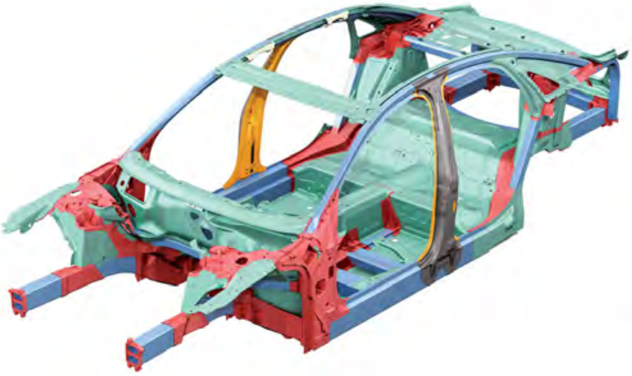
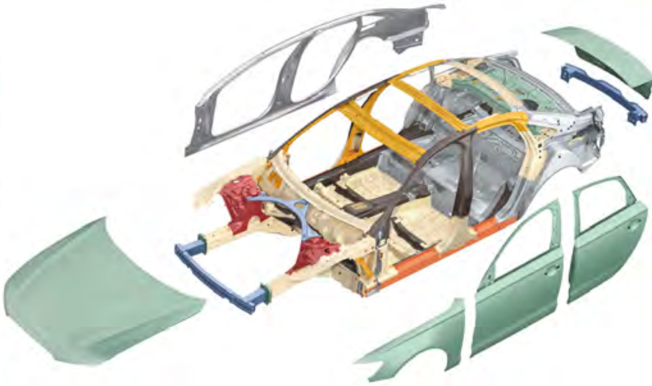
Self-Study Program 200113





Audi Body Construction

Audi Academy

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Table of Contents

The Self-Study Workbook provides introductory information regarding the design and function of new models, automotive components or technologies.

The Self-Study Workbook is not a Repair Manual!
All values given are intended as a guideline only.
Refer to the software version valid at the time of publication.

For maintenance and repair work, always refer to the current technical literature.

Reference	**Note**
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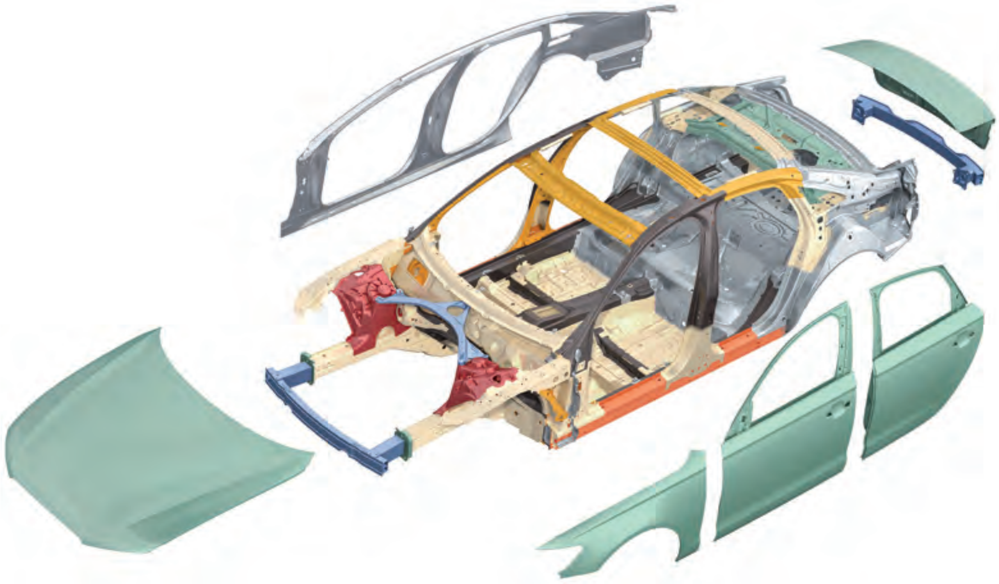
Introduction



What comes to mind when you think about a vehicle? Normally the drivetrain, the engine, the performance and the design come first.

But what would a car be without its body? The body is the central component of a vehicle that connects all other vehicle components and, at the same time, manages to accommodate the passengers.

It meets high technical requirements as well as the comfort expectations of passengers.

The body also creates the vehicle face and brand personality.

A modern body needs to stay in good condition for the whole "life" of the car so that no unnecessary costs arise. This prevents a fast moral decline of a vehicle model and the brand will be held in high esteem.

It is also important that damage to a body can be repaired and this high quality vehicle component can retain its properties and appearance.

This Self-Study Program (SSP) explains the basic associations of material science, steel production and the treatment processes leading up to painting. It will lay the foundations for better understanding of the procedures if body repairs are necessary.

Introduction

Historical Background

Introduction

Car bodies yesterday and today - how have requirements and tasks of car bodies changed with technology?

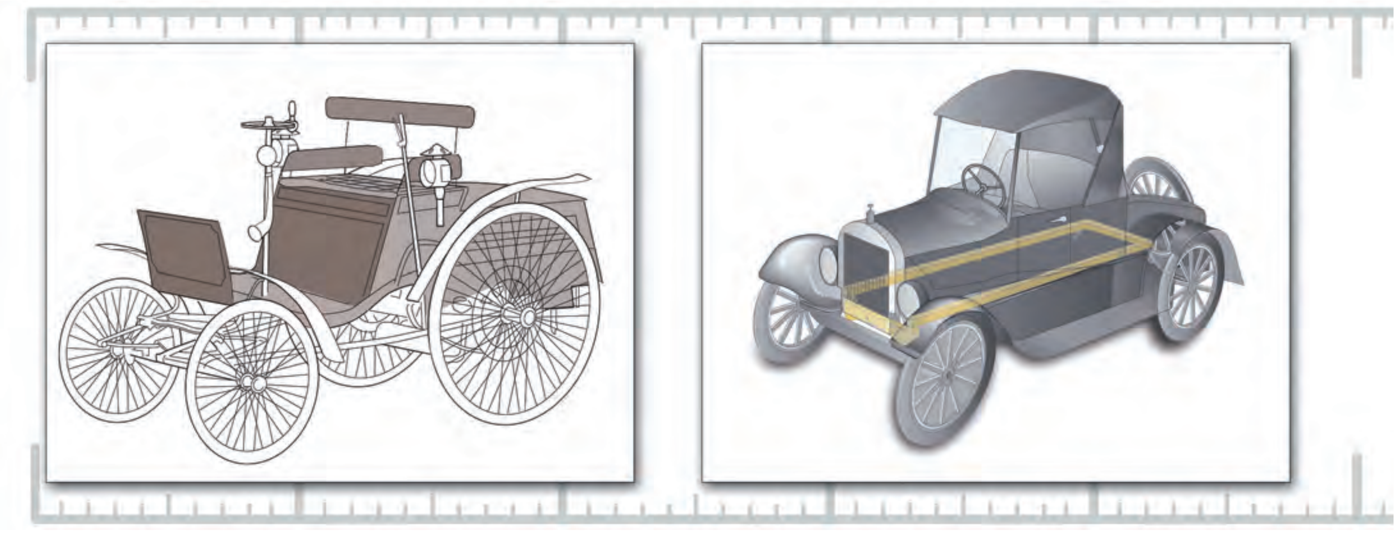
To begin with, let us define the term “body,” which refers to the complete coachwork of a motor vehicle. Historically, the first superstructure on a vehicle with wheels could be considered as the start of body development. We should also include the first open and later closed motor carriages.

We will describe bodies in the context of motor vehicles throughout this SSP.

Non-Load-Bearing Body

The first bodies were not load-bearing, i.e. they were built on a frame or a chassis. Both ladder frames and tubular frames were used. Ladder frames are still used for trucks and off-road vehicles today. Bodies were not necessarily linked to one vehicle manufacturer. There were chassis manufacturers and coachbuilders. This allowed bodies to be adapted to and built onto different drivable chassis as required. As time went on, bodies were produced using a platform frame. The body structure was placed on a platform frame that had been specially designed for it and was then attached. Only then was it fitted onto the drivable chassis.

… from the start of motor vehicle production to today …



Motor Carriage

Wood/Steel

Separate Body on Drivable Chassis,

e.g. Ford Model T

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Unibody Design

Engineers looked for solutions to make bodies without a separate, heavy frame as weight reduction became important in car construction. The resulting body featured a structure that could support itself. Technological developments in sheet metal processes helped with these advances.

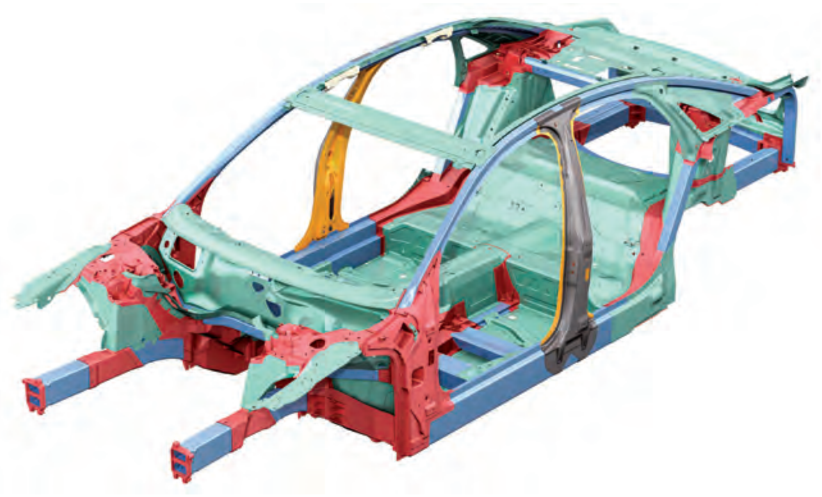
In a unibody design, the load-bearing body structures are joined together securely and permanently using different joining techniques such as welding, soldering and bonding. This method of construction is used in car manufacturing today.

Use of Materials

The first bodies were made of wood. An outer coating of lacquer, fabric or plastic was added to improve the appearance and to protect it from the elements.

Modern body advances are not just located in the structure and cross-sections. Special tailor-made materials are being used more and more for specific body areas.

The materials are distinguished by their composition and their treatment. These different materials are used to improve the ability of specific body sections to bear mechanical stress and resist corrosion. Although steel is used as a material, aluminium and plastics are being used to reduce weight.



Unibody Design

Introduction

Bodies

Bodies are normally thought of as just the panels that create the vehicle design. Construction, support and comfort are often left out.

In a nutshell, the body is the part of a vehicle that allows passengers to be transported - it is the actual “transport case” for the people being carried.

Requirements for Bodies

As a result of technical advances, today’s bodies have an increasingly complex range of tasks to perform:

- Transport space for passengers
- Fulfilment of human needs, for example, comfort, noise insulation etc.
- Accommodation of all technical components for drive and power transmission
- Accommodation of all technical components for convenience systems
- Accommodation of heating, ventilation and air conditioning systems
- Accommodation of all safety systems
- Protect against possible interior and exterior damage, e.g. in accidents
- Exterior design

Structure of a Body

The body can be split into two main areas:

- The inner body structure and
- The outer panels of the body structure

For safety reasons, the inner part of the body structure, also called the passenger cell, needs to be particularly resistant to deformation.

The front and rear ends of the body should allow optimum absorption and reduction of impact energy (crumple zones to meet safety requirements in a crash). This also applies to the side sections and the roofs of modern vehicles.

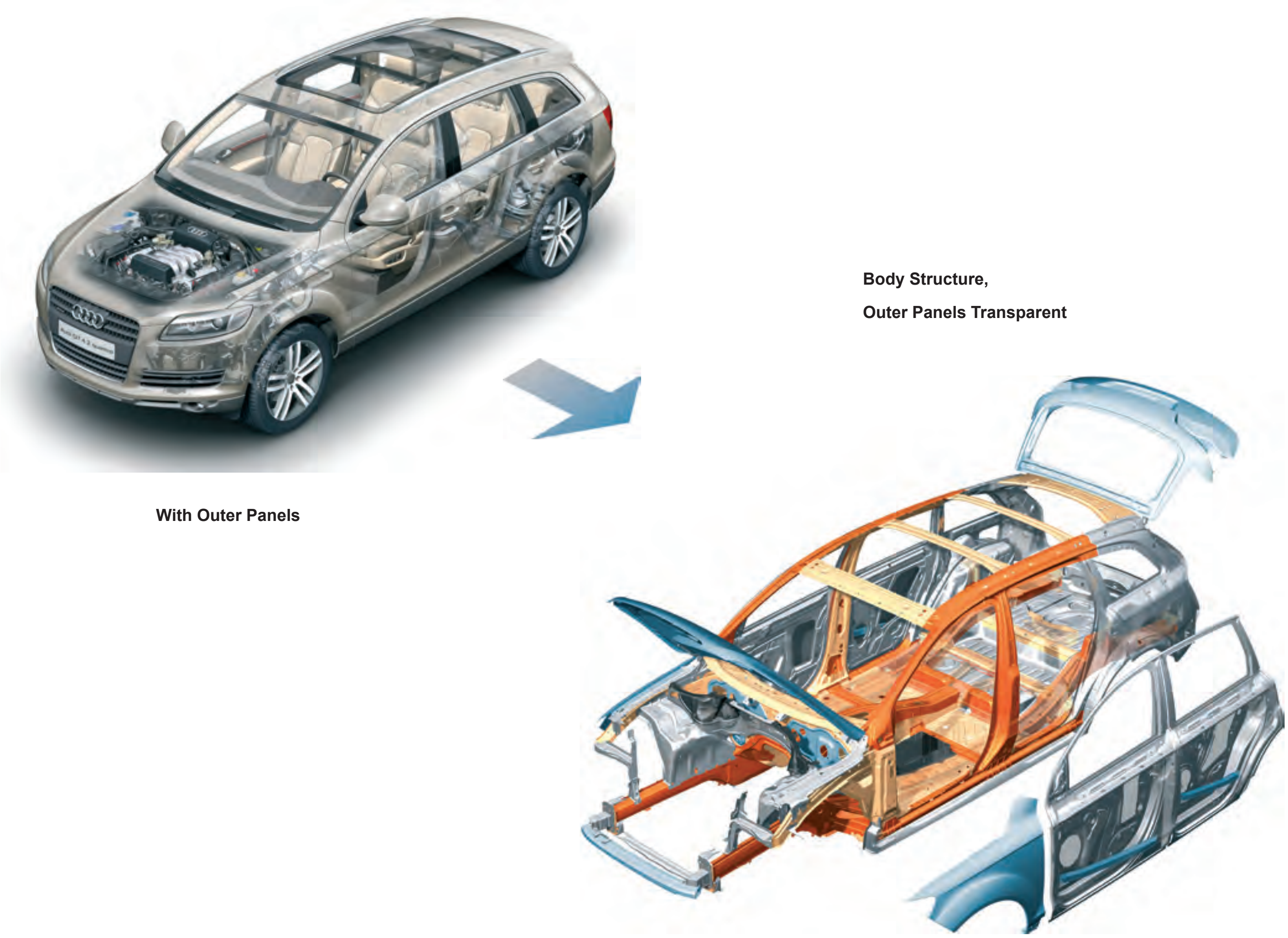
Repairs to a Body

Repairs to the inner body structure are complex due to its sturdy configuration.

Parts fastened to the body structure with bolts (body outer skin) are replaced if badly damaged.

The body images show the internal body structure together with parts of the outer panels.

Body of Audi Q7



With Outer Panels

Body Structure,
Outer Panels Transparent

Basics - Materials

Basics - General Information

Specially configured materials are being used more frequently for specific body parts on modern bodies. Material construction science helps us to understand the reasons for the materials used.

Crystalline Structures

All substances are made from different types of ATOMS (iron, sodium, gold, nitrogen, oxygen etc.), regardless of their state of matter (gas, liquid or solid). The ATOMS behave like solid balls, whose size varies depending on their nature.

The following descriptions cover the relationships with the crystalline structures using metals as an example. When the metals are still in liquid state during melting, the ATOMS move randomly without staying in a set position.

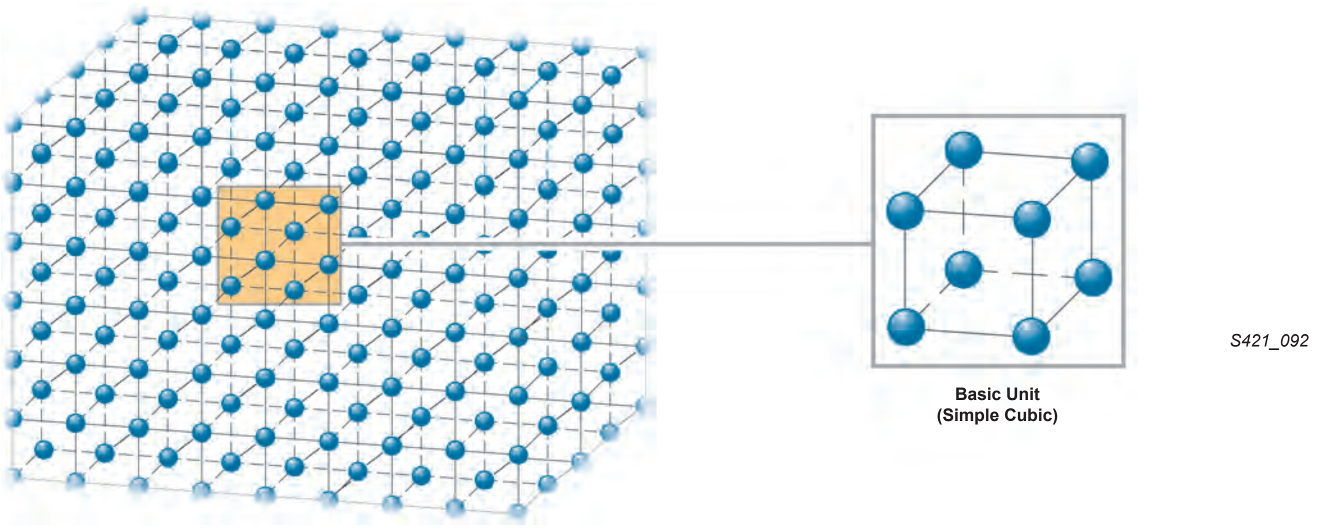
When the materials become solid upon cooling, the ATOMS stop moving and arrange themselves in a set three-dimensional form, i.e. “crystalline structure.”

The crystalline structure can be reduced to the respective smallest basic unit. An example of the simplest form can be simple cubic.

Depending on the type of material, body-centered cubic and face-centered cubic or even hexagonal crystalline forms, for example, are possible in addition to the simple cubic forms.

