Automotive **Engineer**

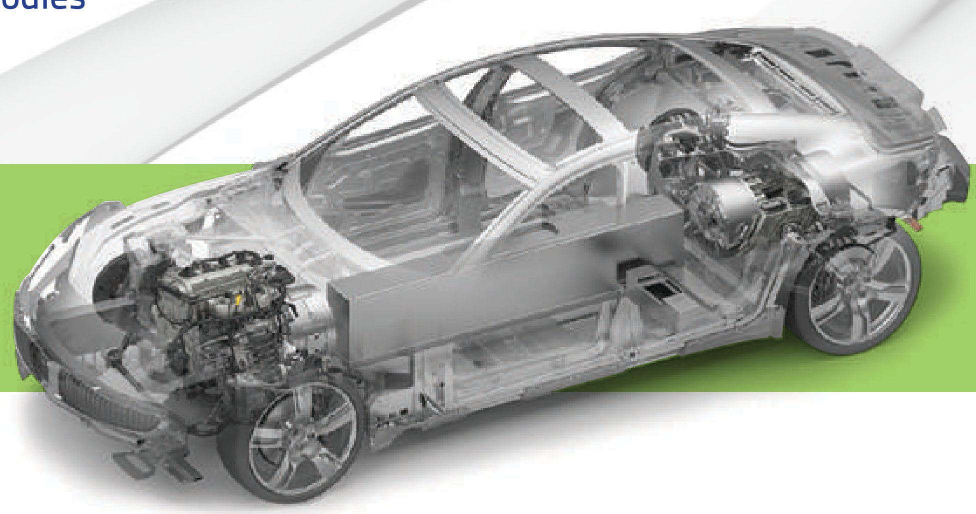
Technical Update

AUGUST 2013

Welcome to the second issue of the Automotive Engineer Technical update for IMI Certificated Automotive Engineers (CAE) and Advanced Automotive Engineers (AAE).

In this issue, we discuss how the use of materials in vehicle structures has changed significantly over the years, and the impact it has had on processes, testing and safety. The topics covered are:

- Use of multi-materials in vehicle structures
- The basics of vehicle structures
- Pressed panels
- Crash testing
- Body engineering with steel
- Multi-material bodies



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Use of **multi-materials** in vehicle structures

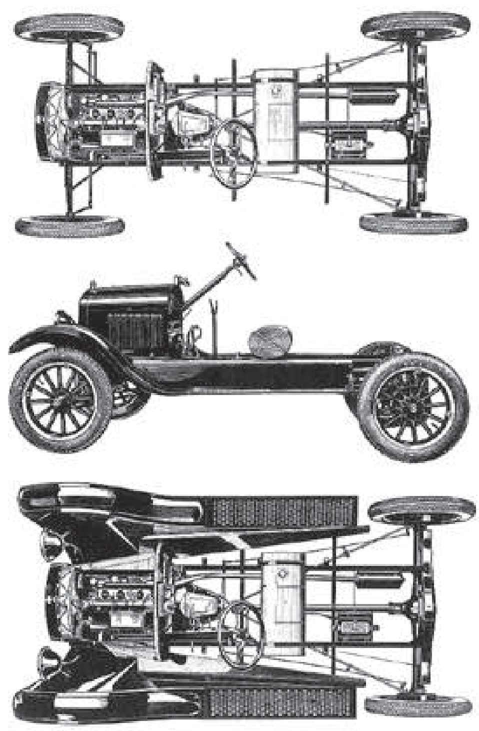
The single item that defines a vehicle is the body structure which provides protection for the occupants and pedestrians, aerodynamic benefits, and is host to all of the vehicle systems. For many decades, the technology behind creating structures was very much an engineering-led art, liberated in recent decades with the advent of relatively inexpensive computing power. We will see how modern pressed steel structures evolved from the systems created in the 1920s, how some sectors can trace structures back to the horse-drawn cart, and the exciting future of any combination of materials in a single structure.

What will be the main impact of this technology revolution in the next 10 years?

In the **beginning**...

