Lightweight Truck Project - Aluminium Door Concept

Short Report 166760

fka GmbH
Body

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Project Number

166760

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European Aluminium

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1 Executive Summary

European Aluminium initiated a research project regarding the use of aluminium in future trucks. The cabin door was chosen as reference assembly to be investigated since the cabin door is a hang-on part and therefore well integrable into the current steel design of truck cabins. Furthermore, it has high stiffness requirements, which are similar for all OEMs, and allows the implementation of aluminium sheet, extrusion as well as casting applications.

The starting point for the concept development phase was the definition of design spaces for a topology optimisation based on the given outer geometry of the steel reference door. This space was considered within an optimisation to derive a weight optimised component structure. The basic idea of the aluminium door concept is the combination of aluminium casting and extrusion components to form a rigid reinforcement structure, which complies with the inner panel sheet geometry of the reference door. The concept envisages that the door beams, i.e. crash beam and inner belt beam, are made of aluminium extrusions while the reinforcements in the front and rear area, i.e. hinge and lock area, are realised as aluminium castings. In an iterative design process making use of CAE optimisation tools and considering feedback on manufacturability, a final concept version (V1.6) was reached. This concept door is performing better than the steel reference door for all considered load cases while achieving a weight reduction of more than 40% compared to the related reference components.

Numerous simulations accompanied the development phase of the door concept. At first, the reference steel door CAE model was analysed in order to set the requirements that the new aluminium door concept had to meet. For the load cases loading the main door structure (door sag, walk on door, operator sit on door & door fall), the displacements of the aluminium door were significantly lower compared to the steel reference door. Regarding the load cases addressing mainly the frame area (lateral stiffness LC1 & LC2), which is the most challenging part of aluminium doors, the maximum displacements of the aluminium door concept were still slightly below the values of the steel reference door.

The intended joining technology for the aluminium door concept is laser welding. It fulfils the requirements regarding accessibility, suitability for visible joints, small or no flanges and is an established process in automotive body production. In order to join the extrusion profiles with the casted reinforcements, flowdrill screws (FDS) in combination with adhesive were chosen. Some components were not considered in the re-design, such as hinges, lock, window guides and mechanism, door module as well as the outer door extension. Hinges, lock and window mechanism remained the same, while the outer door extension was already made out of aluminium. The window guides would offer additional lightweight potential if they were made of aluminium. The same applies to the door module. A carry over part out of aluminium with an adapted thickness, as considered within the simulations, would more than halve the component weight. If the aluminium door module were also included in the weight balance, this would result in an overall weight reduction of 42%.

Contents

2 Lightweight Truck Project

European Aluminium initiated a research project regarding the use of aluminium in future trucks. The starting point was an initial workshop with various European truck OEMs and representatives of the aluminium industry in order to select relevant demonstrator components to be considered within the project, representing aluminium sheet, extrusion and casting applications. The focus within the workshop was on components, which are relevant for all OEMs, have a certain impact on the vehicle weight and are well integrable into an existing steel design. Many components were discussed. Finally, the cabin door was chosen as reference assembly to be investigated within the project since the cabin door is a hang-on part and therefore well integrable into the current steel design of truck cabins. Furthermore, it has high stiffness requirements, which are similar for all OEMs, and allows the implementation of aluminium sheet, extrusion as well as casting applications.

3 Reference Steel Door

Due to several reasons, such as confidentiality or IP rights with regard to the reference data needed for a concept development of an aluminium cabin door, a continuation of the project with several truck OEMs turned out not to be possible. Thus, the work was finally carried on in cooperation with only one OEM, namely Volvo Trucks, who provided a proven reference CAD as well as CAE model of a current cabin door of the Volvo FH along with relevant load cases.

The steel reference door shows a sheet metal design with reinforcements. As usual for vehicle doors, the outer panel is attached to the inner panel by hemming and adhesive bonding. Due to the crash requirements, the crash beam is hot formed. The door module is part of the assembly and had to be considered in the concept development. The door extension is already out of aluminium, but it had to be kept separately due to height restrictions with regard to the factory transport of the truck cabins. Thus, no integration into the door concept was foreseen.

