NEW ALUMINIUM SOLUTIONS FOR CAR BODIES AND CHASSIS

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Abstract

Aluminium is now recognized as a material of choice for car bodies and chassis. However challenges remain in order for aluminium to become a real "game changing" material. This paper describes these challenges for semi-products and components

Introduction

The use of wrought aluminium products has recently been extended to very high volume automotive programs with aluminium components in chassis and car bodies.

Key drivers for aluminium in cars are well known, performance, safety, design, environmental friendliness and above all fuel economy especially in view of the ever increasing vehicle weight (Figure 1)

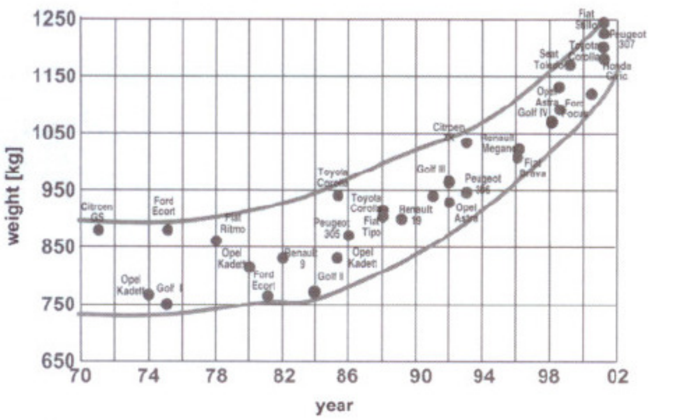

Figure 1: Increasing mass of the European mid-size models

The tremendously differing possibilities offered for aluminium in terms of production of semis and their forming certainly constitutes an advantage over steel (Figure 2).

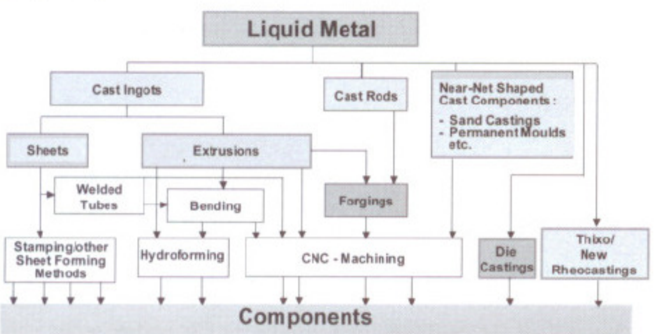

Figure 2: Available aluminium components from liquid metal

However the most significant approach explaining the increased use of aluminium is that of the "multi materials" as exemplified in Figure 3

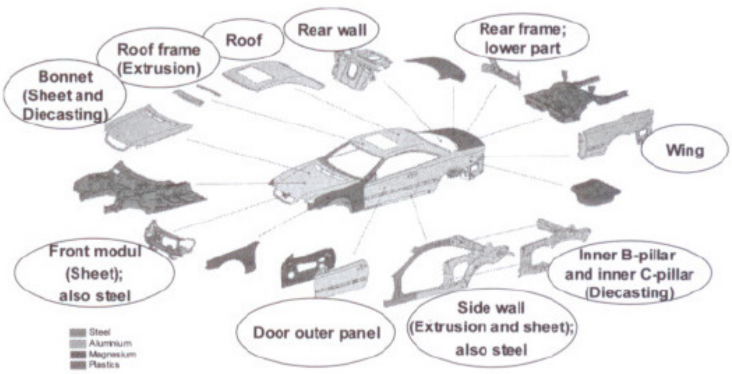

Figure 3: Multi material use on the DC CL model (Source: Automobilentwicklung 04/99)

The economics of the competition between steel and aluminium have been derived elsewhere [1,2] and basically it is now agreed that aluminium offers an economically sound alternative to steel in most cases as long as weight savings are higher than roughly 40%.

