VIRTUAL SIMULATION TO EVALUATE THE BENEFITS OF USING ADVANCED HIGH STRENGTH STEELS (AHSS) IN THE VEHICLE BODY-IN-WHITE

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ABSTRACT

In recent years, vehicle manufacturers are looking for steels that promote weight reduction and improve safety performance during crash tests. A lighter vehicle needs less fuel. If the structure promotes greater energy-absorbing capacity during impact, the vehicle will be safer. All those factors are incentives for automakers to use **A**dvanced **H**igh **S**trength **S**teels (AHSS) instead of standard steels. AHSS are characterized by having high tensile strength and good energy-absorbing capacity. In this work some AHSS were used such as CP800, DP600, DP800, DP1000, DP1200, PHS. The objective was to verify a possibility of having weight reduction and better safety during crash, using AHSS in some vehicle assemblies. Three virtual tests were performed comparing the baseline with a proposal model of a generic sedan vehicle: low speed crash (Allianz test); deformation of rear side impact beam (FMVSS214 standard); frontal impact (64 hm/h, 10°, offset 40%). There were improvements in safety performance, mainly during frontal impact: 67% reduction in foot rest intrusion; 26% increase in absorbed energy of both front rail and crash box; 36% reduction in acceleration at a point below the driver seat. There was a weight reduction of 11 kg in the BIW (Body-In-White) after changing the material to AHSS.

INTRODUCTION

Two major drivers for the use of newer steels in the automotive industry are fuel efficiency and increased safety performance. Fuel efficiency is mainly a function of weight of steel parts. Safety is determined by the energy absorbing capacity of the steel used to make the part. All of these factors are incentives for the automakers to use Advanced High Strength Steels (AHSS) to replace the conventional steels. AHSS are characterized by high strength and good ductility.

In this work, it is demonstrated the benefits of using AHSS in the vehicle BIW for some vehicle assemblies, such as front bumper, side impact beam, b-pillar, front and rear floor, cross member, rocker panel, front rail, front wheel house. Three virtual tests were developed: Allianz test for the front bumper test, FMVSS214 12" impactor for the side impact beam, full vehicle frontal crash test for the entire structure. The evaluation of the benefits regarding material change was made by virtual simulations, using LS-DYNA software. The generic vehicle model was download from website https://www.dynaexamples.com.

The model called **baseline** was prepared with material setup of a standard Brazilian sedan car. The model **proposal** was prepared with more advanced material setup, enforcing the use of AHSS. For the **proposal** model, there was also some geometry change to fulfill some manufacturing process requirements.

AHSS are complex, sophisticated materials, with carefully selected chemical compositions and multiphase microstructures resulting from precisely controlled heating and cooling processes. Various strengthening mechanisms are employed to achieve a range of strength, ductility, toughness, and fatigue properties [1].

The AHSS family includes Dual Phase (DP), Complex Phase (CP), Martensitic (MS), Transformation-Induced Plasticity (TRIP), Hot-Formed (HF), and Twinning-Induced Plasticity (TWIP). These 1st and 2nd Generation AHSS grades are uniquely qualified to meet the functional performance demands of certain parts. For example, DP and TRIP steels are excellent in the crash zones of the car for their high energy absorption. For structural elements of the passenger compartment, extremely high-strength steels, such as Martensitic and boron-based Press Hardened Steels (PHS) result in improved safety performance [1].

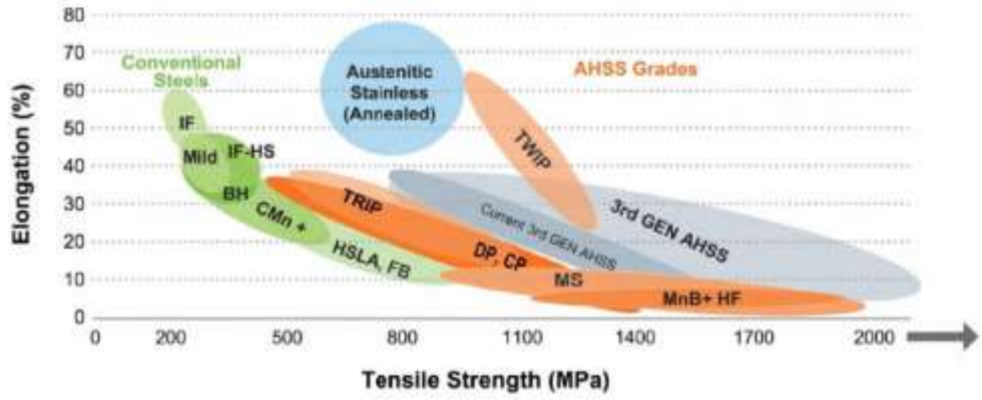


Figure 1: Steel Strength Ductility Diagram, illustrating the range of properties available from today's AHSS grades [1]

AHSS grades contain significant alloying and two or more phases. The multiple phases provide increased strength and ductility not attainable with single phase steels, such as high strength, low alloy (HSLA) grades [1].

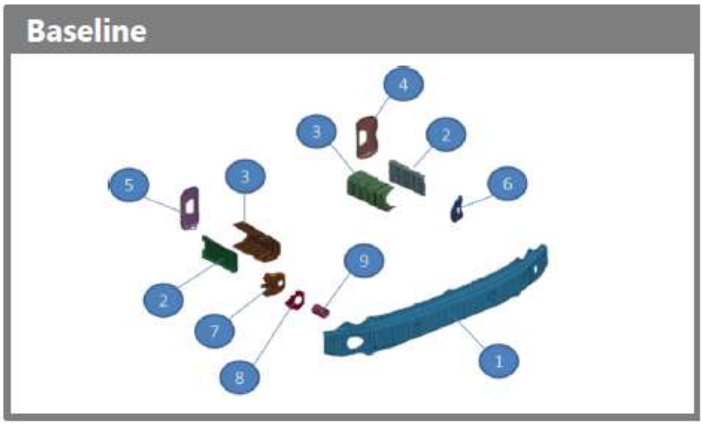
1. BILL OF MATERIALS

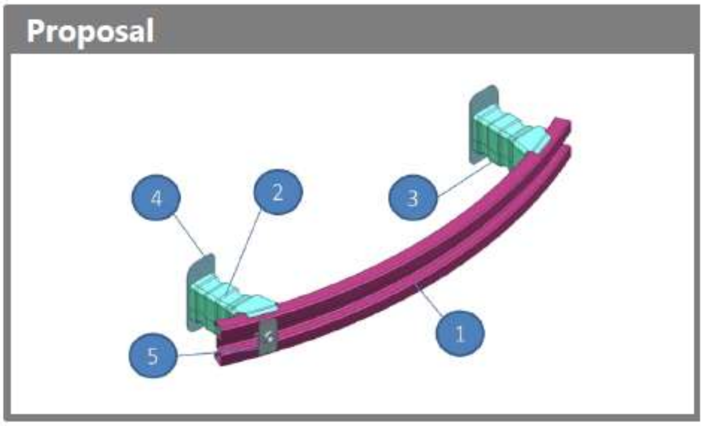
In this work, the following materials have been referenced, the number describe the tensile strength of the material [1]:

- Conventional Steel, **H**igh **S**trength, **L**ow **A**lloy: HSLA280, HSLA320, HSLA440
- AHSS Grade, **D**ual **P**hase: DP600, DP800, DP1000, DP1200
- AHSS Grade**, C**omplex **P**hase: CP800
- AHSS Grade**, P**ress **H**ardened **S**teel: PHS (tensile strength = 1500 MPa)

The bill of materials is presented in the following pages. Lines written in red means there was a change in at least one of the following items: material, geometry or thickness.

Front Bumper Assembly

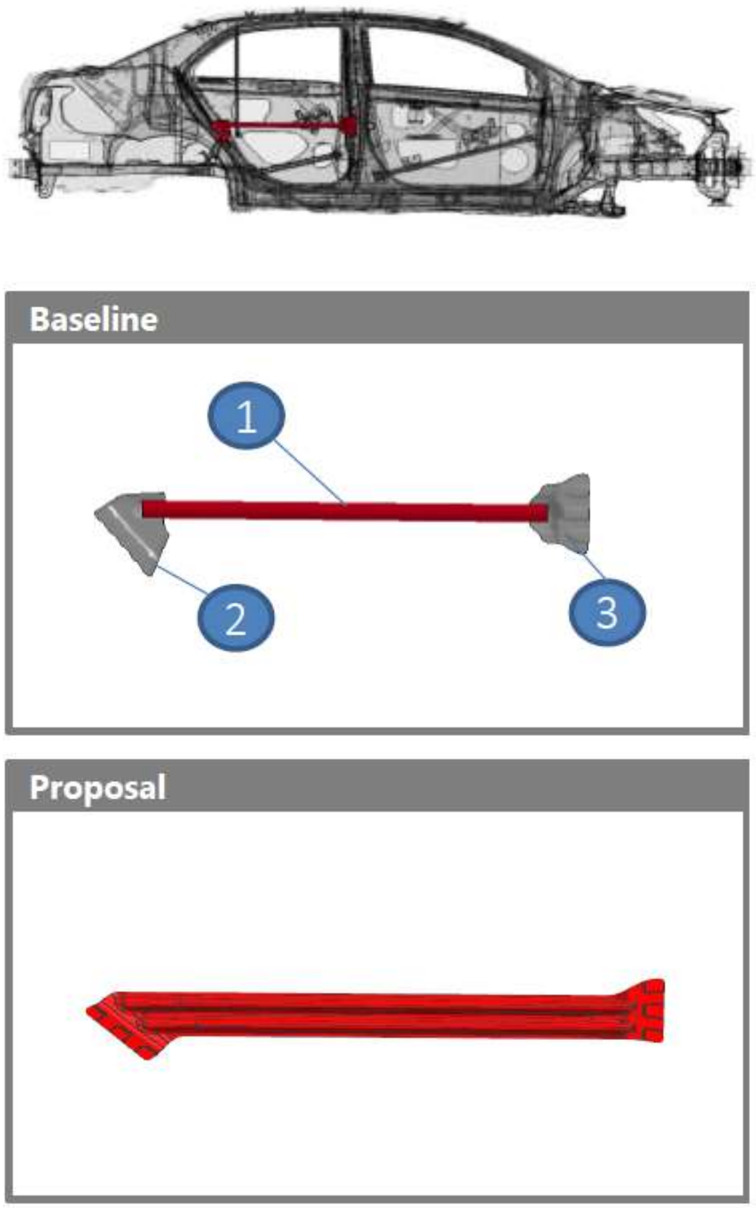




	BASELINE			PROPOSAL		
ITEM	MATERIAL	THICK (mm)	WEIGHT (Kg)	MATERIAL	THICK (mm)	WEIGHT (Kg)
1	DP1000	2.3	4.77	DP1200	1.8	4.33
2	DP600	1.3	0.280 2x	DP600	1.7	0.54 2x
3	DP600	1.9	0.764 2x	DP600	1.7	0.51 2x
4	HSLA280	3.8	0.618	CP800	3.0	0.41 2x
5	HSLA280	4.2	0.684	CP800	3.0	0.20
6	HSLA280	1.4	0.106	-	-	-
7	HSLA280	2.4	0.218	-	-	-
8	HSLA280	3.0	-	CP800	3.0	0.08 2x
9	HSLA280	3.0	-		-	
∑/Car			**8.48**			**7.61 (-10 %)**