The crystalline structure type determines characteristic material properties like density, HARDNESS or melting point.

Crystalline Structure



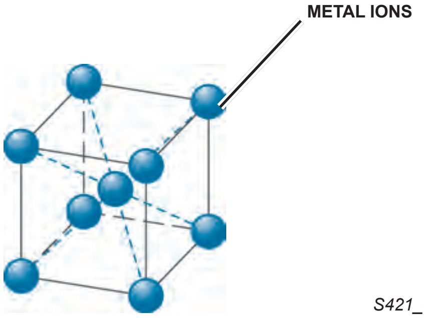
The crystal lattice shown is a random section of a crystalline structure. The ATOMS highlighted in yellow in the illustration show an example of a basic unit of the crystalline structure - in this case a simple cubic crystal. The possible crystalline forms are explained in more detail on the next page.

Metals mostly crystallize in three crystalline forms:

Body-Centered Cubic Crystal:

- The METAL IONS arrange themselves so that the connecting lines between the ions form a cube. Another metal ion is located in the center of the cube.
- This crystallization type is found in chrome, molybdenum, vanadium and tungsten as well as in iron below approx. 900°C (1652°F).

METAL IONS = electrically charged atoms



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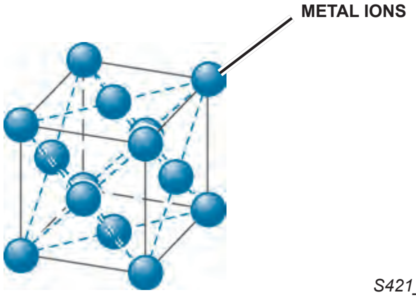
Body-Centered Cubic

Face-Centered Cubic Crystal:

- The basic form of the crystal is also a cube. In addition to the eight METAL IONS at the corners, there is one ion in the center of the six side surfaces.
- This crystallization type is found in lead, aluminium, copper and nickel as well as in iron above approx. 900°C (1652°F).



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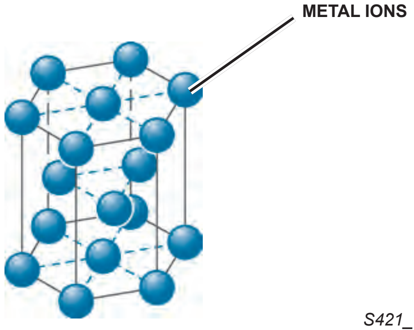
Face-Centered Cubic

Hexagonal Crystal

- The basic form of this crystal is a prism with hexagonal top and bottom surfaces. There is also a METAL ION in the center of the top and bottom surfaces. In addition, three further METAL IONS are arranged inside the crystal. This crystallization type is in magnesium, titanium and zinc.



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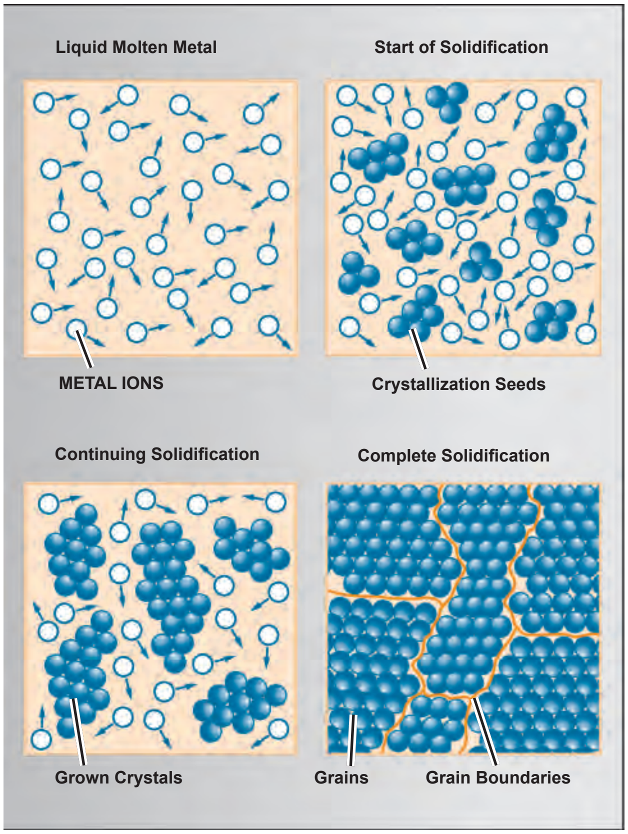
Hexagonal

Metal Structure

In **liquid molten metal**, METAL IONS and free ELECTRONS move randomly among each other. There is no specific arrangement.

An arrangement only forms once **solidification begins**. Formation of crystallization seeds begins at the points where the solidification temperature is reached first.



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As solidification continues, METAL IONS are deposited on these seeds and crystal lattices form. The crystal lattices continue to grow until they meet other crystal lattices that are also grown. They cannot grow any further.

The crystals formed after complete solidification are irregular in their exterior form - they are also called crystallite or grains. They form the structure of a metal.

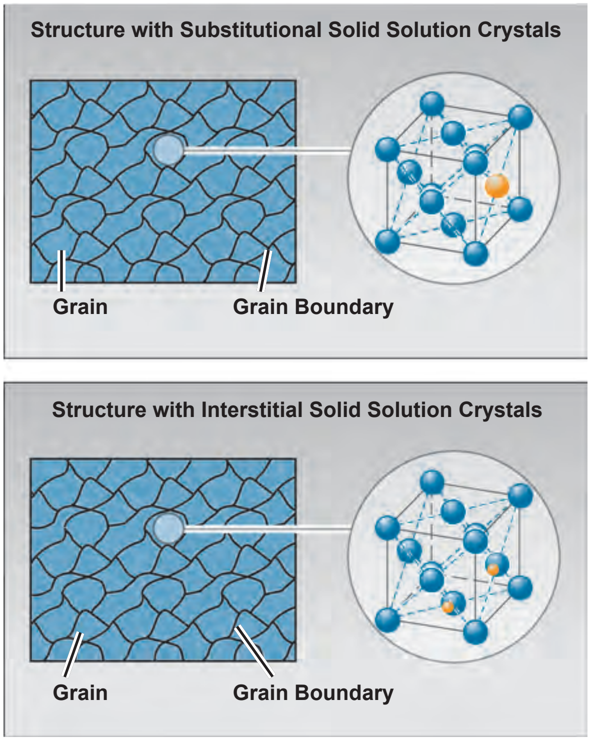
Iron is not used in its pure form for technical applications. Instead, it is used in a wide range of ALLOYS where iron and alloy components are melted together. The alloy additions dissolve in the iron base metal during this process. Different structure types are formed depending on the mixing ratio of iron and alloy components.

Structure Types

Solid Solution Alloy

When ATOMS from the base metal are replaced by an ion from the alloy metal in a crystal, this is known as a substitutional SOLID SOLUTION.

If the ions of the alloy metal arrange themselves between the METAL IONS, this is known as an interstitial SOLID SOLUTION.



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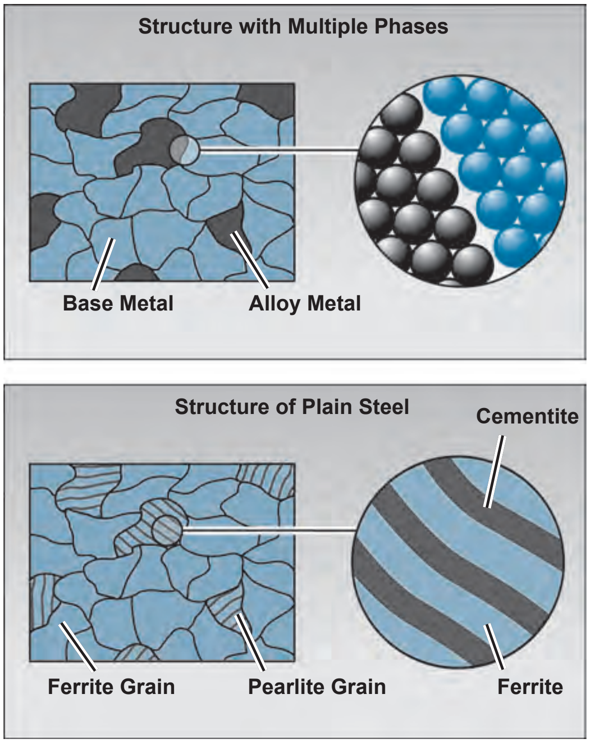
Multi-Phase Alloy

If alloy components do not mix upon solidification of the melt and each component forms its own crystals, this is known as a multi-phase alloy.

Plain steel has one special feature. The alloy component in this case is carbon. It is chemically bonded in the steel as iron carbide (cementite) and forms thin layers between the grains of the iron crystals (ferrite) - these grains are called pearlite.



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Mechanical Properties

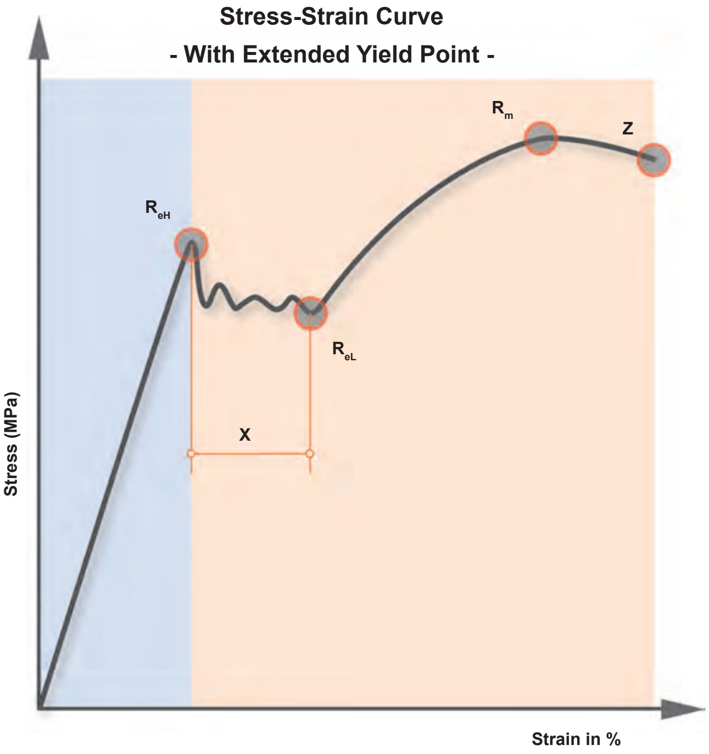
The mechanical properties of materials are discovered and established during laboratory testing. Tensile testing for determining the strength of materials is the most common.

In tensile testing, samples of the test material are subjected to a rising pulling force at room temperature. All test samples are the same size and shape so that the results for different materials can be compared.

The test determines the load required to deform the sample until it breaks. A stress-strain curve (load in relation to the original cross-section of the sample) can be drawn up from the results.

Depending on the type of material, an extended yield point (yield-point runout) or a continuous transition from the elastic region to the plastic region (with 0.2% offset yield point) can occur on the curve.

The following two characteristic curves are examples - they can differ from each other considerably depending on the material or its variation.



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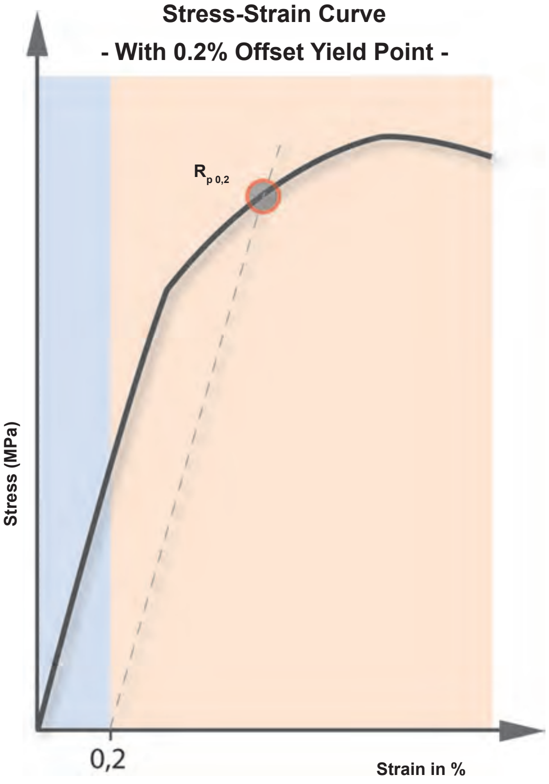

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The unit from the international measuring system, pascal (Pa), is used. Due to the very high values, megapascals (MPa) are mainly used: 1MPa = 1,000,000Pa.

The measuring unit newton (N) per square millimeter is still also used, however: 1MPa = 1N/mm^2.

Analysis of the Stress-Strain Curve

A detailed analysis of the stress-strain curve provides a range of information. The most important are:

Yield point R_{eH} and R_{eL}

At the start of load application, the strain on the sample is elastic. The sample rod returns to its original length when the load is removed. This elastic behavior continues until the yield point R_{eH} is reached. Therefore this point can also be called the elastic limit. The elastic limit separates the elastic region from the plastic region.

This is just an example and a simplified approach for this SSP. In practice, there are, numerous variants of the curve where the elastic limit can be just in front of the yield point. These cases will not be examined further in this SSP.

The sample starts to deform plastically when the yield point R_{eH} (elastic limit) has been passed. Depending on the type of material, the yield point can also cover a region (the yield-point runout “X”) with an upper yield point R_{eH} and a lower yield point R_{eL} (see figure S421_008).

If there is no extended yield point, the 0.2% offset yield point is set as a substitute yield point. This is the point where the 0.2% remaining strain is found. A line is drawn parallel to the linear rise at a distance of 0.2% strain for this purpose. The point where this line crosses the curve is the offset yield point Rp 0.2 (see figure S421_093).

Ultimate strength or tensile strength Rm

The stress reaches maximum here. The stress R_m is the highest load that a cross-section can withstand. From this point on, the sample starts to neck, i.e. the cross-section area becomes smaller. Since the stress is calculated as a force in relation to the cross-section area, the force required for further deformation decreases after point R_m.

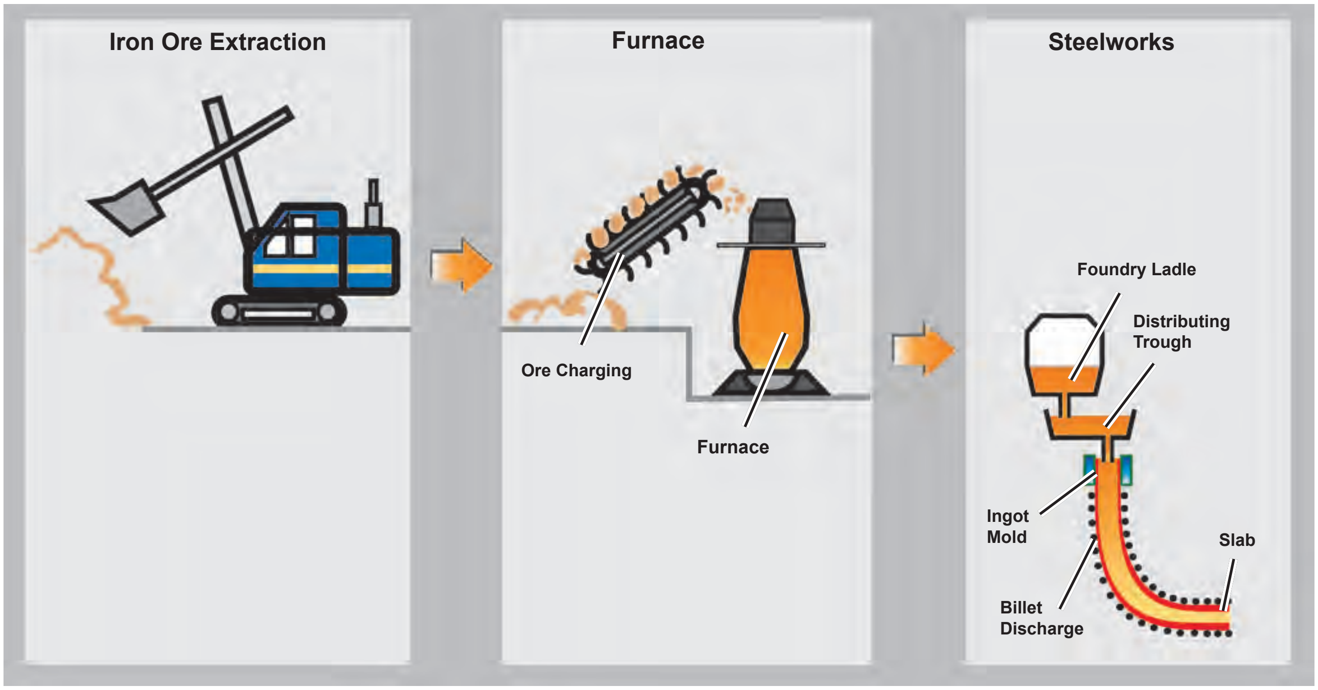
Fracture point (Z):

The sample fails at this point. This value has no significance for technical practice.

Basics - Steel

Steel is one of the most common materials in vehicle body construction. Steel is an ALLOY of iron and carbon with a maximum carbon percentage of 2.06%. Greater percentages of carbon result in castings. Elements like nickel, manganese, phosphor, silicon and chrome can be alloyed to produce the different steel families. There are several types of steel, each of which has a different composition and different properties.

Production of steel



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The iron ore is smelted in a furnace to form iron (pig iron). Depending on the composition of the iron ore used, the smelted pig iron has its own specific composition.

The resulting pig iron is then processed at the steelworks to adjust its chemical composition to specified and required values. This can be achieved by removing and adding certain elements. The process is also called alloying.

At the steelworks, the melt is conveyed to the continuous casting plant and processed into a billet. This billet material then forms the basic product for all future processes. These include rolling, thermal treatment and surface coating, to produce a wide range of SEMI-FINISHED PRODUCTS.

The steel properties are determined by the following main variables:

- The chemical composition of the steel
- The later treatment of the steel products

Chemical Composition

Each type of steel has its own crystalline structure in solid state. This structure gives it mechanical properties that can be determined using a metallographic analysis.

One very important aspect of steel production is the speed at which the raw materials are heated and cooled in both the manufacturing process and subsequent procedures. If you examine iron in its pure state, you can determine how its crystalline structure, its magnetic properties and its solubility vary as the temperature rises or falls.

