

InCar - Advanced Door Design

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ABSTRACT

The ThyssenKrupp InCar Project is a comprehensive R&D development that gives automotive manufacturers modular solution kits for body, chassis and powertrain applications. The solution kits developed within this project offer weight reduction, cost savings or improved functionality. This paper will focus on the two front door solutions developed within the InCar project. The first door solution, called the Lightweight Door, achieved a 13% weight reduction. This door features a 4-piece tailored blank inner panel and a sandwich material outer panel. The second door solution, called the Advanced Door, is a completely new and innovative door architecture that uses a 2-piece tailored blank mid panel and ultra thin Dual Phase 500 outer panel to achieve an 11% weight reduction. Prototypes were manufactured and tested for both door solutions. This paper will provide a detailed description of everything related to the development of these door solutions, including manufacturing and assembly processes, performance, materials, and cost estimation.

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INTRODUCTION

Vehicle doors have many design requirements. These include FMVSS 214 Side Impact Protection, Dent Resistance, Oil Canning, Fatigue, Over Opening, Frame Stiffness, Belt Stiffness, Torsional Stiffness, and Set/Sag. Because most of these tests are stiffness dependent, it is very challenging to develop lightweight steel solutions. With the exception of the door impact beam and door outer panel, most other components in a typical door assembly are stiffness dependent and increased strength does not provide any benefit. For this reason, most of the other components (door inner, window frame, belt reinforcement, etc) are manufactured from either mild steel or high-strength low-alloy (HSLA) steel. However, it is still possible to obtain small mass reductions in these components with geometry optimization, minimal weld flanges, and part consolidation using tailored blanks.

FMVSS 214 is a crash test performed by ramming a 12" diameter steel cylinder into the center of the door structure. The door side impact beam is responsible for carrying the brunt of this load. For this reason, most door impact beams are manufactured from ultra high strength steel (UHSS). The door impact beams are usually either hot-stamped open sections or induction heated tubes with paddles MIG welded on for attachment to the door inner panel. The hot-stamping and induction heating processes are followed by a quenching process to achieve 100% martensite microstructure in

Manganese-Boron (MnB) steel with strength levels as high as 1600 MPa. This is the only crash relevant test for doors and since UHSS are commonly used for door impact beams, there is not much opportunity for mass reduction. However, new steel grades are being developed in Europe with over 1900 MPa minimum tensile strength which should enable up to 25% mass reduction for door impact beams in future vehicles.

Dent Resistance and Oil Canning are performed by applying loads directly to the door outer panel. To meet dent resistance at the lightest possible gauge, most door outer panels are manufactured from either Bake Hardenable (BH) or Dent Resistance (DR) steel grades with minimum yield strength between 180 and 300 MPa. The steel thickness for door outer panels usually falls between 0.65 and 0.8 mm. Dent Resistance can be improved by increasing the material strength which can be accomplished in several ways, such as increasing the amount of surface stretch and subsequent work hardening in the forming process, bake hardening during the paint cycle, or upgrading. The highest strength material currently available in exposed quality for door outer panels is DP500 and it is possible to downgauge the outer panel as low as 0.5 mm using this material while maintaining Dent Resistance performance. However, this thickness reduction will decrease Oil Canning performance since this test applies load evenly over a larger surface area. Therefore, it may be necessary to add more structure, via strainers or reinforcements, beneath the weakest locations of the door outer panel in order to meet Oil Canning requirements.

Another material that can be used for door outer panels is stiffness optimized sandwich material, which is comprised of two ultra thin steel sheets on either side of a thicker plastic core (see [Figure 1](#)). Sandwich material can reduce weight in outer panels because steel thickness is reduced while maintaining the total thickness with a plastic core. Therefore, it is possible to meet both dent resistance and oil canning requirements without adding more structure underneath the outer panel surface. Successful sandwich material manufacturing trials have been completed using steel sheets with thicknesses as low as 0.2 mm, in both mild steel and DP500 grades, with plastic core thicknesses between 0.4 and 1.0 mm. However, this material is currently under development and not yet commercially available. Because the door outer panel is roughly 1/3 the weight of the entire door structure, it is clear that thickness reduction in door outer panels provides the greatest opportunity for mass reduction in conventional steel door structures.