Figure 2: Geometry and material of front bumper assembly

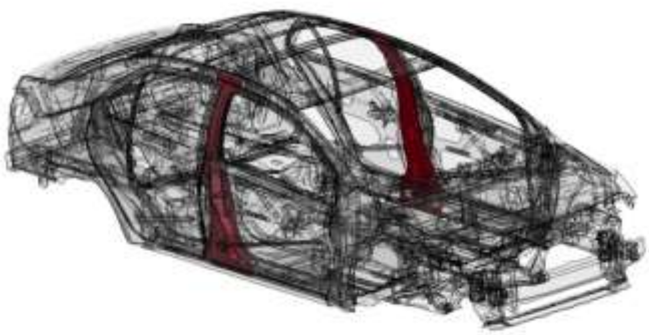
Ride Side Impact Beam

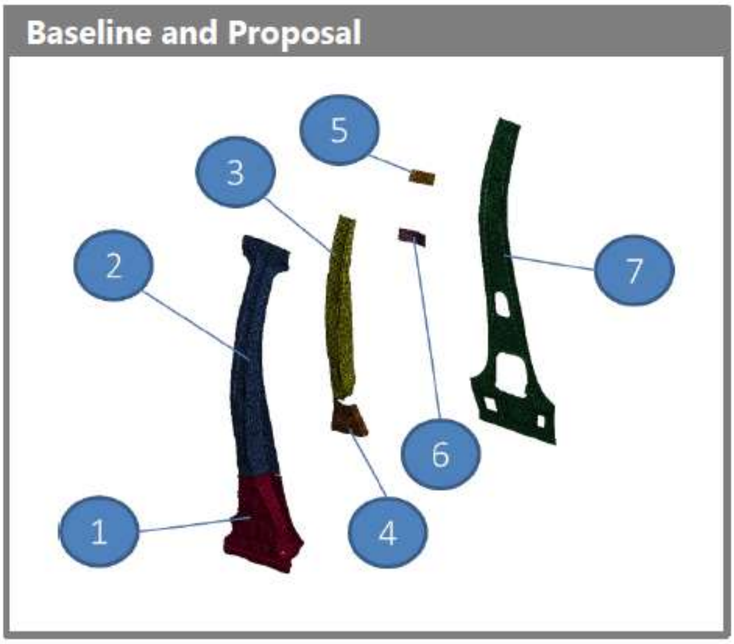


	BASELINE			PROPOSAL		
ITEM	MATERIAL	THICK (mm)	WEIGHT (Kg)	MATERIAL	THICK (mm)	WEIGHT (Kg)
1	DP1000*	1.9	0.99	PHS	1.0	1.13
2	HSLA280	1.3	0.12	-	-	
3	HSLA280	1.3	0.12	-	-	
∑/Car			**1.23**			**1.13 (-11 %)**

Figure 3: Geometry and material of ride side impact beam

B-Pillar Assembly

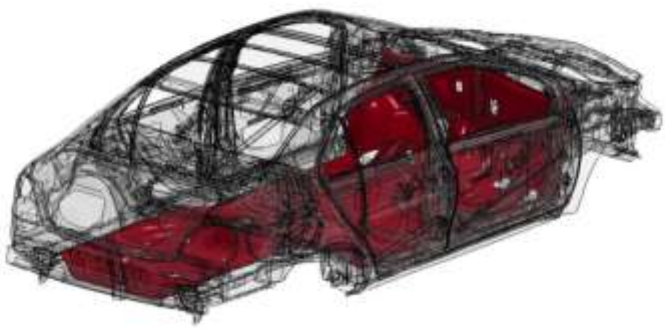


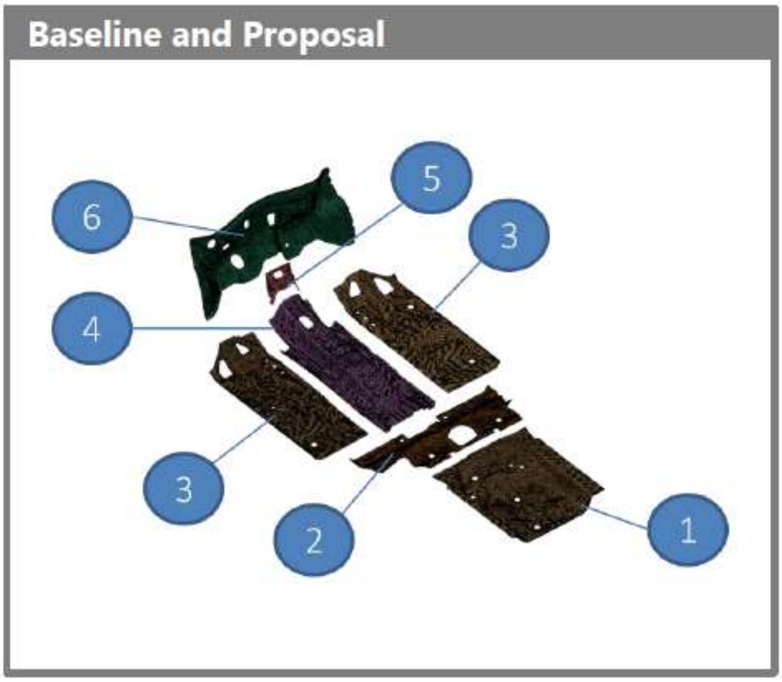


	BASELINE			PROPOSAL		
ITEM	MATERIAL	THICK (mm)	WEIGHT (Kg)	MATERIAL	THICK (mm)	WEIGHT (Kg)
1	DP600	1.2	1.03	PHS	1.2	2.85
2	DP600	2.1	3.19			
3	DP600	2.5	1.87	PHS	1.8	1.34
4	DP600	2.1	0.28	-	-	-
5	HSLA280	1.9	0.06	HSLA280	1.9	0.06
6	HSLA280	1.9	0.06	HSLA280	1.9	0.06
7	DP600	1.0	1.28	PHS	0.8	1.02
∑/Car			**7.77**			**5.33 (-31 %)**

Figure 4: Geometry and material of b-pillar assembly

Front/Rear Floor Assembly

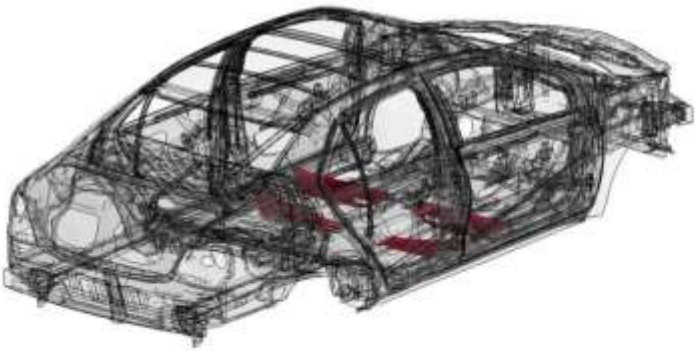


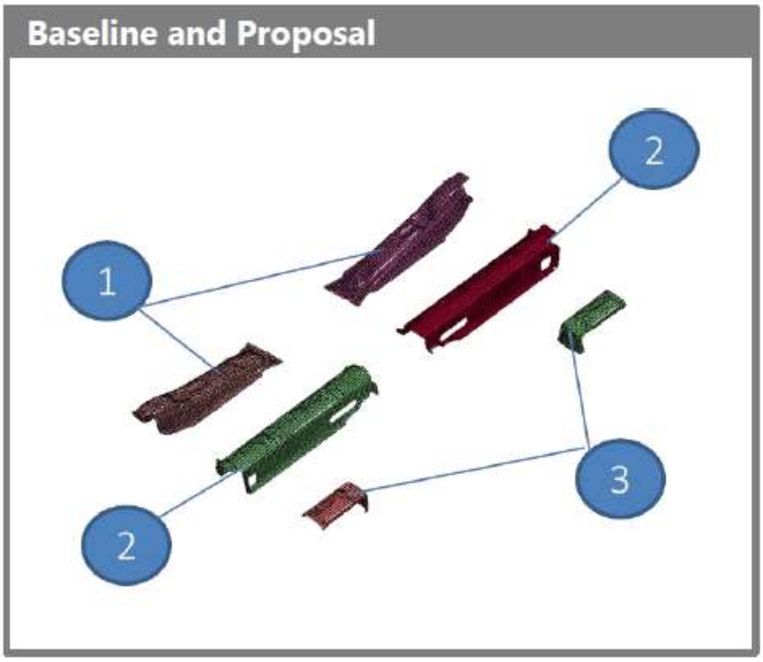


	BASELINE			PROPOSAL		
ITEM	MATERIAL	THICK (mm)	WEIGHT (Kg)	MATERIAL	THICK (mm)	WEIGHT (Kg)
1	HSLA280	0.7	5.4	HSLA280	0.7	5.4
2	HSLA280	0.7	4.6	HSLA280	0.7	4.6
3	HSLA320	0.65	3.6 2X	HSLA320	0.65	3.6 2X
4	HSLA440	1.0	7.62	PHS	0.9	6.8
5	HSLA280	0.8	0.3	HSLA280	0.8	0.3
6	B180	0.7	4.8	B180	0.7	4.8
∑/Car			**29.9**			**29.1 (-3 %)**