Results are self-explanatory. The average use of aluminium in cars in Europe has increased from 50 kg in 1990 to 150 kg today, expected to reach 220 kg by 2015 (Figure 4)

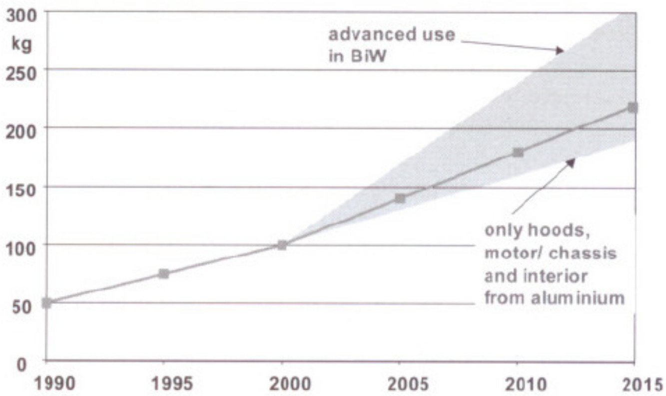

Figure 4: Average use of aluminium in cars in Europe [3]

Successful integration of aluminium also requires the continuous optimisation of the entire value chain from raw material to processing both at the aluminium producer and at the automotive manufacturer including scrap generation and reclamation. The objective of this paper is to underline some technical aspects of this optimisation on current aluminium wrought semis (excluding castings also produced by Alcan) and on new solutions currently at the development stage. Focus will be on components made out of sheet and extruded semi-products bearing in mind that optimal technical choice depends largely upon production volumes (Figure 5). For example sheet forming requires high tooling costs which are better amortized for high volume production

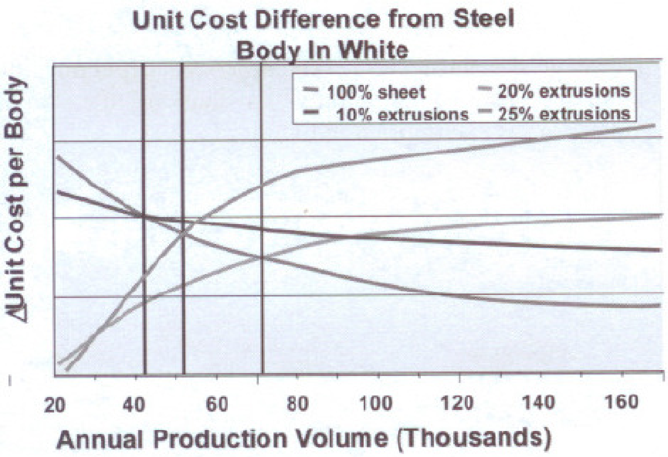

Figure 5: Influence of Sheet/Extrusion ratio on costs

Recent reviews have already summarized major alloy and material development in the field of rolled products. The most significant are:

-Bake hardening alloys (Alcan's "DR" alloys) combining high formability during stamping and high dent resistance after paint baking [4].

-Special surfaces including EDT (Electric Discharge Texturing) and dry lubrication. Figure 6 illustrates the effects of these special surfaces on formability of a door inner panel made out of different alloys.

For automakers there are certain differences between using aluminium rather than steel sheets so that a learning curve is always observed when aluminium is introduced in a stamping line. Such a learning curve due to sliver occurrence on outer hood blanks for a very high volume car is shown in Figure 7 where cleaning stamping die frequency is plotted as a function of time.

This learning curve, which is not repeated when the automaker is simply changing models while continuing with aluminium, can also be much improved by a better understanding of the damage behaviour of the alloy at the tip of trimming blades greatly influenced by blade sharpness, coating and general trimming configuration [5].

Springback behaviour also constitutes a known difference between steel and aluminium. However the introduction of new steel grades leads to equivalent, if not larger, issues (Figure 8). Recent advances in numerical simulation allow for an improved springback prediction such as twist and strain induced distortions during stamping.