Coach building is something that evolved as an art rather than an engineering science, with the connection of wheels by beams and the connection of those beams to the body via more beams. More elaborate coaches used self-contained passenger cells suspended via leather straps from the base vehicle frame, which in turn were also sprung. In all cases the 'art' was evolved to create vehicles drawn by hand or by horses. Typical features included the use of ash or willow for flexibility to overcome flawed structural layouts, large pins or screws to hold it all together and simply huge-diameter road wheels. These features were driven by the condition of many roads and the requirement to create suitably tough vehicles.

The advent of horseless carriages evolved around traditional coach building technology, where additional loads from the powertrain were addressed by cladding the wood frame with metal plates. This process of 'armour' evolved into full metal frames as production volumes increased, and vehicle purchase prices fell from the early 1920s onwards.



A landmark – the Ford Model T chassis. It featured a ladder frame, with two side rails running the length of the vehicle and held together by a cross member at eacch end, along with the gearbox bell housing bolted directly to it in the middle. Whilst the transverse leaf spring front and rear suspension was not typical of 1912 automotive engineering, the frame was. The rail section (depth and width) is surprisingly modest. Everything else is added to this base structure, and offers little to improve torsional or bending stiffness.

The **basics** of vehicle structures

The dynamic behaviour of a vehicle is to a large extent defined by the stiffness of the body structure. When viewed from the side, they are covered by bending (how the structure deflects due to the load on the structure and the reaction load from the suspension pickup points) and by torsion (how the structure resists twisting forces). Over the last century there have been two distinct approaches to body engineering:

The 'monocoque'

An example of a perfect monocoque would be an egg. The structure has no openings, and the entire surface area is dedicated to distribution of almost any imposed load. The more the load is distributed across a larger area, the greater the load that can be imposed before the structure fails. However, vehicles have discontinuities in such perfect monocoques to allow occupants to get into and out of the vehicle, to permit access to the powertrain as well as luggage space, and to permit suspension links between the wheels and the body.

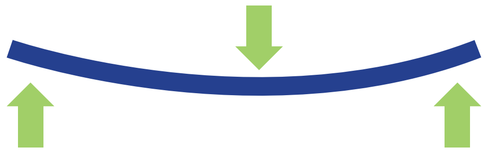
Advantage:

The skin form which is required to reduce aerodynamic drag also assists in structural stability. The occupants sit on a floor which has recesses for underbody parts, so allowing them to be closer to the road and reducing the roll centre height / centre of gravity height. The greater body stiffness is due to connection of the roof to the floor via the roof pillars, therefore dramatically increasing the size of the effective structure without significant weight gain. The stable body structure allows precise wheel control via the suspension.

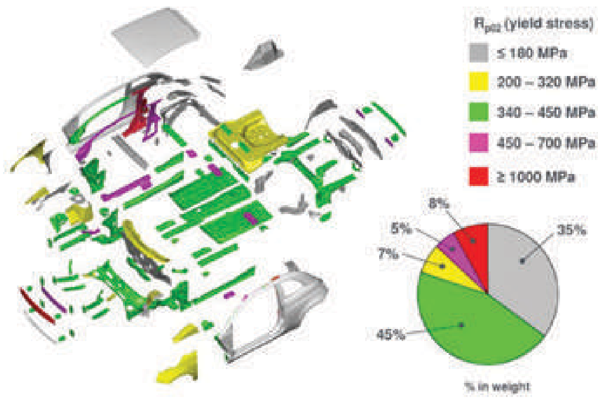
Disadvantage:

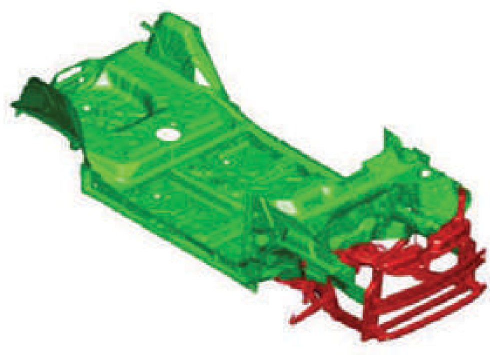
It is more difficult to produce variations in body style from a single platform since the each version has to be built as a single assembly, rather than a series of modules bolted together.

Bending



Torsion





The entire body shell, apart from the front wings, contributes to the bending and torsional stiffness of the car. Most monocoques rely on a stiff floor assembly (frequently referred to as the platform when combined with the steering, suspension and fuel tank) which is then stiffened by the body sides and roof. The Fiat 500 is shown here with the three load path front end structure.