Figure 5: Geometry and material of front/rear floor assembly

Crossmember Assembly

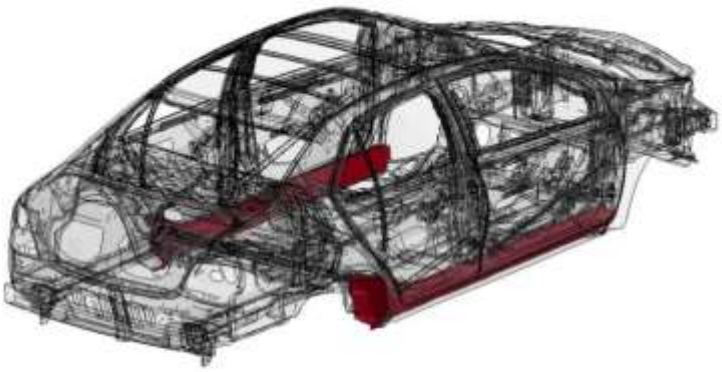


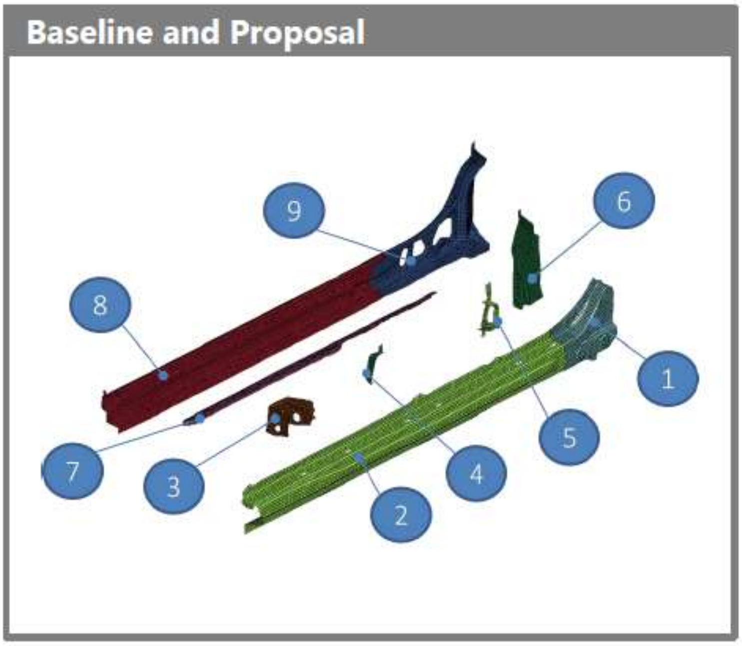


	BASELINE			PROPOSAL		
ITEM	MATERIAL	THICK (mm)	WEIGHT (Kg)	MATERIAL	THICK (mm)	WEIGHT (Kg)
1	DP600	1.5	1.26 2X	DP600	1.5	1.26 2X
2	HSLA320	1.4	1.59 2X	DP600	1.2	1.36 2X
3	HSLA280	1.3	0.26 2X	DP600	1.2	0.24 2X
∑/Car			**6.2**			**5.7 (-8 %)**

Figure 6: Geometry and material of crossmember assembly

Rocker Panel Assembly

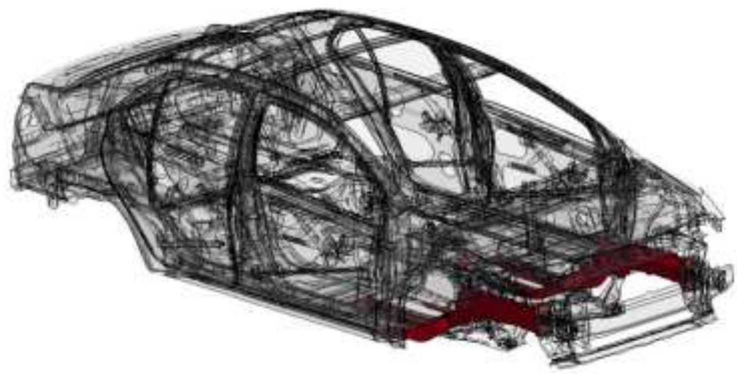


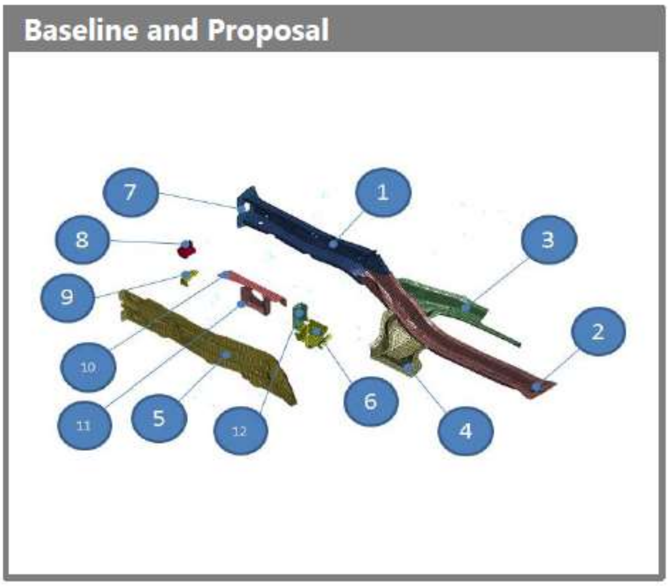


	BASELINE			PROPOSAL		
ITEM	MATERIAL	THICK (mm)	WEIGHT (Kg)	MATERIAL	THICK (mm)	WEIGHT (Kg)
1	DP800	1.0	0.6	DP800	1.0	0.6
2	DP600	1.4	4.2	DP1000	1.2	3.6
3	HSLA280	1.0	0.15	HSLA280	1.0	0.15
4	HSLA280	1.3	0.08	HSLA280	1.3	0.08
5	HSLA280	1.0	0.08	HSLA280	1.0	0.08
6	HSLA280	2.0	0.5	HSLA280	2.0	0.5
7	HSLA280	1.9	1.0	HSLA280	1.9	1.0
8	DP600	1.4	3.2	DP1000	1.2	2.7
9	HSLA280	1.5	1.8	HSLA280	1.5	1.8
∑/Car			**11.6**			**10.5 (-9%)**