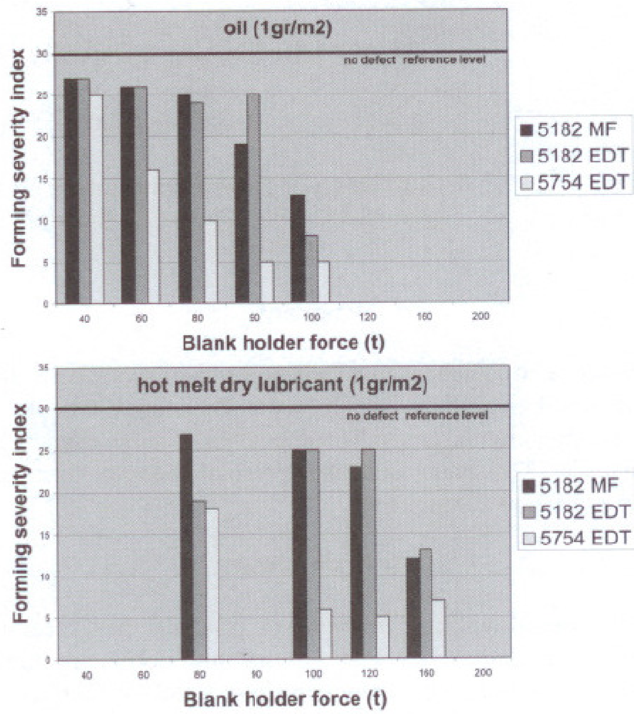

Figure 6: Effect of surface texture, lubrication, alloys and blank holder force on formability. Higher forming severity index implies better performance in terms of all surface defects after stamping. MF: Mill Finish as opposed to EDT

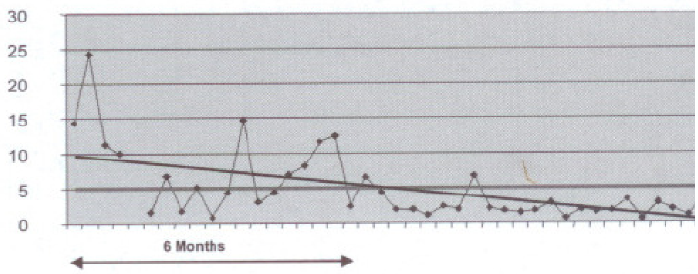

Figure 7: Number of stamping die cleaning operations for 1000 hoods

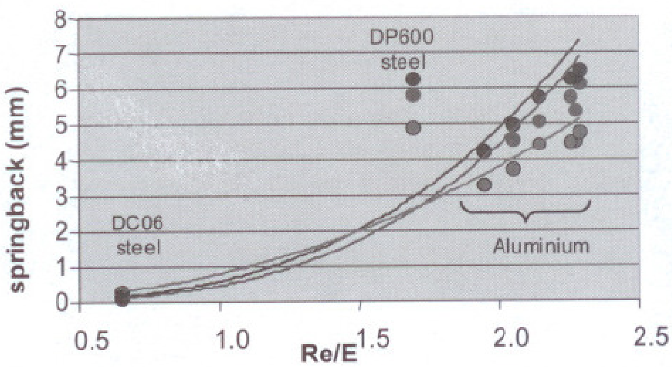

Figure 8: Springback on an outer door panel (R: Yield strength, e: thickness, E: Young's modulus)

The technical and economical viability of using aluminium for high volume production cars has now been fully demonstrated for some components like hoods, tailgates… However some uncertainties still remain for the economic viability of high volume doors for example. Weight gains of existing models barely exceed 35% and new design and joining techniques are necessary to achieve 45% weight gains. These techniques include the use of tailored blanks for the inner panel and extensive studies, in particular at the Alcan Research Center in Voreppe, have shown that Friction Stir Welding is clearly the method of choice over Laser Welding for process reliability and economics.

Figure 9: Friction Stir Welding, 5182 alloy, tailored blanks (1,2 mm/2,5 mm)

Maximizing weight gain on the top of the car is particularly interesting since it lowers the centre of gravity thus greatly improving handling. However, the use of aluminium for the roof on a steel structure constitutes a challenge because of differential dilatation between steel and aluminium during the paint baking operation causing the aluminium to buckle. In addition to solutions based on design and assembly, new 6XXX alloys are being developed to tackle this issue particularly observed on standard alloys such as AA6016 (Figure 10)

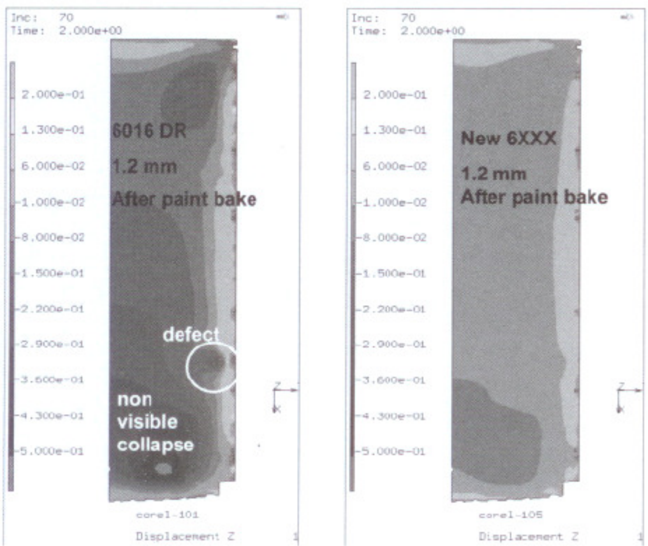

Figure 10: Numerical simulation of the buckling of an aluminium roof on a steel structure during paint baking

