both models receive the 5 star ANCAP and ASEAN NCAP safety ratings.*