Design – Case study: Crash Management Systems (CMS)

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5 Case study: Crash Management Systems (CMS)

5.1 Introduction

Crash protection priorities vary with car speed when crash occurs:
- at speeds up to 15 km/h, the main goal is to minimize repair costs;
- at speeds between 15 and 40 km/h, first aim is to protect pedestrians;
- at speed over 40 km/h, the most important concern is to guarantee occupant protection.

The overall objective remains to reduce the aggressiveness of the crash event.

These issues are solved through controlled crash deformation. This case study deals with the effectiveness of the crash management system, composed of the bumper and the crash tubes.

Bumper systems influence the following performance measures:
- Overall vehicle mass
- Front end nod; related to overhang from the suspension supports and mass of system
- Front end lateral stiffness

In next sections, bumper systems (i.e. including crash tubes) will be also used to designate CMS.
5.1.1 Purpose of a bumper system

Minimise damage or injury by absorption of energy through elastic and, eventually, plastic deformation during frontal and rear collisions with pedestrians, other vehicles and fixed obstacles at relatively low velocities.

Legislative and insurance test procedures are found in FMVSS 581, EC 78/2009 and RCAR member sites. They specify the conflicting requirements of a soft absorber for pedestrian safety with the following functionality:

- Prevent structural and visible damage resulting from low speed impacts
- Minimise cost of repair (insurance rating) resulting from medium speed (15 km/h) impacts
- Manage load path and structural integrity for higher speed impacts to maximise occupant protection.

Source: Alcan (Constellium since 2011)
5.1.2 Additional functionality

Bumper system functions include:
- structural mounting surfaces
- lashing points
- towing points
- spot light mountings.
5.2 Design Aspects

5.2.1 Design Boundary Conditions

The boundary conditions for commencing a new design process can be identified and analysed by grouping together requirements using affinity matrix methods. The following example captures the major aspects that need to be considered for an aluminium reinforced bumper system.

<table>
<thead>
<tr>
<th>Vehicle quality</th>
<th>Occupant Safety</th>
<th>Cost of ownership</th>
<th>Pedestrian Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Stiffness</td>
<td>Impact &gt; 16 km/h No brittle fracture</td>
<td>Impact &lt; 8 km/h Elastic</td>
<td>Low Surface Stiffness</td>
</tr>
<tr>
<td>Low mass</td>
<td>Impact &gt; 16 km/h Max. Plastic Energy absorption</td>
<td>Impact &lt; 16 km/h Damage Limitation</td>
<td>No Sharp Features or Knife edges</td>
</tr>
<tr>
<td>Short Overhang</td>
<td>Towing Point No damage allowed</td>
<td></td>
<td>Surface Geometry Considerations</td>
</tr>
<tr>
<td>Good Corrosion Resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Main conclusions from affinity matrix:

- The bumper should be treated as a system
  - Impact energy is shared by the bumper components and the rest of the vehicle.
- Conflicting requirements should be handled by different parts if the system
  - Low stiffness foam on high stiffness beam to satisfy quality and safety
  - High elastic limit beam to achieve no permanent damage for low velocity impact
  - Vehicle structure protected by force limiting feature of bumper beam or its supports (crash tubes)
  - High strength to resist towing forces through bumper system
5.2.2 Design options assessment

Aluminium enjoys the advantage of being available in a wide range of product forms that may closely represent the output from topological optimisation tools. Each product form possibility may be combined with the intrinsic properties of aluminium in order to identify the most suitable design space for this application.

Herring-bone diagrams are a good way to start to develop a Design Failure Modes and Effects Analysis (DFMEA). They are also a good starting point for identification of the key design requirements, wishes and constraints in order to assist the selection of candidate materials, product forms and assembly methods, etc.

Desired characteristics and manufacturing techniques arranged in a herring-bone diagram
5.2.3 Whole vehicle system considerations

Experienced automotive engineers design functional components in the context of their surrounding elements. For example, a bumper should not be stronger than the structure it is intended to protect. Likewise, the stiffness of the vehicle structure to which the bumper is mounted contributes to the total elastic displacement of the bumper surfaces, and hence to its energy absorption.

The accuracy and quality of design and analyses predictions is improved by considering the system as a whole.

The following table shows clearly the interaction of each element of the crash management system and the surrounding structure for different impact events.

