LIGHT WEIGHT BODY STRUCTURE WITH ALUMINIUM SPACE FRAME

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Abstract

Current and expected future legislation regarding ecology, emissions and safety poses a major challenge to the automotive industry. Besides engine developments, reduction of vehicle weight plays an important role in meeting the environmental challenge. A main target for weight reduction is the body itself that constitutes an automobile's largest component with up to 25% of the total vehicle mass. By using aluminium instead of conventional steel a weight saving of up to 50% for a body in white can be achieved.

Aluminium space frame structures, utilising extrusions to a large extent, offer an interesting alternative for a lightweight body and have received increasing attention in concept cars.

The purpose of this paper is to give a general overview of aluminium space frame issues such as design principles, alloy selection, crash behaviour, corrosion, joints and joining methods, recycling, tooling cost and ecology.

Introduction

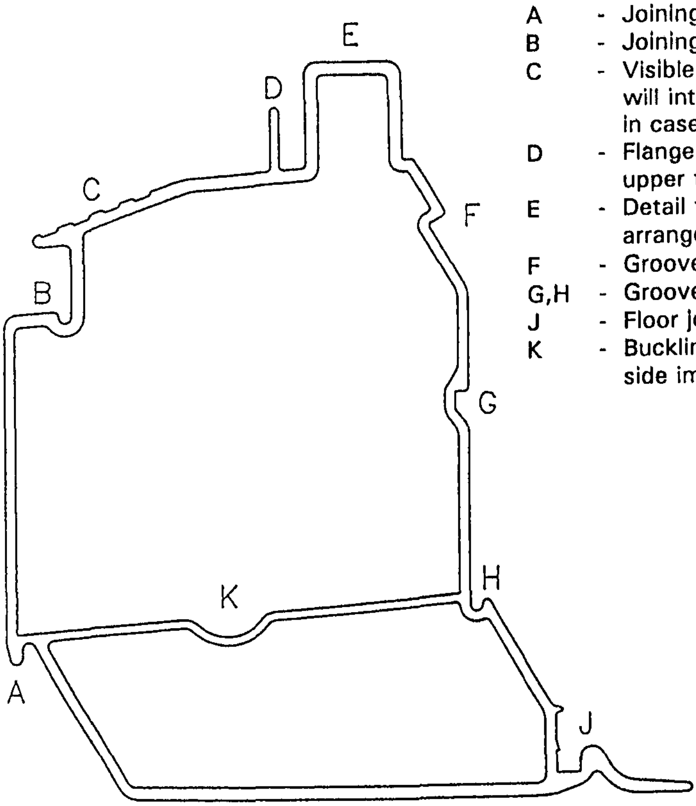
Today the automotive industry is using more than 20% of the aluminium produced in the Western world thus representing the largest single user.

One major challenge for the automotive industry is to react properly to increasing environmental awareness in public opinion and resulting legislation. Current laws and laws under review show a clear request for automobiles with reduced emission values and energy consumption. The weight of a vehicle plays an important role and the body structure, representing up to 25% of the curb weight, can be considered a main target for reducing weight. Various results have shown that by using aluminium instead of steel as structural material, the body-in-white weight can be reduced up to 50%. Due to the fact that aluminium raw material is about 4 times more expensive than steel, it is necessary for acceptable body-in-white costs to use aluminium specific design and production processes. The aluminium space frame concept, which utilises a framework of mainly extrusions, offers that possibility and presents a large growth potential for aluminium in the automotive industry.

Aluminium extrusions are characterised by low tooling costs, short tooling lead times and a high degree of production flexibility. The particular shape and alloy selection depend on technical requirements such as strength, stiffness, crash, formability, corrosion, recycling and cost driven production issues such as extrusion press productivity, bending process, joining method and assembly sequence.

Integration of functions.

In order to utilise the full potential of extruded section the greatest possible number of functions should be integrated into the section. This will have very little influence on the cost of the section, but permits a reduction of the mounting parts. In Figures 1 and 2 a sill section with and without additional pieces illustrates this important principle.