The reference steel door was presented by Volvo Trucks during a kick-off meeting for the concept development phase in Lyon, where Volvo employees as well as representatives from the aluminium industry took part. It was decided that the outer geometry of the reference door should not be changed to ensure compatibility with the current truck cabin, i.e. only minor changes to the inner and outer panel geometry were possible with regard to the aluminium door concept. Furthermore, a minimum target of 30% weight reduction was set together with the boundary condition that the different aluminium manufacturing technologies had to be considered, i.e. the aluminium door concept should comprise sheet, casting as well as extrusion applications. The reference steel door CAE model was analysed based on the provided load cases. The corresponding simulation results lay down the requirements the new aluminium door concept had to meet.

4 Concept Development

The concept development was an iterative design process making use of CAE and numerical tools, such as topology, topography and size optimisation. Thus, the design of the aluminium lightweight door concept was optimised regarding manufacturability as well as fulfilment of the reference requirements and performance at minimum weight. The starting point was the definition of design spaces for a topology optimisation based on the given outer geometry of the reference door. Thereby, a theoretically available space for structural material is described. This space is considered within an optimisation to derive a weight optimised component structure, where all material, which is not necessary to fulfil the requirements, is left out.

The basic idea of the aluminium door concept is the combining of aluminium casting and extrusion components to form a rigid reinforcement structure within the given inner panel sheet geometry. The concept envisages that the door beams, i.e. crash beam and inner belt beam, are made from aluminium extrusions while the reinforcements in the front and rear area, i.e. hinge and lock area, are realised as aluminium castings. The corresponding design spaces defined for the casting and extrusion applications are illustrated in Fig. 4-1.