<table>
<thead>
<tr>
<th></th>
<th>Low speed (2.5-8 km/h)</th>
<th>Medium speed (15-16 km/h)</th>
<th>High speed (about 60 km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumper</td>
<td>30-100 %</td>
<td>10-100 %</td>
<td>2-4 %</td>
</tr>
<tr>
<td>Foam</td>
<td>20-60 %</td>
<td>5-20 %</td>
<td>2-3 %</td>
</tr>
<tr>
<td>EA elements</td>
<td>2%</td>
<td>20-75 %</td>
<td>4-6 %</td>
</tr>
<tr>
<td>Attachment brackets</td>
<td>2%</td>
<td>3%</td>
<td>&lt;1 %</td>
</tr>
<tr>
<td>Compliance of</td>
<td>NA</td>
<td>20%</td>
<td>89-95 %</td>
</tr>
<tr>
<td>surrounding structures</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2.4 Requirements for Crash Management System (CMS) components

The functional requirements, the design options and the system considerations have now been formalised. Each element of the design may now be assessed for materials selection using a prioritisation matrix.

In this case study, we first consider the bumper system, then the beam, its supports, and auxiliary parts afterwards. Our system considerations clearly show that a single element, like the beam, cannot by itself satisfy all of the conditions required of the system. For example, the system needs to have a very low stiffness for pedestrian safety and yet a relatively high stiffness to absorb low speed vehicle to vehicle impact energy through limited elastic deformation.

A prioritisation matrix enables visualisation of both materials’ characteristics and functional requirements together. It can assist the designer to take a holistic view.

As each function is added their specific materials’ requirements can be easily compared to existing functions. Functional or property conflicts for the whole system can then be broken down into specific requirements for elements of the system, or assigned to an adjoining component or system.

| BUMPER SYSTEM | Functional Requirements | Vehicle Quality | High Stiffness | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | Low Mass       | Min | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | Short Overhang | Min | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | Corrosion Resistance | Min | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | Occupant Safety | No brittle fracture | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | Cost of Ownership | High plastic energy absorption | Min | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | Damage Limitation | Min | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | Towing with no damage | Min | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | Pedestrian Safety | Low Surface Affinity | Min | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | No Sharp Features | Min | Min | Min | Min | Min | Min | Min | Min | Min | Min |
|               |                           | Surface Geometry | Min | Min | Min | Min | Min | Min | Min | Min | Min | Min |

### Prioritisation Matrix for Bumper System

The prioritisation matrix is constructed by listing all of the candidate materials properties and characteristics in columns. The functional requirements obtained from the affinity matrix are listed as rows. Each of the properties and functional requirements is then assessed as not being linked (blank) or as requiring a minimum or maximum value of the related property to obtain the best functional performance.

In this case some columns are totally blank. The judgement (or result of experience / analysis or test) indicates that this property does not apply for the load cases or product requirements that have been identified for this system. These columns may be collapsed to enable other conclusions to be obtained.
Bumper Beam

Assigning the low stiffness requirements for pedestrian safety to a foam element in front of the beam, and assigning the majority of the occupant protection energy absorption requirements to the crash tubes, simplifies the requirements for the beam itself.

### Prioritisation Matrix

<table>
<thead>
<tr>
<th>Functional Requirements</th>
<th>Elastic Modulus (E)</th>
<th>Tensile Yield Strength (σy)</th>
<th>Uniform Tensile Elongation (Ag)</th>
<th>Total Tensile Elongation (A80)</th>
<th>N-Value</th>
<th>R-Value</th>
<th>Density</th>
<th>Machinability</th>
<th>Weldability</th>
<th>Bondability</th>
<th>Extrudability</th>
<th>Castability</th>
<th>Machinability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Quality</td>
<td>High Stiffness</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Low Mass</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Short Overhang</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Corrosion Resistance</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>No brittle fracture</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>High plastic energy absorption</td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td>Occupant Safety</td>
<td>High elastic deformation</td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>Damage Limitation</td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td>Cost of Ownership</td>
<td>Low surface stiffness</td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
<td>Min</td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>No Sharp Features</td>
<td>Max</td>
<td>Min</td>
<td>Min</td>
<td>Min</td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
<tr>
<td>Pedestrian Safety</td>
<td>Surface Geometry</td>
<td>Min</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
<td>Max</td>
</tr>
</tbody>
</table>

### Conclusions from Priority Matrix for Bumper Beam

#### Safety
- Aluminium does not show any low temperature embrittlement (DBTT).
- UTS, Ag, A80, n-value, r-value, corrosion resistance, weldability, bondability, castability, extrudability and machinability should all be as high as possible.
- Density should be as low as possible.