To give a better understanding of the properties of a type of steel, three items must be explained:

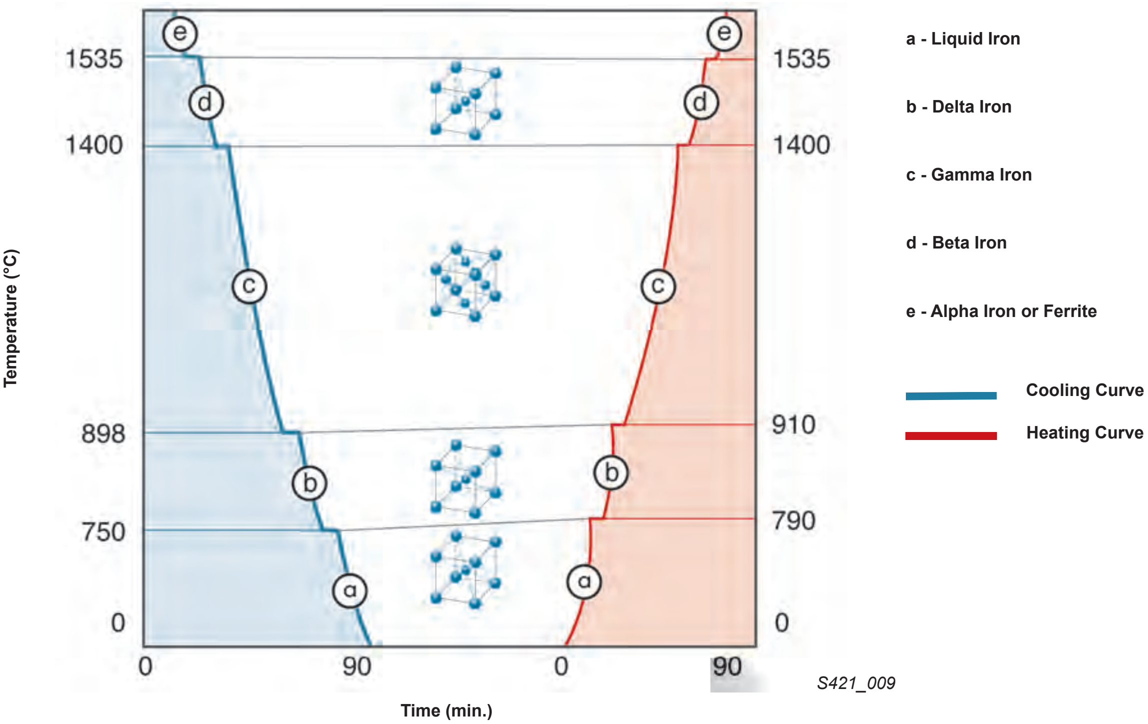
1. The properties of pure iron
2. The properties of different iron-carbon ALLOYS
3. The properties of ALLOYS made from iron, carbon and other components

Pure Iron

The temperatures at which pure iron changes its crystalline structure, i.e. the arrangement of its ATOMS needs to be known to provide a basis for observations of the steel types.

This new arrangement requires a specific amount of time during which the temperature remains constant. The temperatures where the structure changes are called “critical points” (see diagram “Transformation points of pure iron” on the next page). These “critical points” are shown on the diagram as horizontal lines resembling steps.

Transformation Points of Pure Iron



Heating

At temperatures between 0 and 790°C (32°F to 1,454°F), iron is called “alpha iron” or “ferrite” and has a body-centered cubic crystalline structure consisting of nine iron atoms. Alpha iron is very magnetic and does not dissolve carbon.

If the iron is heated further to 790 to 910°C (1,454°F to 1,670°F), it is called “beta iron.” It still has a body-centered cubic crystalline structure that also does not dissolve carbon, but it loses part of its magnetism.

Between 910 and 1,400°C (1,670°F to 2,552°F), it is called “gamma iron.” The cubic structure becomes face-centered at this stage. Gamma iron is not magnetic and dissolves carbon.

Between 1,400 and 1,535°C (2,552°F to 2,795°F), it is called “delta iron”. The crystalline structure is body-centered cubic. Since it only occurs at very high temperatures, it is only of little importance in the investigation of thermal treatment types.

At temperatures above 1,535°C (2,795°F), pure iron is liquid. In comparison with heating, the opposite process occurs during cooling (with minor deviations in the “critical points”).

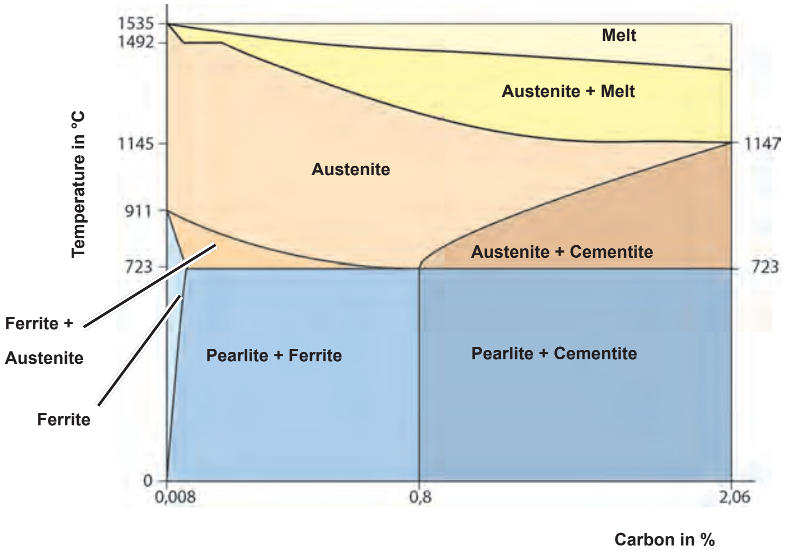
Note

At the “critical transformation points”, the absorbed heat is used to change the crystalline structure and there is no rise in temperature. This means that the iron atoms group themselves in different crystalline structures with different magnetic properties and different carbon solubility depending on the temperature.

Transformation Points of Iron-Carbon Alloys

Steel crystallizes in different microstructures depending on the temperature and carbon proportion. Steel is an iron-carbon alloy with a maximum carbon percentage of 2.06%.

Iron-carbon diagram



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Interpretation of “iron-carbon diagram”

The lines on the diagram show the “critical points” at which the steel changes its crystalline structure. Depending on the carbon percentage, the temperature at which the structural change occurs varies. The areas bordering on the “critical points” show the crystalline structure that the steel adopts in each case. At high temperatures, the steel is molten and all of its components are dissolved - like salt in water.

As the steel cools, parts of the iron and the carbon solidify. The so-called “austenite crystals” form (the solidification temperature varies depending on the carbon percentage). If the temperature decreases further, the ALLOY solidifies completely to become austenite.

Under approximately 723°C (1,333°F) austenite can form two different structures depending on the carbon percentage in the ALLOY:

- If the carbon percentage is below 0.8%, austenite becomes pearlite and ferrite, which are distributed within the steel in crystal form.
- If the carbon percentage is 0.8%, the steel will only contain combined pearlite crystals.
- If the carbon percentage is greater than 0.8%, austenite becomes pearlite and cementite.

!

Note

The illustration shows only the area of the iron-carbon diagram that is relevant to steels. The complete version of the diagram reaches to over 6% carbon.

Structure Types

The table below explains the most important structural and mechanical properties of the compositions listed in the iron-carbon diagram (only the area of the diagram relevant to steel).

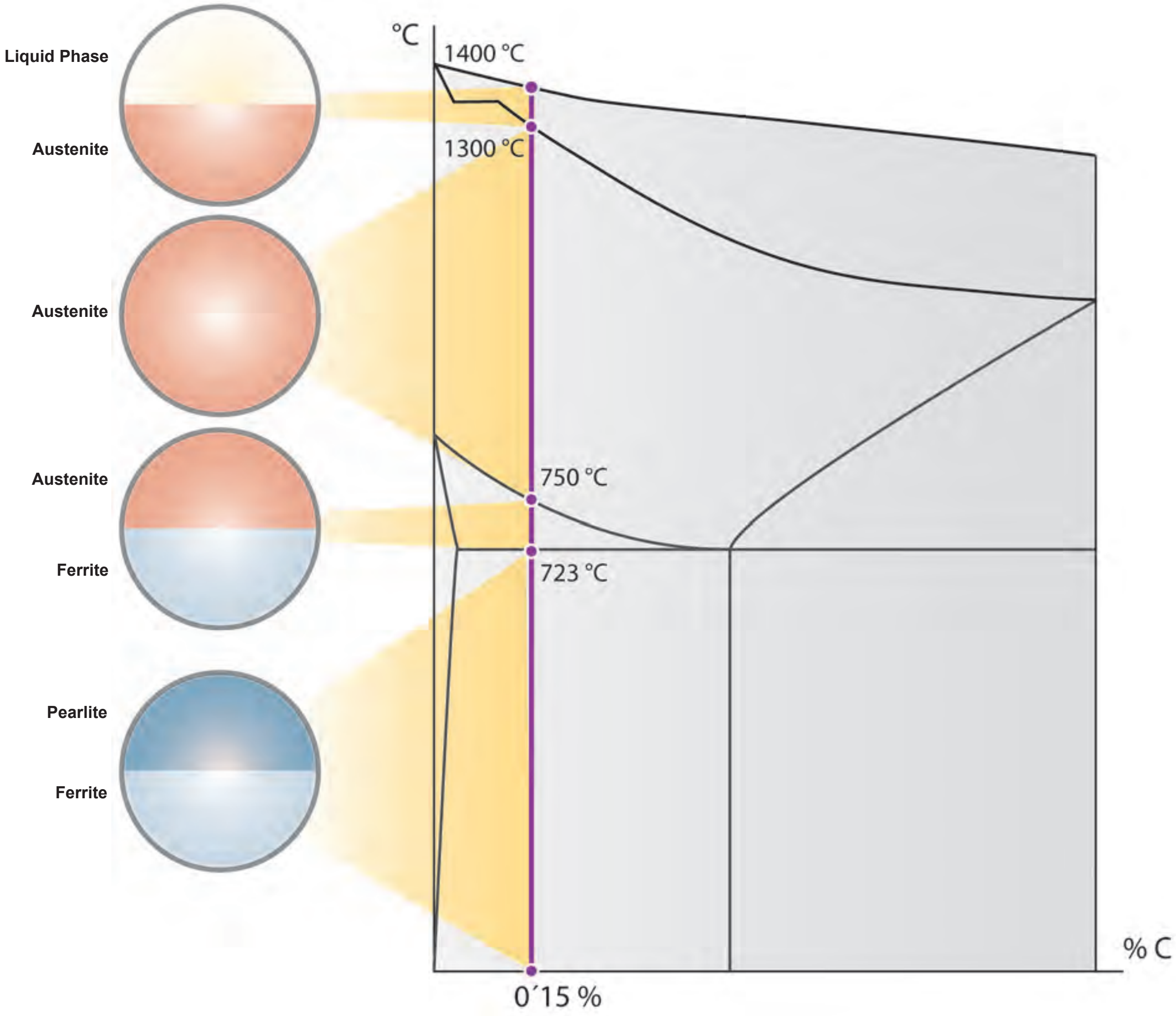
(The listed compositions also occur above this area, i.e. with more than 2.06% carbon.)

Types of Microstructure	Explanation
Ferrite	Ferrite consists of alpha-iron crystals, which form a body-centered cubic crystal lattice. Carbon is deposited between the iron atoms (interstitial SOLID SOLUTION). Ferrite is the softest component of steel. In terms of mechanical properties, ferrite is characterized by an ultimate strength of 28MPa and a strain of 35 to 40%.
Carbon	Pure carbon atoms can be connected to each other in two ways. Graphite or diamond results depending on the type of bonding. Of course, for steels, only carbon in the form of graphite is important. Its bonds are weak and easily broken. Carbon is either incorporated atomically in the lattice (interstitial SOLID SOLUTION) or in the form of bonds - an example is cementite.
Cementite	Cementite is a chemical compound of iron and carbon. In chemistry, it is known as iron carbide (Fe_3C). Cementite contains 6.67% carbon and 93.33% iron. Cementite can be deposited in the structure in a different form, in separate formations (e.g. rods or needles) or in groups on the grain boundaries of the crystalline structure. Cementite is the hardest, but also most brittle component of steel with an ultimate strength of 215MPa.
Austenite	Austenite consists of gamma-iron crystals, which form a face-centered cubic crystal lattice. It contains carbon, which is deposited between the iron atoms like with ferrite (interstitial SOLID SOLUTION). Due to the larger interstices in the face-centered cubic crystal lattice, more carbon can be incorporated compared with ferrite. The carbon percentage varies between 0 and 2.06%. Austenite has an ultimate strength of 88 to 105MPa and a strain of 20 to 23%. It is characterized by a high wear resistance and low HARDNESS and is the substance that occurs most frequently in steels.

Types of Microstructure	Explanation
Pearlite	Pearlite is a mixture of cementite and ferrite layers that results from austentite transformation. Pearlite has an ultimate strength of 55–70MPa and a strain of 20–28%. The mechanical parameters of pearlite are between those of ferrite and cementite; it is harder and more resistant than ferrite, but softer and easier to shape than cementite.
Martensite	Martensite is produced by cooling austentite very quickly. During this process, the face-centered cubic lattice of the austentite is transformed into a body-centered cubic lattice. More carbon is dissolved in the face-centered cubic lattice due to there being more space available than in the body-centered cubic lattice. As a result, the carbon cannot find enough space during the structural transformation, distorts the crystal lattice and expands it. Plate-like crystals are formed, which look like needles in the microsection - so-called martensite needles. The compression stress caused by the greater volume of the martensite results in the greater HARDNESS, but also the brittleness of the martensite. As the cooling speed increases, less and less pearlite is formed so that an almost complete transformation into martensite occurs. After cementite, martensite is one of the hardest components of steel. The ultimate strength of martensite is between 170 and 250MPa and the strain is between 0.5 and 2.5%.
Bainite	Like pearlite, bainite consists of the ferrite and cementite phases, but differs from pearlite in form, size and distribution. Bainite has a structure containing either bundles of ferrite laths with film-like carbide layers between them or ferrite plates with layers of carbide between them. Bainite is formed by accordingly controlled fast cooling of the austenite at temperatures and cooling speeds between those for pearlite and martensite. After cooling the austentite to temperatures above the martensite start temperature, the conversion into bainite occurs in the so-called bainite phase at a now constantly maintained temperature (isothermal). The cooling speed is controlled so that no pearlite is formed. The ultimate strength ranges between 15 and 220MPa and the strain is 1.5 – 2%.

In the following section, two examples of structural changes, which occur in the production of steel with a carbon percentage of 0.15 or 1.20%, are explained using illustrations.

Steel with 0.15% Carbon



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The starting temperature is over 1,500°C - the steel is liquid.

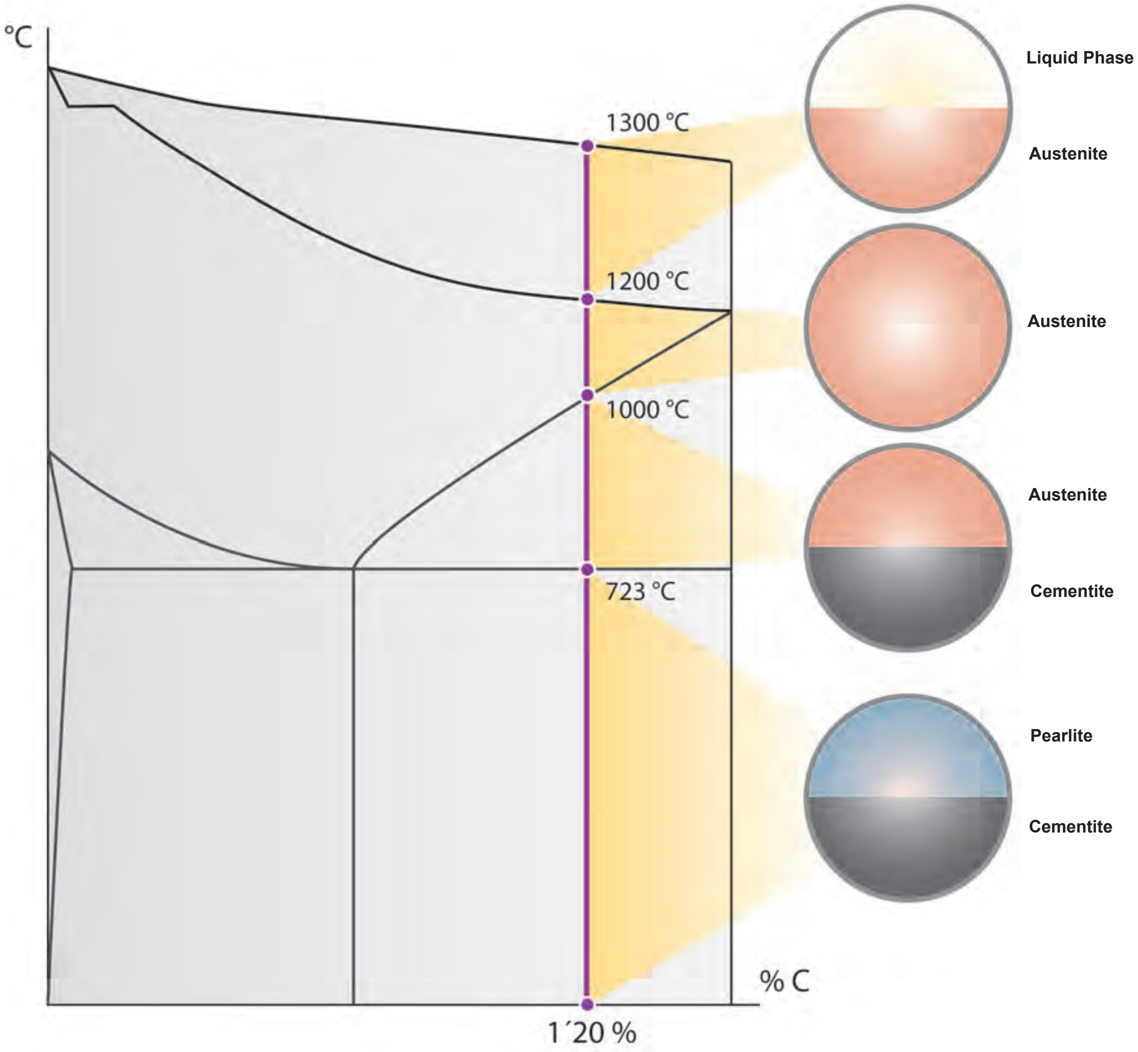
If the temperature falls below 1,400°C, part of the iron and the carbon solidifies and a mixture of a liquid phase and austenite is created.

When the temperature drops below 1,300°C, the steel with 0.15% carbon percentage is already completely solid and has become austenite. It remains like this until the temperature falls below 750°C.

Between 750 and 723°C, a mixture of austenite and ferrite is formed.