The observed improvement stems for the higher strength measured at the paint baking temperature (Figure 11)

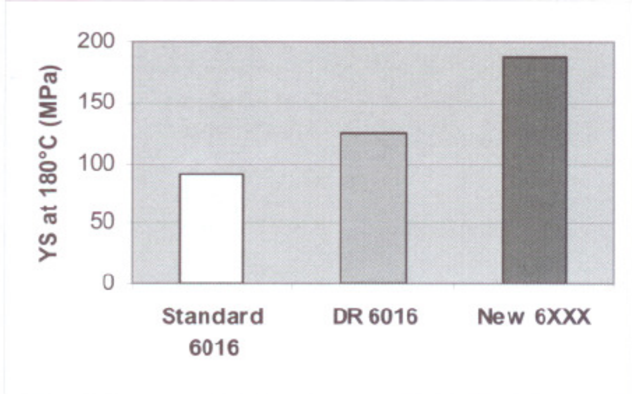

Figure 11: Yield Strength at 180°C of 6016 and new 6XXX alloys

Achievements and new challenges for extruded semi-products

One of the main characteristics of aluminium extrusions is their extraordinary diversity in terms of shape, mechanical properties (yield strengths typically vary from 60 to 400 MPa) and consequently applications in the automotive industry. Extrusions are found in most inner parts of any aluminium modules such as structure (space frame, reinforcement beams in doors…), suspension parts and all crash related components (bumpers, front end and door safety systems…). Properties of extrusions are for example easily customized by slightly varying the final aging treatment (Figure 12)

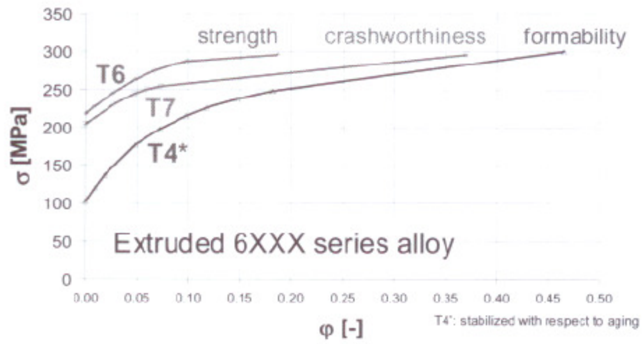

Figure 12: Tailoring properties with aging treatment

Crash behaviour of aluminium extrusions is of particular interest since the deformation energy of a beam varies as $t^{5/3}$ where t is the wall thickness. Consequently 40 to 50% weight reductions are readily available compared to an equivalent steel beam. Obviously even larger reductions are achieved when inner walls and function integration are added to aluminium extrusions. Crash behaviour may be characterized in bending or axial compression. Figure 13 shows such quantification for axial crash.

