# Steel – the basics

**Steel is a very special material. With the addition of tiny amounts of other elements, iron can be transformed into a versatile engineering metal capable of withstanding extreme gearbox pressures or the immense forces in a car crash.**

**In this section**
The following pages illustrate some of the basic facts about carbon steel and how its versatility enables it to be used throughout automotive manufacturing and endlessly recycled into new products.

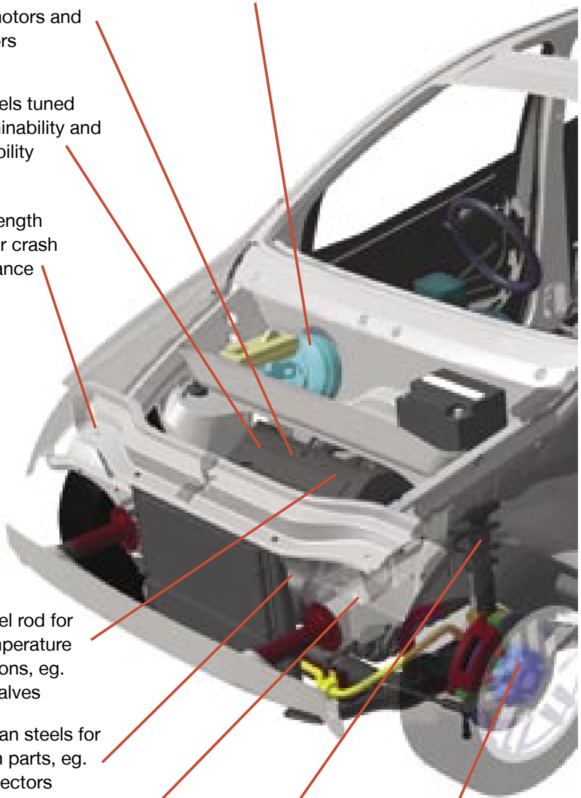


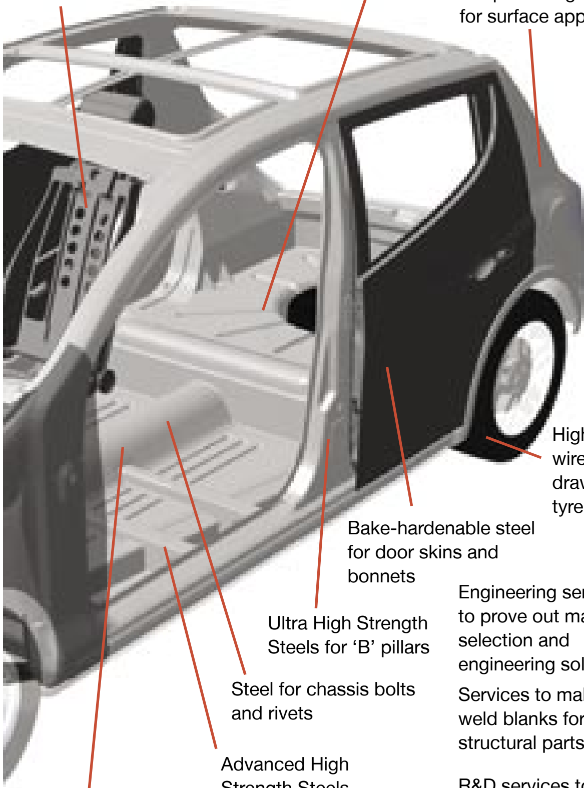


**Did you know?**
Steel is the most widely recycled engineering material in the world. It can be recycled over and over again without loss of properties.