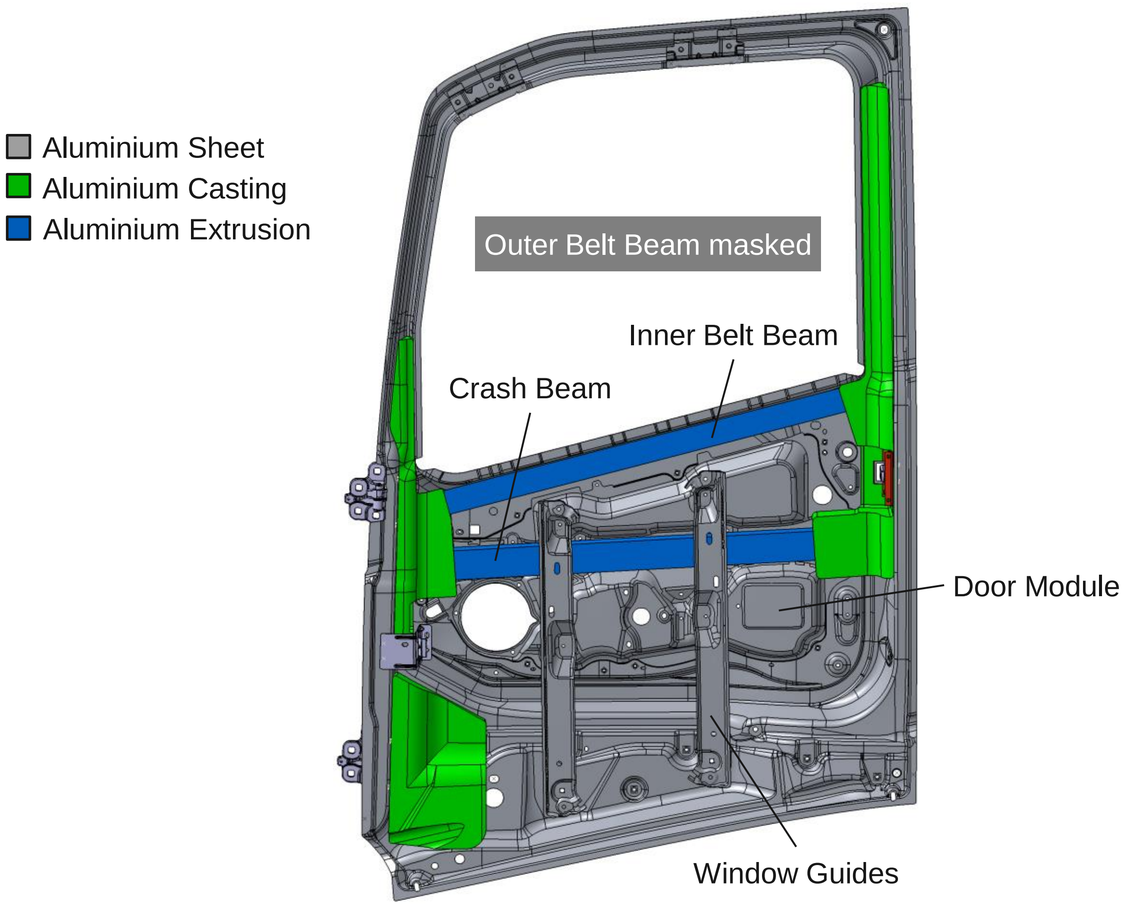

Fig. 4-1: Design spaces for casting & extrusion applications (outer panel masked)

The use of casting and extrusion applications enables a reduction of parts compared to the reference steel door, which offers further benefits in terms of lightweight design. This means, for example, that the reinforcements in the upper hinge area and the crash beam mount, but also the inner belt beam mount, can be combined to one component. Regarding the reinforcement of the lock and the rear door frame area, a single-piece casting design was preferred for maximum component integration, also comprising the crash beam and inner belt beam mounts. A topology optimisation based on the defined design spaces was performed to indicate where structural material is actually necessary to fulfil the requirements and where it might be left out to further save weight.

Based on this work, the actual concept development phase began, which consisted of several iteration steps. In the course of this, the package boundary conditions, e.g. due to the window and door opening mechanisms, were considered as well. Fig. 4-2 illustrates the final concept version V1.6.

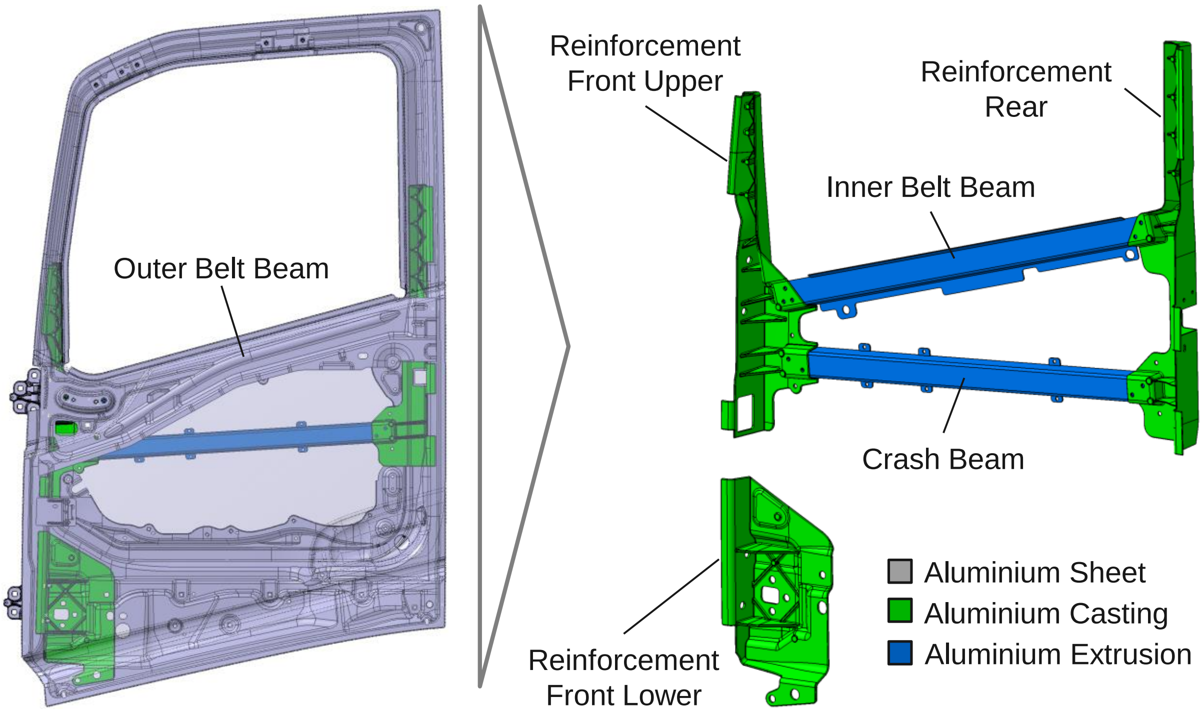

Fig. 4-2: Aluminium Door Concept V1.6

The aluminium door concept consists of five completely redesigned components, two extruded beams and three casted reinforcements with a rib geometry. The extruded beams both comprise a cross-like inner rib structure. The casting components enable a substitution of several sheet reinforcements of the reference door. All other remaining components are “carry over sheet parts”, i.e. here the material is changed from steel to aluminium and the thickness is adapted accordingly.