#### Cost of Ownership
- E should be low for maximising ratio of elastic to plastic strain in conflict with global vehicle stiffness requirement.
  - Bumper system stiffness has a weak influence on global vehicle torsion stiffness, and almost no influence on global vehicle bending stiffness.
  - Vehicle global stiffness can be obtained from other components that are better located for this purpose, so the elastic modulus does not need to be maximised for this component.
  - The lower elastic modulus of aluminium than steel has the benefit of enabling a higher elastic deformation than an equivalent strength steel beam

#### Energy Absorbing (EA) elements (crush tubes)

High strength steels (HSS) and ultra high strength steels (UHSS) can employ yield strength more than 3 times that of the high and ultra high strength aluminium grades. At a first glance, considering the material densities of steel and aluminium, the aluminium solution would, at its best, have the same weight as the steel one.

Thin sections, however, suffer from being susceptible to premature “compression buckling” collapse, preventing HSS and UHSS from reducing thickness down to 1/3 that of aluminium.
Taking this into consideration and also exploiting the design flexibility of an extruded profile, high and ultra high strength aluminium typically allow:

- between 40 and 60% weight saving compared to HSS used in EA elements;
- 30% compared to UHSS used in bumpers;
- 40% (average) saving compared to steel alloys for full bumper beam and EA system.

<table>
<thead>
<tr>
<th>Prioritisation Matrix</th>
<th>Elastic Modulus (E)</th>
<th>Tensile Yield Strength (σy)</th>
<th>Ultimate Tensile Strength (UTS)</th>
<th>Uniform Tensile Elongation ( Âu)</th>
<th>Total Tensile Elongation (Âtu)</th>
<th>N-value</th>
<th>R-Value</th>
<th>Density</th>
<th>Ductile Brittle Transition Temperature</th>
<th>Corrosion resistance</th>
<th>Weldability</th>
<th>Bondability</th>
<th>Casability</th>
<th>Extrudability</th>
<th>Machinability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gpa</td>
<td>Mpa</td>
<td>Mpa</td>
<td>Mpa</td>
<td>Mpa</td>
<td>%</td>
<td>%</td>
<td>kgm-3</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
</tbody>
</table>

**Conclusions from Priority Matrix for EA elements**

**Safety**

- Aluminium does not show any low temperature embrittlement (DBTT).
- UTS, Ag, A80, n-value, r-value, corrosion resistance, weldability, bondability, castability, extrudability and machinability should all be as high as possible.
  - Since an increase in strength usually results in a decrease in elongation, it is necessary to find the right balance of properties using FE modelling and test procedures.
  - Ultra high strength materials may give the lowest weight or the most economical solution depending on section stability, ductility limitations and manufacturing costs.
- Density should be as low as possible.
- Conflicting requirements for global vehicle stiffness, yield strength and strain rate sensitivity.
  - Global vehicle stiffness is not the main function of this part as already discussed.
  - Crash tubes undergo severe deformation in high speed collisions. Brittle fracture should be avoided by careful alloy and temper selection in order to obtain stable predictable behaviour for the life of the vehicle. This is more important than high yield strength.
  - Joint strength is critical to ensure system integrity and avoidance of unpredictable collapse behaviour.
  - Aluminium is not sensitive to strain rate at room temperature.
    - Initial peak collapse force is lower than comparable steel section. This reduces the potential for premature collapse of the vehicle backup structure.

At present, age hardenable extruded profiles from the 6xxx alloy series dominate the EA segment of aluminium bumper systems.
Energy Absorbing Foam for low speed impact and pedestrian safety

Foam is used to improve pedestrian safety and to soften the impulse reaching the structure. The special characteristics of foam enable it to absorb relatively high levels of energy with complete recovery and no visible damage.

Foam absorbs energy when compressed.

Its characteristics depend on the rate of strain, the plastic and the foaming parameters used in its manufacture. Specific foam characteristics should be obtained from the foam manufacturers for FE analysis.

The total energy absorbed by the foam is also a function of the contact area and the compression distance. A good starting point is to make the foam thickness roughly equal to the external depth of the beam.
5.2.5 Main advantages of aluminium components

Extrusions are the most competitive aluminium product form for bumper beams.