A - Joining groove outer trim
B - Joining groove outer trim
C - Visible surface; the flange will interlock with the door in case of a side impact.
D - Flange for door seal and upper trim
E - Detail to protect seal and arrangement for upper trim
F - Groove for floor carpet
G,H - Grooves for seat console
J - Floor joining detail
K - Buckling initiator in case of side impact

Figure 1 Example of Integration of Function on a Sill Member (circumscribed circle 176 mm in diameter)

A	-	Joining groove outer trim
B	-	Joining groove outer trim
C	-	Visible surface; the flange will interlock with the door in case of a side impact.
D	-	Flange for door seal and upper trim
E	-	Detail to protect seal and arrangement for upper trim
F	-	Groove for floor carpet
G,H	-	Grooves for seat console
J	-	Floor joining detail
K	-	Buckling initiator in case of side impact

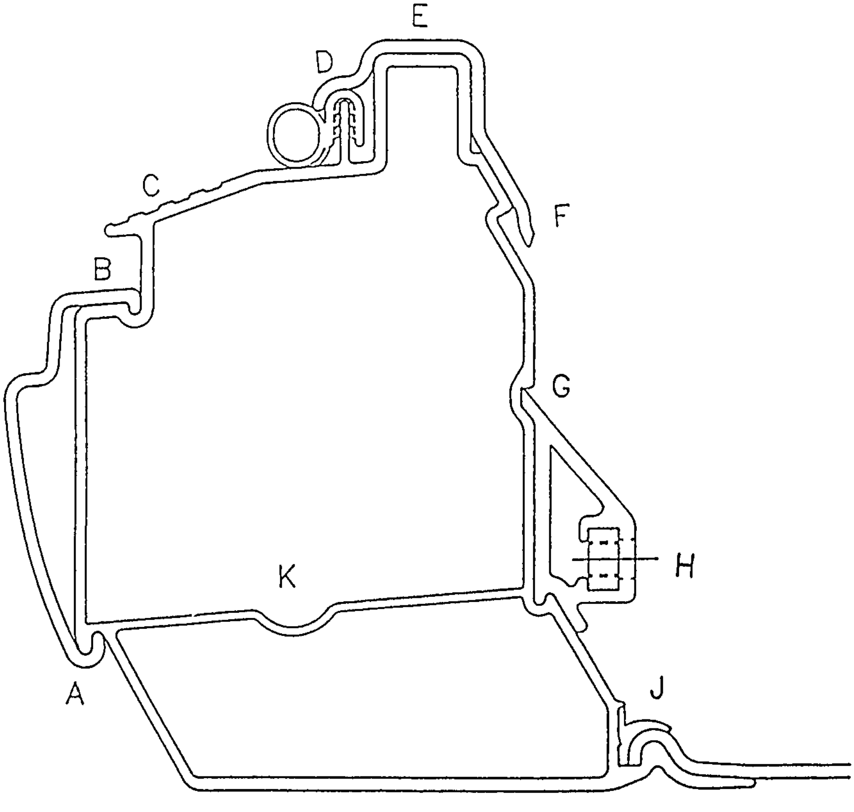


Figure 2 Sill Member with Attachments (c.f. Figure 1)

Joining of extrusions

In principle stiff connection between two or more extrusions can be made by directly joining the profiles or with the aid of an additional joining element such as extruded section, sheet, forging or casting part.

Figure 3 and 4 shows a joint solution without an additional part. The mutual penetration of the members that have joined is an important factor with regard to stiffness and stability in a crash situation. To obtain a cost favourable solution the joint design should be done by machining the section ends with simple processes, as e.g. punching or straight sawing.

