A-Pillar and Roof Crush Resistance Development of a Convertible Vehicle

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AbstractCHERY has adopted the test standard stated in FMVSS 216a as their 'in-house' requirement for the convertible vehicle platform (codename the M14) and taking on as an engineering challenge.

Referring to the FMVSS 216a, the standard itself is to establish the strength requirements for the passenger compartment roof. The pass criterion for this standard is that the roof must withstand at least 3 times of the vehicle weight.

For any convertible vehicle, the worst scenario during a rollover accident is when the roof is in folded or lowered position for a Retractable Hard Top (RHT). Hence, the design of the A-Pillar structure becomes critical, as it must be able to bear at least 3 times the weight of the vehicle.

This paper contains information in relation to the FEA work carried out from the initial design and development to optimization for the roof crush resistance development of the M14 BIW. It was also unfortunate that at the time of this paper was being written, the roof crush resistance test was yet to be performed. As a result, it is still unknown how the M14 BIW would perform at the actual test.

1 Introduction

Figure 1 shows the first convertible vehicle platform currently being developed at CHERY Automobile. As stated in the technical paper [1] for SAE Wuhan Automotive Safety Conference 2009, the design concept of this vehicle has considered the roof crush resistance performance in the even of a roll over. For this particular vehicle platform, CHERY has adopted the FMVSS 216a as the 'in-house' target for developing the BIW, in particularly at the A-Pillar Assembly.

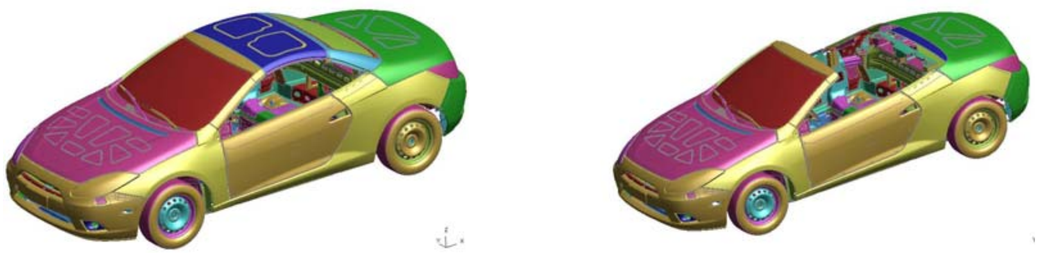


Figure 1: CHERY M14 RHT 2+2 Sport Car

2 Objectives

Design and Development of the A-Pillar Assembly and Tubular Reinforcement in order to meet the Roof Crush Resistance Requirement as stated in the FMVSS 216a for a convertible vehicle.

3 Methods

In order to ensure that the M14 Vehicle Platform will meet the FMVSS 216a[2] requirement, the Project Team has adopted the use of Finite Element Analysis Technique to design, development and optimisation of the A-Pillar Assembly structures.

3.1 Design Concept

Since the M14 was a convertible vehicle, the load path for the Roof Crush Resistance will be solely relying on the strength of the Wind Screen Surround and the A-Pillar Assembly. In order to meet the target, a high strength steel pipe was used and embedded into the A-Pillar Assembly (see Figure 2). One must also note that the fixtures of the pipe within the A-Pillar Assembly and the complete A-Pillar System are also critical for the strength performance of the Roof Crush Resistance.