Below 723°C, the crystalline structure changes and a mixture of pearlite and ferrite is formed. If, during this phase, the cooling speed changes at any point, differing structure components, like, bainite, martensite etc., can form.

Steel with 1.20% Carbon



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This steel type is also liquid at 1,500°C (2,732°F).

Between 1,300 and 1,200°C (2,372°F and 2192°F), a mixture of a liquid phase and austenite occurs.

When the temperature drops below 1,200°C (2,372°F), the steel with 1.20% carbon is completely solid and has become austenite.

Between 1,000 and 723°C (1,832°F and 1,333°F), a mixture of austenite and cementite is formed.

At temperatures below 723°C (1,333°F), the crystalline structure is transformed into a stable state and forms a mixture of pearlite and cementite.

Alloying Steel with Further Components

The carbon percentage is responsible for the STRENGTH of the steel. If alloy elements such as silicon, phosphor, titanium, niobium or chrome are added, other specific properties can be created. The effects of these elements are noticeable even if they are added only in small quantities in relation to the other alloy components.

The ALLOYING of an iron-crystalline structure can happen in the following different forms:

Substitution:

- ATOMS of other elements replace iron atoms in the crystal matrix.

Gap:

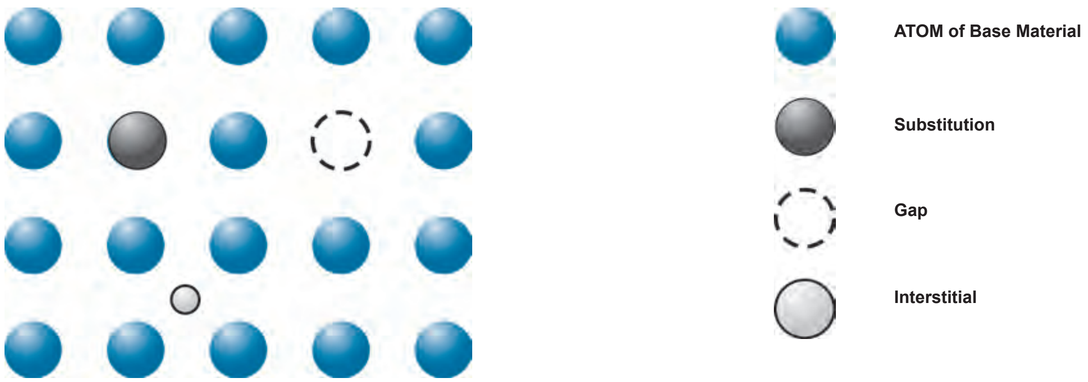
- Iron atoms are removed from the crystal matrix and the corresponding space remains free.

Interstitial:

- ATOMS from other elements like titanium occupy interstitial* positions between the iron atoms of the crystal matrix. They hinder possible sliding of the atom surfaces against each other and thus increase the strength, for example. Their quantity in the steel alloy is decisive for the later mechanical properties.

* Interstitial - located in an intermediate position within a structure

Crystalline Structure/Crystal Matrix



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The table shows you how the steel properties can be influenced using some important alloy elements.

Alloying Element	**Changed Properties of the Steel**
Chrome	Increases the passivity of the steel towards corrosive influences. It is the main alloying element for increasing the rust- and acid-resistance of steels.
Manganese	Refines the grain; increases the STRENGTH; improves the temperability; increases HARDNESS, strain and wear resistance; improves weldability and malleability.
Molybdenum	Increases the STRENGTH and the tenacity; enhances the passivity of the steel towards corrosive influences; improves the temperability, reduces the tempering brittleness in CrNi and Mn steels; favors fine grain formation and improves the weldability.
Nickel	Increases the STRENGTH and tenacity; contributes to stabilization of the austenitic lattice structure; improves the formability even at low temperatures.
Niobium	Behaves similar to titanium.
Phosphor	Increases the STRENGTH; contributes to an equal balance between press-formability and mechanical STRENGTH.
Silicon	Increases the STRENGTH and the elastic limit; refines the grain.
Nitrogen	Increases the STRENGTH of austenitic steels; improves the mechanical properties at higher temperatures.
Titanium	Increases the STRENGTH and tenacity; inhibits grain growth and contributes to a fine-crystal microstructure; suppresses the precipitation of chrome carbide in chrome alloy steels and grain boundary corrosion.

Basics - Materials

Basics - Treatment of Steel

There are numerous types of treatments that can be grouped into three large families:

Treatment Type	Treatment
Mechanical Treatments	Cold Forming
	Hot Forming
Thermal Treatments	Hardening
	Annealing
	Normalizing
	Tampering
Thermochemical Treatments	Case Hardening
	Carbonitriding
	Nitrating

Mechanical treatment

This includes processes in which permanent forming of the metal occurs using mechanical energy. These processes do not have an effect on the crystalline structure, but instead change the elasticity, tenacity, plasticity and HARDNESS.

The most common mechanical processes are listed on the following pages.

Thermal treatment

Thermal treatment includes processes that modifies metal properties by changing their structure and the structural constitution. The material with these new properties can perform the intended tasks better.

The application possibilities and performance are much better than if the steel was not treated. Thermal treatment includes the thermal treatment of steel.

In general, thermal treatment is simply “heating and maintaining” a certain temperature in the steel for a specified period of time. It should then be cooled in a suitable way. This results in changes to the microscopic structure of the steels that are responsible for the adjustment of HARDNESS and STRENGTH.

This means that, in thermal treatment, only the thermal energy has an effect. This effect is on the crystalline structure, but not on the chemical composition.

The four most important thermal treatment methods:

Process	**Procedure**
Hardening	The steel is hardened by cooling it quickly to avoid changes to the crystalline structure.
Annealing	The steel is annealed when it has been subjected to deformations through mechanical influences or other causes. The steel is cooled very slowly.
Normalizing	The steel is normalized to remove tension. The steel produced is harder and stronger than full annealing. A medium cooling speed is required for this.
Tempering	The steel is heated (tempered) again after hardening. It is less brittle without significantly reducing its hardness or strength. Tempering partly reverses the hardening. These effects become greater as the target heat temperature rises.

Microstructures

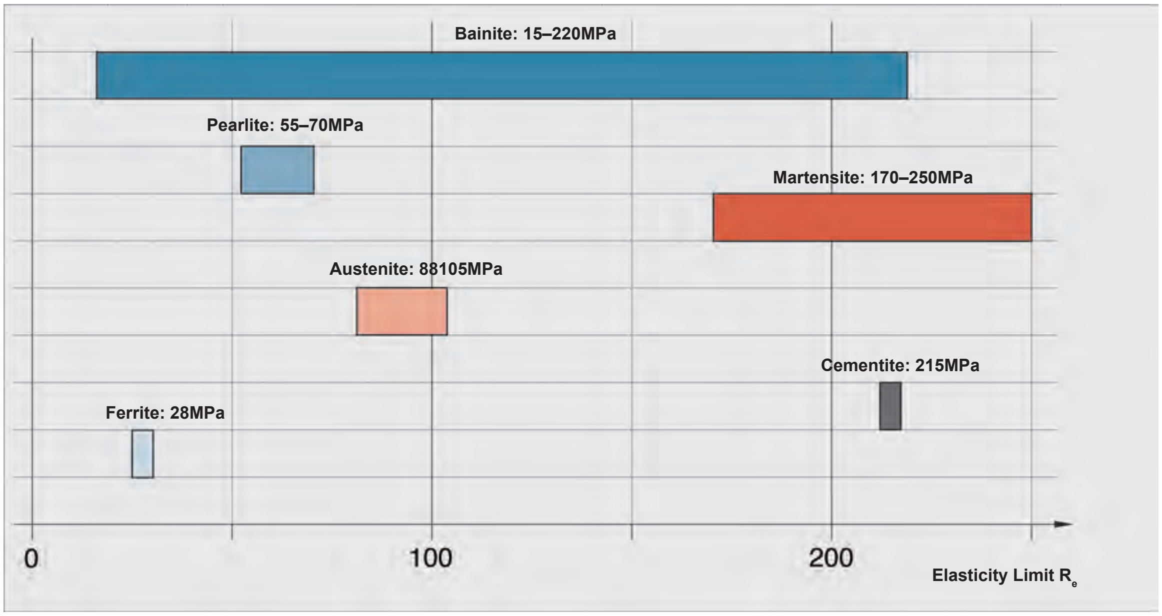
Thermal treatment methods allow variations in the structural composition of the steel. This is also depends on the composition of the steel (proportion of alloying elements).

Thermal treatment can make the steel meet the requirements for different applications.

This approach is used with the body. Depending on the requirements for the different body areas, steels with the necessary structural compositions and necessary strength parameters are used.

The basic structural components with their respective strength areas are shown in the diagram.

Elasticity Limit R_e of Selected Structural Components



S421_023

Thermochemical Treatment

This includes processes in which chemical components are involved in the steel treatment in addition to thermal energy (heat, maintain temperature, cool). The microstructure and the chemical composition of the steel vary accordingly.

The most important thermochemical treatment methods are:

Process	Procedure
Case Hardening	In case hardening, the steel surface is enriched with carbon (carburization) creating the conditions for later hardening. The part is heated and kept at a specific temperature while simultaneously being in contact with materials that can release carbon. The enrichment with carbon can be achieved by gas carburizing, powder carburizing and carburizing in salt bath. During the subsequent cooling, the exterior layers are hardened while the noncarburized material core remains unchanged. The process results in greater tenacity and impact strength.
Carbonitriding	Carbonitriding is actually an advanced variant of case hardening. In this process, the surface of steel parts is also enriched with nitrogen in addition to carbon. The enrichment is performed in a cyanide salt bath at specific temperatures. The material is then cooled in a controlled process. There is little warpage due to the low hardening temperatures and the milder quenchant. In this process, hard outer layers with a low thickness are created in a simple and fast way.
Nitrating	Nitration also forms hard layers on the surface of the steel part by forming nitrides. These layers reach a high level of HARDNESS that is even greater than the HARDNESS of the layers formed in case hardening (see above). This process is based on steel absorbing nitrogen in its microstructure. The process occurs at low temperatures which is why deformation is minimal. There is no quenching and no transformation of the structure.

Basics - Aluminium

Weight is playing an increasingly important role in vehicle design due to desire for economic and environmentally friendly vehicles.

In addition to advanced solutions in body design, lower weight can be achieved by using lighter materials. The lightweight metal aluminium is being used more and more.

Production of aluminium

Aluminium is extracted from bauxite in a digestion process using caustic soda (NaOH). This method is called the Bayer process.

Bauxite:

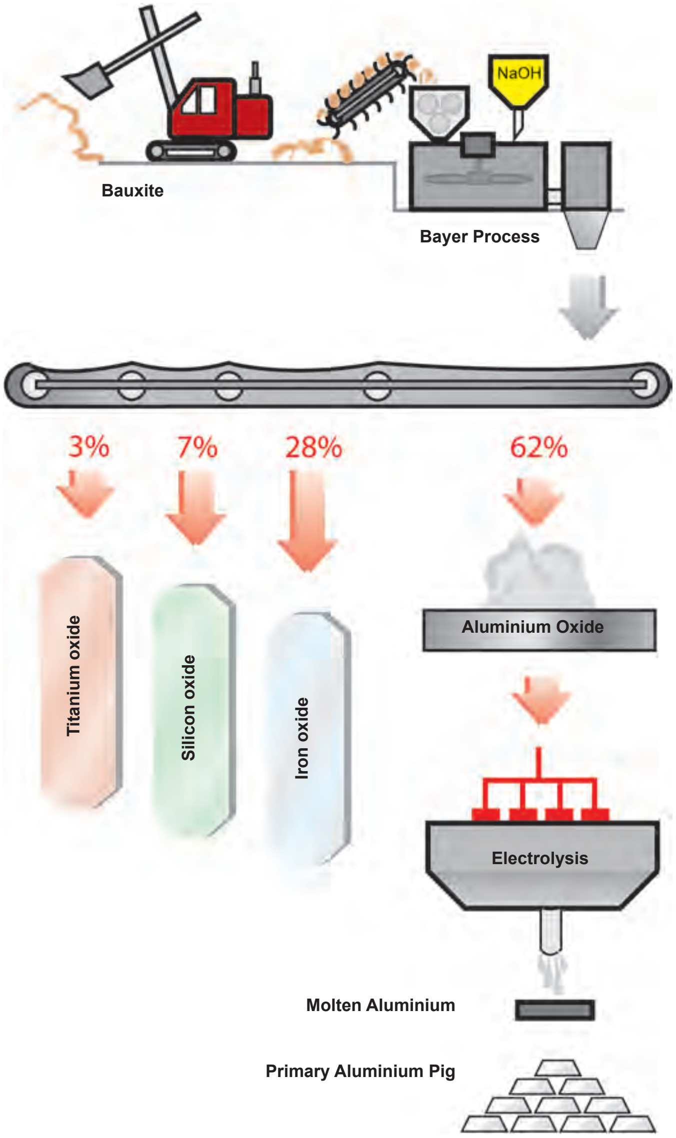
- Formed by the weathering of limestone and silicate stone in the appropriate climatic conditions
- The name comes from its place of discovery, Les Baux (southern France).

Aluminium is readily found on earth, but economic extraction has only been possible for around the past 100 years.

It is difficult to extract the aluminium from the ore because it is in a very stable oxide bond with oxygen. It cannot be extracted from the ore by smelting with the aid of carbon like iron production.

It was not until possible to produce aluminum on a large scale until the end of the 19th century. The dynamo invented by Werner von Siemens allowed for electrolysis.

Audi uses large amounts of aluminum in its vehicles to reduce weight.



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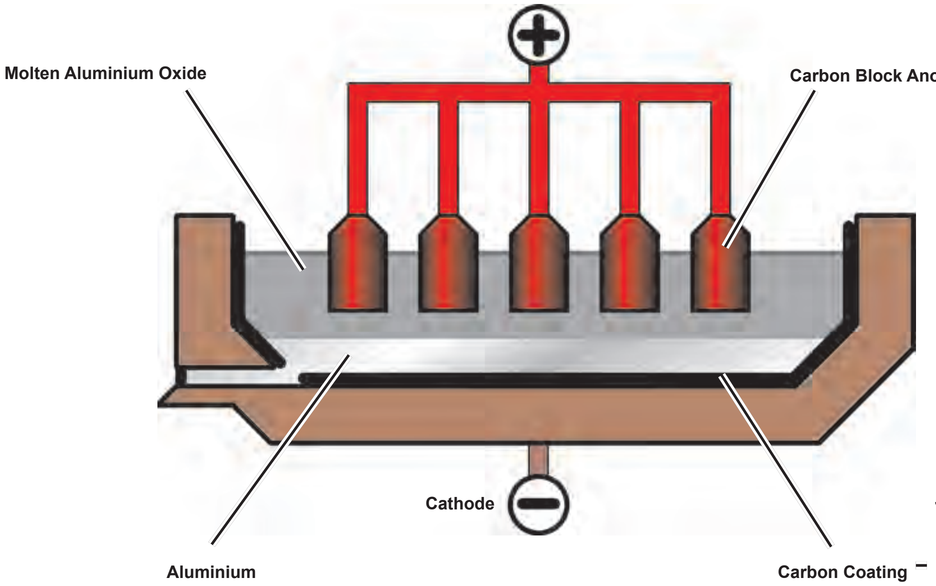
On an industrial level, the extraction of aluminium by electrolysis is performed in large iron vats of molten aluminium oxide that are lined with a coating of carbon. The vat serves as the cathode. Carbon blocks submerged in the aluminium oxide are used as anodes.

The aluminium is deposited on the floor of the vat since the distance to the floor is shorter than to the side walls. This causes a layer of liquid aluminium to form under the molten aluminium oxide. The aluminium is tapped off every two to four days and can be cast in bars.



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Alloying Aluminium

Aluminium alloys are used instead of pure aluminium to guarantee optimum material properties for the respective body components.

Aluminium is low STRENGTH in its pure state. The properties of aluminium can be changed by adding other elements, i.e. by ALLOYING. This concerns primarily the STRENGTH and the corrosion resistance. The most frequent alloy components are magnesium and silicon. These ALLOYS then form the basis for extruded profiles, cast nodes and aluminium sheet.

The STRENGTH of aluminium alloys can be increased by forging and curing.

One requirement for the usability of aluminium in technical applications is its curing capability.

In curing, precipitation of brittle structure components within the alloy structure can be achieved with specific temperature control. This builds up inner resistance to deformation and results in an increase in STRENGTH.

Steels for Body Construction

Classification of Steels for Body Construction

Due to the large number of possible steel types, it is useful to classify them according to specific features. This allows steels to be classified according to their mechanical values such as ultimate strength and yield point. One example is the differentiation of conventional, high-strength, higher-strength and ultra-high-strength steels.

Classification According to Strength	Ultimate Strength in MPa	Classification According to Steel Family	Manufacturing Method
Conventional Steels	Up to approx. 300	Deep-drawn steels	Rolling
High-Strength Steels	300-480	Bake-hardening steel	Bake hardening
	350-730	Micro-alloyed steel; Isotropic steels	Grain refining and precipitation hardening
	340-480	Phosphor-alloy steel Interstitial-Free (IF) steel	Solid solution hardening
Higher-Strength Steels	500-600	Dual-Phase (DP) steel	Hard phases
	600-800	TRansformation Induced Plasticity (TRIP) steel	Hard phases
Ultra-High-Strength Steels	>800	Complex-Phase (CP) steel	Hard phases
Ultra-High-Strength Thermoformed Steels	>1,000	Martensite steel	Hard phases

It is possible to classify steels according to their mechanical values, but this is imprecise. There is no fixed value for a boundary between the different steels. Normally quite a large bandwidth is involved. There can, for example, be cases where high-strength steels have identical or higher values than higher-strength steels. For this reason, steels are normally grouped into families according to manufacturing method.

Steels from these families will be looked at over the following pages as they are increasingly used in body construction. The mechanisms for increasing the STRENGTH compared with conventional deep-drawn steels are explained. It is necessary to achieve a balanced ratio between increasing strength and plasticity.