- Variable wall thickness throughout the cross section
- Complex section shapes and internal features possible with high strength alloys
- Low tooling and investment costs compared to sheet stamping and high performance castings

High toughness and strength needed over -40 to +40°C temperature range.

- Aluminium is naturally resistant to low temperature embrittlement (DBTT) and corrosion weakening mechanisms.

Aluminium joint strength

Joint strength can be either designed out of the potential failure modes or tuned to deliver special functionality, but this requires detailed characterisation and analysis of these regions in the whole system (aluminium joints do not exhibit the same strength and failure modes as those of steel joints).

Weight reduction potential calculations

Weight reduction potential is dependent on differences in the candidate materials’ shape capability, their mechanical properties and the design space available.

We have already found that the energy absorption requirements for a bumper system can be split into an elastic requirement for parking impacts and elastic plus plastic for higher speed impacts that should not normally damage the vehicle structure.

Most of the plastic impact energy is managed through axial collapse of the EA tubes that mount the beam onto the vehicle structure.

The advantage of aluminium in axial collapse is derived from two distinct mechanisms; the thickness effect and the section capabilities of the extrusion process.

The thickness effect may be explained as follows:

Impact energy = elastic + plastic deformation energy

Plastic deformation energy from axial collapse of a single cell tube \( \approx \sigma t^{5/3} \)

\( \sigma = \text{average flow stress} = (\text{proof stress} + \text{ultimate tensile stress}) / 2 \)

\( t = \text{thickness} \)
Thickness of aluminium compared to another candidate material such as steel

\[ t_{al} = \left( \frac{\sigma_{st}}{\sigma_{al}} \right)^{\frac{3}{5}} t_{st} \]

Rearranging the equation and including density enables us to obtain the weight ratio of the two materials for identical energy absorption of a single cell tube in axial collapse

\[ \left( \frac{Weight_{al}}{Weight_{st}} \right) = \left( \frac{\rho_{al}}{\rho_{st}} \right) \times \left( \frac{t_{al}}{t_{st}} \right) = \left( \frac{\rho_{al}}{\rho_{st}} \right) \times \left( \frac{\sigma_{st}}{\sigma_{al}} \right)^{\frac{3}{5}} \]

Source: Alcan (Constellium since 2011)

Substituting the ultimate tensile strength for a typical ductile high strength steel DP600 Flow stress (Strain rate of 100 s\(^{-1}\)) \(\approx 680\) MPa, Density = 7.8 Tonnes m\(^{-3}\) and two typical 6xxx aluminium alloys with Flow stresses of 230MPa and 325MPa, Density = 2.7 Tonnes m\(^{-3}\).

Weight ratio range = 0.66 and 0.54 respectively

Conclusion: A 40% weight saving is obtainable from the thickness effect alone.

The collapse mode can be modified by the addition of an internal diaphragm and other geometrical features. Forcing the section to deform in a different mode of collapse can deliver very much higher collapse energy absorption. Care, however, must be taken to maintain section stability.

The extrusion process enables a very high degree of freedom in section design at low process costs.
### 5.2.6 Value Analysis

The bumper system as a whole can now be evaluated according to the importance attached to each function and the cost required to achieve it. Value can then be estimated by dividing the importance of each function by the real or estimated cost.