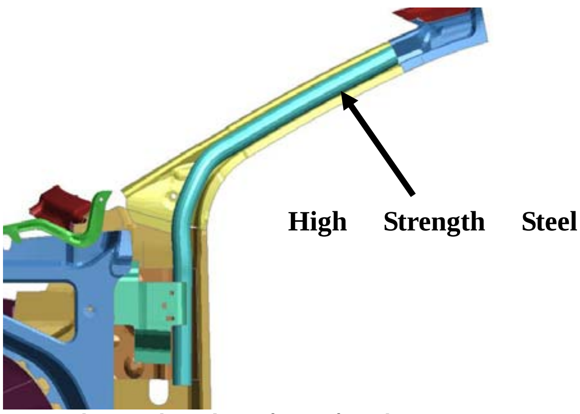


Figure 2: High Strength Steel Pipe for Roof Crush Resistance

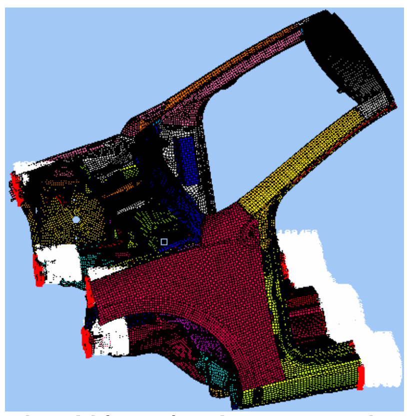


Figure 3: M14 Sub-model for Roof Crush Resistance Analysis

3.2 FE Model

In order to reduce the computational time, it was decided sub-modelling technique was applied at the initial stage of the development for the FMVSS 216a FE analyses on the M14 BIW. This is because by using sub-modelling technique, it enables the Project Team to carry out many design iterations for improvement in a short period of time. When the design was finalized, complete BIW FE model will be used for validating the result obtaining from the sub-model (see Figure 3). Altair Hypermesh© version 8.0 was used for constructing the FE model and LS-DYNA 970 (double precision) explicit solver was used for the calculations.

3.3 FE model Boundary Conditions

The boundary conditions of the sub-model was set up in accordance with the FMVSS 216a[2], and the extracts from the standard are as follow:

a) A test device placed on the vehicle as described in the standard is used to apply a force in Newton equal to 3.0 times of the unloaded vehicle weight measured in kilograms and multiplies by 9.81 (g).
b) The performance requirement: for test device shall not travel more than 127mm before achieving the load specified in the standard.
c) Apply force in a downward direction perpendicular to the lower surface of the test device at a rate of not more than 13 mm/s. Complete the test within 120s.

The curb vehicle weight of M14 is 1250Kg, so the target force for which the M14 BIW must be able to withstand was calculated as follow:

$$F=1250kg\times3.0\times9.81=35561N=36.78kN$$

4 Results

4.1 Baseline Analysis

When the CAD geometry was available, baseline analysis was performed for the initial design of the A-Pillar Assembly. The baseline analysis result (see

Figure 4 to Figure 6) indicated that the calculated loading force of the moving ram was found to be 27.88kN, which was 8.9kN less than the target value of 36.78kN. One must also note that, the dimensions and the material used for the High Strength Steel Tube for the A-Pillar Reinforcement was initially calculated and was about to withstand at least 80% of the loading. One must also note that in order to meet the requirement, the A-Pillar Assembly and the adjacent structures must work as a system. Consequently, during the development the project team was concentrating on the design of the fixtures for the tubular reinforcement, adjacent and supporting structures of the BIW.

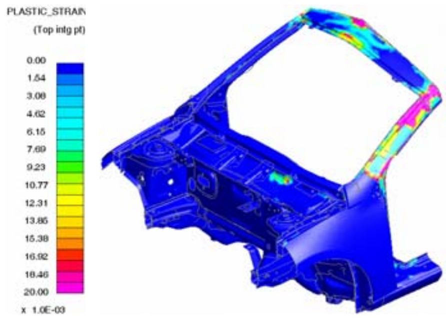


Figure 4: Strain Plot on the Sub-Model (Baseline)

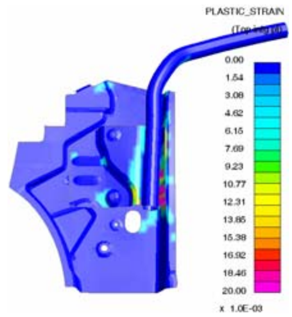


Figure 5: Strain Plot on the Tubular Reinforcement (Baseline)