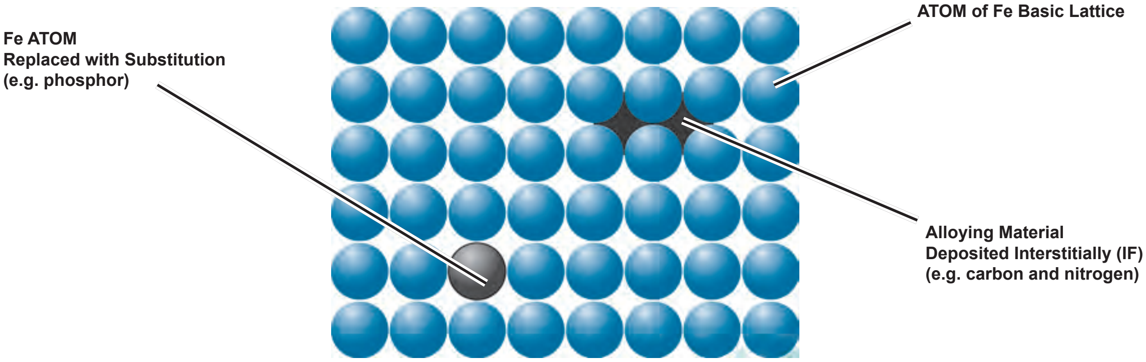
Basically, the STRENGTH of steels can be increased in four ways:

- Solid solution hardening
- Grain refinement and precipitation hardening
- Bake hardening
- Hardening using hard phases (hard phases = hard structure phases)

Increasing Strength of Steel

Increasing strength - with solid solution hardening

Normally, hardening calls to mind the thermal treatment of steel for achieving greater HARDNESS. Increasing the STRENGTH and also the HARDNESS can also be achieved by ALLOYING with other elements. This method is known as solid solution hardening. The hardening method allows the two steel types higher-strength IF steels (Interstitial Free steels = IF steels) and phosphor-alloy steels to be produced.



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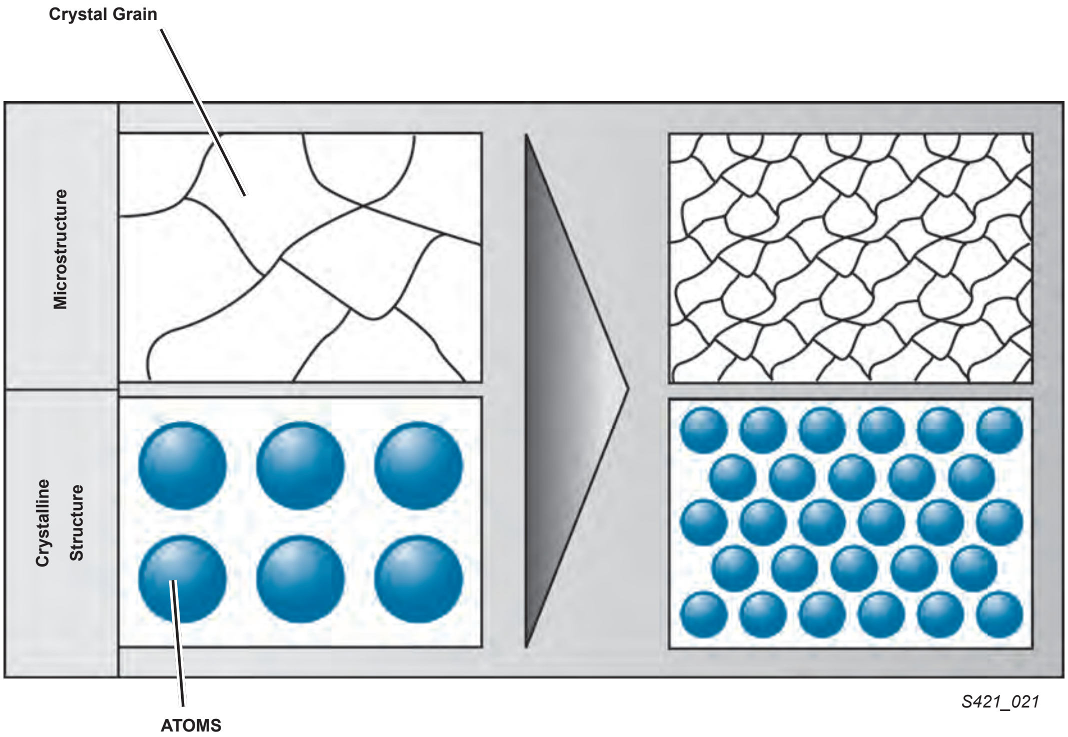
- Higher-strength IF steels:
  These steels have a ferrite matrix without interstitially (interstitial = inside lattice) dissolved alloying proportions. Early in the steel melting process, a lower proportion of carbon and nitrogen is set with specific treatment. Remaining ATOMS from these elements are bound by microalloying titanium and niobium. The steels have good malleability due to the lack of blockages by carbon and nitrogen (interstitial free). Phosphor and manganese are added to the steel to obtain the required STRENGTH. This is then known as higher-strength IF steel. The steels mostly have a minimum ultimate strength between 340 and 460 MPa or a minimum yield point (here the 0.2% offset yield point RP0.2) between 180 and 340 MPa.
- Phosphor-alloy steels:
  These steels also have a ferrite matrix and contain hardening elements from solid solution hardening with phosphor (substitution), which can have a percentage up to 0.12%. The steels are characterized by their compromise between “mechanical STRENGTH and press formability”, which is why they have a wide range of applications such as structural or reinforcing parts (longitudinal members, crossmembers, pillars etc.), parts that need to be fatigue-resistant or parts that play an important role in crashes. These steels mostly have a minimum ultimate strength between 340 and 480 MPa or a minimum yield point between 220 and 360 MPa.

The steels have a good balance between press formability and mechanical STRENGTH.
If repairs are required, the steels weld well in any welding method.

Increasing Strength - By Means of Grain Refinement/Precipitation Hardening



The STRENGTH of a steel can also be increased by reducing the grain size (grain refinement) and with precipitation hardening. This principle of grain refinement is used for micro-alloyed steels. Vanadium, niobium and titanium are alloyed in small quantities. This micro-alloying creates a fine dispersion of carbide/nitride precipitation during hotrolling. The grain growth is limited by this and ferrite grains measuring <10 micrometers are formed. Carbide/nitride precipitates again over the course of the transformation, but also during the subsequent slow cooling. These are even finer - they cause precipitation hardening.

This produces micro-alloyed fine grain steels with a high STRENGTH and simultaneous limitation of the alloy elements contained.

Micro-alloyed steels mostly have a minimum ultimate strength between 350 and 730 MPa or a minimum yield point of 260 to 550 MPa.

These steels are used for parts in the inner body structure that need to have a high fatigue strength, like reinforcing parts and mounts. Their mechanical properties allow lighter reinforcing parts and structural components to be produced.

Isotropic steels are one variant of the micro-alloyed steels whose material parameters are not dependent on the rolling direction. The isotropic behavior happens during a special alloying technique using manganese and silicon. The isotropic steels mostly have a minimum ultimate strength between 300 and 400MPa or a minimum yield point of 260 to 550MPa.

Isotropic steels are particularly suitable for outer skin parts where the isotropic behavior is very important.

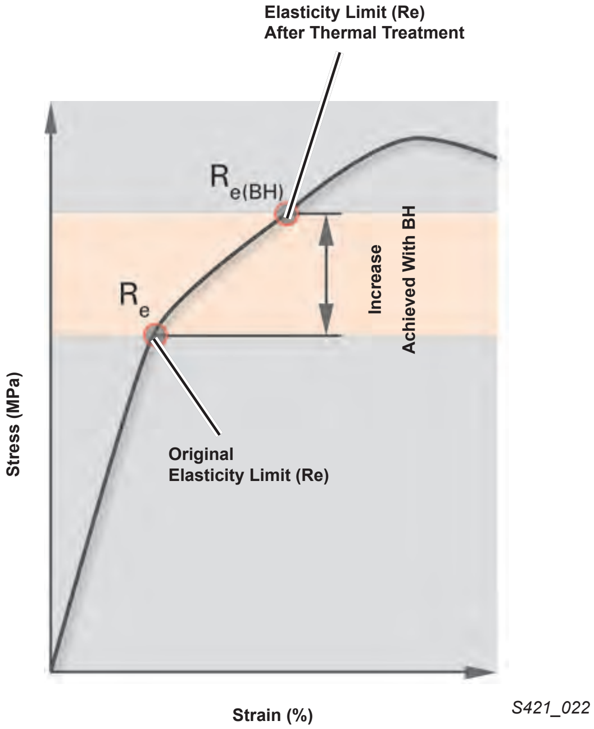
Micro-alloyed fine grain steels can be welded with all methods.

Increasing Strength - By Means of Bake Hardening

Bake hardening steels are easy to form in their original condition. They do not acquire their final higher strength until the formed component goes through the paint baking process. These steels have good formability and component strength. This is a great advantage in the production of a body.

Raising the elasticity limit Re to Re(BH) happens during thermal treatment at a low temperature, such as baking paint in the paint oven. This is also known as a "bake-hardening effect" (BH effect). Heating and drying in the oven at 180°C (356°F) is compared with a baking process.

This heating process is sufficient to change the molecular structure of the sheet to increase the elasticity limit.



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BH steels comprise a ferrite matrix, which contains the carbon required for the "bake-hardening effect" in the form of a solid solution. The improvement through thermal treatment normally exceeds 40MPa. This means a steel with a fracture strength (Rp 0.2) of around 220MPa has a fracture strength of up to 260MPa following the "bake-hardening effect".

Bake-hardening steels mostly have a minimum ultimate strength between 300 and 480MPa or a minimum yield point of 180 to 360MPa.

Advantages of "bake-hardening effect":

- It improves the deformation resistance of all processed parts, even those with a slight deformation level hoods, roofs, doors, fenders …).
- Thinner sheets can be used to provide the same mechanical properties as thicker sheets of different steels. This reduces the weight of the body while increasing deformation resistance.

BH steels are used for parts of the body panelling (doors, hoods, tailgates, front fenders and roofs) or for structurally important parts (pillar reinforcements or longitudinal members).

Due to the higher elasticity limit, more force is required for reshaping. It welds well with any due to the minor ALLOYING.

Increasing Strength - with Hard Phases

Increasing the STRENGTH of steels using hard phases leads to so-called "multi-phase steels" that achieve their STRENGTH through the coexistence of "hard" and "soft phases" - i.e. multiple phases - in their microstructure.

These hard and soft phases are structural components in the steel, which are characterized by their respective different HARDNESS.

When a steel is manufactured with hard phases, the starting steel is subjected to a specific process and is transformed into a steel with modified structural composition.

Production of Multi-Phase Steels

The production of multi-phase steel makes use of the steel's properties to form different microstructures depending on the forming and cooling conditions.

These different structural components and intelligent combinations of them allow a varied configuration of material properties.

Today, multi-phase steels are produced with ultimate strengths ranging from 500 to around 1,400MPa.

Different methods can be used for production depending on the manufacturer. For example, the required microstructure can be obtained after initial production by heating the cold-rolled metal strips.

Also the metal strips produced by hot-rolling can immediately be cooled and the required microstructure configured.

!

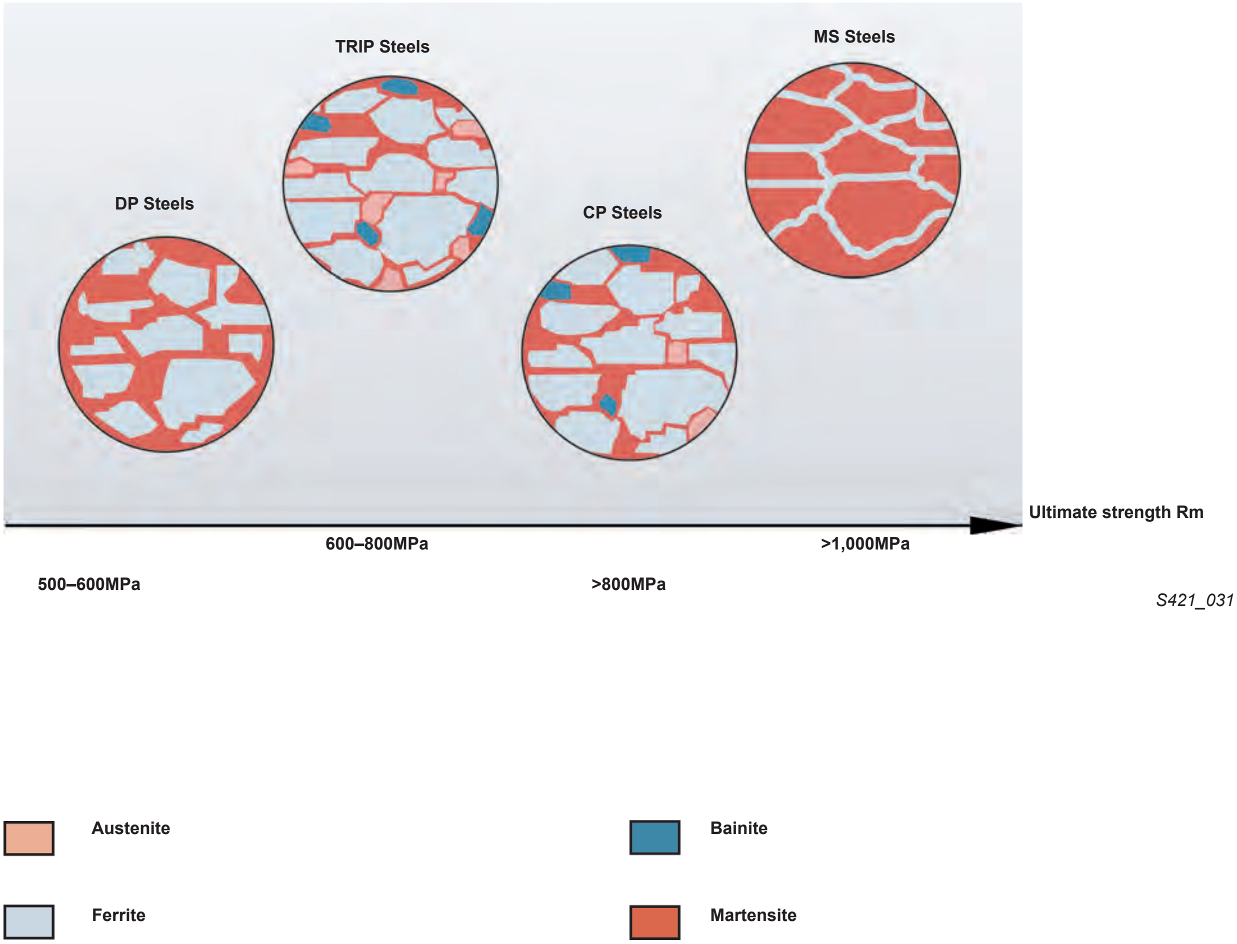
Note
The explanation of the multi-phase steels and their production - including simplified illustrations of the temperature and transformation processes - uses the treatment of hot-rolled metal strips.

The category of multi-phase steels includes

- DP steels (Dual-Phase steels)
- TRIP steels (TRansformation Induced Plasticity steels)
- CP steels (Complex Phase steels)
- MS steels (MartenSite steels)

All of these steels have a high level of stiffness, high energy absorption and great deformation resistance. The most frequent applications are those in which a high level of energy absorption without deformation of the part is required such as reinforcement for the B-pillar and inner reinforcements for the side members.

It is generally difficult to reshape this kind of sheet which is why the part is normally just replaced. However, it can be welded with any method.



S421_031

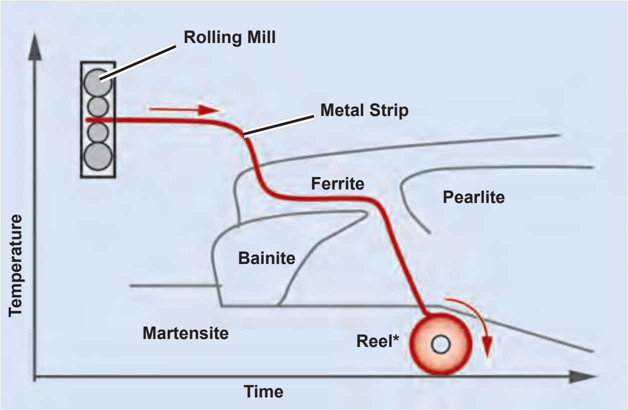
Steels for Body Construction

“DP” (Dual-Phase) Steels

DP steels have a high mechanical STRENGTH and good malleability. The ultimate strength Rm is between 500 and 600MPa.

The STRENGTH is achieved by fast cooling of the hot metal strip - immediately after the rolling process – in the ferrite area. A cooling pause in the ferrite area allows the formation of sufficient ferrite. Then it is cooled more quickly to a low reeling temperature so that the remaining austenite is turned into martensite.

The cooling speed and the steel composition are adjusted to each other so that no pearlite and as little bainite as possible are formed. A mixed structure results with approx. 80–90% ferrite and 10–20% insularly deposited martensite.



S421_028

“Dual-phase steels” contain approximately 0.12% carbon, 0.5% silicon and 1.46% manganese.

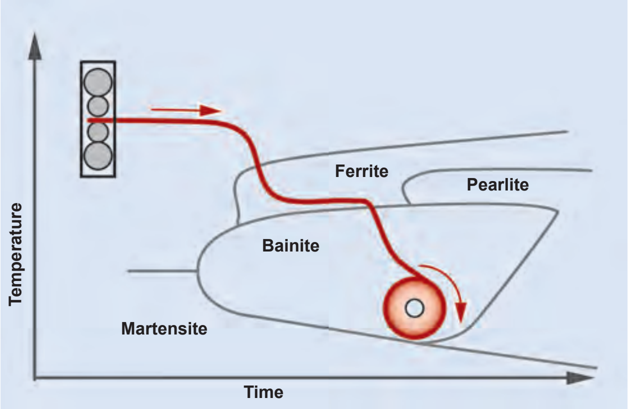
* Reel = reeling device for hot metal strip

“TRIP” (TRansformation Induced Plasticity) Steels

TRIP steels have a very good ratio of STRENGTH and plasticity; the ultimate strength Rm is between 600 and 800MPa.

The STRENGTH is achieved by fast cooling of the hot metal strip - immediately after the rolling process. It is cooled in the ferrite area where ferrite is formed in a cooling pause. The austenite is enriched with carbon during this process. Then the bainite area is cooled and the hot metal strip is reeled up. The enrichment of the austenite with carbon continues. If the martensite starting temperature is below room temperature, the austenite that has not yet been transformed remains as so-called “residual austenite” in the structure. Undesired martensite forming in the bainite is prevented by ALLOYING.

The temperature of the reel is important for the process.



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“TRIP” steels have up to 20% residual austenite in their structure. This residual austenite is not transformed into martensite until the material is shaped and hardened in the process.

TRIP steels normally contain about 0.15–0.4% carbon, 1–2% silicon and 0.5–2% manganese.