An optimisation of the component thicknesses (size optimisation) was performed in the respective iteration steps using a CAE tool. This requires the definition of intervals for each relevant component, specifying the lower and upper bound to be considered within the optimisation. The thickness values, which are finally assigned to each optimised component, must lie within these intervals and at the same time fulfil the defined overall weight target as a further given boundary condition. The objective of these optimisation runs is to minimise the door compliance, i.e. maximise the door stiffness, with regard to the considered load cases.

The ribs were optimised separately. This means, that the rib structures were treated as separate components with particular thickness intervals. Thus, the thickness values calculated for the ribs were independent from the base component. This applies to both the ribs of the casting components and the cross-like inner rib structures of the extrusion beams. Regarding the reinforcement front upper and the reinforcement rear, a distinction was made between the upper rib structure in the frame area and the lower rib structure in the hinge and lock area respectively. Within the particular rib structures, the ribs were assigned the same thickness.

The casting components are suitably designed for casting due to the implementation of rounded edges, draft angles and ejector eyes. The reinforcements front upper and lower (Fig. 4-3 left) replace five steel parts of the reference door in total. Not all cast ribs have the same thickness. With regard to the upper front reinforcement, the ribs in the door frame area have a lower thickness of 1.6 mm compared to the thickness of 4 mm calculated for the other ribs, always measured at top of the ribs. The base thickness for both front reinforcements is 4 mm, which is significantly higher than the thicknesses of the steel reference parts.