# Steel in cars

**Steel accounts for more than 50 per cent of the weight of an average passenger car. The major applications are shown here.**

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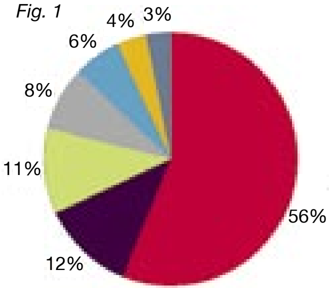
# The multi-materials car

### A brief guide to the materials that make up the cars of today.

A car is built from many different materials, although the main structure – known as the Body In White (BIW) – is usually made of steel pressings welded together to form a strong and stiff frame. This method of construction accounts for 99.9 per cent of all the cars produced in the world. The remaining 0.1 per cent are mostly constructed with an aluminium BIW, while a very small number (less than 0.01 per cent) are constructed from carbon-fibre composite (see Fig. 2 opposite).

*Fig. 1*




| | |
|---|---|
| steel 56% | iron 12% |
| plastics 11% | others 8% |
| aluminium 6% | rubber 4% |
| glass 3% | |

*Source: SMMT 2001 report*

**Did you know?**
The human body contains 4.2g of iron, enough to make a piece of car door 27mm x 27mm.

The material properties of steel (with its wide range of yield strength combined with high modulus) together with ease of manufacture and low cost, mean that steel-intensive vehicles have by far the largest share of the market. The high cost of alternative materials such as aluminium or composites mean that steel's position as the first-choice material is secure.

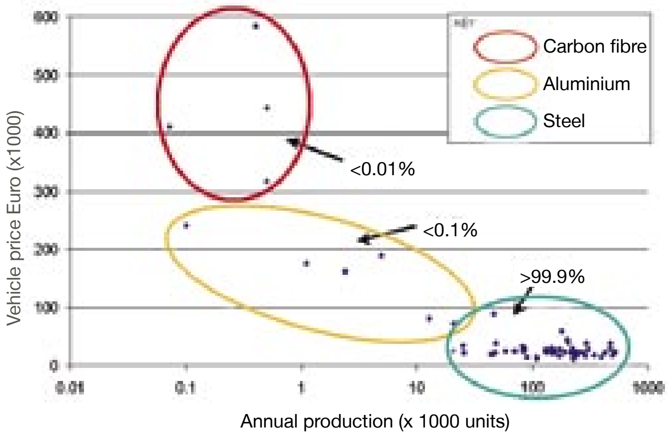
The BIW of a vehicle accounts for 20 per cent of the vehicle mass. The weight of the closures (doors, bonnet and boot/rear hatch), chassis (suspension parts) and driveline bring the total amount of steel and other ferrous metals to more than 60 per cent (see Fig. 1).

In recent years, the amount of ferrous metal has declined, mostly driven by manufacturers replacing iron with aluminium for engine castings. The percentage of sheet steel per car has also dropped, mainly due to:

- Higher levels of equipment, trim and soundproofing.
- More aluminium used in wheels and suspension parts.
- More moulded plastics, especially under the bonnet.

The environmental and economic requirements for reduced fuel consumption have also led to an increase in the use of lightweight materials for components that bolt on to a conventional steel vehicle, but at a cost: see Table 1 opposite.

*Fig. 2* **Vehicle production vs vehicle price vs market share**




*Source of Fig. 2 and Table 1: Corus*

**Table 1: Alternative materials - potential weight saving vs cost**

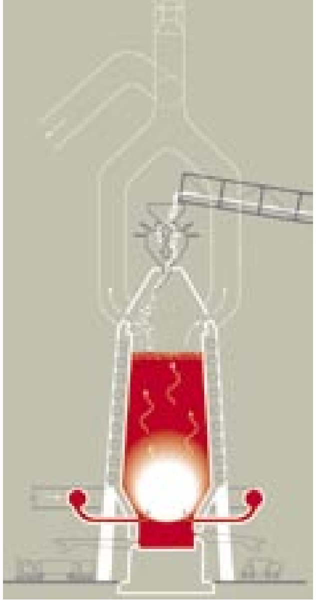
| | steel (kg) | aluminium (kg) | magnesium (kg) | % weight reduction (part) | % weight reduction (vehicle) | % cost increase (part) |
|---|---|---|---|---|---|---|
| Body in white (BIW) | 285 | 218 | N/A | 23.5 | 3.90 example vehicle mass of 1700kg | 250 |
| Bonnet (assembly) | 14.8 | 8.3 | N/A | 44 | 0.48 example vehicle mass of 1350kg | 300 |
| Door (assembly) | 15.7 | 9.5 | N/A | 39 | 0.40 example vehicle mass of 1550kg | 275 |
| IP Beam (instrument panel support) | 11.4 | N/A | 6.3 | 45 | 0.33 example vehicle mass of 1550kg | 350 |