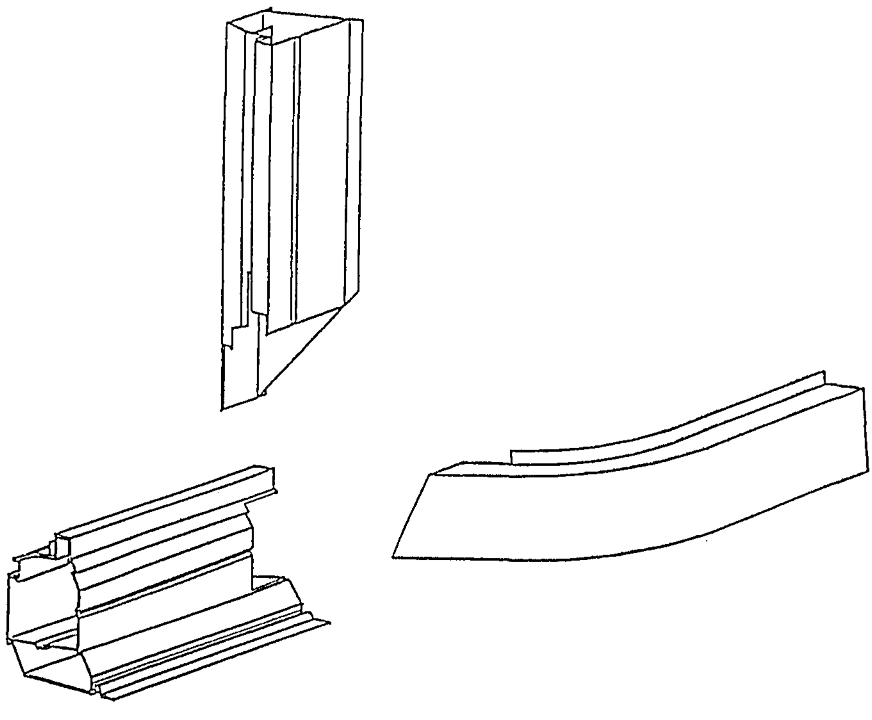


Figure 3 Direct Joining of Extrusions

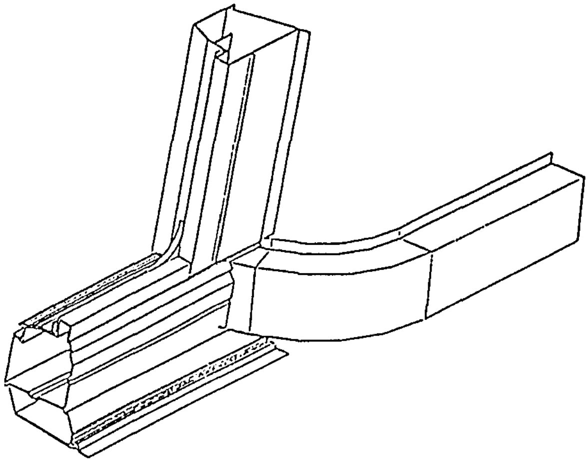


Figure 4 Structural Joint without additional Elements (c.f. Figure 3)

Figure 5 illustrates a joining of 3 sections by means of an extruded section adapter. The integration of other functions, as e.g. suspension arms or similar, in the adapter is also possible.

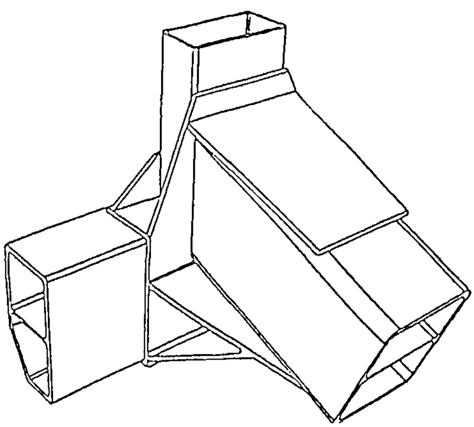


Figure 5 Joint with an Extruded Connector

Figure 6 illustrates the principle of joining two sections by means of sheet parts. This joining method, like cast nodes, permits a good stress distribution, stiffness, ability to take up tolerances and the possibility to integrate functions in the joining element, e.g. wheel housing, shock absorber, mounting etc. It increases however the total joining length. For all the joint types it is possible to weld or bond and mechanically fasten. During arc welding one should be aware that the weld, with its heat affected zone, in which up to 40% lower mechanical strength properties can occur, follows a three-dimensional path. Otherwise closed, "soft" areas are lying in one plane which in a crash situation can give problems.