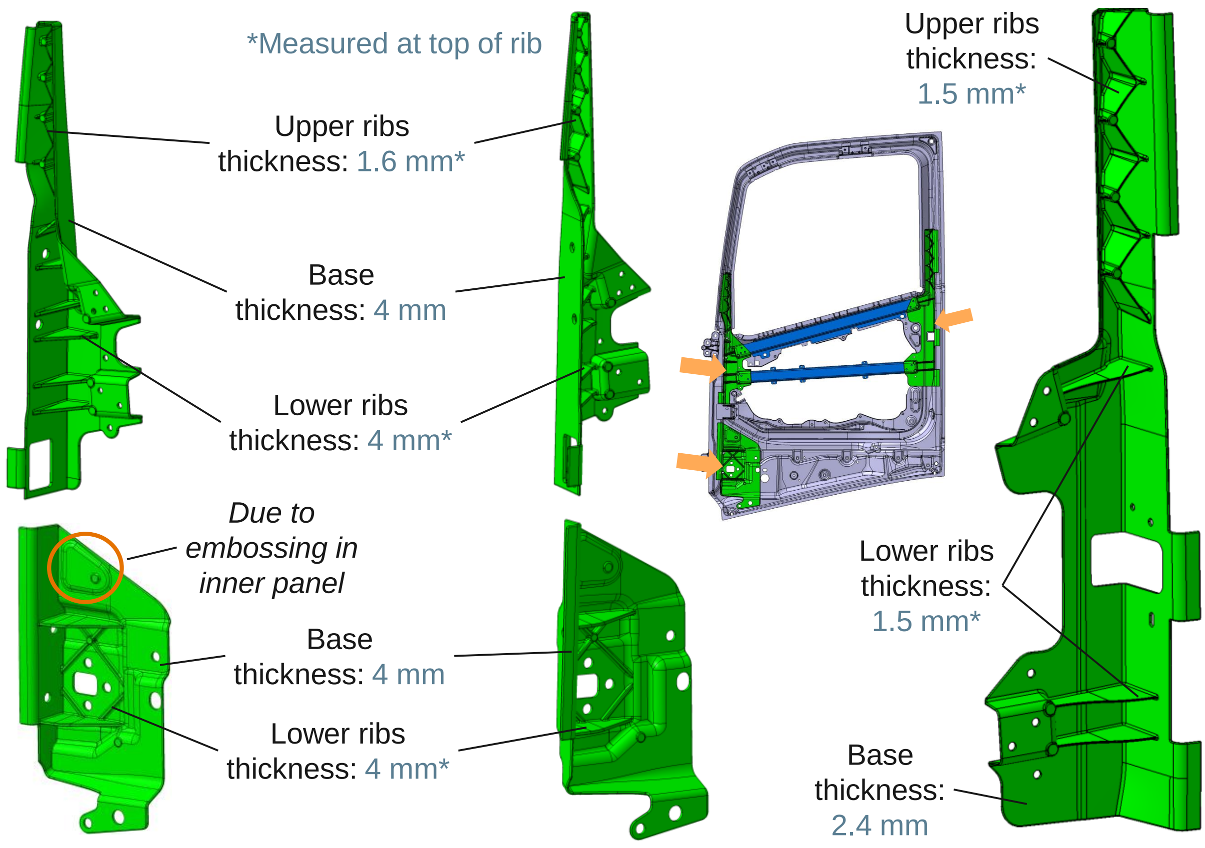

Fig. 4-3: Aluminium Door Concept V1.6 - Casted Reinforcements

The embossing at the top of the lower front reinforcement (see orange marking in Fig. 4-3) is due to the geometry of the inner panel at this location and could be omitted in case the inner panel is flattened here. The upper front reinforcement includes the mounts for the crash and inner belt beam. Compared to the weight of the steel parts that are used to reinforce the front area of the reference door, a reduction of 35% is achieved by the two casted front reinforcements of the aluminium door concept. For the reinforcement of the rear area (Fig. 4-3 right), i.e. lower door frame, lock and connection of crash and inner belt beam, only one casting component is used. It substitutes two steel parts. The calculated thickness values of the rear reinforcement are lower compared to those of the front reinforcements. The base thickness is 2.4 mm while the thickness for the ribs is 1.5 mm (measured at top of the ribs). Due to its height of 740 mm to reinforce the rear door frame, there is no noteworthy weight reduction compared to the steel reference parts, which only include the lock area and the crash beam mount. As for the front reinforcements, the mounts for the crash and inner belt beam are part of the rear reinforcement and the design is already cast-ready. The front and rear mounts of both crash beam and inner belt beam are reinforced by straight ribs in order to transfer the loads through the door in case of a frontal crash.

Also with regard to the extrusion beams, manufacturability aspects were considered during the concept development, e.g. the minimum wall thickness. In the punching areas, a remaining flange had to be considered. Because of the thin walls of the inner rib structures, a 6063 alloy is envisaged for both extrusion beams. The assembly of the crash beam to the door module is done similar to the reference door, i.e. by means of screwing. So the same flange geometry is used, which means a rework of the flange area of the extrusion profile. As a result of the performed thickness optimisations, the extrusion profile has a thickness of 2 mm while the value for the inner rib structure is 1.5 mm, resulting in a total weight of 0.96 kg. The weight reduction in comparison to the replaced steel part amounts to 20%.

For the inner belt beam a distinction must be made between right and left door applications. The extrusion is equal but the subsequent mechanical processing is side specific (Fig. 4-4). The outer thickness of the extrusion profile is 1.8 mm, the thickness of the flanges is 2.0 mm and the thickness of the inner ribs is 1.5 mm. The end cuts are perpendicular without fillets.