# Steelmaking

**Here we explain the principal commercial methods for making steel: Basic Oxygen Steelmaking (BOS) and the Electric Arc Furnace (EAF).**

Since BOS relies on a supply of liquid iron from a blast furnace, we must first describe iron making. Iron ore (iron oxides), coke and limestone are fed into a blast furnace where they are heated to around $1500^0$ C. At this temperature carbon monoxide is formed by the reactions of coke and limestone with furnace gases. The lime now acts as a fluxing agent, removing impurities in the form of a slag which floats on top of the iron. Carbon monoxide reacts with iron ore to give molton iron, which collects at the bottom of the furnace. The resulting carbon-rich 'pig iron' is then poured off and transported to the BOS plant.

*Blast furnace*



### Basic Oxygen Steelmaking

In the BOS process, steel is made by blowing oxygen into liquid iron using a water-cooled lance. Oxygen reacts with excess carbon and other impurities, which are released as gases. This exothermic reaction takes place under alkaline conditions (i.e. 'basic'), with the rise in temperature controlled to some extent by the addition of scrap steel.

A steelworks that makes steel by this route and shares a site with a blast furnace for the provision of liquid iron is known as an 'integrated' steelworks.

The BOS process is used where large volumes of similar steel types are required. It is the most common route for making formable strip steels for car bodyshells and ultra-clean steels with low residuals for products such as tyre cord and valve springs.

These steels have low levels of trace elements, which make them ideal for forming into body panels and other thin-section, deep-drawn parts.

### Electric Arc Furnace steelmaking

The Electric Arc Furnace (EAF) process is simpler and more flexible. The process uses electric current to produce a high-temperature arc inside a furnace containing scrap steel. One furnace can be used to produce smaller batches of a wider variety of steel types than the BOS process.

While the feedstock for the BOS process is molten pig iron, for the EAF process it is almost 100 per cent steel scrap – resulting in steel being the most recycled engineering material in the world.

The EAF process is preferred for making specialist steels such as heat-treatable forging billets, high-temperature alloys and stainless steels.

### Secondary steelmaking

The steel from either BOS or EAF then goes through a series of operations while still liquid, which can include vacuum degassing, argon stirring and the addition of other metallic alloying elements by powder injection. Fine tuning of the steel chemistry in this way allows the steelmaker to produce thousands of grades of steel from the same basic composition. The steel is then poured by a continuous-casting process to form a range of thickness known as slabs, blooms or billets.

### Further processing

Billets may be supplied directly to forgers for hot forging components such as crankshafts, camshafts and connecting rods, or hot rolled into sections for reinforcement brackets and door hinges.

However, most steel for automotive use is supplied in the form of sheet, ranging in thickness from 0.5mm to 4mm, in widths up to two metres. This sheet is produced by hot rolling a slab, with the resultant oxide surface being removed by 'pickling' in an acid bath. For optimum mechanical properties and control of surface finish, most automotive sheet steel is cold rolled. A corrosion-preventing metallic coating, usually zinc based, is then applied by electro or hot-dip galvanizing. Cold-rolled sheet requires heat treatment (annealing) that is often carried out within the coating process, before a final cold roll (temper rolling).

Sheet steel is rolled into coils weighing up to 20 tonnes for shipment by road or rail.