**Fictitious costs** are used in the bumper system case study to illustrate the principle.

<table>
<thead>
<tr>
<th>FRONT END BUMPER MODULE</th>
<th>COMPONENTS OF MODULE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Customer Requirements &amp; Functions</strong></td>
<td>Importance for Module</td>
</tr>
<tr>
<td>&lt;= 15 km/h Minimise repair cost</td>
<td>30</td>
</tr>
<tr>
<td>&lt;= 40 km/h Protect Pedestrian</td>
<td>20</td>
</tr>
<tr>
<td>&gt; 40 km/h Occupant Protection</td>
<td>20</td>
</tr>
<tr>
<td>Assist City Parking</td>
<td>5</td>
</tr>
<tr>
<td>Support Number Plate</td>
<td>5</td>
</tr>
<tr>
<td>Tow hook mounting</td>
<td>20</td>
</tr>
<tr>
<td>Engine Cooling Duct</td>
<td>5</td>
</tr>
<tr>
<td>Styling / Visual Aspect</td>
<td>30</td>
</tr>
<tr>
<td>Aerodynamics</td>
<td>10</td>
</tr>
<tr>
<td><strong>Weighting</strong></td>
<td>Column 1955</td>
</tr>
<tr>
<td></td>
<td>Normalised column 100%</td>
</tr>
<tr>
<td></td>
<td>8% 21% 14% 22% 11% 6% 18%</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Target 87.00</td>
</tr>
<tr>
<td></td>
<td>Real Cost 95.00</td>
</tr>
<tr>
<td></td>
<td>5.00 50.00 5.00 5.00 12.00 5.00 5.00</td>
</tr>
<tr>
<td><strong>Value</strong></td>
<td>Column / Real Cost 0.1284</td>
</tr>
<tr>
<td></td>
<td>Normalised Value 100%</td>
</tr>
<tr>
<td></td>
<td>12% 3% 22% 17% 9% 10% 28%</td>
</tr>
<tr>
<td><strong>Weighting</strong></td>
<td>Strong 5</td>
</tr>
<tr>
<td></td>
<td>Medium 3</td>
</tr>
<tr>
<td></td>
<td>Weak 1</td>
</tr>
</tbody>
</table>

The weighting of the module components has ranked the bumper beam, the joining system, the Foam and the EA support in order of most to least important for the functional requirements of the module.

The value gives a ranking that is strongly influenced by the cost of the mechanism. Fictitious costs are used to show the principle that low normalised value indicates an opportunity to look for cost savings. For example EA elements

- Can the stamping / extrusion cost be reduced?
- Can some machining costs be eliminated?
- Is section design and alloy choice optimised to minimise material cost?
- Can expensive features on this part be handled cheaper on another part or in another way?
5.2.7 Comparison of two ‘state of the art’ bumper systems

Assembly
- System A is welded
- System B is bolted

Beam
- Section details are relatively shallow or nicely rounded to deliver a good balance between performance and extrudability. Internal diaphragm ensures good resistance of section to local buckling.
- System A is cut to length, press shaped and punched.
- System B is cut to length, bent and punched.

EA elements
- Both utilise extruded sections
- System A does not utilise additional geometric features to trigger axial collapse. The manufacturer is here exploiting the weld metal properties at each end of the EA element as a *metallurgical trigger* resulting in a cost saving. Careful assembly sequencing and post weld heat treatments ensure that collapse is initiated next to the beam rather than the end plate.
- EA elements in system A are cut to length, but have no further machining requirements, resulting in an additional cost saving.
- EA elements in system B are cut to length, stamped and formed with geometrical collapse initiation features.

End Plate
- System A uses a blanked and punched plate.
- System B has dispensed with the end plate. The EA elements are directly inserted into the vehicle front longitudinal members, resulting in a weight and cost saving.

Despite the apparent simplicity in design of system A, careful attention has been paid to the geometry and production variability of the weld material.

Materials

AA-6082 T6/7 is a good choice for high strength complex section beams. Extrusion rates are high enough to enable a good compromise on section complexity and minimum wall thickness for closed sections at an economical cost.

AA-7XXX T6/7 may be used for very high performance bumper beam sections. It is usually more difficult to extrude than 6xxx alloys. Avoidance of thin walls, internal diaphragms and sharp features improve extrusion speed with a consequent cost reduction. Fabrication of the beam from an open section and a closing plate can make economical sense in some cases with 7xxx alloys.
AA-6060 T6/7 can be processed to have a good balance between strength, ductility and property stability, making it a good choice for EA elements.

- Both systems use a 6xxx alloy for the EA elements.
- The beams can be made from 6xxx or 7xxx alloys

### Joining

#### Welds

- Heat treatable aluminium alloys exhibit a **heat affected zone** (HAZ). Properties of the HAZ are dependent on the composition of the alloy, its initial temper and any post weld heat treatment (PWHT) processes used. Material characterisation and modelling of the properties in the HAZ is one of the key factors used to obtain reliable Finite Element predictions of the behaviour of the beam system.

- **Weld metal** in the fillet can have low yield strength compared to the parent material. However, the weld strength depends on the alloy in the weld metal (combination of alloys welded and filler wire, post weld heat treatment cycles and geometry of the fillet).

- **Joint strength** can therefore be a tunable parameter within the limits of the materials and processes available. Major suppliers have invested in the characterisation and detailed modelling of joints in order to correctly represent the complex combination of behaviour of the weld metal, the HAZ and the geometrical features.