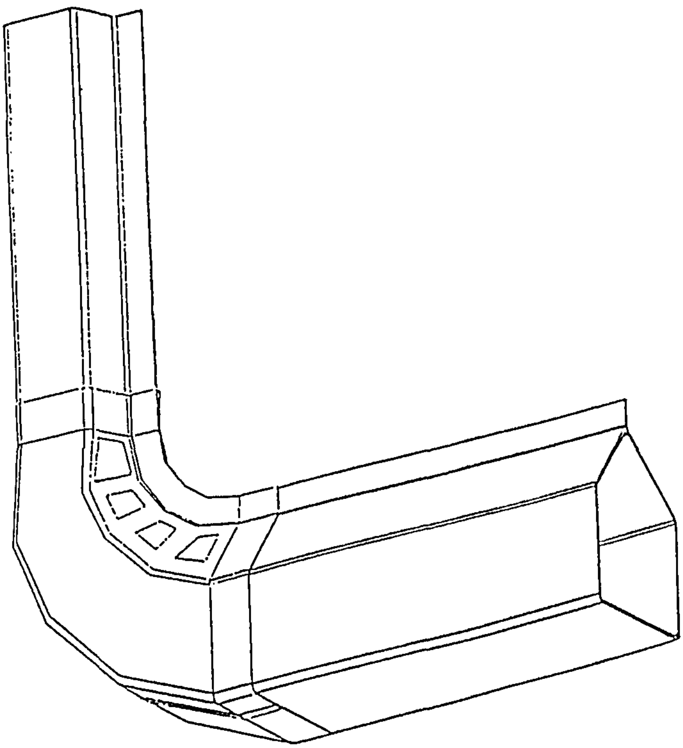


Figure 6 Extrusion Joining with Sheet Stamping

In Figure 7 a joint principle is obtained from a multichamber section.

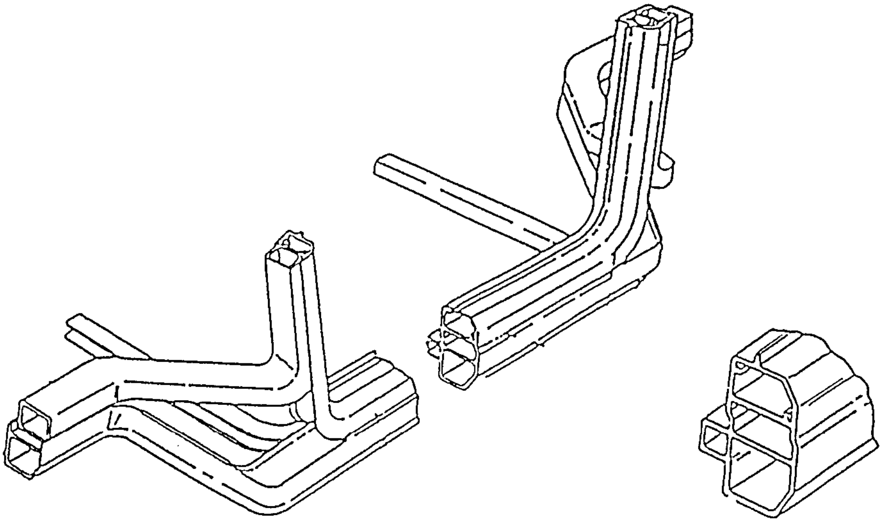


Figure 7 Joint through Split Extrusion
The middle chamber of the member is split lengthwise in the illustrated example. The lower chamber continues in the original direction and the upper chamber takes a new course.

In Figure 8 a joining method which can only be used in combination with extrusions is shown; especially floor areas where relative straight parts are present can utilise such permanent interlocking.