The separate frame

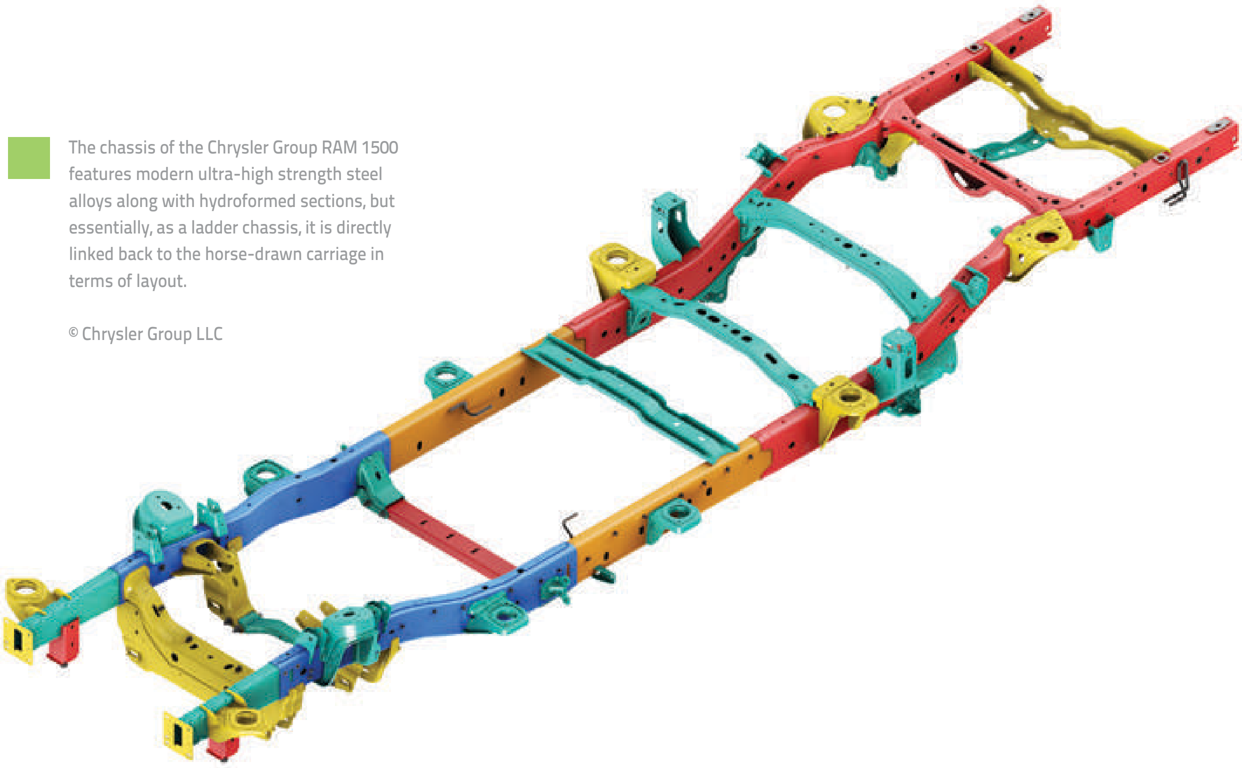
The original motor vehicle structure has a single structure (typically known as a chassis, the French name for frame), which links together all the vehicle elements. The section height is effectively only the depth of the side rails, and the torsional stiffness is governed by the side rail form (open C section or a closed 'box'), the number of cross members and the ultra-critical joint system.

Advantage:

It is relatively easy to produce a range of wheelbase and body style configurations since the major modules (cab, load bed, body) are a series of modules bolted together. However, the stiffer these sub-modules are, the more critical it is to allow the frame to flex relative to them – otherwise, it induces premature frame failure.

Disadvantage:

The skin form which is required to reduce aerodynamic drag does not assist in structural stability. The occupants sit higher than in a monocoque because the frame runs below the floor and in turn, the under body parts are attached to the underside of the frame, so increasing the roll centre height / centre of gravity height. The greater body stiffness is due to connection of the roof to the floor via the roof pillars, therefore dramatically increasing the size of the effective structure without significant weight gain.
The wheel control via the suspension is via the frame which forms part of the suspension system.