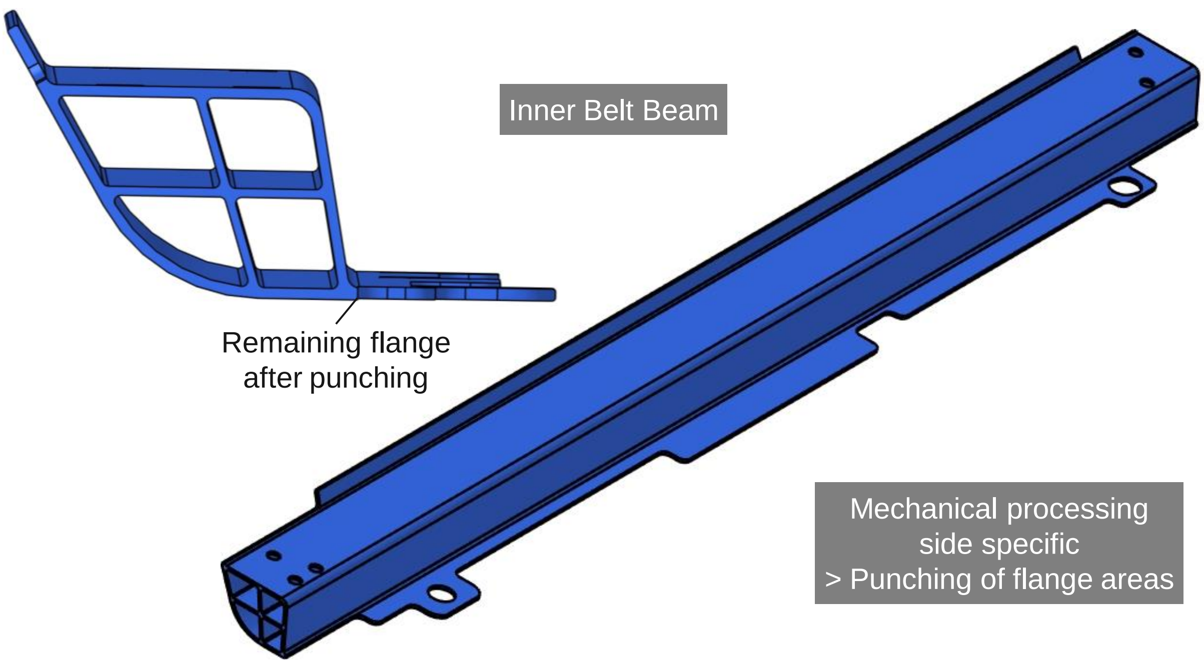

Fig. 4-4: Inner Belt Beam geometry for left door (driver's door) - V1.6

The inner belt beam fills the space between the inner panel and the outer belt beam and thereby achieves a high bending stiffness. The net weight of the inner belt beam amounts to 0.98 kg, which means a weight reduction in comparison to the replaced steel parts of 51%. Again, the flange areas need rework, particularly the lower one in order to fit to the reference design of the inner panel. A continuous flange or other ways to join crash beam and door module, which might reduce rework efforts, are conceivable as well, but these alternatives were not considered.

The largest part of the door is the inner panel. Since the outer geometry of the reference door should remain the same, only minor changes were possible. It was for example necessary to fit the inner panel geometry to the new inner belt beam. The thickness of the aluminium inner panel is 1.6 mm, which is twice as thick as the reference steel inner panel. Nevertheless, the weight saving is considerable and amounts to more than 32%. A 6016 alloy was chosen for the inner panel as well as for the outer panel and outer belt beam. Generally, the drawing depths of the inner panel geometry have already been implemented and the corresponding material is a standard product. Furthermore, the sheet thickness of 1.6 mm defined for the door concept is positive for the formability, but even with a lower sheet thickness, the present drawing depths should be achievable. An important aspect of course are the radii defined. Small radii increase the crack sensitivity. However, they reduce springback and increase the stiffness of the part. A restrike station is recommended, also with regard to the potential to further reduce the sheet thickness. Radii, which are to be restriked, do not need to be changed within the aluminium door concept on the basis of the information shared with the project partners. Nevertheless, some specifications for radius magnification in the context of a better formability were given. A drawing simulation was not performed within the project, but is recommended for a final evaluation.

Another big sheet part is the outer panel, covering the inner panel completely. Compared to the reference steel design, the thickness of the aluminium concept part is increased by 50% (from 0.8 to 1.2 mm), resulting in a mass of 4.2 kg. No further changes to the geometry were made. However, as with the inner panel, the weight saving is considerable and amounts to almost 49%. The outer panel is connected by hemming to the inner panel and the outer belt beam.