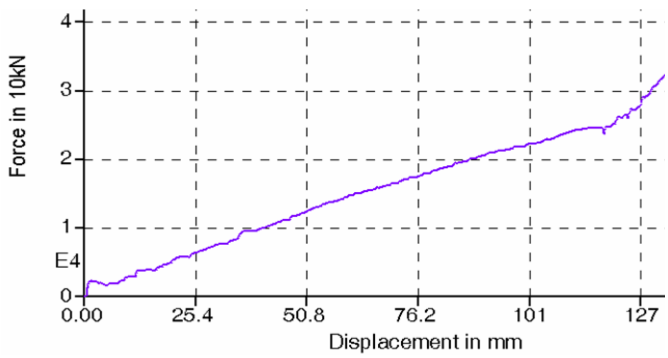
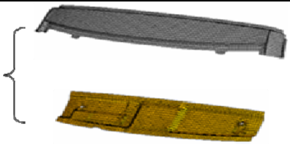
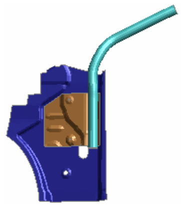
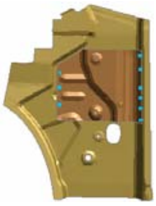


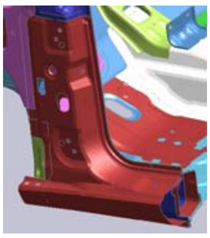
Figure 6: Force vs. Displacement Plot (Baseline)

4.2 Design Iterations

During the development phase of the project, majority of the work conducted was to eliminate the 'hot-spots' which caused the BIW unable to meet the target requirement. The baseline analysis result and sensitivity studies of the vehicle structures were carried out. The aim was to identify the weakest link in the system for roof crush resistance, hence an efficient design for the system can be developed and achieving the target. Based on the design iterations conducted, from thickness and material changes to section sizes changes. Table 1 shows the design changes implemented the vehicle structure during the design and development phase of the project.

Table 1: Baseline and Design Iterations Break Down of the Parts to achieve the Target

Design Iterations	Part Assembly/Part Details	Parts/Part's Detail/Changes Applied	Part Name, Material and Thickness
Baseline			Windshield Cross Member Outer Panel (Material = Normal, t = 0.8) Windshield Cross Member Inner Panel (Material = B340/590DP, t = 1.5)
1			Lower A-Pillar Inner Panel/Dash Panel Side Panel (Material = Intermediate, t = 2.1) Tubular Reinforcement Fixing Plate (Mat = Intermediate, t = 1.50) and Spot Weld Pattern
2			All parts are the same as Baseline Design, only height reduction of the Interior Lamp Fitting and including detailed features. Material and
3			Thickness remain unchanged. The FE model was more or less the same as in Design Iteration 1, only the amount of spot welds at the Tubular Reinforcement Fixing Plate to the Dash Panel Side Panel were increased significantly. All spot welds shown has a pitch of 30mm (approx.).

7			The FE Model was approximately the same as Design Iteration 3, but Material Changes to intermediate strength Panel and thickness increased from 0.8mm to 1.20mm were applied.
8			Same model as Design Iteration 7, but Material Changes to high grading of normal mild steel.
12			Material and thickness of all parts remains the same as in design iteration 8, but cross sectional area of the A-Pillar Lower changed.
15			Same Design Concept as Design Iteration 12, but Sill Side Reinforcement removed.
18			Same Design Concept as Design Iteration12, but changes to one grade lower material of the Header Rail Outer Panel.

*Material Definition
Normal = Normal Mild Steel with a yield stress of 120MPa to 220MPa
Intermediate = Intermediate Strength Steel Panel with a yield stress of 250MPa to 480MPa
HS = High Strength Steel with a yield stress of 500MPa and Above

Table 1 only shows the most significant design iterations of parts which have the highest contributions to the performance of the structure. In reality, a total of 20 FEA design concept loops, including optimization studies were performed, from thickness and material changes to actual A-Pillar Lower section size changes.

Table 2 shows the maximum loading value achieved by the FE Moving Ram and Figure 7 to Figure 14 shows the plastic strain distributions over the BIW.