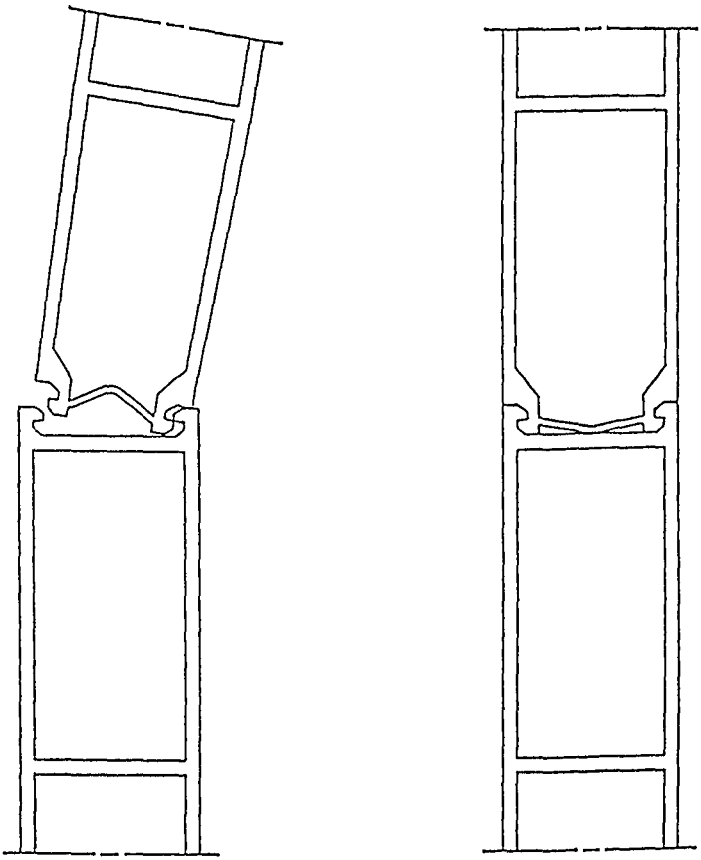


Figure 8 Longitudinal Joining of Extrusions

Proper joint design is critically important for a successful space frame concept. Important criteria are packaging, technical requirements (stiffness, crash), joining lengths, method of joining, production, feasibility, cost and the production volume which has influence on the acceptable investment costs.

Joining of sheet to extrusion

The joining of sheets with extrusions is normally done to an attachment flange on the extrusion. For this a number of methods are available such as arc welding, spot welding, laser beam welding, bonding, self piercing rivets and other mechanical joining.

Several extruded joint details are available for sheet connections. Figure 9 shows the principle of a mechanical joining method. The sheet is fastened by means of a V-shaped expansion profile that is deformed through a rolling or press cycle during assembly.

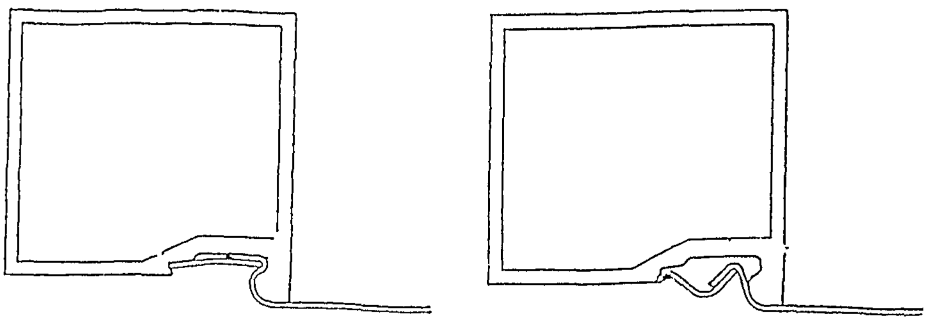


Figure 9 Mechanical Fastening Sheet/Extrusion

If such a joining is carried out continuously it shows considerably better properties than spot welding with respect to strength and stiffness. Other advantages of this joining technology are ease of repair and free choice of sheet material (steel, aluminium, plastic). For acoustic reasons and to avoid the contact in a steel-aluminium construction a sealant is used.