The outer belt beam (Fig. 4-2) is treated as a carry-over sheet part with adapted thickness as well. Based on the performed size optimisations, the outer belt beam thickness has been reduced by 0.2 mm compared to the reference steel design, which has a thickness of 1 mm. Thereby, its mass is reduced by 75% to only 0.4 kg. The outer belt beam is hardly relevant for the overall door stiffness due to the stiff inner belt beam design. However, it still fulfils various functions, e.g. ensuring a sufficient local stiffness for the lower mirror attachment. Since the available load cases do not allow a detailed analysis of the local stiffness requirements, the proposed outer belt beam thickness might have to be increased in order to consider all requirements. In any case, the aluminium version of the outer belt beam will remain significantly lighter than the steel design. Moreover, a possible alternative sheet design was investigated, which offers further lightweight potential.

The aluminium concept door is performing better than the steel reference door for all considered load cases while achieving a weight reduction of more than 40% compared to the related reference components. For the load cases loading the main door structure (door sag, walk on door, operator sit on door & door fall), the displacements of the aluminium door are significantly lower compared to the steel reference door. Regarding the load cases addressing mainly the frame area (lateral stiffness LC1 & LC2), which is the most challenging part of aluminium doors, the maximum displacements of the aluminium door concept are still slightly below the values of the steel reference door.

Fig. 4-5 gives an overview about thickness and weight of the different components of aluminium door concept V1.6. Additionally, the corresponding values of the steel reference door are illustrated as well.

	Aluminium Parts V1.6		Corresponding Steel Parts	
Part	Thickness [mm]	Weight [kg]	Thickness [mm]	Weight [kg]
Crash Beam	2 / 1.5 *(ribs)*	0.96	1.5	1.2
Inner Belt Beam	1.8 / 2 / 1.5 *(ribs)*	0.98	1.2 - 1.5	2
Reinf. Front Upper & Lower	4 / 1.6 *(upper ribs)*	2.1	1.2 - 2.5	3.3
Reinforcement Rear	2.4 / 1.5 *(ribs)*	0.95	1.5	1
Inner Panel	1.6	5.2	0.8	7.7
Outer Panel	1.2	4.2	0.8	8.2
Bracket	2	0.06	1.5	0.14
Outer Belt Beam	0.8	0.4	1	1.6
Attachments	1.5 / 2	0.12	1 / 1.5	0.25
Total Weight BIW *		14.97		25.4
		- 41%*		

Aluminium Extrusion
Aluminium Cast **
Carry over Sheet Parts *(only material substitution & adapted thickness)*

* *Without hinges, lock, window guides & mechanism, door module, outer door extension*

** *Weight of casting parts already considers design suitable for casting*

Fig. 4-5: Aluminium Door Concept V1.6 - Weight Balance

This weight balance does not represent the whole door assembly since some components are not considered in the re-design, such as hinges, lock, window guides and mechanism, door module as well as the outer door extension. Hinges, lock and window mechanism will remain the same, while the outer door extension is already made out of aluminium. The window guides would offer additional lightweight potential if they were made of aluminium. The same applies to the door module (Fig. 4-1). A carry over part out of aluminium with an adapted thickness, as considered within the simulations, would more than halve the component weight. Adding the aluminium door module to the weight balance results in an overall weight reduction of 42%.

5 Joining Concept

In general, a distinction can be made between the joining of components to the inner panel, the joining of the extrusion beams to the casted reinforcements and the joining of the extrusion crash beam to the door module. With regard to the components joined to the inner panel, there are various joining constellations, as illustrated for the casting and extrusion components in Fig. 5-1, resulting in different material and thickness combinations. There are sheet-to-sheet, extrusion-to-sheet as well as casting-to-sheet joints.