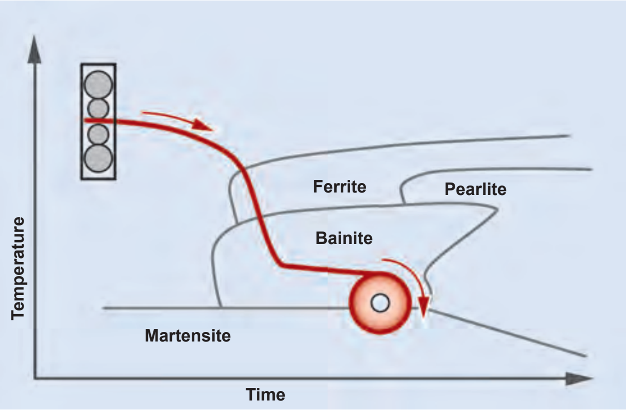
“CP” (Complex-Phase) Steels

CP steels mark the transition to the ultra-high-strength steels, which can have an ultimate strength value Rm of over 800MPa.

CP steels are characterized by high energy absorption and high deformation resistance.

The STRENGTH is achieved by fast cooling of the hot metal strip - immediately after the rolling process. It is cooled quickly to a reeling temperature in the bainite range and then reeled. Only a small amount of ferrite and martensite is formed.

Micro-alloying additives like niobium and titanium are used for grain refining. This gives the steel a very fine grained structure.



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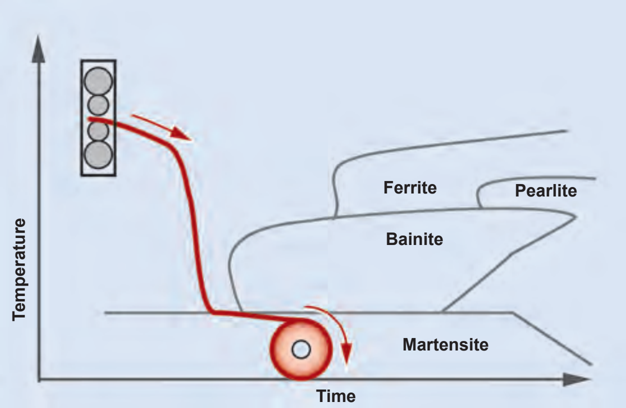
CP steels have a low carbon proportion of less than 0.2%; and contain alloying elements like manganese, silicon, molybdenum and boron.

“MS” (MartenSite) Steels

MS steels are among the highest-strength steels. They are characterized by ultimate strength values Rm of around 1,000MPa to over 1,400MPa.

The STRENGTH is achieved by cooling the hot metal strip at maximum speed - immediately after the rolling process. In the process, it is cooled to approximately 200°C and the strip is reeled. A predominantly martensitic microstructure is produced.

Due to the high STRENGTHS over 1,400MPa, thermoforming is necessary for the later shaping of parts made from martensitic steels.



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Even small ferrite proportions need to be avoided due to the danger of material properties being dispersed. The transformation is controlled by alloying Mn, B and Cr.

The STRENGTH is controlled via the carbon content.

Steels for Body Construction

Body Structure

Overall, the body structure is the most important and central part of the body.

Today, modern bodies need to meet extensive and very complex requirements. They are modified according to the following main points:

- Passive safety
- Lightweight construction
- Stability and vibration resistance
- Pedestrian protection
- Corrosion protection

In addition to the geometric/constructive design of the SEMI-FINISHED PRODUCTS and profiles, this modification happens by using tailor-made materials with different strengths in various body areas.

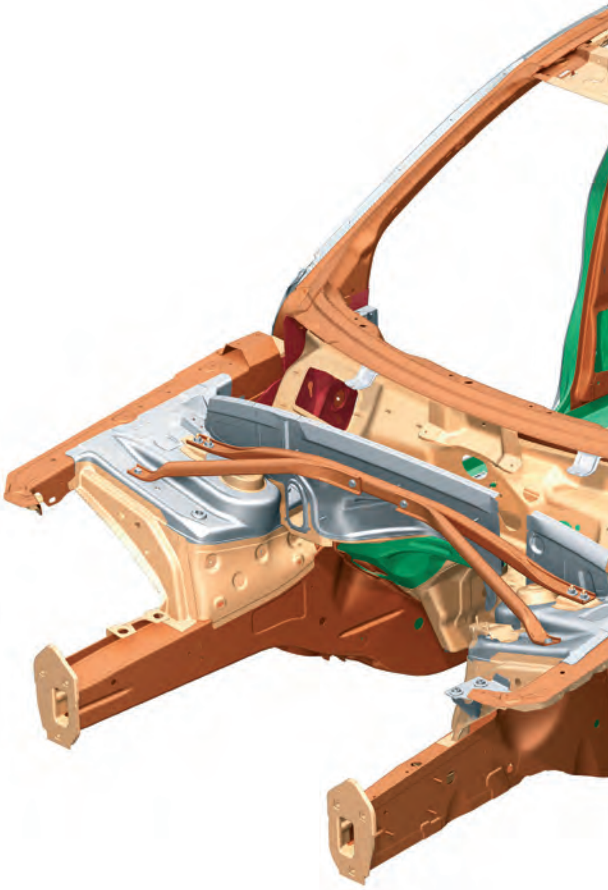
Steel is used more than any other material. Aluminium and plastics are also used to create lightweight constructions.

Sheets with higher STRENGTHS are increasingly being used – the greatest STRENGTH is provided by thermoformed ultra-high-strength sheets.

What are the characteristics of these sheets?

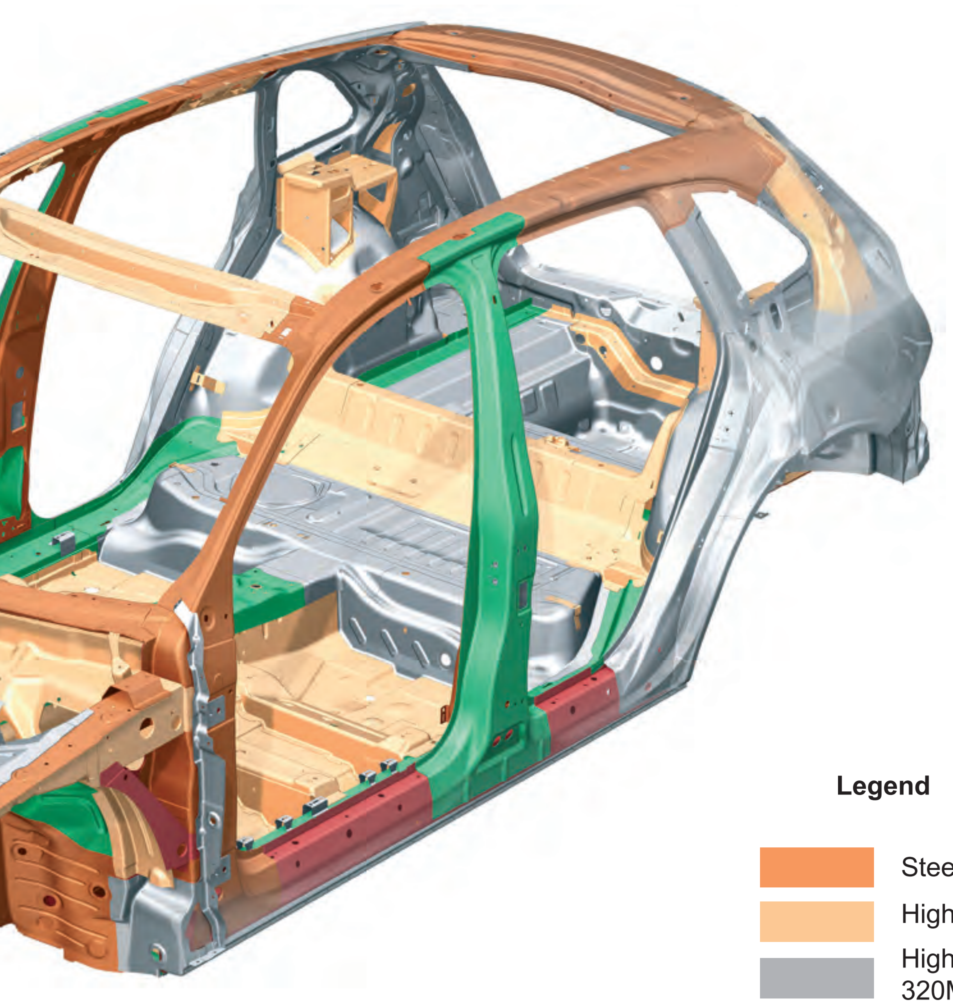
- They are steel sheets that are formed in heated state at temperatures between 900 and 950°C (1,652°F and 1,742°F)
- A specific cooling process produces a microstructure that provides greater STRENGTH and HARDNESS
- There are die-quenched sheets
- These allow very slim and light body parts to be produced without losing strength

Taking the Q5 as an example, we will show the different materials that are used in the body assemblies



Ultra-high-strength sheets in the assemblies:

- Inner A-pillar
- Seat brackets
- Outer side member
- Front brackets on front longitudinal members
- Rear bumper cross member



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Legend

🟧 Steel sheet up to 140MPa
🟨 High-strength steel sheet from 180 to 240MPa
⬜ Higher-strength steel sheet from 260 to 320MPa
🟥 Ultra-high-strength steel sheet from 340 to 700MPa
🟩 Ultra-high-strength, thermoformed steel sheet over 1,000MPa

Thermoformed ultra-high-strength sheets in the assemblies:

- Front bumper cross member
- Cross member in footwell area
- Inner side members
- Center tunnel
- A-pillar/roof frame area
- B-pillar

The strength figures in MPa refer to

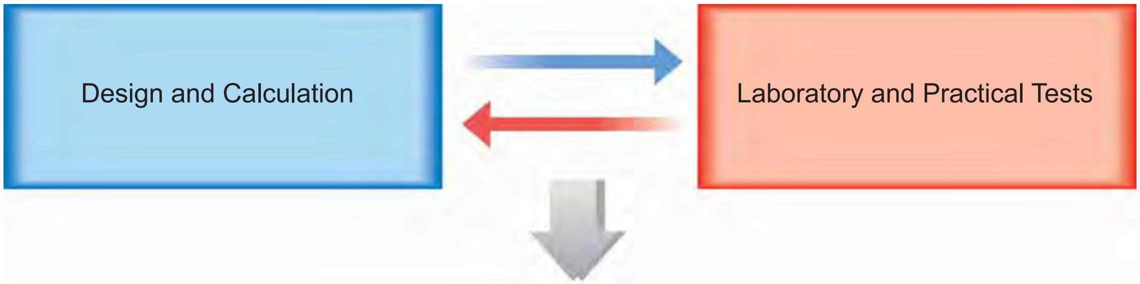
R_m = ultimate strength.

1 MPa = 1 newton/mm^2

Manufacture of Semi-Finished Products

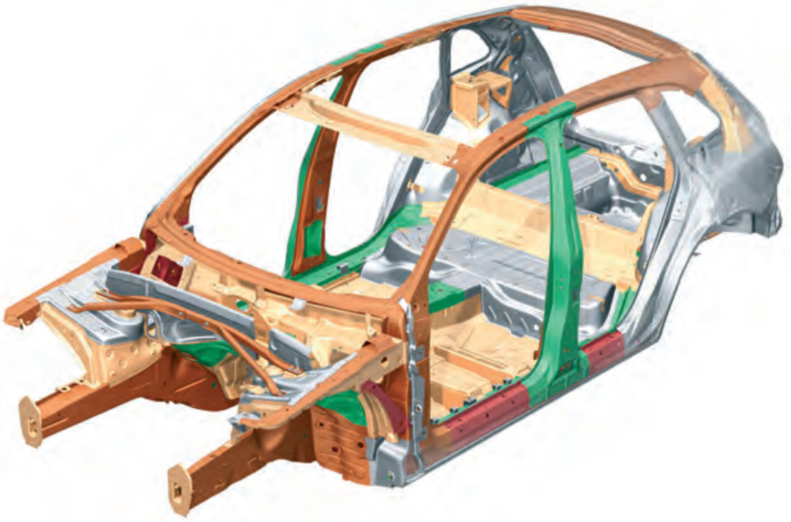
Modern bodies have greater and different constructive requirements than ever before. To meet these requirements, the materials/SEMI-FINISHED PRODUCTS are selected and used so they are precisely tailor-made for the load profile.

Today's computers allow for accurate prediction of body calculations and load curves within the body.



The calculations and tests are used as a basis to configure the body structure:

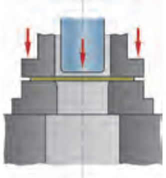
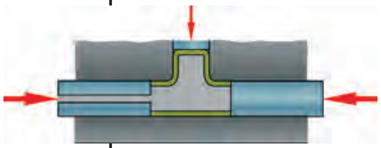
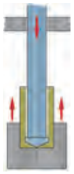
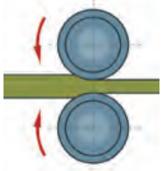
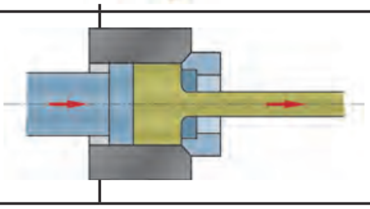
- Defining the semi-finished product profile
- Selecting the semi-finished product material
- Selection of the respective body parts and the material that will be treated during production (e.g. hot forming in forming die)
- Selection of the body areas and the respective parts that have cross-section variations within the part (tailored blanks)



Forming Process

Different processes are used to produce SEMI-FINISHED PRODUCTS.

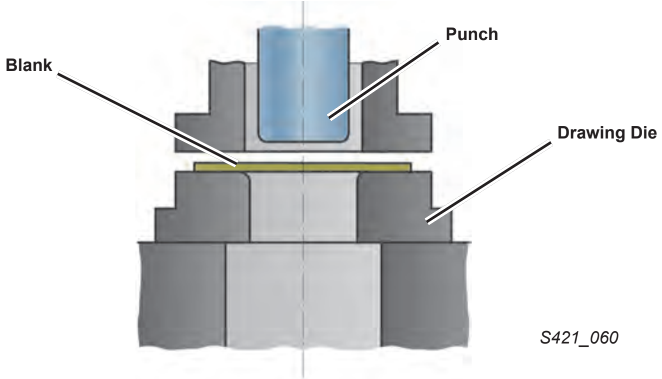
Today’s thin steel sheets are ideal for meeting the requirements of lightweight construction while simultaneously providing high STRENGTH to meet safety requirements. However, they also need good malleability for shaping.

The main forming methods are:	
Deep Drawing	
Hydroforming	
Impact Extrusion	
Rolling	
Extrusion	

Deep Drawing

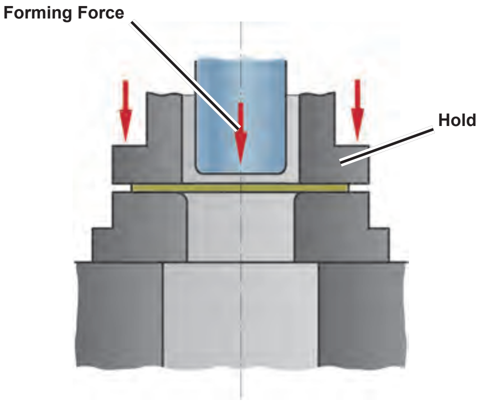
In deep drawing, the sheet metal is formed by using the simultaneous effect of pulling and pushing forces. The sheet metal is shaped in one or more operations. Materials with corresponding deformability are used - deep-drawn sheet. One special type of deep-drawing is stamping. Embossed structures and shapes, for example, inscriptions, can be added to the surface - this is often performed simultaneously with the deep-drawing process.

The cut sheet metal is placed on the drawing die …



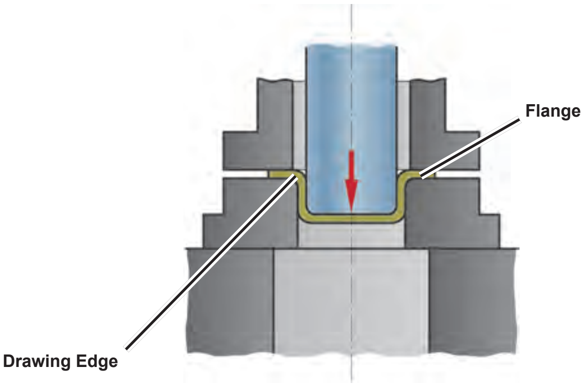
S421_060

… and clamped by the holder.



S421_061

The punch is then pushed downwards and draws the sheet metal over the drawing edge into the opening in the drawing die. The sheet metal is pressed so firmly onto the drawing die by the holder that creases cannot form in the flange area.



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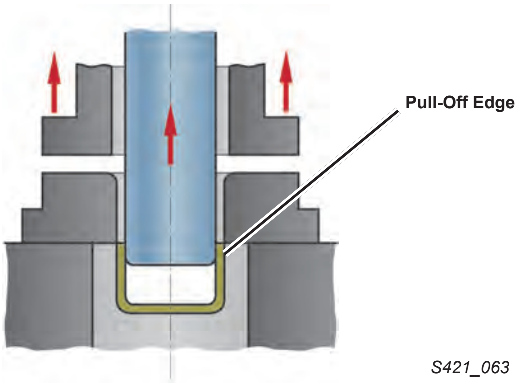
Upon completion of the drawing process, the punch releases the workpiece as it moves upwards.

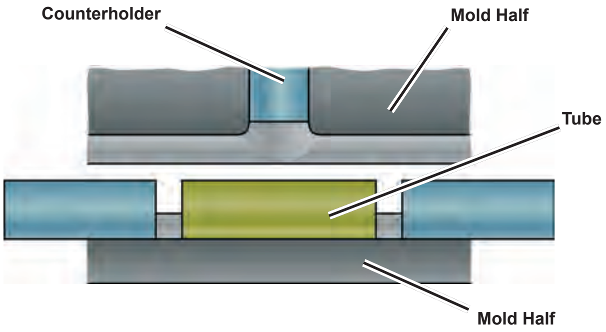


S421_063

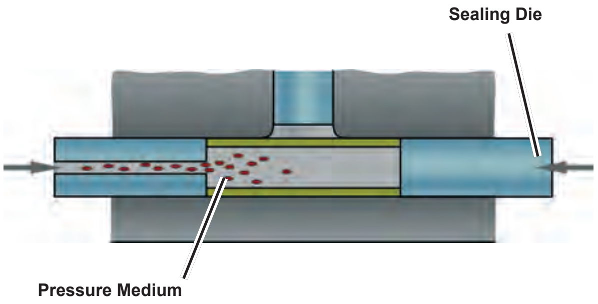
Hydroforming

Hydroforming uses pressure to shape metal. In this process, high pressure is used to press a sheet-metal profile against a hollow mold. This method also allows parts with different and complex geometries, e.g. with subsections, to be produced very quickly. It also allows weld seams to be avoided. The strain hardening that occurs during forming increases the component strength or stiffness.