The chassis of the Chrysler Group RAM 1500 features modern ultra-high strength steel alloys along with hydroformed sections, but essentially, as a ladder chassis, it is directly linked back to the horse-drawn carriage in terms of layout.

There are crossovers of both structure types. The Land Rover Discover '3', Discovery '4' and the Range Rover Sport, for example, use a 'T5' platform which, when combined as a full structural frame and body unit, offer exceptional torsional stiffness - a requirement for off-road use with fully independent suspension. However, the older live axle off-road platforms, such as the Land Rover Series I to III, relied on frame flex to improve wheel articulation. In addition, it is possible to produce a very low sports car with a ladder frame, as typified by Morgan, but getting all the systems on board and packaged around the frame leads to a longer overall vehicle compared with a monocoque approach.

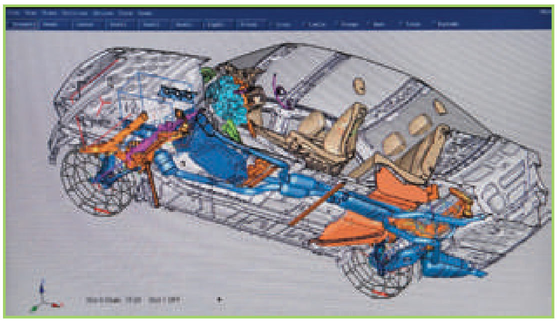
Pressed panels

The main automotive revolution of creating progressively less expensive cars to reach new markets was greatly aided by the migration from artisan intensive hand-built bodies to mass-produced bodies. This required the development of pressed panel manufacture which originated, in the main, from the USA. The transition from vehicle manufacturers producing a frame equipped with a powertrain and suspension which was then equipped with a body built by a third party, to fully-assembled vehicles was driven by the desire to improve profit margin and to rapidly expand new markets. This process started by 1900 but really took hold after 1920.

The production of press tools used to rely on years of experience and knowledge of the grain flow / structure of the material, but for the past 20 years, software has evolved to model the panel forming inside press tools. These software packages combine the material properties with the tool form to alert the risk of tear, rippling and crush during the pressing process, and hence the number of press tools as well as raw material thickness required to form the finished panel. This revolution ran in parallel with the mass adoption by the automotive industry of computer aided design (CAD), ensuring that the desired shape could be achieved without any deviation.

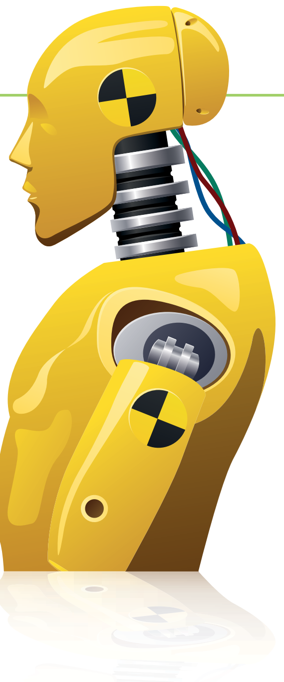
The technology of pressed panels – and especially sheet steel alloy as the cheapest raw material – represents around one third of the investment required for a new model programme, whilst the presses / transfer lines typically take up to a further third of the total available investment. Due to this large scale investment the viable production run for a single vehicle is around 100,000 units per year. There are options however, to use softer tools which can lower this minimum annual volume towards just 20,000 per year. The lower the production volume, the higher each part can cost in return for much reduced investment. This is why the Audi A8 is made almost entirely from aluminium (softer tooling than for steel) and has a skeletal frame rather than a monocoque.

Mercedes-Benz C-Class W204 used computational fluid dynamics combined with 3D visualisation to model not only the under body airflow but also the heating, ventilation and cooling (HVAC) for the interior too.



Mercedes-Benz C-Class W204 was the first vehicle programme in the world to use finite element analysis for noise, vibration and harshness (NVH) development. This technique has been used on every single Mercedes-Benz vehicle programme since 2007.

To produce each pressed panel there will be at least two press tools – one to cut the panel from the coiled sheet metal and one to form the final shape. The more complex the shape, the greater the number of press tool sets are required, to avoid tearing or the damaging the panel.