Table 2: Results Summary from the Most Significant Design Iterations

Design Iterations	Max. Loading Achieved at Moving Ram (z = -127mm)	Remarks
Baseline	27.88kN	Unable to meet the target (refer to Figure 5 and Figure 6)
1	28.10kN	Unable to meet the target with only very little improvement (see Figure 7 and Figure 8)
3	34.42kN	Significant Improvement, but still below the target (see Figure 9 and Figure 10)
7	37.36kN	Able to Meet the requirement (see Figure 11 and Figure 12)
8	37.02kN	Able to Meet the requirement, but a fraction lower than Design Iteration (see Figure 13 and Figure 14)
12	38.36kN	Able to meet the requirement, improved and the highest performance based on the existing vehicle architecture (see Figure 15 and Figure 16
15	37.98kN	Able to meet requirement (see Figure 17 and Figure 18)
18	37.72kN	Able to meet requirement (Figure 19 and Figure 20)

4.3 Strains Plots and Force vs. Displacement/Time Curves

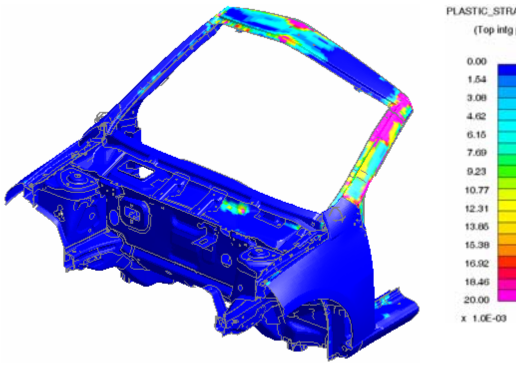


Figure 7: Strain Plots for Design Iteration 1

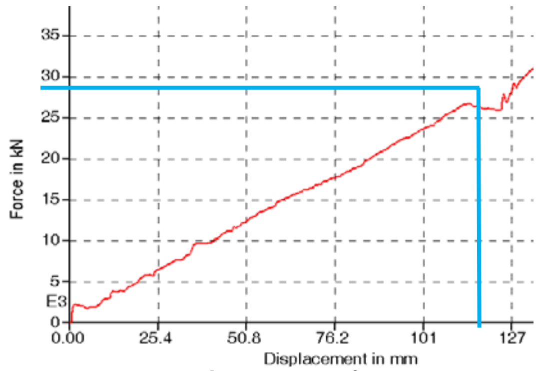


Figure 8: Force vs. Displacement Curve for Design Iteration 1

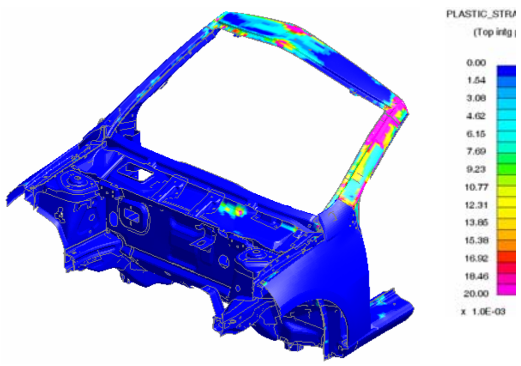


Figure 9: Strain Plots for Design Iteration 3

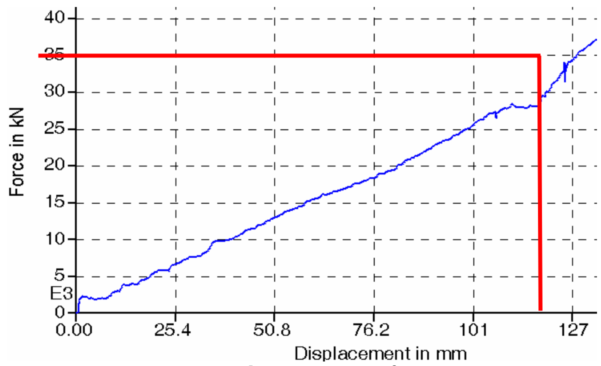


Figure 10: Force vs. Displacement Curve for Design Iteration 5

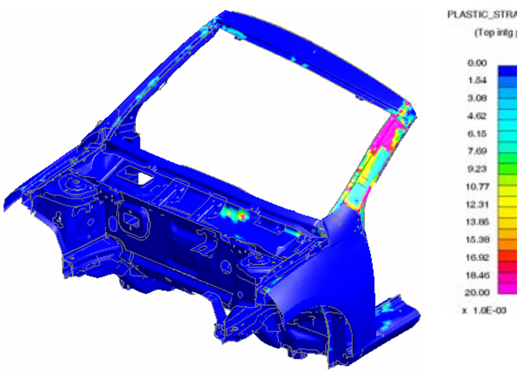


Figure 11: Strain Plots for Design Iteration 7

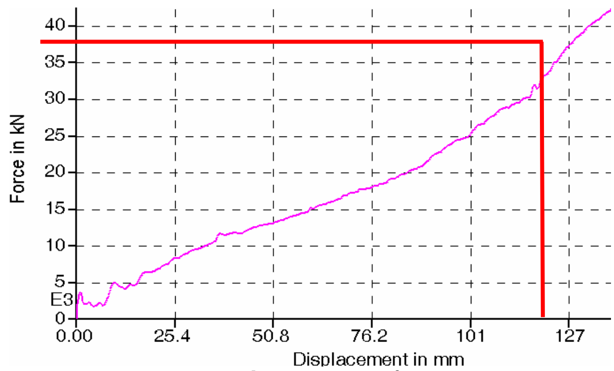


Figure 12: Force vs. Displacement Curve for Design Iteration 10

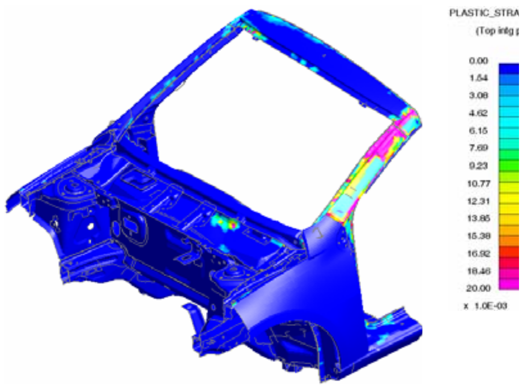


Figure 13: Strain Plots for Design Iteration 8

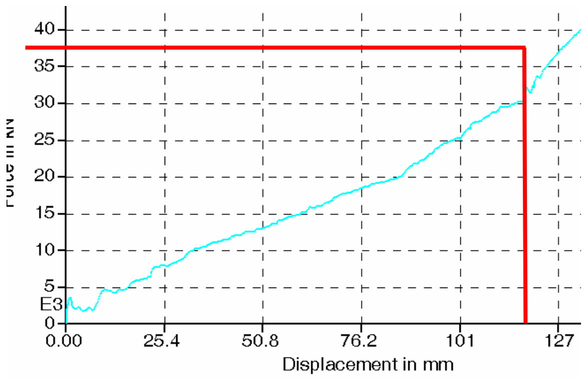


Figure 14: Force vs. Displacement Curve for Design Iteration 8

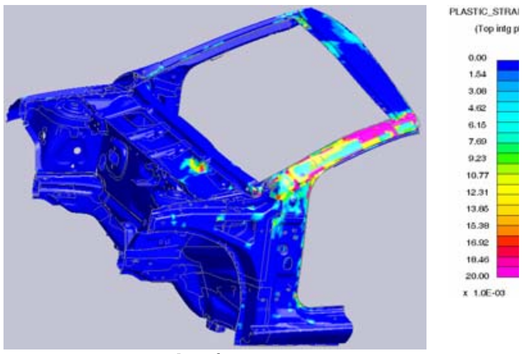


Figure 15: Strain Plots for Design Iteration 12 (Optimisation Phase)