Failure to correctly represent the weld metal and the HAZ in crash simulations can give as much as a 30% error in the peak Force. In the past, some prototype parts were found to exhibit completely different collapse behaviour to the simulations during crash-testing because the weld region was not modelled accurately.

The manufacturing of welded automotive components from age-hardening aluminium alloys involves a series of thermal and mechanical operations. These alloys have a strong memory of the past process steps due to interactions between different types of particles that form at various temperatures. In particular, the different heat treatment and welding operations that are used toward the end of the process chain have a large influence on the resulting structural performance.

![Diagram of alloy processing steps](source)

### Variables

Variables involved in the fabrication of welded crash components made of age-hardening aluminium alloys. The designations T1–T7, WP1–WP4, and PWHT1–PWHT3, refer to different temper, welding, and heat-treatment conditions, respectively.
Predicted peak temperature

Calculated stress-strain curves for the three HAZ positions, A, B, and C

Careful design of the weld and its process history create a controlled metallurgical discontinuity that can trigger crush initiation. Gains include tooling investment and process cycle time costs.

Mechanical Fasteners,

- The bearing strength of the aluminium, rather than the strength of the fastener, usually controls the failure mode and strength of the mechanically fastened joint.
- Joint design detail including position and additional reinforcement influences the onset of failure and the mode of failure. Such parameters are sometimes tuned to promote a beneficial failure mode in which energy is absorbed and forces are limited in extreme cases through tearing of a bolt through a given length of a support.

All joining systems

- **Joint location** should avoid high deformation zones and unfavourable loading directions for the specific joining system that is being used.
Summary of Aluminium Design

Beam:
- High strength 6xxx / 7xxx alloy
- Peak stable temper
- Closed section extrusion mono / multi-cell
- Cut to length
- Press bent and punched

EA elements:
- Soft 6xxx alloy delivering a low initial collapse load
- Extruded mono / multi-cell section
- Peak stable temper optimised to crush without fracture
- Cut to length
- Geometrical or metallurgical collapse initiation features

End Plate:
- 6xxx thick plate or extruded plate
- Blanked and punched
5.3 Performance evaluation

The critical performance of a crash management system is evaluated by applying test methods developed by international bodies to enable insurance ratings to be issued.

We will consider two such tests that demonstrate the efficiency that has been obtained from modern aluminium systems.

1. Allianz 10° 16 km/h test procedure to evaluate the potential for repair.
2. Extreme tow eye loading at 45° to vehicle longitudinal axis.

**Allianz 10° 16 km/h test procedure**

The aim is to maximise the energy absorbed by the CMS for a given collapse distance. It is crucial to limit the peak force to a level that is below collapse initiation of the vehicle main members in order to limit the extent and cost of repair necessary.

![Allianz 10° 16 km/h test procedure diagram]

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\text{CMS Performance (\%)} = \frac{\text{CMS Absorbed Energy}}{\text{Maximum possible absorption}}
\]
The following images show the excellent performance that can be obtained from high performance aluminium bumper systems delivering a weight saving close to 50% compared to steel.

Collapse of the EA element is initiated at around 30mm displacement with almost no initial peak force. This feature ensures that collapse initiation of vehicle impact members cannot be initiated by low speed impact (approx. 15km/h) resulting in low repair costs.

Source: Hydro & Benteler

AZT-testing of welded crash system
(10°, i.e. the new AZT Test)

Start of crash
The crash-box is undeformed

During crash
The crash-box has been slightly deformed (just a small part of the box is still visible in the picture)

Source: Hydro & Benteler
5.3.1 Comparison of the performance of an Aluminium and a Steel CMS

Aluminium Development (3.5 kg)
Source: Alcan (Constellium since 2011)

Recent Steel System (VW Polo, 5.0 kg)
Source: Alcan (Constellium since 2011)
Extreme tow eye loading at 45° to vehicle longitudinal axis

Extreme towing condition: Test force finally reaches nearly 200 kN at an angle of 45° with no visible damage to CMS.

Source: Alcan (Constellium since 2011)
5.4 Market Penetration

Aluminium CMS have achieved a high market penetration despite their slightly higher cost than competitive systems.

![European front Bumpers Aluminium market share (%)](image_url)

Source: Alcan (Constellium since 2011)
5.5 Conclusions from CMS case study

Careful design with aluminium can produce very high performance crash management systems that satisfy all functional product requirements.