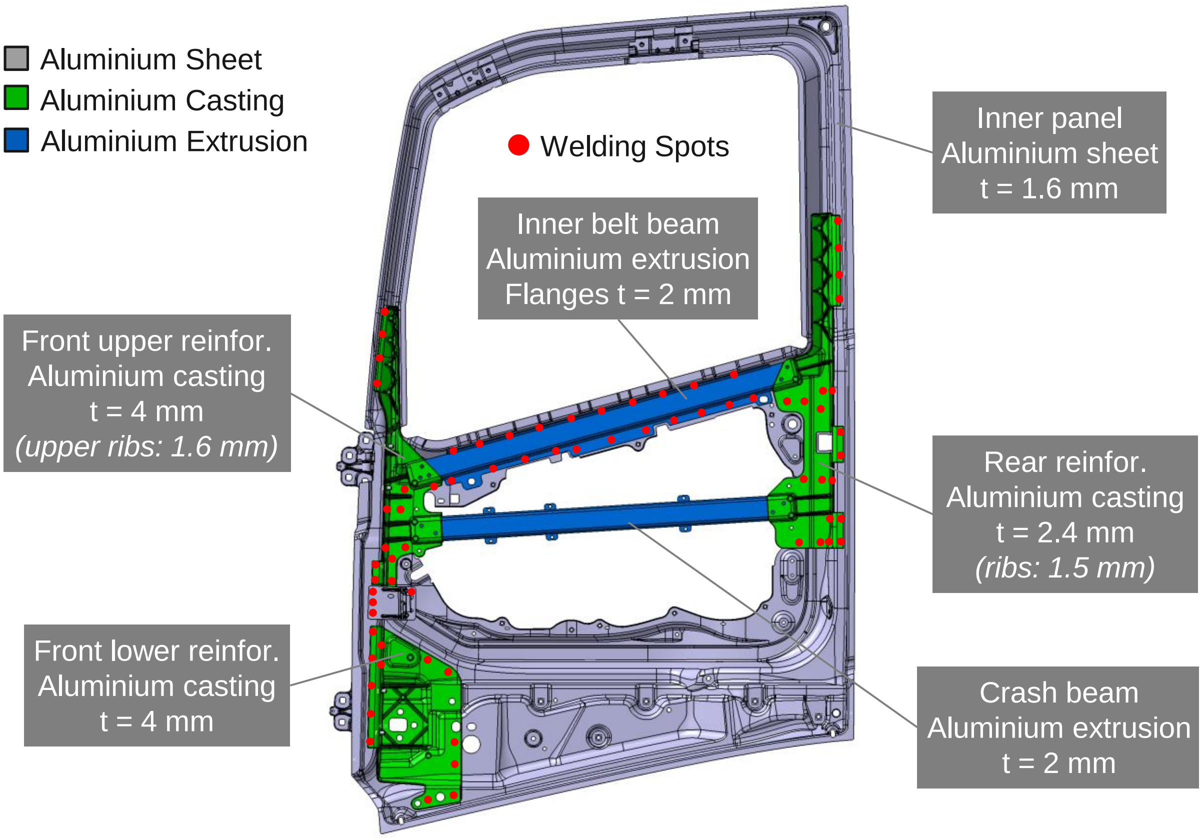

Fig. 5-1: Components to Inner Panel - Overview joining constellations

The intended joining technology for the casting-to-sheet joints is laser welding. It fulfils the requirements regarding accessibility, suitability for visible joints, small or no flanges and is an established process in automotive body production. Due to the advantages it offers, laser welding is the intended joining technology for the sheet-to-sheet joints as well. Regarding the extrusion components, only the inner belt beam is joint to the inner panel. Here, the general boundary conditions are less challenging. A two-sided accessibility is given and the welding flange widths lie between 10 mm and 25 mm. Nevertheless, there is limited space on the outer sides. In order to be consistent with the other inner panel joints, laser welding was chosen for the connection of the inner belt beam as well.

In order to join the extrusion profiles with the casted reinforcements, flowdrill screws (FDS) in combination with adhesive are intended. Flow drill screws are economic, offer one-sided accessibility and tolerance problems do not apply. They are used for the joining of the door module and the crash beam as well, but without additional adhesive so that the door module is detachable.

6 Cost estimation

Finally, a first cost estimation was done for the aluminium casting and extrusion parts based on two scenarios defined by Volvo Trucks regarding the annual number of units. For each component, the total costs per part as well as the tooling costs were calculated. These calculations were done by corresponding European Aluminium member companies. Depending on the scenario, and the aluminium alloy considered, the manufacturing costs for the three casting parts vary between 22.70 € and 27.10 € per door (without tooling costs). For the two extrusion parts, the resulting manufacturing costs per door are about 8.50 € (again without tooling costs).

7 Summary

European Aluminium initiated a research project regarding the use of aluminium in future trucks. The cabin door was chosen as reference assembly to be investigated since the cabin door is a hang-on part and therefore well integrable into the current steel design of truck cabins. Furthermore, it has high stiffness requirements, which are similar for all OEMs, and allows the implementation of aluminium sheet, extrusion as well as casting applications.

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