Crash

In principle, for typical crash member dimensions, an extruded aluminium profile can absorb twice as much energy as a steel sheet member of the same weight. In both cases this happens through formation of buckles. In spot welded members problems with the opening of spot welds can occur especially in case of structures that have been on the road for some time.

Figure 10 shows the influence on the "crush force" of a section with the same outer dimensions in one-chamber and three-chamber lay out. In general the deformation curve will flatten out with increasing number of chambers after peak load as smaller buckles are formed. In the example of Figure 10 the energy absorption for the three chamber profile is approximately twice that of the single chamber with a weight increase of ca. 20%.

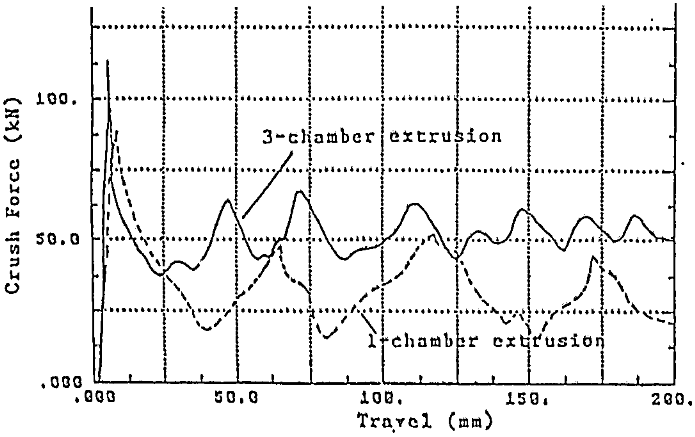


Figure 10 Quasi static crush experiment with one- and three-chamber extrusion with same outer dimensions (160 x 65 mm, 1.7 mm wall thickness, AlMgSi0.5)

Usually a crash member with a "soft" front part is desired for introduction of buckling with not too high a peak force and in the case of curved members, to avoid a high load on the structural joints (Figure 11).

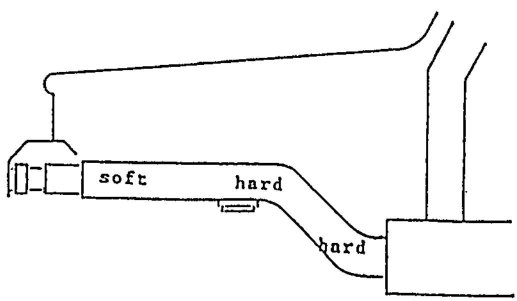


Figure 11 Soft and hard zones in a crash member

Instead of geometrical modifications of the crash member achieving lower peak loads, such as holes, slots or similar, a soft area, in which the wrinkling is initiated, can also be achieved metallurgically. The area, in treatment (overaging) can take place after the standard heat treatment of the whole member.

The yield points in the soft and hard zones can be adjusted up to a maximum of 45% difference. Figure 12 shows a "force-displacement" curve of a typical crash member (Alloy AlMgSi0.5) with and without additional heat treatment. The different force levels during buckling in the soft and hard zone appear clearly.