Crash testing

For most of the 20th Century there was a strong desire to have very few variations of material in a vehicle structure, so that sheet metal coils would arrive at one end of the manufacturing plant and finished vehicles would roll out of the other end. The advent of whole vehicle type approval followed by establishment of consumer-driven crash test programmes (such as Euro NCAP) changed that situation forever. Fortunately, the revolution in modelling and mass adoption of CAD in the vehicle design process enabled far more sophisticated engineering to meet these challenges.

The rise of specialist materials – which for 2000 onwards was higher strength steel alloys – allowed far greater structural impact energy absorption performance for all types of structure. This was a direct response to providing a stable survival cell for the vehicle occupants, from which the airbag system could work reliably, as well as ensuring impact energy, was shared across the maximum area even if the contact point was rather small.

The typical modern mass-production steel alloy 'identi-kit' body structure has two box sections running longitudinally through the engine bay, a series of transverse members in the region of the front bulkhead, the first upright pillar to which the front door hinges are attached, the lower longitudinal box member (the 'sill') which is cross braced to the central tunnel, a second pillar which the front door latches to, and an upper longitudinal box member (the 'cant rail') which connects the upper ends of the vertical pillars. Transverse members at roof level connect the two cant rails together. For vehicles with four doors, there is a third upright pillar, and for vehicles with a tailgate there is a surrounding frame which is tied into the vehicle structure too. The rear longitudinals run underneath the boot floor, and are connected to the vehicle via transverse members at floor level.

For frontal impact, the typical three load path approach means:

- Initial impact – the bumper, bumper beam and front longitudinal members.
- If the energy to be absorbed is too great then the lower path with the front subframe comes into play.
- Finally, if the energy to be absorbed is still too great, then the inner front wing box member starts to absorb energy. From this point onwards there are three box members per side absorbing energy.

A sample of some of the impact tests the BMW 1 series F21 / F21 was subjected to. These impact tests define the design requirements for the body structure along with stability for deployment of the airbag system, NVH, aerodynamic performance and minimal weight.

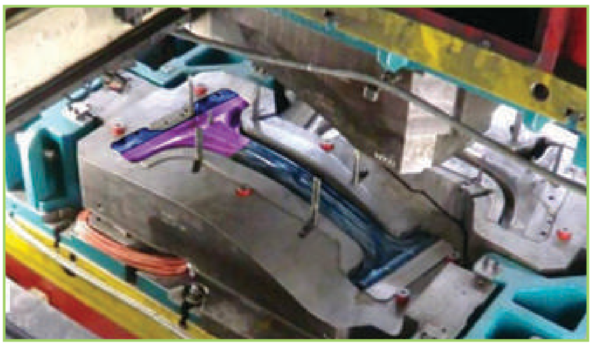
The 2013 Mazda3 5 door hatch body shell uses key structural box sections to enable impact energy to be both absorbed at point of impact as well as distributed across to the remaining structure. High strength and ultra-high strength steels are used selectively, depending on location in the crash energy distribution load path and thus the required strength

Body engineering with **steel**

Initiated by the demands for greater occupant safety during an accident, the market for steel alloys that were significantly stronger than 180 MPa yield strength arose from the late 1990's onwards. The art was to produce steels that could become much harder once they had been pressed so that pressing technology, as well as the amount of energy to form panels, did not change too much. The result was a range of steel alloys that transformed their properties up to 590 MPa yield strength as they passed through the vehicle manufacturer paint ovens which run typically at 160°C. In recent years, such steel alloys have achieved yield strengths up to 800 MPa. For special areas where even harder materials are required, special steel alloys are processed by heating to orange heat and then pressed whilst being selectively cooled in the press tool to temper the material. The result is pressed parts with yield strengths up to 1800 MPa.

Why go to all this trouble?

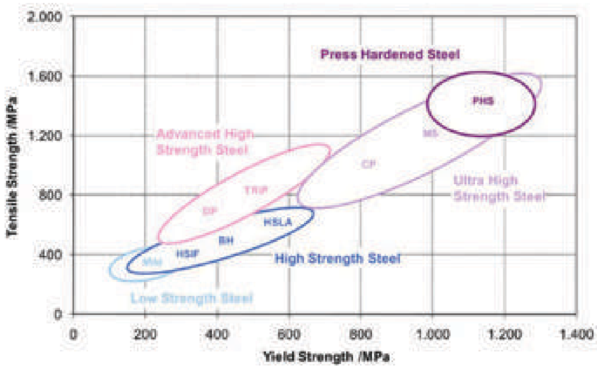
If one uses only mild steel, to make a stronger part, the only option is to use more material. In some areas – especially the pillars either side of the windscreen for example – the objective is to make the box member as thin but also as strong as possible. This drives the requirement of more exotic steel alloys with more strength in less space, and with less weight too.