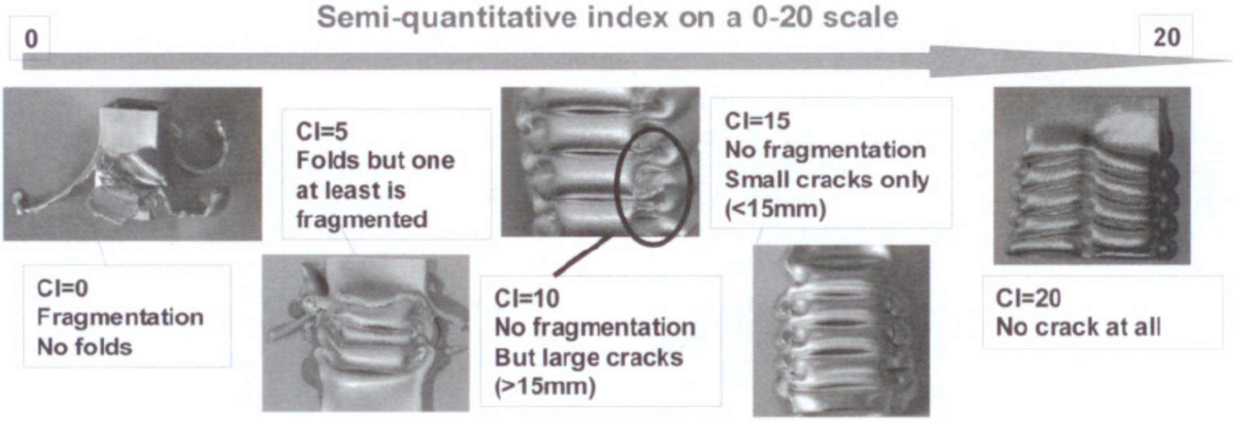

Figure 13: Semi-quantitative scale of axial crash behaviour

Crash behaviour is influenced by all steps of the extrusion manufacturing, chemical composition, homogenizing before extrusion, extrusion itself, quenching have a definite impact. Most striking is the influence of final aging. This is illustrated in Figure 14 for two quenching conditions on 6005A alloy. Overaging clearly helps crash behaviour while guarantying in service stability.

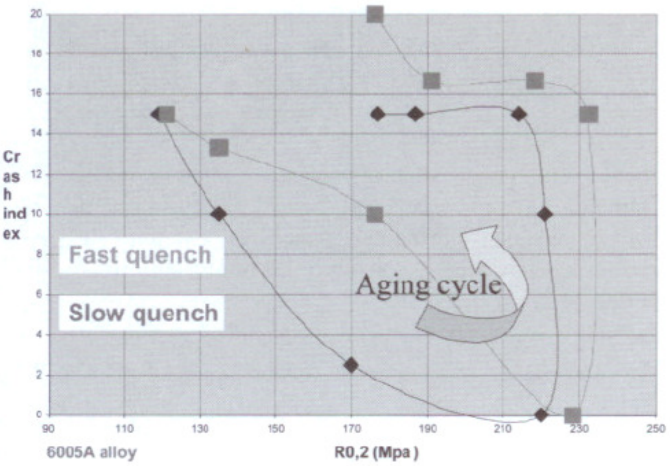

Figure 14: Effect of aging and quenching steps on crash behaviour of 6005A alloy vs yield strength

In addition to developing new alloys for high strength and crash application (especially for intricate extrusions where fast quenching is not possible), current challenges for aluminium extrusions include obtaining better mechanical and geometrical tolerances and increasing extrusion speed for optimum productivity.

Table 1 illustrates the current standard tolerances. Wall thickness tolerances should particularly be improved since final weight is typically computed from the minimal thickness given by design calculations to which must be added half of the tolerance. Some producers like Alcan are able to guarantee better tolerances but room for improvement exist particularly with the help of computer assisted die design.

All dimensions mm - CD is the profile circumscribing circle diameter

1 PROFILE CROSS SECTIONAL WIDTH TOLERANCES

	CD max 200		CD max 500	
	Extrusion width		Extrusion width	
	25max	50max	300max	450max
ALLOY GROUP I	±0.40	±0.60	±2.1	±2.8
ALLOY GROUP II	±0.70	±0.90	±2.8	±3.5

2 PROFILE WALL THICKNESS TOLERANCES (Up to max 300 CD)

	no hollows		no side hollow		Both sides hollows	
Wall thickness max.	1.3	3.0	1.3	3.0	1.3	3.0
ALLOY GROUP I	±0.20	±0.25	±0.30	±0.40	±0.35	±0.50
ALLOY GROUP II	±0.25	±0.30	±0.40	±0.50	±0.50	±0.65

Alloys Group I; EN6060, EN6008, EN6106, EN6005A, EN6063, AA6014
Alloys group II; EN 6082, EN6016

Table 1: Standard (EN 755-9) extrusion tolerances

Increasing extrusion speeds is a continuous challenge knowing that the overall economic balance strongly depends on alloy type and extrusion complexity (Figure 15)