*Electric arc furnace*

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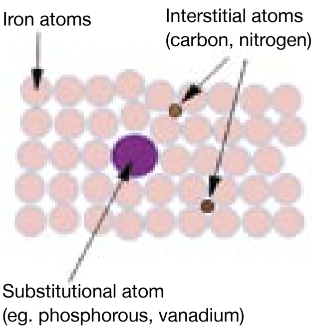
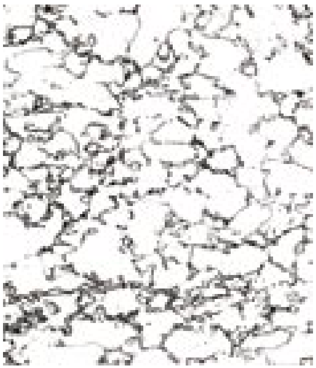
# Chemical compositions

**Alloying elements are added to steel to create the desired strength and formability properties for specific automotive components.**




*Source of diagrams above and below: Corus*

*Steel grade DP600 through microscope at x1000 magnification*



Steel for automotive purposes is made up of iron (generally more than 99 per cent) and a range of other alloying elements, the most important of which is carbon.

Under a microscope, at x1000 magnification it can be seen that steel is actually made up of tiny crystals known as grains. These grains of steel are formed when liquid steel cools to a solid, the atoms of iron within each grain, aligning in a precise crystalline array. The size, shape and composition of these grains has a major effect on the strength and formability of the steel.

A carbon atom is smaller than an iron atom, and provides a strengthening mechanism by sitting between the iron atoms, preventing the rows of atoms sliding over one another. At carbon levels below 0.001 per cent, the steel is known as interstitial free (IF) and therefore has a low yield strength.

Other alloying elements, such as phosphorous or vanadium, have larger atoms that strengthen by substitution for an iron atom. This is known as solid-solution strengthening. Steel manufacturers combine this with other techniques to produce steel with an optimum balance of properties.





# Characteristics

**Steel offers an impressive range of properties to meet the demands of every automotive application.**

Steel for use in automotive applications ranges from the most formable grades with a low yield strength of 140 N/mm² to ultra-high-strength tyre-cord steel with a strength of 2,500 N/mm².

Some grades have specialised processing for a specific end use, such as super-clean steels for use in fuel injection systems and forging grades for crankshafts, camshafts and connecting rods. Grades specific to connecting rods, for example, can be deliberately fracture split as part of the manufacturing process.

A key requirement for sheet steel intended for use in automotive pressings is that it is formable, so that it can be stretched without undue thinning in a press to form complex shapes. Softer grades of steel, having low yield strength, tend to be highly formable but lack the strength needed for the main load-bearing members of a vehicle. Higher-strength steel parts may be more difficult to form, since they do not stretch so readily, but offer potential for weight reduction.

*Above: Automotive crankshaft hot forged from a steel billet. Component shown is from an in-line six-cylinder engine.*

*Below: A tailgate inner pressing*

Find out more: **www.corusgroup.com/en/responsibility**

# Steel types

**Steel grades fall into a number of general types, each suitable for different categories of component in a car.**

As well as solid-solution strengthening, steel manufacturers can use a range of techniques to make higher-performance steels. These techniques include grain refinement, work hardening, precipitation hardening and heat treatment.

Using these techniques, sheet steels can be developed with the ideal combination of formability and strength for specific automotive applications.

For example, Fig. 3 below demonstrates the range of formability (elongation) and yield strength for a wide range of automotive sheet steel types.

(Yield strength is defined as the point at which the steel begins to permanently stretch or deform.)

Each ellipse below represents the grades available within each steel type or 'family'. The name for each family – see Table 2 – reflects the method by which the steel achieves its formability or strength.