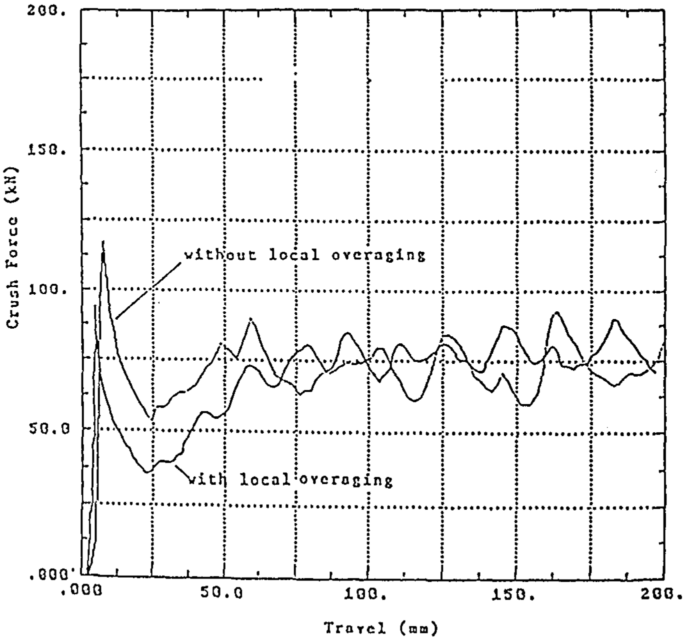


Figure 12 Quasi Static Crush Experiment with and without Soft Zone

The curves in figure 10 and 12 were determined by quasi-static tests. In case of higher strain rates, as e.g. impact at 35 mph, the loads are increased by ca. 20% to 30% due to inertia effects.

Corrosion

The experiences from the transport - and offshore industry show that extrusions of the 6000 alloy family without special surface protection can be used. Surface reactions occur which technically are unimportant, but cosmetically do not permit applications in the visible area of the automobile. If it is possible to move the space frame structure to the invisible area by covering trim and skin, costs and investments for surface treatment can be greatly reduced.

Alloys

Alloy selection has to be determined by technical criteria, such as strength, stiffness, crash behaviour, required forming, corrosion, recycling, and by cost effective production methods, such as extrusion press productivity, bending process, joining principle (welding, bonding, mechanical fastening) and sequence of assembly.

Generally aluminium extrusions show at least twice the wall thickness as comparable steel members, caused by stiffness requirements. By taking this into account the following table on mechanical properties demonstrates that the most common extrusion alloys (6000 family) are strengthwise on the conservative side. Because of their good properties with respect to extrusion capability, forming, corrosion and welding the 6000 alloys are an excellent choice for space frame applications.

	Rp(0,2) (MPa)	Rm (MPa)	A5 (%)	Temper
5182	110	250	13	H
6060/6063	195	245	15	T6
6005	225	270	8	T6
6082	260	310	10	T6
2017	230	380	10	T6
7020	290	350	10	T6
Mild steel	185	310	30	T6

Table: Mechanical Properties

Bending

There are several bending/forming methods available such as roll bending, stretch bending, press bending, hydro forming etc. The choice of methods, or combination of methods, is governed by the complexity of the final member, the required tolerances and by the production volume which in turn dictates the allowable investment (special versus universal equipment). 6XXX alloys are preferably bent in the soft condition where the ductility values are over 20%. Heat treatment to maximum strength is then performed after the final forming operation.

Ecological and financial aspects

The energy needed to produce one kilogram of aluminium is about four times that of steel, i.e. 40kWh versus 10kWh, respectively. It can be shown, however, that due to the lower weight of an aluminium body, the reduced fuel consumption pays off in terms of total energy within two to five driving years. If one considers the fact that recycled aluminium consumes only 5% of the primary energy, the time needed to be more energy efficient is even shorter than a steel body. Results from complete life-cycle studies show the strong competitiveness of aluminium.

From a financial point of view, it can be said that low weight bodies out of aluminium will achieve success in commercial production if the cost figures are acceptable. Since the metal price of an aluminium body will be higher than that of a steel body, a cost reduction has to focus on special designs that demand cost effective production methods. This makes the space frame concept with extrusions very interesting.

Extrusion tooling prices for typical space frame applications (circumscribed circles between 50 and 250 mm) are in the order of 600. - to 13,000. - US$. Forming tooling for extrusions is also lower in cost compared to stamping/deep drawing tools for sheet. The investment and tooling cost for a space frame will therefore be definitely lower than for a steel unibody construction. According to the present stage of development it has been shown that aluminium space frame constructions present a cost advantage up to several 10,000 units per year. It is expected that several vehicles in that production range will be commercialised world-wide within this decade. Commercial applications of that technology in large scale mass production may have to wait until after the year 2000. A prerequisite for mass production is a close co-operation between the aluminium and car industry which has to deal with the development and implementation of not only suitable space frame packaging and low cost production technologies but also to deal with aspects of metal supply, recycling and elimination of raw material price fluctuations.