Figure 7: Geometry and material of rocker panel assembly

Front Rail Assembly

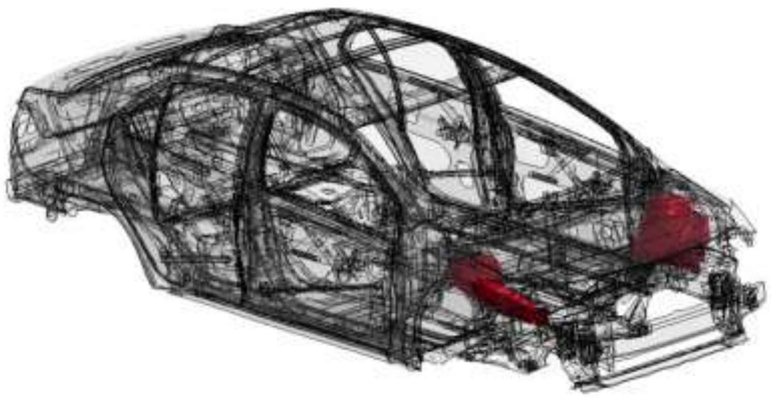


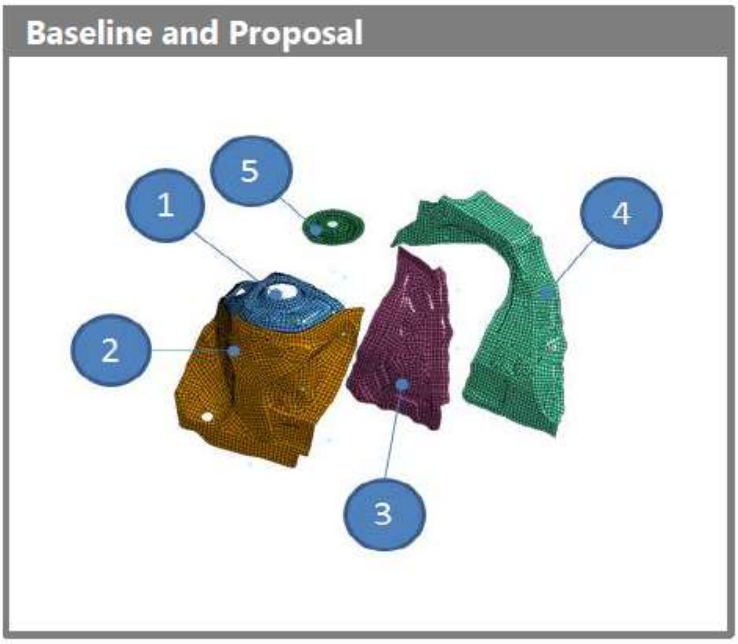


	BASELINE			PROPOSAL		
ITEM	MATERIAL	THICK (mm)	WEIGHT (Kg)	MATERIAL	THICK (mm)	WEIGHT (Kg)
1	DP600	1.9	2.3	PHS (TWB)	1.4/1.2	1.62
2	DP600	2.0	2.8	PHS	1.5	2.1
3	DP800	1.7	1.3	DP800	1.7	1.3
4	HSLA280	1.8	1.1	HSLA280	1.8	1.1
5	DP600	1.7	1.4	PHS	1.1	0.9
6	HSLA280	1.7	0.2	HSLA280	1.7	0.2
7	HSLA280	1.6	0.2	HSLA280	1.6	0.2
8	HSLA280	2.3	0.07	HSLA280	2.3	0.07
9	HSLA280	2.3	0.08	HSLA280	2.3	0.08
10	DP600	1.9	0.2	Patch/PHS	1.5	0.15
11	DP600	1.9	0.2	DP600	1.9	0.2
12	DP600	1.9	0.1	DP600	1.9	0.1
∑/Car			**10.0**			**8.02 (-20 %)**

Figure 8: Geometry and material of front rail assembly

Front Wheel House Assembly





	BASELINE			PROPOSAL		
ITEM	MATERIAL	THICK (mm)	WEIGHT (Kg)	MATERIAL	THICK (mm)	WEIGHT (Kg)
1	HSLA280	1.8	0.6	FB590	1.6	0.5
2	HSLA280	0.8	0.7	HSLA280	0.8	0.7
3	HSLA280	1.3	0.5	HSLA280	1.3	0.5
4	HSLA280	1.7	1.4	DP600	1.5	1.2
5	HSLA280	1.9	0.2	HSLA280	1.9	0.2
∑/Car			**3.4**			**3.1 (-9 %)**

Figure 9: Geometry and material of front wheel house assembly

2. VIRTUAL TEST DESCRIPTION

2.1. AZT 10º, Offset 40% [2]

Allianz Test for a front bumper test.

- Moving car is allowed to move just in the x direction
- Fixed wall, 10°, offset 40%
- Moving car speed v = 16 km/h, weight = 1.045 kg