Press hardening with in-tool quenching can be used to produce variable hardness in a single component. The B pillar reinforcement has a slightly softer lower section to allow the upper section to rotate around the upper cant rail in side impact, allowing energy absorption but also maintaining the maximum head space for the occupant and curtain airbag deployment.

The big key to multi-panel vehicle structure is how all of these parts are held together. For many decades this has been achieved via a combination of resistance spot weld and (in the past) seam welding. However, with selective panel hardness increasing, greater resistance welder tip pressures are required. To partially address this, bonding agents have been introduced in welded seam joints to allow the number of required spot welds to be reduced in return for superior joint performance. This has seen in the past decade alone adhesive joint lengths increase from a few metres towards 130m in the latest designs.

The process that allowed a mix of externally-produced pressings and a variety of steel alloy grades to come together into a single structure centres around bar codes. By being able to track the movement of every single panel, the need to uniform materials in bulk to feed the body structure assembly lines is reduced. That has allowed non-ferrous materials to be included to a greater extent than ever before.



Steel alloys ranging from mild steel on the left to ultra-high strength steel alloys on the right.

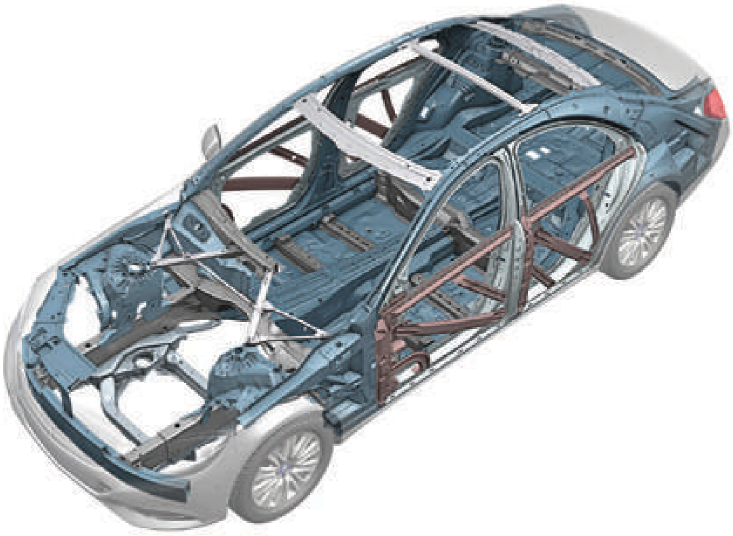
Multi-material **steel**

The press tool manufacturing process which has usually used steel alloy and that has served the bulk of the automotive industry for more than a century is about to undergo another revolution. Resistance spot welding structures, together with the type of materials required to meet the desired occupant safety, refinement and weight targets, are becoming more energy intensive and will soon be replaced by bonding. The elegance is more materials can be selectively used in the vehicle structure than steel. For example:

- Sheet aluminium alloys have lower strength than the equivalent sheet steel alloy, but are inherently stiffer. That means applications such as bonnet skins and formers designed to absorb pedestrian impact could well be better served with sheet aluminium alloy than sheet steel alloy due to the superior rate of deformation / elongation.

- Sheet aluminium alloy is in direct competition with bake hardened ultra-thin sheet steel alloy to provide lighter outer skin panels, where weight savings may well be greater with aluminium. The next generation Mercedes-Benz S-Class W222 and 2014 C-Class feature an outer skin mostly made from aluminium alloy, even though the load bearing structure is made from steel alloy.

- Use of fibre reinforced plastics (including carbon fibre) for large flat panels such as floors, rear bulkhead and selected structural stiffeners.



Apart from the bumper skins, most of the external surfaces of the 2013 Mercedes-Benz S-Class W222 are made from aluminium alloy. These parts are riveted and bonded to the load bearing inner structure made from steel alloy.