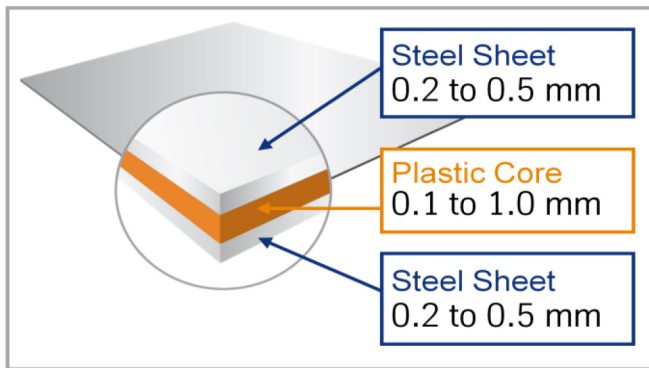


Figure 1. Stiffness Optimized Sandwich Material

REFERENCE DOOR STRUCTURE

For comparison purposes, a state of the art reference door structure concept (see [Figure 2](#)) was developed as part of a complete reference body structure. A modular design was used with a window lift mechanism and an equipment mounting plate. The equipment mounting plate (10) serves to support the window lifter mechanism (11), loud speaker, and central locking motor. The door inner panel (1a/b) was designed as a tailored welded blank in order to reinforce the hinge attachment area. This design helped meet the door over opening and door sag requirements. A tailor welded blank was also used for the window frame (2a/b). This design consolidated the upper hinge reinforcement and mirror reinforcement into the window frame while simultaneously increasing the frame stiffness. A crash bracket (7) was included to improve overall crash performance for side impact. The material selection (see [Table 1](#)) was based on current volume production standards. The reference door had a total weight of 17.17 kg. This translates to a weight per unit area of 20.69 kg/m². This value is in the mean range of the results of a door benchmark study completed by ThyssenKrupp (see [Appendix A](#)).

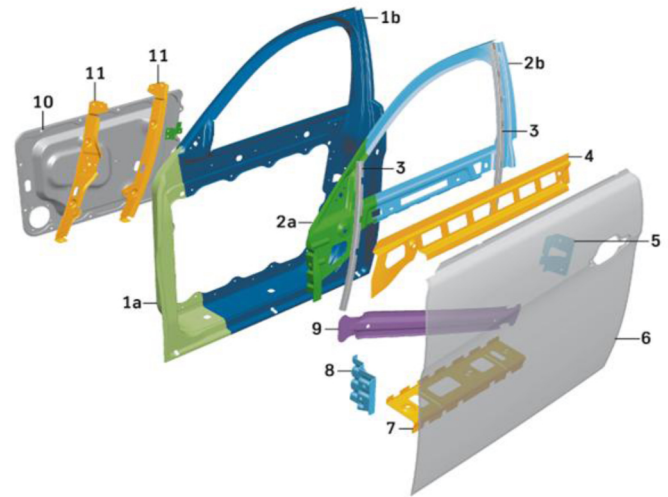


Figure 2. Reference Door Structure.

Table 1. Material Information for Reference Door Structure.

Part #	Part Name	Material	Gauge (mm)
1a	Inner Panel Front	IF 160	1.50
1b	Inner Panel Rear	Mild Steel	0.70
2a	Sash Front	IF 220	1.80
2b	Sash Rear	IF 180	1.00
3	Window Guide	HSLA 250	0.70
4	Belt Rnf. Outer	HSLA 340	0.70
5	Latch Rnf.	HSLA 250	0.90
6	Outer Panel	BH 220	0.75
7	Crash Bracket	CP 780	1.20
8	Hinge Rnf. Lower	HSLA 340	1.80
9	Intrusion Beam	MS 1200	1.70
10	Carrier Plate	-	-
11	Lift rail	-	-

LIGHTWEIGHT STEEL DOOR CONCEPT

The goal for the Lightweight Steel Door was to retain the architecture of a conventional door while maximizing weight reduction with reasonable cost increase. To achieve this goal, modern steel grades, semi-finished products, and joining methods are used (see [Figure 3](#) and [Table 2](#)). The door inner panel (1a/b/c/d) is designed as a tailored blank similar to the reference door. However, the hinge area was divided into three zones corresponding to the stiffness requirements and required sheet thicknesses. This 4-piece tailored blank inner panel reduces weight by 5% compared to the reference design while delivering equivalent stiffness performance. Most of the weight reduction in the Lightweight Steel Door was obtained through use of a stiffness optimized sandwich material for the outer panel (6). The sandwich material uses

two 0.25 mm mild steel outer sheets on either side of a 0.4 mm thick PE/PA core with a density of 1.03 g/cm³. This results in a lightweight outer panel with excellent dent resistance and oil canning performance due to the relatively large total thickness of the sandwich material (0.9 mm). The use of a MnB steel hot-stamped side intrusion beam (9) enabled a reduction in part thickness from 1.7 to 1.2 mm. The crash bracket (7) was upgraded to DP980 enabling a reduction in part thickness from 1.2 to 1.0 mm. Further weight reduction was achieved by changing the joining technology from resistance spot welding to laser welding in the window frame area. This enabled a decrease in flange width and the sheet thickness of the rear sash (2b) to be reduced from 1.0 mm to 0.9 mm. Overall, the Lightweight Steel Door ended up with a total weight of 14.86 kg, which is a 2.31 kg (13%) mass savings compared to the reference door.