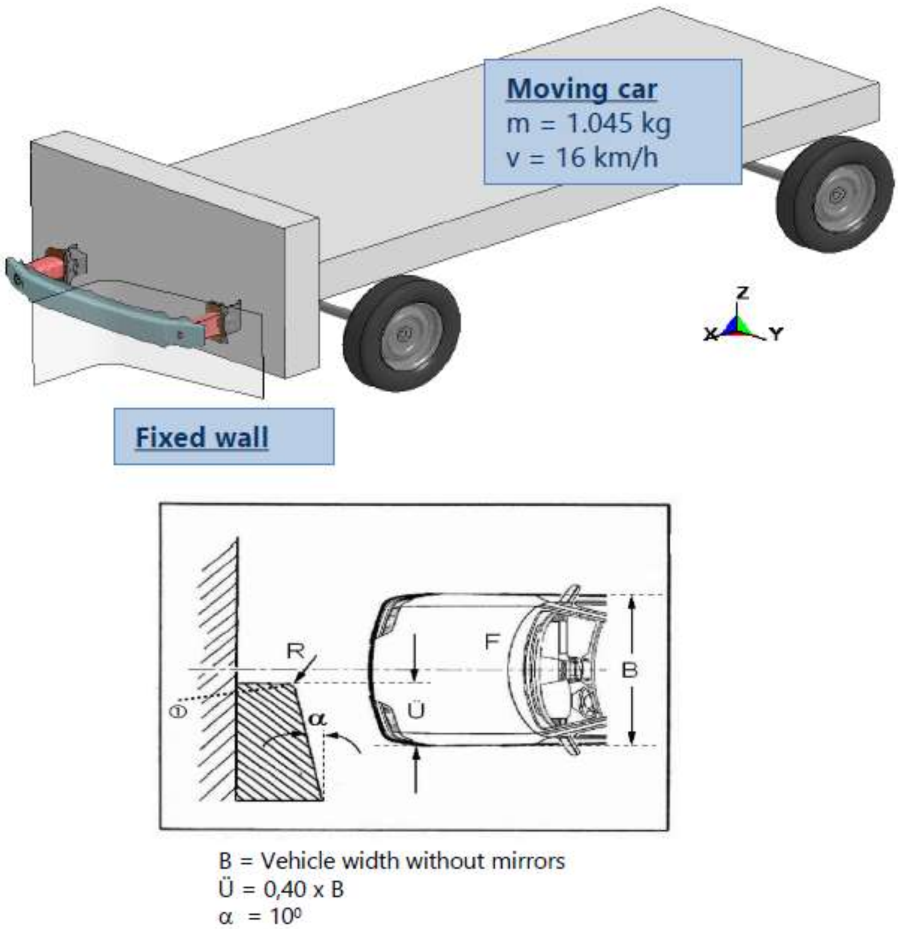


Figure 10: Allianz test setup [2]

2.2. FMVSS214 12” Impactor

Impactor for a side impact beam test.

- Axial spring (2x) of 250 N/mm to simulate door
- Simply supported (3-point bending)
- Free in x-translation
- FMVSS214 static 12” impactor, allowed to move just in y direction
- Contact point – half length of the beam: L/2

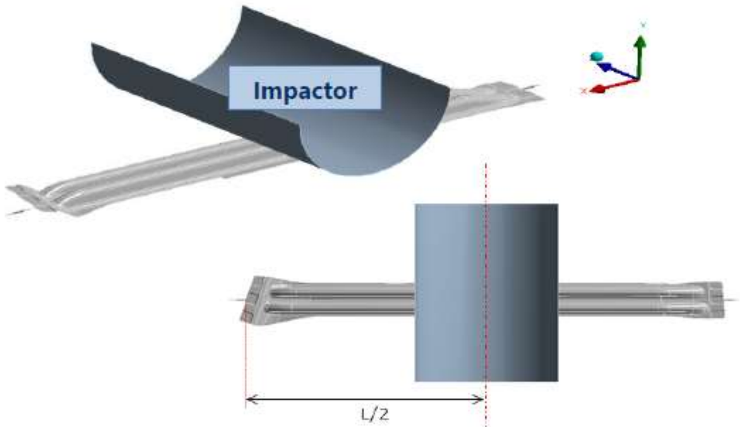
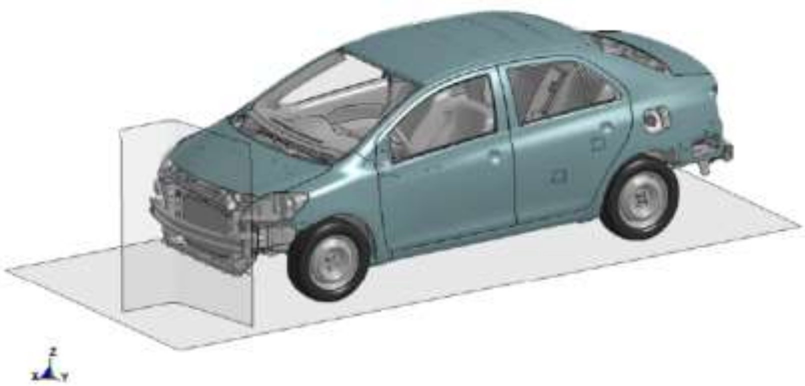


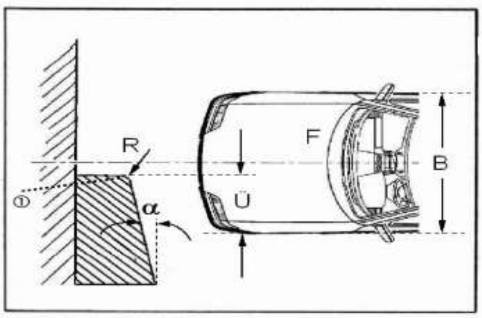
Figure 11: FMVSS214 12” impactor test setup

2.3. Full Vehicle, 64 km/h, 10°, Offset 40% [3]

Full vehicle frontal crash test.



- Rigid and fixed wall, 10°, offset 40%
- Car speed v = 64 km/h, weight= 1.045 kg



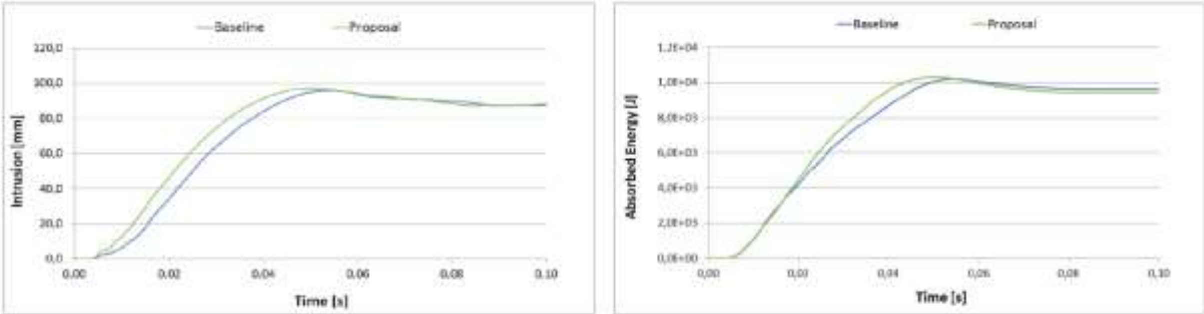
B = Vehicle width without mirrors
Ü = 0,40 x B
α = 10°

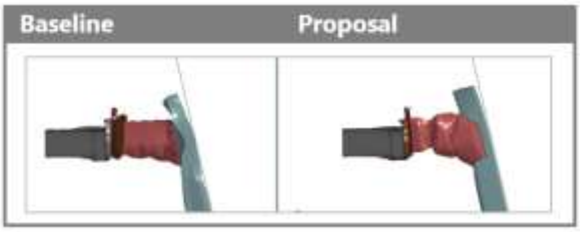
Figure 12: Full vehicle crash test setup

3. RESULTS

AZT 10º, Offset 40% (front bumper test)

Proposal model had intrusion and absorbed energy at the same level of baseline, with 10% less weight.