Some material selection is achieved because of market perception rather than engineering performance. This applies currently to aluminium for luxury cars and carbon fibre reinforce plastic (CFRP) for exotic sports cars. The reality in both cases is that whilst material costs are notably higher than steel alloys, the investment required to turn those materials into parts for a vehicle structure is reduced.

The future could mean lower overall investment even for high volume production cars, as bonding allows even more of the vehicle structure to be made from a greater array of materials, produced in different locations to the final vehicle assembly. This would allow specialist production centres to feed high value parts to several plants. This would shift the break-even point and introduce to mass market vehicles, materials which could be considered today as 'exotic'.

What does this mean for **me?**

Vehicles engineered with large tooling budgets will deploy a large range of diverse materials, following the mantra 'the right material selected for the right job'. Further the body structure will be joined by more bonding, some more riveting and less welding. Component by component optimised material selection will mean in the aftermarket:

- Never assume what material each part is made from. Always check with the manufacturer data sources or known third party data providers.
- Be prepared to approach both regular servicing as well as accident repair with an open mind.
- There will be few generic repair solutions – even in the same vehicle manufacturer model range.

As long as due research into the correct repair method has been completed before attempting to do anything, the process should work. It is however imperative to keep up with the changes to vehicle structures through Continuing Professional Development (CPD) and research. We have listed a number of related CPD courses available through the IMI, all of which are at a discounted price for you as a member on the **IMI Professional Register.**

Questions:

1. What is a 'chassis'?
2. How did early coach builders strengthen wooden structures?
3. What are the two types of vehicle structure commonly used?
4. What do NVH, HVAC and CAD mean?
5. How are steel alloys panels formed?
6. How is a typical mass market vehicle steel structure laid out currently?
7. What is the minimum number of press tools required to make a panel?
8. How do some steel alloys change strength through the vehicle manufacturing process?
9. What does press hardening steel alloy parts involve?
10. Is sheet aluminium alloy stronger or weaker than sheet steel alloy?
11. How can different materials be joined together?
12. What is CFRP and where might it be used on a mass-production vehicle?

Logging **CPD**:

Don't forget that these technical updates count towards your CPD target. To log CPD, simply visit **www.theimi.org.uk/mycpd**, and you will be taken to the CPD portal.

You can claim a CPD credit by reading this update, considering the questions above and updating your CPD record. In order to gain additional CPD points, you'll need to demonstrate how this piece of learning has had an impact on your behaviour and/or your working practices.

Related **CPD**:

Courses: if viewing online, click on the title for more information

- **MIG and Spot Welding For Automotive Applications**
  This course is designed for body repair technicians looking to improve their skills and techniques with MIG and Spot welding. Technicians will also benefits from the explanations of techniques used to perform a series of welds to National Occupation Standards.
- **MIG Brazing For Automotive Applications**
  Designed for body repair technicians looking to improve their skills and techniques with MIG braze welding.
- **Aluminium Repair, Bonding and Welding Techniques**
  Designed for body repair technicians looking to learn the techniques needed to rivet, bond, weld and reform aluminium body panels.
- **Structural Alignment Vehicle Jig Repairs**
  This course is designed for body repair technicians looking to improve or learn the techniques needed to perform structural alignment Jig repairs using bracket and electronic measuring systems.
- **VDA Familiarisation**
  This course aligns to the VDA ATA criteria and provides a useful training / evaluation package for those who undertake vehicle estimating as part of their job role and intend to undertake the full VDA ATA process. The course includes health & safety and use of e-scribe and Glass's evaluator to produce a structured and detailed repair assessment using published repair methods.
- **Cosmetic Aluminium Repair**
  This course is designed to upskill technicians to required standards on aluminium repair techniques and includes health & safety, tools and equipment required, repair techniques, a theory test and a practical skills assessment.
- **Introduction to MIG Welding**
  Designed to upskill technicians to meet industry requirements in relation to MIG welding, this course includes how to carry out correct set-up and welding procedures/techniques, health & safety regulations and identifying faults and faulty equipment.

Further **study**:

1. Crash test standards
2. Strength of materials – steel alloys, aluminium alloys

All CPD courses can be found online at www.theimi.org.uk/courses-and-events.

You can also download a copy of our CPD Course Guide at www.theimi.org.uk/cpdbrochure