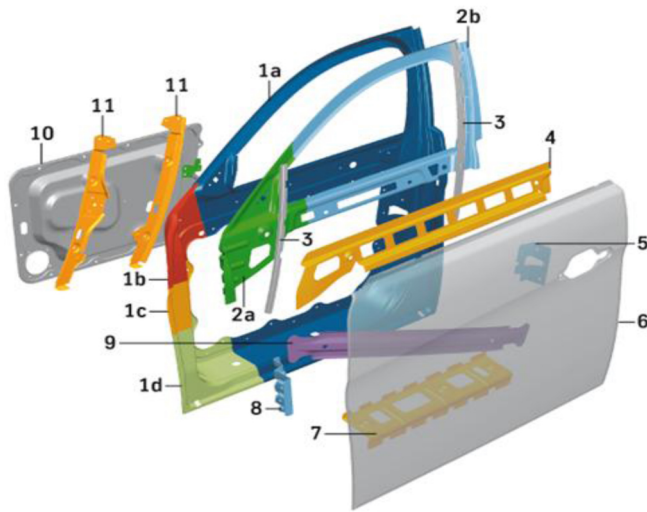


Figure 3. Lightweight Steel Door Concept.

Table 2. Material Information for Lightweight Steel Door Concept.

Part #	Part Name	Material	Gauge (mm)
1a	Inner Panel	Mild Steel	0.70
1b	Inner Panel	Mild Steel	1.50
1c	Inner Panel	IF 160	0.90
1d	Inner Panel	IF 160	1.50
2a	Sash Front	IF 220	1.80
2b	Sash Rear	IF 180	0.90
3	Window Guide	HSLA 250	0.70
4	Belt Rnf. Outer	HSLA 340	0.70
5	Latch Rnf.	HSLA 250	0.90
6	Outer Panel	Sandwich	0.25/0.40/0.25
7	Crash Bracket	DP 980	1.00
8	Hinge Rnf.	HSLA 340	1.90
9	Intrusion Beam	MnB 1500	1.20
10	Carrier Plate	-	-
11	Lift Rail	-	-

ADVANCED DOOR CONCEPT

The goal of the Advanced Door was to develop a unique door design that achieved significant mass reduction through part consolidation (see Figure 4 and Table 3). To achieve this goal, the inner door panel was changed to a monolithic design and the belt reinforcement outer, door impact beam, crash reinforcement, and latch reinforcement were all consolidated into one innovative 2-piece tailored blank mid panel (4a/b/c/d). There are two variants for the highly integrated tailored blank mid panel. Variant 1 uses a hot stamped (HS) mid panel with MnB steel for the lower portion and HSLA steel for the upper portion. Both steel grades have aluminized coating. Variant 2 uses a cold stamped (CS) mid panel with DP980 steel for the lower portion and TRIP steel for the upper portion. The steel thicknesses for both variants are the same, 1.1 mm for the lower portion and 0.7 mm for the upper portion. The monolithic inner panel is mild steel with a thickness of 0.75 mm. Because the inner panel was changed from a tailored blank to a monolithic design, the front portion of the tailored blank window frame (2a) thickness needed to be increased from 1.8 to 2.3 mm, compared with the reference. For the outer panel, 0.55 mm DP500 was used. Due to the very thin gage of the outer panel, support struts were designed into the mid panel to help meet Oil Canning requirements. Overall, the Advanced Door ended up with a total weight of 15.21 kg, which is a mass savings of 1.96 kg (11%) compared to the reference door.

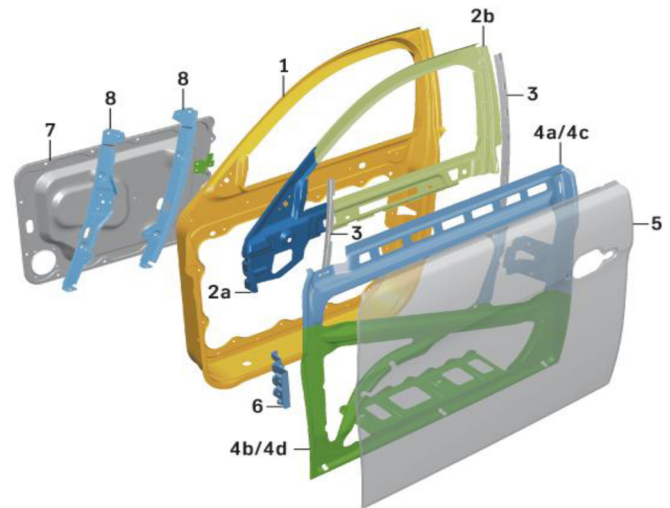


Figure 4. Advanced Door Concept.