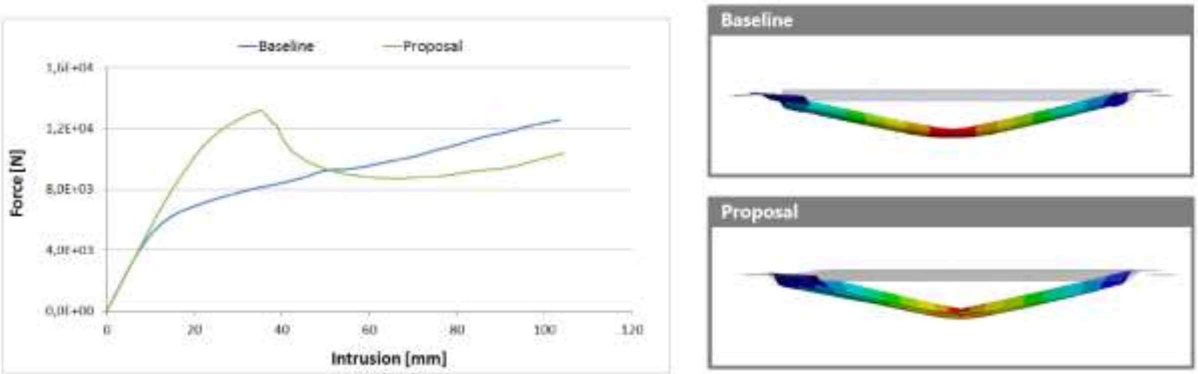


AZT 10º, Offset 40%	Baseline	Proposal
Intrusion [mm]	96.0	97.2 (+1%)
Absorbed Energy [J]	1.02e4	1.03e4 (+1%)
Weight [kg]	8.48	7.61 (-10%)

Figure 13: Results of the Allianz test

FMVSS214 12" Impactor (side impact beam test)

Proposal model had a maximum force and an average crush resistance 5% higher, with 8% less weight.



FMVSS214	Baseline	Proposal
Maximum Force [N]	1.26e4	1.32e4 (+5 %)
Avarage Crush Resistance * [Nmm/mm]	8.84e3	9.28e3 (+5 %)
Weight [kg]	1.23	1.13 (-8 %)

Figure 14: Results of the FMVSS214 12" impactor test

Full Vehicle, 64 km/h, 10°, Offset 40% (entire structure test)

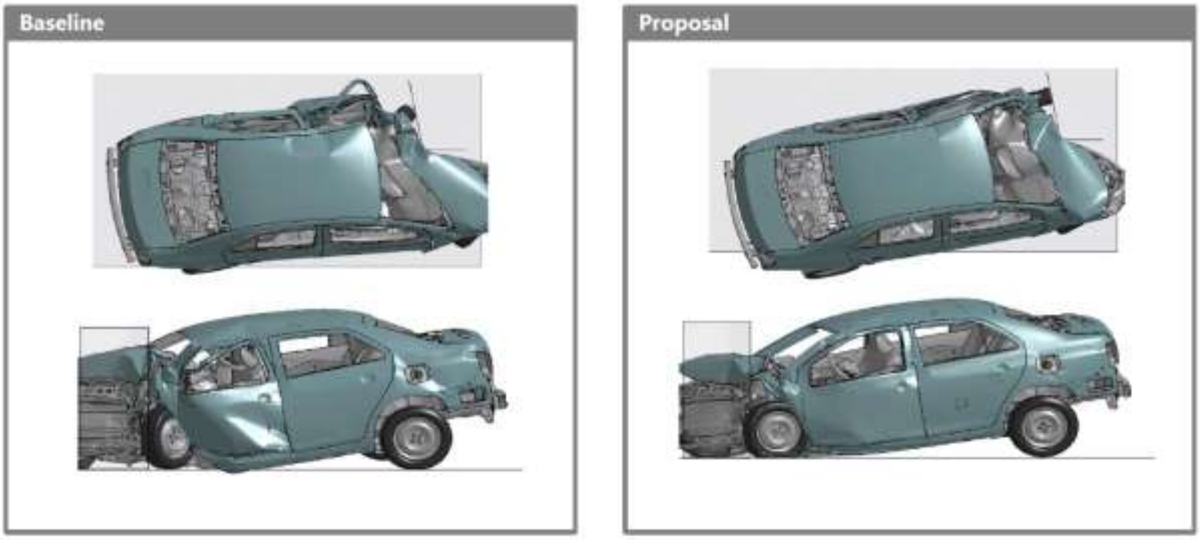


Figure 15: Results of the crash test, general deformation of the structure

Proposal model had 67% less intrusion for the foot rest position on the firewall

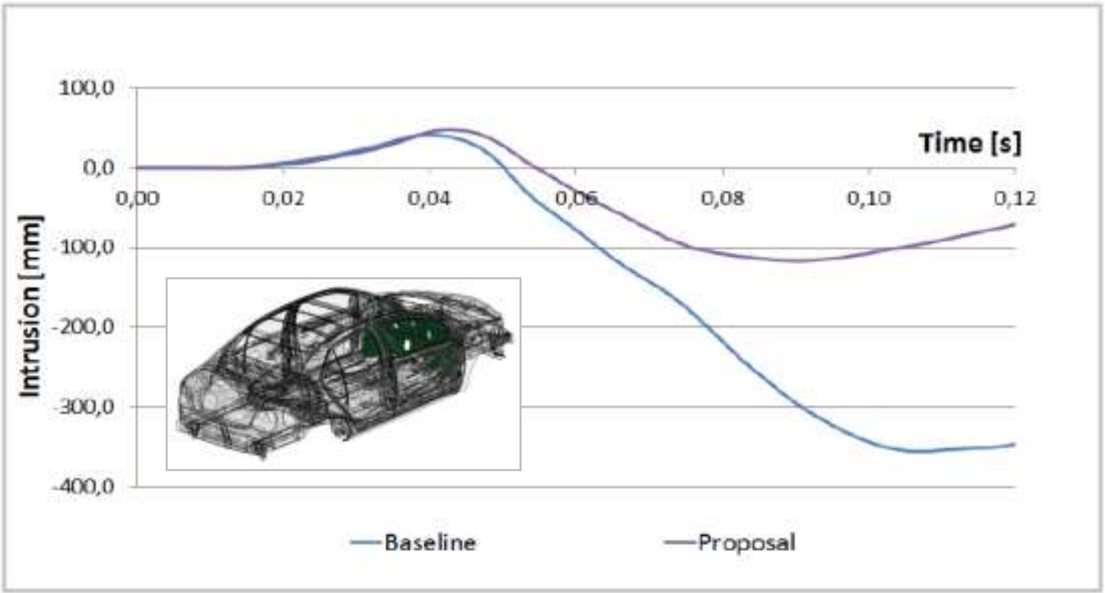


Figure 16: Intrusion for the foot rest position on the firewall

Proposal model absorbed 26% more energy in the assembly of front rail + crash box