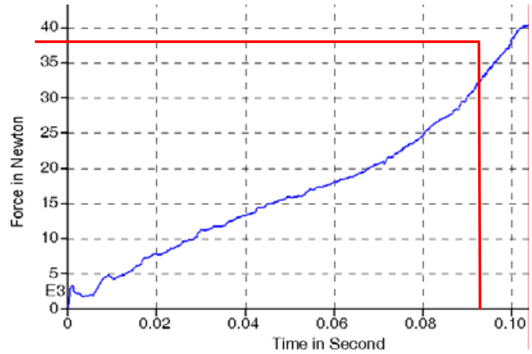


Figure 16: Force vs. Time Plot for Design Iteration 12 (Optimisation Phase)

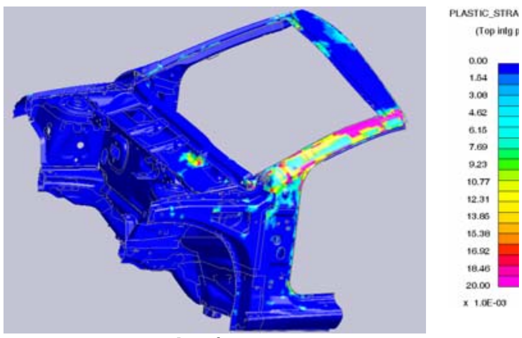


Figure 17: Strain Plots for Design Iteration 15 (Optimisation Phase)

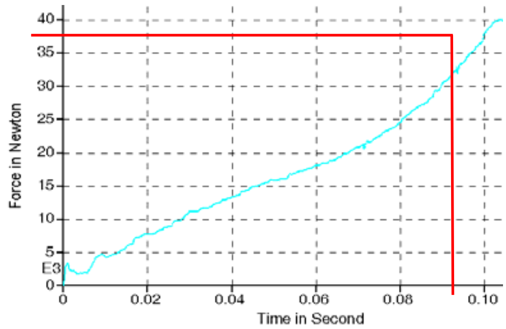


Figure 18: Force vs. Time Plot for Design Iteration 15 (Optimisation Phase)

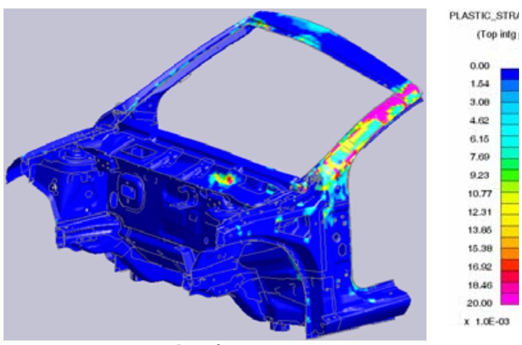


Figure 19: Strain Plots for Design Iteration 18 (Optimisation Phase)

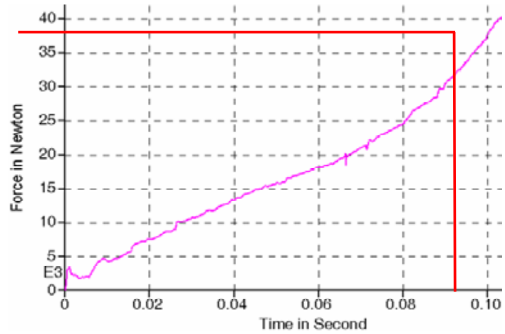


Figure 20: Force vs. Time Plot for Design Iteration 18 (Optimisation Phase)

5 Discussions

At the start of the engineering activities, one would argue whether or not the use of LS-DYNA explicit solver was the correct solver to be used for tackling a quasi-static problem. The project team had investigated this matter, by comparing the results of the same model using another solver, ABAQUS. The project had found that by controlling the moving ram speed in LS-DYNA model, the Force, Stress and Strain outputs were similar to the ABAQUS model. Moreover, the computational time for the model using LS-DYNA solver to calculate was much quicker than the ABAQUS solver. The project also conducted 'back to back' comparisons during the design and development phase. Therefore graphs presented in this paper for the development models, the results were using Force vs. Displacement Curves (refer to Figure 5 to Figure 14).