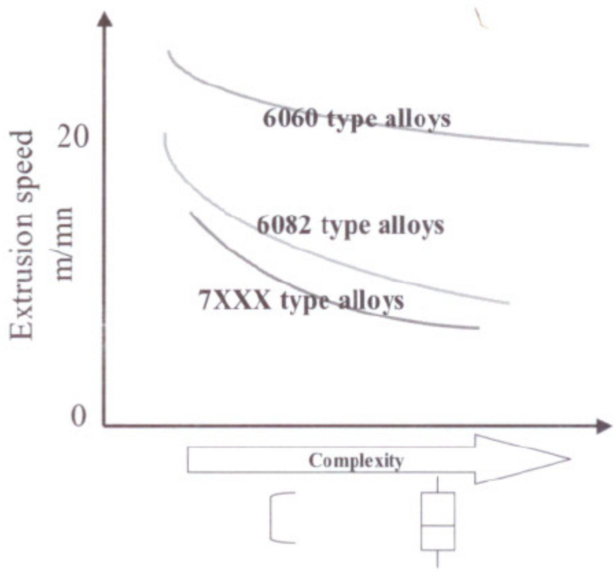

Figure 15: Typical extrusion speeds as a function of shape complexity and alloys

The use of numerical modelling is obviously of great help to infer and improve extrusion speeds, as well as the deep knowledge of microstructural changes occurring during preheating stages that have a definite influence on flow stress and extrusion speed; Such changes are illustrated in Figure 16.

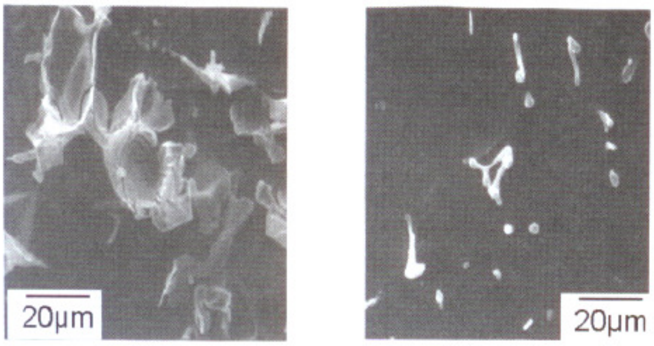

Figure 16: Phase transformation in a 6060 alloy from casting to preheating 48h at 580°C

Achievements and new challenges for components

The design of a lightweight and crashworthy car body requires that all structural components contribute to the safety concept of the vehicle. Therefore it is most important that the other aluminium structural modules which may be built into the car are also optimised from a crashworthiness point of view. The crashworthiness of the alloy and not its strength often dominates the decision of the type of alloy and the heat treatment.

Body in White

All current aluminium car models show an extremely good crash performance as exemplified for instance by the Audi A8 with its aluminium spaceframe consisting of large structural die castings and fabricated (bent / hydroformed) extruded profiles or the sheet-intensive monocoque body structure of the Jaguar XJ (Figure 17). Also the all-aluminium front end of the BMW 5XXX model proves the excellent crash behaviour of a lightweight structure.

Figure 17: Aluminium body concepts offer excellent crash performance and significant weight reduction (> 40 %)

But there is no need to change to the complete aluminium body structure to benefit from the obvious advantages of aluminium in crash management applications. Even though different steel grades are still the dominating construction material for the stiff passenger cell, which ensures occupant protection in high-speed crash situations, aluminium has made significant inroads in applications such as bumpers, side impact beams and other crash-relevant structural modules. Today, crashworthy aluminium designs are not only used in niche volume production, but also for large series models where cost-effectiveness has a high priority.

Safety Systems: Aluminium Bumper Modules

The primary function of the bumper system is the protection of the vehicle in a low speed crash (no damage of functionally relevant parts and only defined, limited damage to other vehicle components). In addition, the bumper system plays an important role within the total passive safety concept of the vehicle and has to satisfy all pedestrian protection requirements in particular in relation with lower leg impact (for SUV's also upper leg impact).

Today's aluminium bumper concepts involve a bent, extruded hollow beam which absorbs the total low speed crash energy (up to 8 km/h) through deformation and two longitudinal crash boxes that absorb the energy of an impact up to 16 km/h and therefore prevent any damage to the rest of the vehicle. The crash boxes are connected to the longitudinal members by brackets (Figure 18).