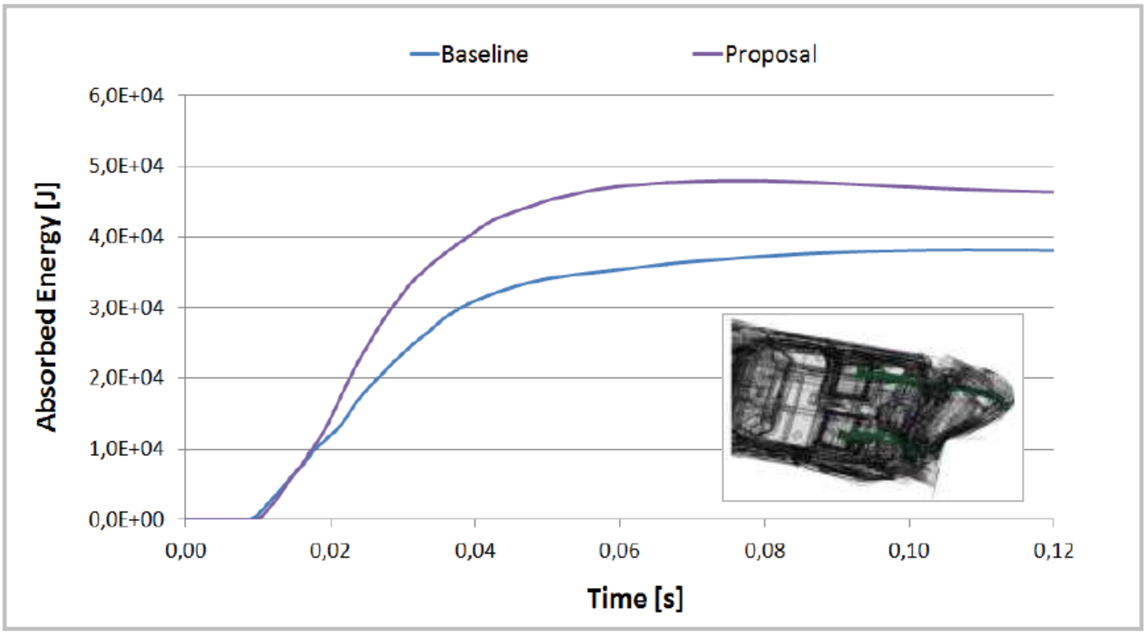


Figure 17: Absorbed energy: front rail + crash box

Proposal model had a maximum acceleration 26% lower for the driver seat crossmember

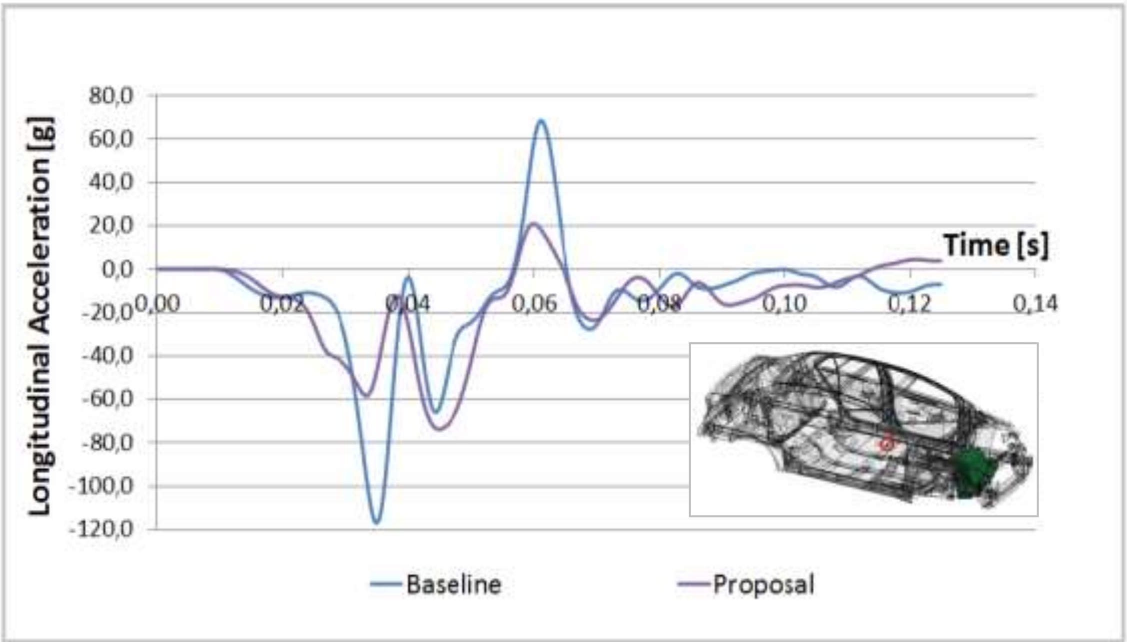


Figure 18: Acceleration for the driver seat crossmember

CONCLUSIONS

There were important improvements in vehicle safety and weight reduction while using AHSS in vehicle BIW:

- 11 kg reduction in whole vehicle weight;
- 67% reduction in foot rest intrusion;
- 26% increase in absorbed energy of front rail and crash box;
- 36% reduction in acceleration at a point below the driver seat.

Additional benefits may be obtained using AHSS for other vehicle assemblies such as rear bumper, rear rail and roof.

REFERENCES

[1] KEELER, S.; KIMCHI, M.; MOONEY, P. Advanced High-Strength Steels Application Guidelines Version 6.0. Disponível em https://www.worldautosteel.org/projects/advanced-high-strength-steel-application-guidelines/
[2] Front crash test for the calculation of the type classes. Avaliable on: http://www.rcar.org/Papers/Procedures/CrashStandards_GermanRatingSystem.pdf
[3] Adopted from: https://www.euroncap.com/en/vehicle-safety/the-ratings-explained/adult-occupant-protection/full-width-rigid-barrier/