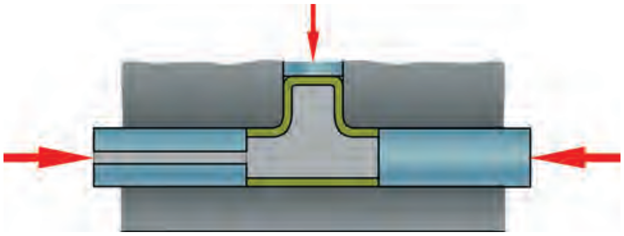
The sheet-metal profile is placed in the lower half of a two-piece die.



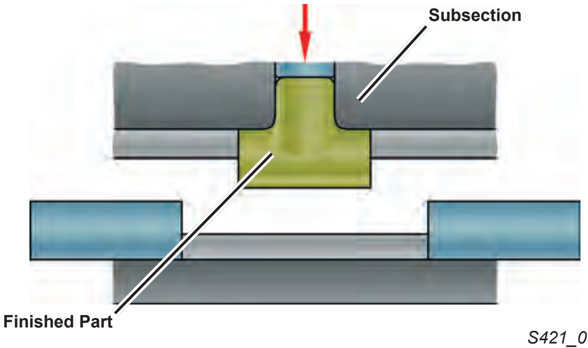
The die is then sealed and filled with a liquid pressure medium.



The liquid pressure medium is then pressurized to approx. 170MPa. The resulting forces press the inserted sheet-metal profile against the die and thus produce the new form.



Upon completion of the forming process, the mold halves separate and the finished formed part can be removed.

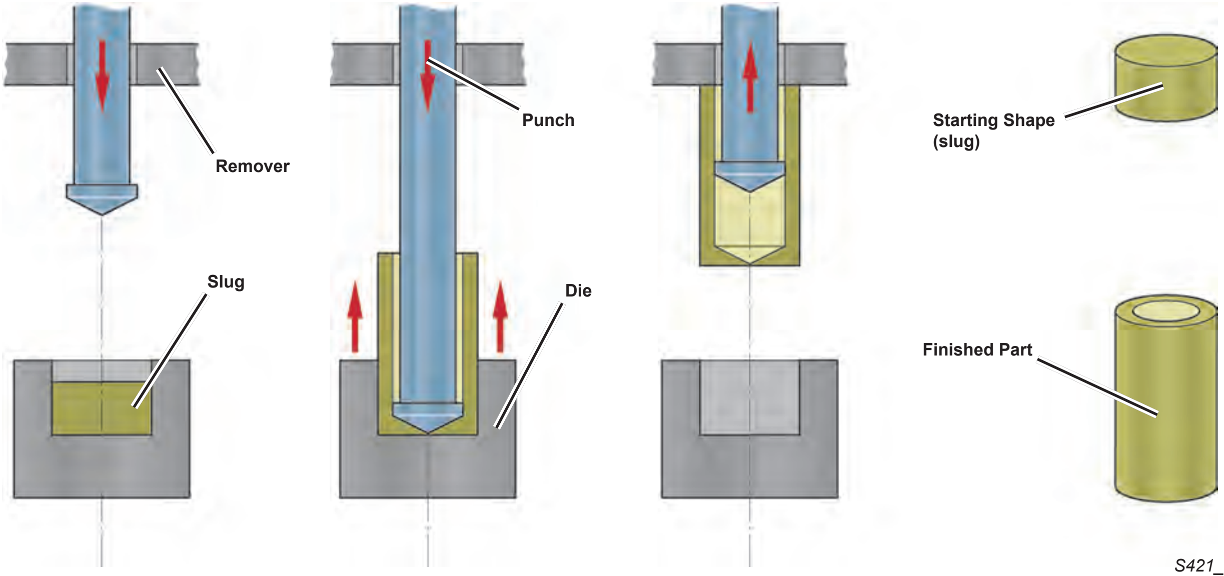


S421_080

Impact Extrusion

Impact extrusion uses pressure to shape metal. The materials used in this process need to have a high level of malleability.

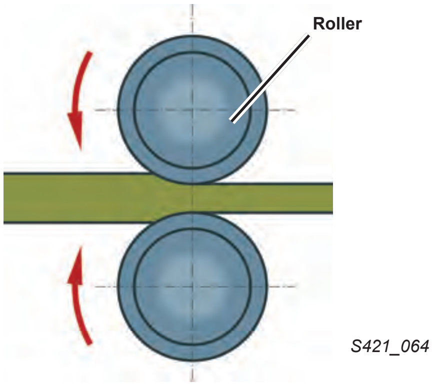
- In impact extrusion, materials are pressed into solid or hollow parts using a punch and a die.
- A slug is placed in the forming die as the starting material. When the punch pushes this material together under high pressure, it is forced on the other side into the die opening.
- Forming hardens the material.
- Surface quality can be controlled with the die.



S421_066

Rolling

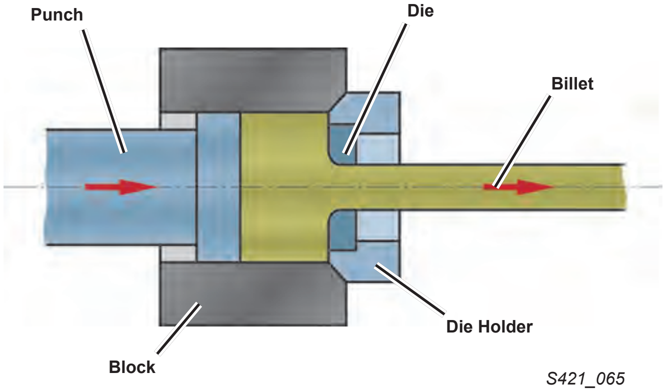
- Rolling uses pressure to shape metal.
- Profiles, sheets, tubes and wires are fed between rotating rollers and shaped in the process.
- The material is compressed by the rollers and hardened accordingly.
- Varying surface qualities can be produced.



S421_064

Extrusion

- Extrusion uses pressure to shape metal.
- In this process, heated materials are pressed through a die and extruded as a billet.
- Different profiles can be produced depending on the shape of die used.
- The material is compressed by the reshaping in the die and hardened accordingly.
- Varying surface qualities can be produced.



S421_065

Basics - Process Engineering

Tailored Blanks

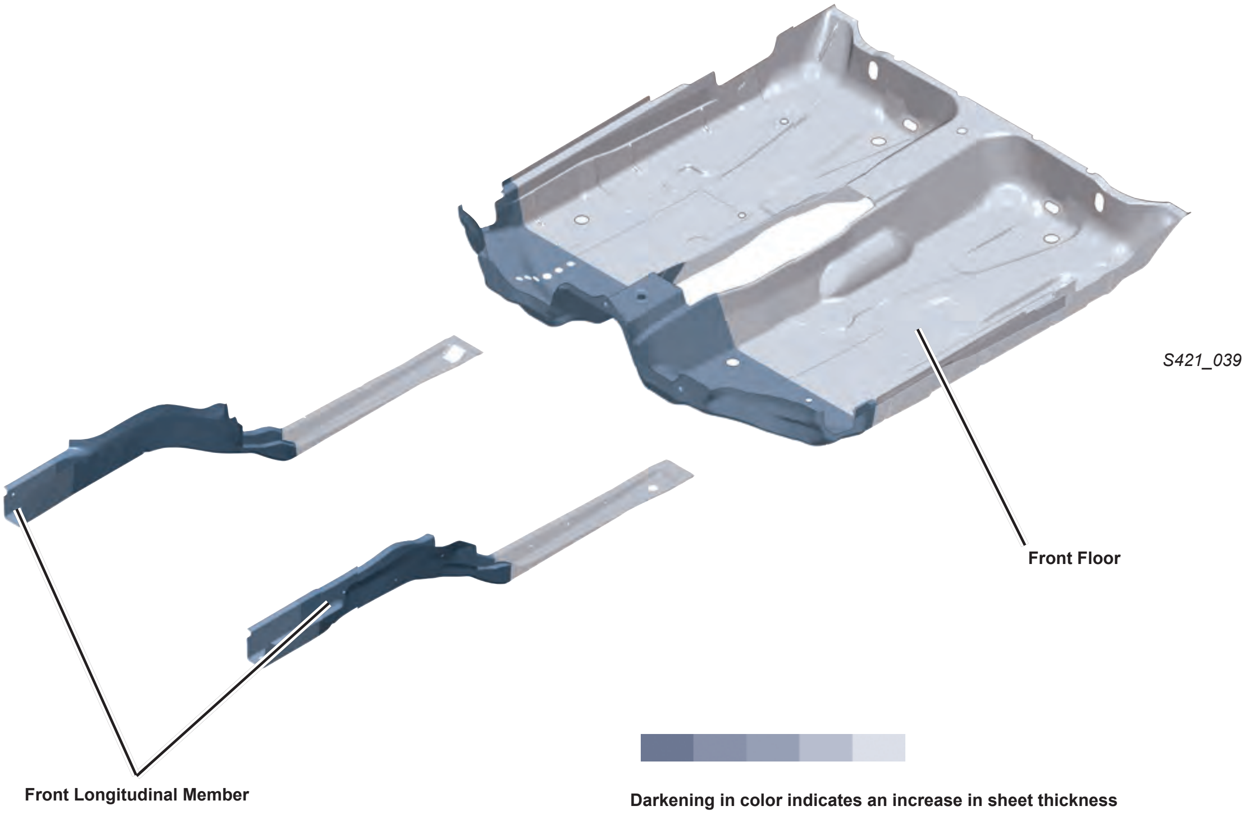
As the term “tailored” indicates, tailored blanks are parts that are made to a specific measurement. “Blanks” are the starting material.

Tailored blanks were originally developed to produce sheet metal plates with widths that could not be produced with the rolling technology of the time. Today, producers make use of the advantage that tailored blanks allow different steel grades and sheet thicknesses to be joined together in a finished part.

Tailored blanks allow for better and more precise adjustment of the body structure to the loading of certain body sections. This allows parts with complex shapes and precisely fitting designs to be produced.

The individual parts of the tailored blanks are joined together by welding. After welding the blank can then be shaped.

Example - floor pan - front with tailored blanks

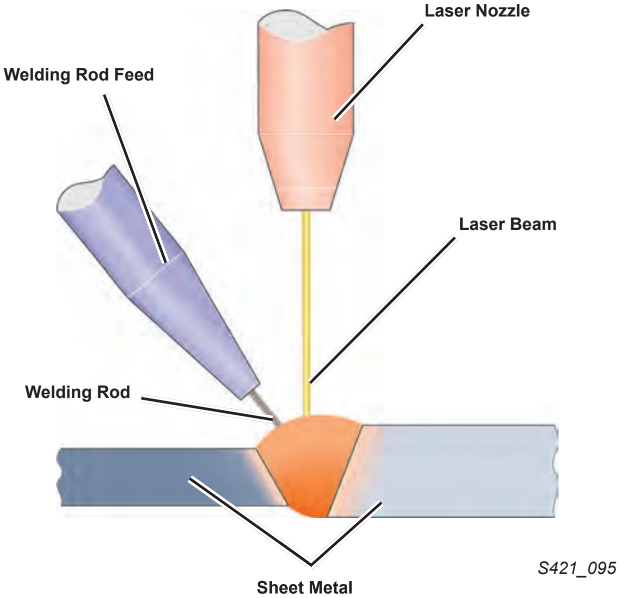


Different welding methods are used to join the individual components of tailored blanks.

One method that was frequently used in the past was mash seam welding. Today, this has, mostly been replaced by more modern laser welding. As a result, mash seam welding is not covered in this SSP.

The seam edges must be prepared well to obtain the necessary seam quality in laser welding.

... joining with laser welding



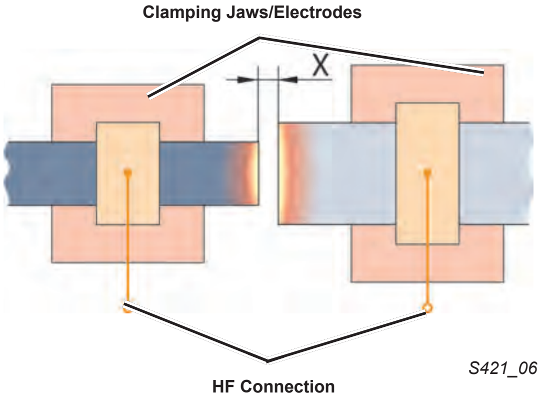
S421_095

In addition to laser welding, high-frequency welding is also used for tailored blanks.

In this process, metal sheets are clamped at a defined gap “x” from each other.

The high-frequency current is conducted directly through the sheets via clamping jaws/electrodes. Electrodynamic effects cause the welding current to be concentrated on the edges of the sheets. Once the necessary temperature has been reached, the current is switched off and the heated joining edges are squeezed together.

... joining with high-frequency welding



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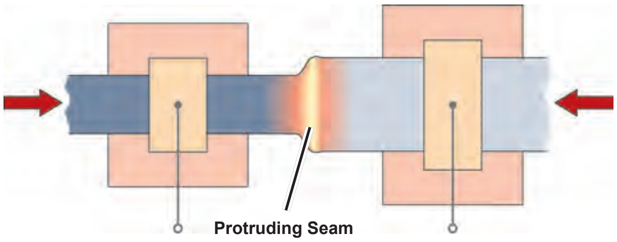


S421_084

Extremely short welding times can be achieved with high-frequency welding. The requirements for the seam preparation are fewer than in laser welding. Even non-straight seams can be welded easily. One disadvantage of the process is the protruding seam left upon completion of the welding process. The seam needs to be reworked after welding.

Joining Processes

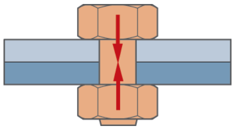
Unibodies need a structure that provides the necessary stability and stiffness - without a supporting frame. The joining methods used to produce the body are very important. Parts are connected to each other using varying joining processes.

The following joining methods are used for body construction:

Frictional Connection:

- Screw joint

  Frictional connections such as screw joints represent only a small proportion of the joining methods in body construction today. The necessary requirements for stability and stiffness of the body cannot be met with screw joints.



S421_086

Positive-Fit Connection:

- Rivet joint

  Rivet joints are one of the positive-fit connections. At least two parts are interlocked and connect the parts. Rivet joints only meet the requirements for stability and stiffness to a limited extent.

S421_087

Firmly Bonded Connection:

- Weld joint
- Solder joint
- Adhesive joint

  The stability and stiffness requirements can be easily met with firmly bonded connections. Parts joined in this way can be considered to be more or less a new part. Material mixing does not occur during soldering and bonding. However, direct contact in the joining gap is considerably more intensive so high STRENGTHS can be achieved.

S421_088

Screw Joint

Screw joints have the advantage that repairs and replacement operations are easy and cheap to perform.

However, the disadvantage is that the body stiffness normally required for today's unibodies is very difficult to attain.

In many cases, the advantages are minor compared with the advantages of a firmly bonded connection. A very stiff body is important for crash safety and in general driving.

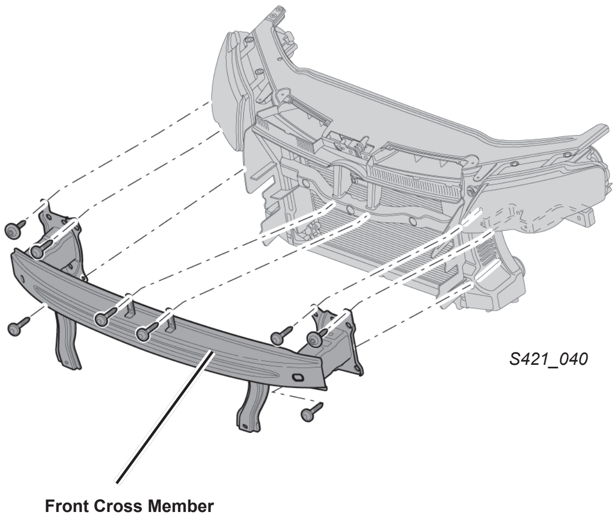
Screw joints reach their limits in these applications.

For this reason, screw joints are used in places where the load bearing capacity of the body structure is not an issue.

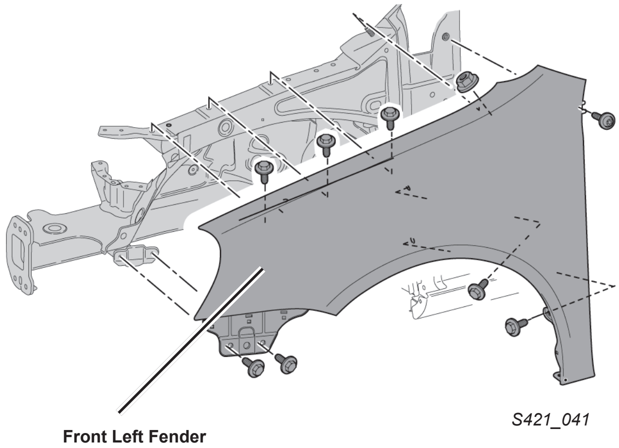
Where are screw joints used?

- Fastening fenders to the body structure
- Securing the front cross member to the longitudinal members

Screws for Front Cross Member



Screws for Front Left Fender



Rivet Joint

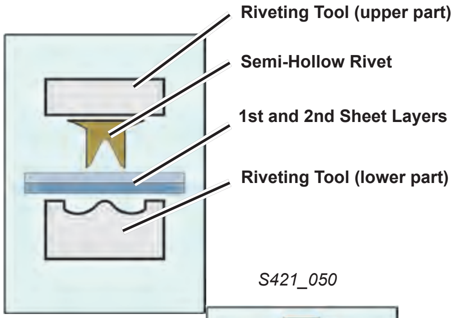
Punch Riveting

Punch riveting involves a semi-hollow rivet being pressed through the first layer of sheet metal. The second layer of sheet metal is only deformed by the rivet and is not penetrated. The foot of the semi-hollow rivet spreads and forms a closing head that gives the rivet joint the necessary hold.

Advantages:

- No pre-drilling of sheets
- Second layer of sheet metal is not cut
- Greater STRENGTH and lower energy requirements than with resistance spot welding

Steel is used as a material for punch riveting. If the rivets are used for aluminium sheets, they need to have a zinc/nickel coating to avoid galvanic corrosion.