In the optimization phase, the project team was confident with the use of LS-DYNA solver. In order to have a quick turn around time with the results, Force vs. Time graphs were used for comparing the performance of the structures instead (see Figure 15 to Figure 20).

In terms of the FE sub-modeling technique applied to this project, the constraints of the sub-model was actually developed from the original Full BIW model. The condition of the baseline FE sub-model had the same stress and strain distributions when it was compared with the full FE BIW model.

The results of the analyses enabled the project team to identify two main areas which had the most significant contribution to the M14 BIW Roof Crush Resistance Performance. They were as follows;

a) Header Rail Assembly and its Joint Condition to A-Pillar Upper,
b) High Strength Steel Tubular Reinforcement Attachment, and
c) A-Pillar Lower Assembly.

One must also note that, all the design iterations performed were drawn and provided by the M14 design team using CAD software. Each design loop had also considered both manufacturing and assembling sequences. Therefore, all design iterations performed were possibly ready for manufacturing.

Despite the result from Design Iteration 7 had got the highest performance during the initial design and development phase of the project, the M14 Project Team had chosen design iteration 8 as the final design for the kick-off of the M14 BIW initial soft tooling (see also Table 2, Figure 11 and Figure 12). This was mainly due to the Header Rail Outer Panel, which was considered as the A-Class Surface of the vehicle. Hence, surface quality, such as the finishes, is very important. With the use of intermediate strength steel, there would be an element of risk which blemishes could be incurred on the texture and finishing surface.

Although the final design was frozen after Design Iteration 10 was completed, further optimisation studies to the vehicle structure had performed in case a much improved structure is needed and can be developed from the existing architecture. Moreover, at the time of this paper was being written, the physical testing activities of the BIW was yet to be performed. Hence the further engineering design and development activities of the structure could not have been conducted until there is a test validation.

The work conducted at the optimisation phase of the vehicle structure was based on further studies to the material, thicknesses and cross section area within the design constraints at the load bearing structures such as the A-Pillar Assembly. Despite Design Iteration 12 was found to have a significant improvement (refer to Table 2) with the current vehicle architecture, the design changes applied to the A-Pillar Assembly were immense. This was because not only design changes applied to the Body Outer Panel in order to accommodate another type door hinges, design work would have to be performed for the inside structures such as A-Pillar Inner Reinforcement, Door Hinge Plates, and etc. Moreover, by changing the door hinges, all the FE Analyses for door strength and stiffness would have to be re-performed. As a result, it was considered to be unviable however, the project team had made reservations for the changes in case there are some other unknown factors which may cause the M14 unable to meet the in-house requirement for the Roof Crush Resistance Test.

6 Conclusions

It can be concluded that the work conducted on the M14 Roof Crush Resistance development was a success. In particularly, after three attempts in design iterations, the project was able to achieve almost 20% increase in performance from the baseline design. For the rest of the work conducted, they were trying to fine turn the structure to meet the in-house requirement. At the optimization phase, it was an attempt to determine the designs envelop and the maximum limit of the M14 BIW could possibly achieve. If the FEA technique was not applied in this phase of development cycle, the project team would not be able determine some of the most sensitive and/or influential panels of this BIW. For example, the cross sectional area at the A-Pillar Lower Assembly, the material type to be used for the Header Rail Outer, and etc.

As mentioned in previous section (refer to Section 0), it was unfortunate that the M14 Prototype Roof Crush Resistance was yet to be performed at the time when this paper is being written. Hence comparison between FEA model and Test Results were not able to be presented in this paper.

Finally, it was a valuable lesson for the engineers, from which they are now becoming more aware in term or design and development for the vehicle’s roof crush resistance requirement.

Acknowledgement

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References

[1] Rahman K, Shen HJ, Chen CZ, Zhu ZJ. “Passive Safety Design Awareness for a 2+2 Retractable Hard Top (RHT) Sport Vehicle’. Conference Paper for 2009 China International Conference of Automotive Safety Technology and The 12th Automotive Safety Technology Annual Conference of SAE – China.
[2] Federal Motor Vehicle Safety Standard, Part 571.216a/ Standard No. 216a, US Department of Transport.