Table 3. Material Information for Advanced Door Concept.

Part #	Part Name	Material	Gauge (mm)
1a	Inner Panel	IF 160	0.75
2a	Sash Front	IF 220	2.30
2b	Sash Rear	IF 180	1.00
3	Window Guide	HSLA 250	0.70
4a	Inner Panel Outer	TRIP 700	0.70
4b	Inner Panel Outer	DP 980	1.10
4c	Inner Panel Outer	HSLA 340	0.70
4d	Inner Panel Outer	HSLA 1500	1.10
5	Outer Panel	DP 500	0.55
6	Hinge Rnf.	HSLA 340	2.40
7	Carrier Plate	-	-
8	Lift Rail	-	-

PERFORMANCE

WEIGHT

Table 4 summarizes the weight savings for the Lightweight Steel Door and Advanced Door concepts.

Table 4. Weight Performance.

	Reference Door	Lightweight Steel Door	Advanced Door
Weight (kg)	17.17	14.86	15.21
Savings (kg)	-	2.31	1.96
Savings (%)	-	13%	11%

STIFFNESS

The stiffness performance of the door was validated with finite element analysis for the frame stiffness, door sag, over-opening, belt stiffness, and bending/torsion natural frequencies. Table 5 shows comparable performance for all doors. For door sag and over-opening, the values given represent permanent deformation.

Table 5. Stiffness Performance.

	Reference Door	Lightweight Steel Door	Advanced Door
Frame Stiffness, Front Disp. (mm)	0.75	0.85	0.78
Frame Stiffness, Rear Disp. (mm)	2.31	2.31	2.43
Door Sag (mm)	0.01	0.02	0.01
Over-opening (mm)	1.17	1.07	1.30
Belt Stiffness (N/mm)	60	58	75
1 st Torsion Mode (Hz)	54.6	55.7	49.5
1 st Bending Mode(Hz)	70.2	71.6	80.0

OIL CANNING AND DENT RESISTANCE

The Oil Canning performance of the Reference Door and Advanced Door was initially evaluated using finite element analysis. These results are shown in [Appendix B](#) and [C](#). An initial static performance of 20 N/mm was targeted. The reference door exhibits good Oil Canning behavior with one exception, beneath the handle recess. For the Advanced Door concept, the support struts helped stabilize the outer panel surface resulting in good Oil Canning performance, despite the lower outer panel thickness of only 0.55 mm. The simulations show that the critical region beneath the handle recess for the Advanced Door is clearly smaller than for the Reference Door.

Oil Canning and Dent Resistance tests were also performed on the prototype doors for all three door designs. These results are shown in [Appendix D](#) and [E](#). The Dent Resistance of the Lightweight Steel Door with stiffness optimized sandwich material for the outer panel was slightly below that of the reference outer panel. However, the use of higher-strength DP500 steel for the sandwich material sheets can provide improved Dent Resistance performance if required. Oil Canning performance for the Lightweight Steel Door was comparable to the Reference Door. For the Advanced Door, it was verified that the dent resistance performance of the 0.55 mm DP500 outer panel exceeds that of the 0.75 mm BH220 Reference Door outer panel. The Oil Canning performance of the Advanced Door was comparable to the Reference Door. Traces of adhesive bleed-through, which can occasionally be observed when using very thin outer panels, were not detected on the Advanced Door outer panel.

CRASH

The contribution of the door to passenger safety is clearly present in IIHS Side Impact load cases. For IIHS Side Impact, door performance is deemed acceptable if the maximum intrusion speed of the door is less than 10 m/s and the door does not jam, which could prevent extrication of the driver and passengers from the vehicle after the crash. Full vehicle IIHS Side Impact crash simulations showed that all door designs developed met the criteria. As would be expected, the hot-stamped variant of the Advanced Door concept produced the best results for IIHS Side Impact with less intrusion and more energy absorbed than for all of the other doors tested.

FMVSS214 door crush simulations were performed for all doors and the results are shown in [Table 6](#). All doors met the force level criterion at the different intrusion levels. Due to the similar architecture of the Lightweight Steel Door compared to the Reference Door, the results were comparable. In the case of the Advanced Door, the unique architecture helped improve the door crush performance significantly. The hot-stamped variant of the Advanced Door required 20% higher force than the Reference Door at 305