**Table 2: Steel types**

| Type | Description |
|---|---|
| IF | Interstitial Free |
| BH | Bake Hardening |
| HSLA | High Strength - Low Alloy |
| CMn | Carbon Manganese |
| DP | Dual Phase |
| Boron | Boron steel |
| TRIP | Transformation Induced Plasticity |
| MART | Martensitic |
| TWIP | Twinning Induced Plasticity |

*Fig. 3* **Types of sheet steel**

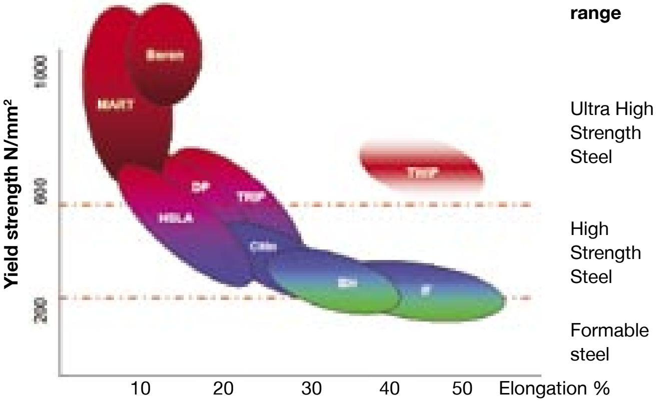
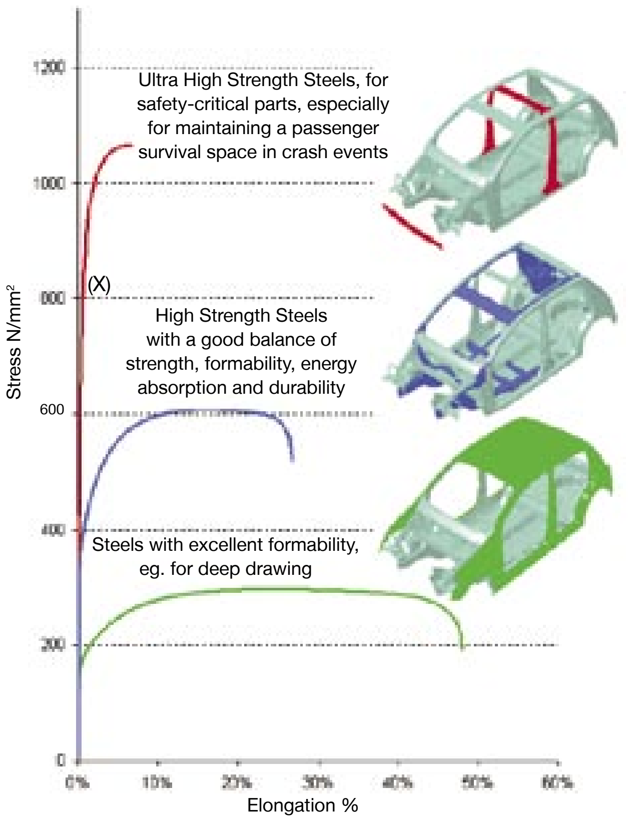



Fig. 4 below illustrates the properties of three different grades of sheet steel, and identifies where in a vehicle structure they are most likely to be found.

The highest strength steel shown here has a yield strength (at point X) of 800N/mm² – roughly equal to eight tonnes per square centimetre.

*Source of diagrams Fig. 3 and Fig. 4: Corus*

*Fig. 4* **Application of types of sheet steel**



# From steelworks to assembly line

**A range of secondary processes is used to give a steel component its final properties and shape.**

### Heat treatment
Heat treatment alters the mechanical properties of metal, improving ductility or strength or a combination of both.

Annealing at around 600$^{0}$ C is used to remove the work hardening that results from cold rolling – creating a softer, more formable steel.

Quenching (rapid cooling) of steel from a temperature of around 750$^{0}$ C results in the formation of (very hard) martensite.

Bake-hardening (BH) steels gain additional strength as the pressed components (such as outer panels and closures) go through the paint oven after painting.

### Coatings
Coil-applied coatings (i.e. applied at the steelworks) for automotive use are generally metallic and based on zinc, aluminium, copper and tin. Zinc coatings are used to enhance corrosion resistance, while other metal coatings can enhance wear resistance and electrical conductivity or promote adhesion.

It is now possible for a vehicle manufacturer to offer 30-year anti-perforation warranties due to the combined performance of coil-applied metallic coatings and paint-shop applied organic coatings.