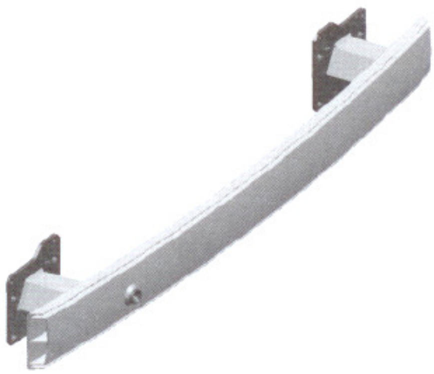

Figure 18: Aluminium cross member with steel crash boxes for high volume production

The application of aluminium extrusions allows for an optional initial deformation of the transverse beam and the crash box ensuring highly controlled energy absorption characteristics.

Today Alcan alone produces more than 4 millions bumpers per year in Europe and is starting production in America

Safety System: Aluminium Side Impact Beam

Extruded aluminium side impact beams have been used for years for their good energy absorption characteristics and buckling performance, but are recently being challenged more and more by steel designs based on new highest strength qualities. However, the total systems approach still allows the offer of innovative aluminium solutions, which are competitive on a cost per kg weight saved basis by a load-oriented cross section design with varying wall thickness. In addition, innovative solutions for easy assembly of the aluminium part without any surface protection into a steel door have been developed, i.e. by bolting or spot welding with the help of a steel sheet stamping previously riveted to the aluminium beam (Figure 19). For the future, new opportunities are opened by the need for improved side impact protection using the sill member as an additional reinforcement. In this context, it may be interesting to note the possibility to integrate an extruded, multi-chamber aluminium sill section into the steel body which acts as a stiff member in the longitudinal direction, but readily absorbs side crash energy.

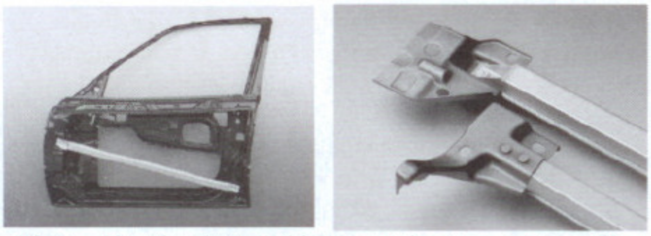

Figure 19: Aluminium side impact beams can be easily integrated in a steel door

Sub-frame Structures

Subframes are linked to the chassis of cars and are used as engine mounting, suspension cradle and drive shaft holder. Welding sidemembers and crossmembers into a square structure with complex cast parts and extrusions makes engine and suspension sub frame structure. It is a structural, highly dynamic loaded part with many load transmission points. Lightweight aluminium solutions are increasingly applied, because of the design freedom of the different sub components, which allow a better use of the design space. Figure 20 shows a sub frame study consisting of a large cast part linked to an extrusion extension.

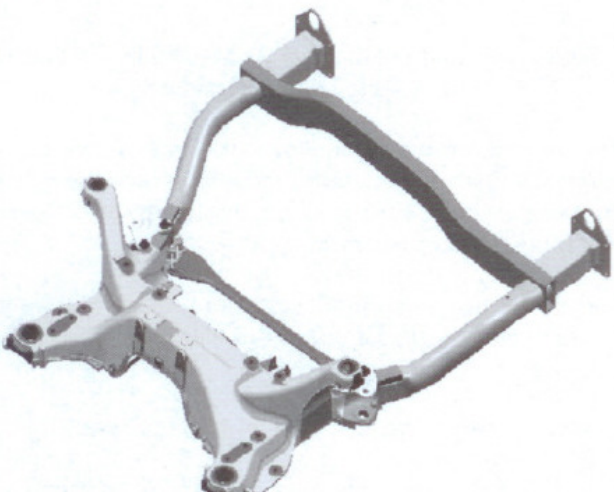

Figure 20: Cast aluminium subframe with an extrusion (courtesy of PSA)

Cockpit Carrier

Figure 21 shows as an example an aluminium cockpit carrier, which combines different aluminium product forms. In this case, a significant weight reduction compared to the steel solution was achieved with superior crash performance along with excellent NVH (Noise Vibration Harshness). The chosen multi-product design using innovative joining technologies ensures lowest possible system costs.

Figure 21: Aluminium cockpit carrier for high volume production with a transverse beam joined by non-vacuum electron beam welding

Conclusion

Great progresses for aluminium in the automotive industry have been achieved at a very rapid rate. It is now recognized that aluminium meets most of the technical and economical challenges. It is also expected that further progress in semi-product, component characteristics and use of hybrid structures will ensure the continuous increase in the market share of aluminium with respect to steel.

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