**Did you know?**
The highest strength steel in everyday use is the cold-drawn wire used for piano wire and tyre cord – a 12mm diameter cable made from this wire is strong enough to lift a 30-tonne truck.

### Blanking
Steel strip leaves the steelworks in the form of coils. The process of de-coiling and cutting the strip into shapes ready for pressing into three-dimensional components is known as blanking.

Blanks of different thicknesses, grades or coatings can be welded together. These Tailor Welded Blanks (TWBs) are typically used for parts that need additional strength and stiffness in applications such as door inners, reinforcing the areas where hinges and locks are attached.

**Did you know?**
A 283mm x 230mm bloom measuring four metres long can be rolled into a coil of rod measuring up to 11 km long (for 5.5mm diameter rod) and weighing 2.2 tonnes.

### Forming
Press forming converts flat sheet steel into the three-dimensional shapes used to generate complex parts and box sections in a car's body in white (BIW). Sheet steel blanks are inserted into a press, the outer edge of the sheet is clamped and the sheet stamped between a male and a female die. To obtain a deep section requires extra metal, which is pulled from the clamped region; the part is then described as 'drawn'. Very deep shapes, such as door inners or spare-wheel wells, are 'deep drawn' and require the most formable grades of steel. The higher-strength steel used in modern cars requires presses with higher press forces.

Press Hardening, also known as die-quenching, is similar to press forming, but in the press-hardening process the steel is first heated to 950$^{0}$ C and simultaneously pressed and quenched in the die to produce a very strong martensitic steel.

Roll forming is a process where sheet metal is progressively folded to shape through a series of rollers.

# From steelworks to assembly line

The resulting profiles are used for seat rails and chassis rails for trucks.

Hydroforming can be used to form tube or sheet steel. In tube hydroforming, a tube is filled with fluid and pressurised. The tube then expands to match the shape of an external die. Chassis frames, subframes and instrument panel support beams are examples of hydroformable parts.

**Forging**
Engine parts such as camshafts, crankshafts and piston connecting rods are examples of parts made by forging. In the forging process, a steel billet is first heated in a furnace. The red-hot billet is then transferred to a press where it is progressively stamped into shape between two dies. The steel forging produced is close to the final part shape and therefore requires little machining. The flow of material in the forging process results in a preferred grain structure, enhancing both toughness and fatigue performance.

**Joining**
Commonly used joining techniques in automotive assembly include spot welding, laser welding, hybrid welding, arc welding, adhesive bonding, mechanical joining and brazing. Efficient and reliable joining is a critical technology in the assembly of automotive structures, and the quality of joins can greatly affect the durability of the finished product. Joining of dissimilar metals (eg. steel to aluminium) is an emerging technology, as carmakers tune weight distribution to enhance a vehicle's handling or stability.

**Machining**
As well as forgings, steel in the form of rod, bar and tube is machined to produce a wide range of powertrain and suspension components, such as gear shafts, stub axles and constant-velocity joints. Typical machining operations are cutting, milling, boring and grinding. Grinding provides the high surface finish required for the longevity of plain bearings and oil seals.

Find out more: **www.corusautomotive.com/hydroforming**

Free-cutting engineering steels are designed to enable the rapid removal of metal during machining, and to prolong tool life.

**Surface treatment**
Wear resistance of bearing surfaces or cylinder bores can be increased by a number of chemical, thermal and mechanical methods. One popular method is nitriding – where a heated component is immersed in nitrogen-rich fluid. The atoms of nitrogen that diffuse into the surface of the steel increase surface hardness without causing embrittlement.

A mechanical method, such as shot peening (hammering with metal beads), leaves residual compressive stresses in the surface of the component, which considerably improves fatigue performance.

**Fracture splitting**
Connecting rod 'big ends' are bolted together to produce a strong and stiff circular housing for the big end bearing shells. These big ends can be made by fracture splitting using a grade of steel that, under the right conditions, breaks cleanly to provide precision-matching surfaces. This method reduces the number of further machining operations and is a good example of material choice enabling lean manufacturing.

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