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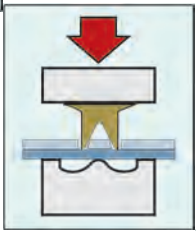

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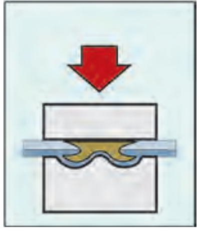


S421_052

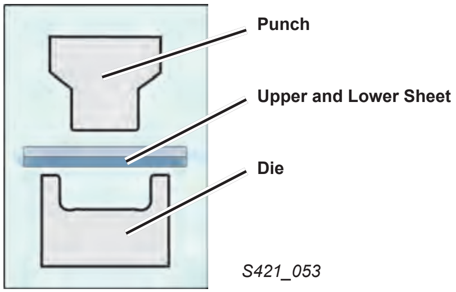
Clinching

Clinching is used to connect non-load bearing simple components because the connection point has a low STRENGTH. Rivets are not required here. The punch presses the two sheets into a die at the joining point. By sinking and clinching the upper sheet into the lower sheet, a frictional and positive-fit connection is formed.

Advantages:

- Fast and clean joining technique
- Low cost

If the sheets are made from different materials, an electrochemical insulation coating is required to prevent galvanic corrosion.



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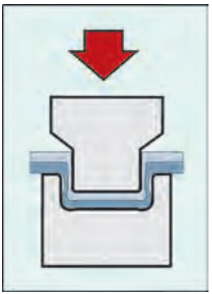

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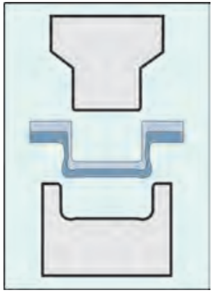


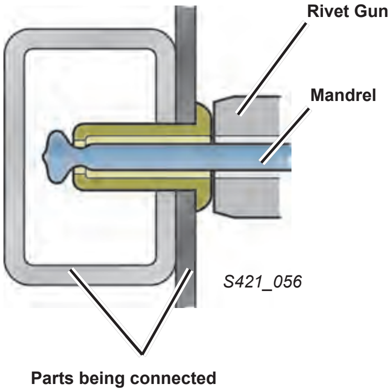
S421_055

Blind Riveting

Blind riveting can be used whenever the riveting point can only be accessed from one side.

Pop rivets are hollow rivets with a mandrel.

The pop rivet is inserted into the aligned holes of the parts being connected with a rivet gun.



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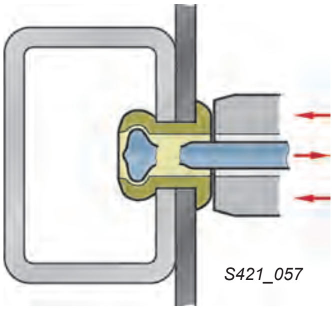
The gun now pulls the mandrel back. This causes the mandrel head to expand the protruding rivet body and form the closing head.

The mandrel then snaps at its break point.



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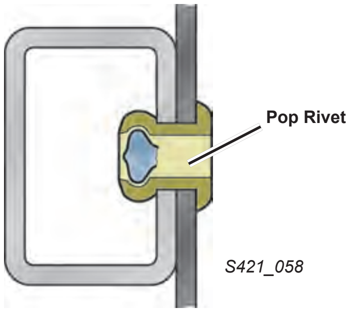
The rivet gun is removed with the broken-off mandrel.
The rivet joint is complete.



S421_058

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Note
The illustrations show an example of blind riveting using pop rivets.

Welding

Laser welding and electric resistance welding are used for a wide range of welding applications. We will look at both methods as examples of welding.

In addition to laser welding, plasma welding - a further development of TIG welding (TIG = tungsten inert gas) - is also used. This method is currently not very widespread in body construction and will not be covered in this SSP.

Laser Welding

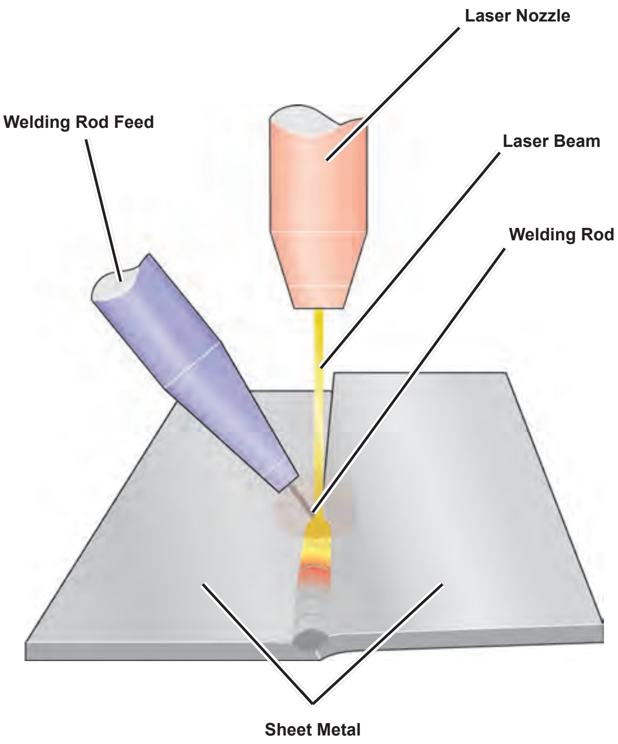
In laser welding, the heat to melt the materials is produced by a laser beam. Laser welding was first used to produce tailored blanks for body construction. It is finding increasing use in the assembly of vehicles thanks to many advantages:

- Laser welding allows an “almost seamless” connection of parts - this is particularly advantageous for connecting higher-strength sheets. The structural behavior of the material is also largely retained in the area of the seam.
- Complicated seams, for example, single-sided welds, are possible. In addition to butt welds, the use of an additional rod also allows other types of seams such as hollow welds.
- At high working speeds, a very good surface quality is obtained.
- The surface of a laser weld seam is already so good that reworking for a good paint finish, only requires a minimum amount of time.

The 2006 A3 has 82 feet of laser welded seams:

- Floor panels
- Center tunnel
- Front and rear of the roof
- Luggage compartment floor

In laser welding, the materials to be joined and the welding rod are liquefied by the high energy of the laser beam.



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Electric Resistance Welding

This method allows electrically conductive materials to be welded. An electrical current flowing through the welding joint melts the material and the parts are welded together - without additional material. Normally low voltages and high currents are used so that the welding effect is possible, but there is also no danger.

This welding principle is applied in different ways, for example:

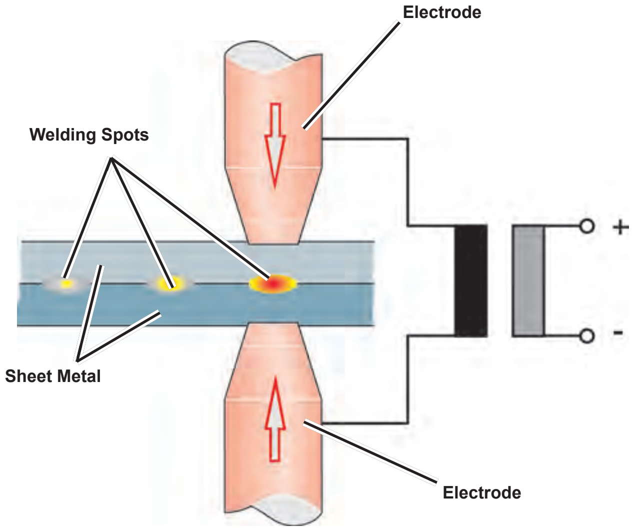
- Resistance spot welding
- Resistance butt welding

Resistance Spot Welding:

Resistance spot welding continues to be very important in body construction. Today, modern control and regulation allow resistance spot welding to be also performed on higher-strength and coated sheet metals.

In modern body construction, adhesive is also added to the joining level to improve the structural behavior and stiffness of the joint and increase the vibration resistance. The adhesive layer also prevents penetration of substances such as water or other liquids, preventing crevice corrosion.

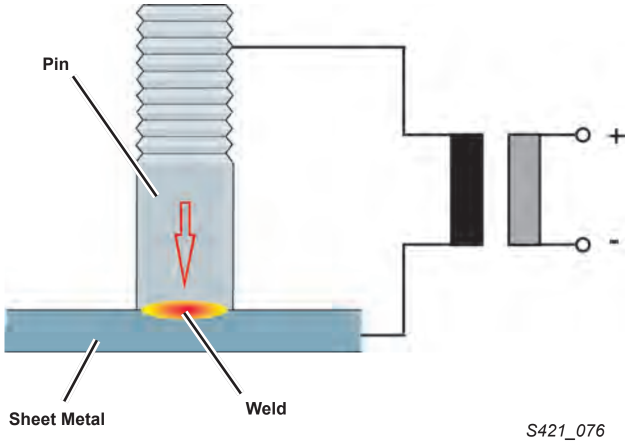
One variant of resistance spot welding is resistance roller spot welding that uses rollers as electrodes. The parts being joined run between the two electrodes and a weld seam is produced.



S421_067

Resistance Butt Welding

Resistance butt welding is only used on joints that do not carry any loads. Two parts are pressed together and connected to a current. The material melts and is welded at the pressure point. In body construction, this is used to weld bolts to sheet metal parts.



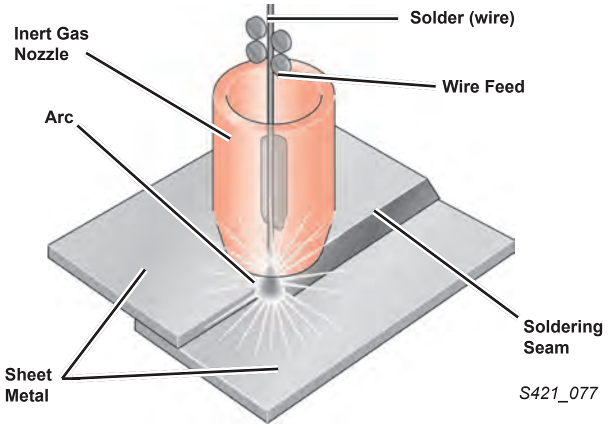
S421_076

Soldering

In contrast to welding, the actual parts being joined are not melted at the joint during the soldering process. The solder material is bronze. The melted solder fills the space at the joint and connects the parts being joined with a high STRENGTH. Due to the low temperatures used for soldering, the zinc coating on galvanized sheet metal is less affected and substantial hardening is avoided in the join area. Join gaps can be bridged better by the solder. The lower process temperatures allow less heat distortion.

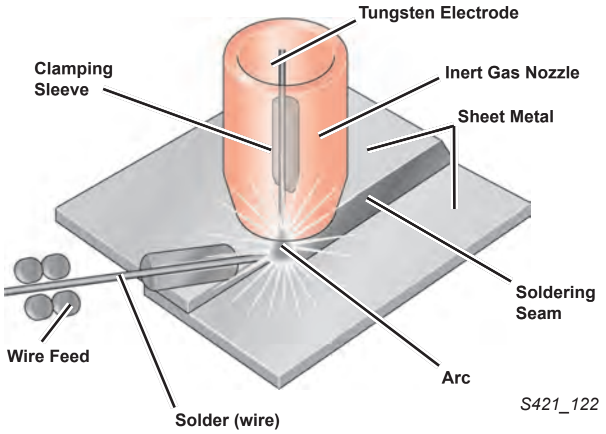
The main soldering methods are explained briefly below.

MIG Soldering



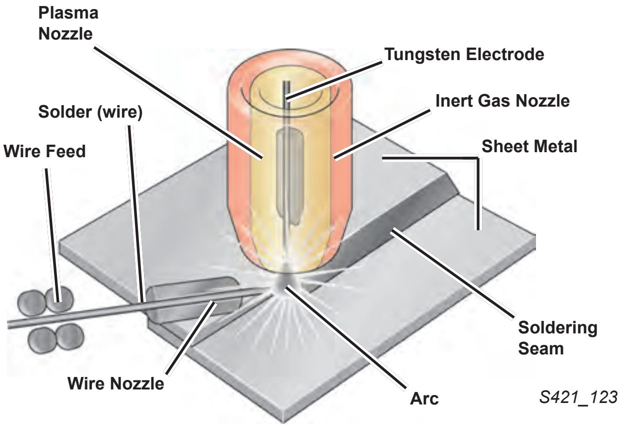
The solder is melted by the arc between the solder and the part being soldered under the inert gas.

TIG Soldering



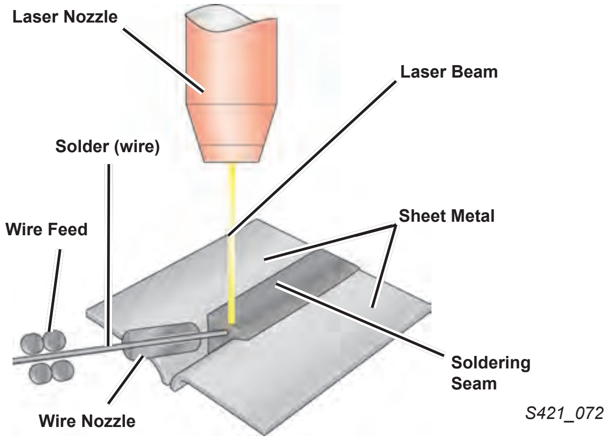
The solder is melted by the arc between a tungsten electrode and the part being soldered under the inert gas.

Plasma Soldering



Compared with TIG soldering, the arc is constricted by a plasma nozzle in plasma soldering. This allows a higher energy density and narrower seams. Also, higher soldering speeds are possible.

LASER Soldering



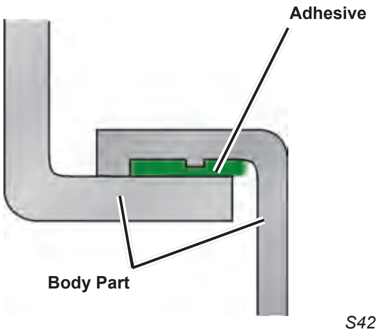
In LASER soldering, the soldering heat is produced by a laser beam.

Bonding

Bonding is a method for the permanent connection of components using an adhesive. Depending on the type of adhesive, the hardening process can be reinforced by heating the bond slightly. Due to the continued development of new, more efficient adhesives that are tailored to the applications, adhesives and bonding processes are becoming increasingly important in body construction. Bonded joints can even be STRONGER than welding points.

Bonding is not just used to join parts together. In body construction, the method is used for a range of other tasks, for example:

- Sealing the joint area against penetrating moisture or corrosive substances
- Joining different materials such as sheet steel sheet with plastics
- Noise and vibration insulation
- Gas and liquid sealing
- Increasing component stiffness
- Avoiding crevice and galvanic corrosion
- Low-warpage joins by avoiding temperature loading
- Cross-area application of force



S421_043

Certain preparations are necessary for proper bonding, for example:

- Surfaces should be clean and free of grease
- A primer should be applied (bonding agent)

Different adhesives are used depending on the application.

They differ …

… according to composition
Single-component adhesives
Two-component adhesives

… according to processing temperature
Cold adhesives (room temperature)
Hot adhesives (120–250°C)

Coating Processes

The goal of surface coatings is to protect the steel against possible oxidation (CORROSION) due to the effect of air and weather. Different coatings are used, but coatings based on zinc are most common.

In production today, the body is not completely galvanized by immersion. For example, the body components or their initial SEMI-FINISHED PRODUCTS will be coated before further processing.

Zinc is a material that, compared with steel, tends to oxidise faster. This results from its position within the electrochemical series - according to the table, zinc is less precious than steel.

The zinc coating covers the steel surface and protects it against CORROSION. Optimum protection is provided as long as this coating system is not damaged.

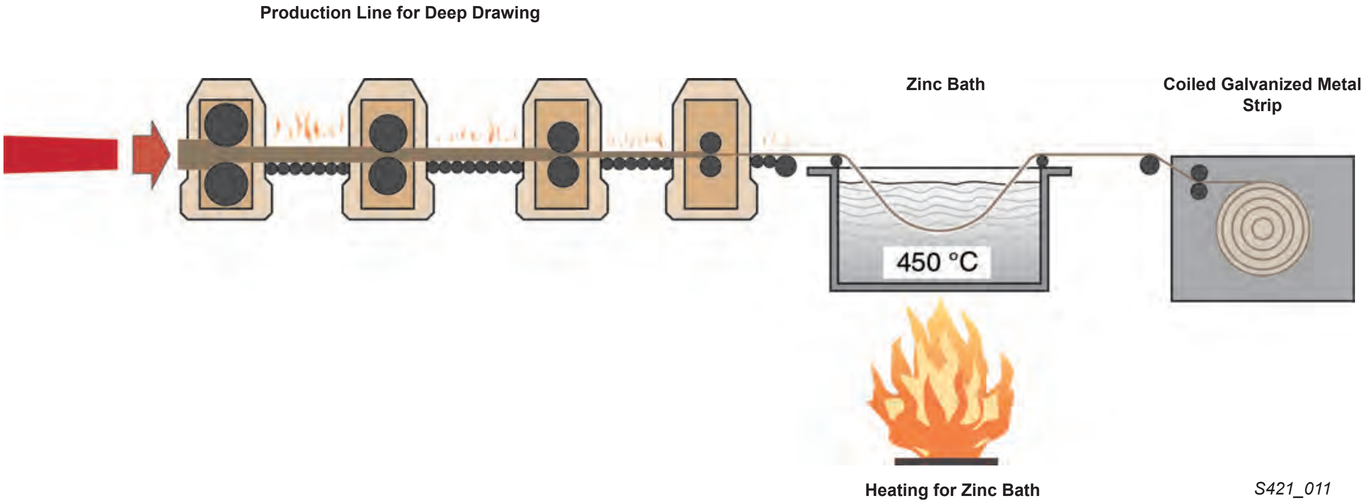
If there is an intrusion which damages the zinc coating and reveals the surface of the steel, contact with water can lead to premature disintegration of the zinc coating because of the potential difference between the two different materials. The surface of the steel is then exposed and CORROSION starts on the respective steel surface areas.

Optimum protection is achieved if the zinc coating is combined with a coat of paint. This is known as a "duplex system".

Normal zinc coating methods for bodies:

Hot dip galvanizing for all parts that are not visible from the outside	Galvanealed" and zinc electroplating for all outer skin panels
Rough surface	Smooth surface
Zinc coating approx. 10 micrometers	Zinc coating approx. 8 micrometers
Poor formability	Good formability

Hot Dip Galvanizing



Hot dip galvanizing is performed after rolling and before deep drawing of the sheet metal. After rolling, the sheet metal is immersed in a 450°C (842°F) liquid zinc bath causing a coating of zinc to be formed. The first coatings of zinc consist of an iron/zinc compound and are followed by a coating of pure zinc.

Hot dip galvanizing is not normally used on visible parts as it leaves a rough surface with markings on the sheet metal. Visible parts would need to be further processed.

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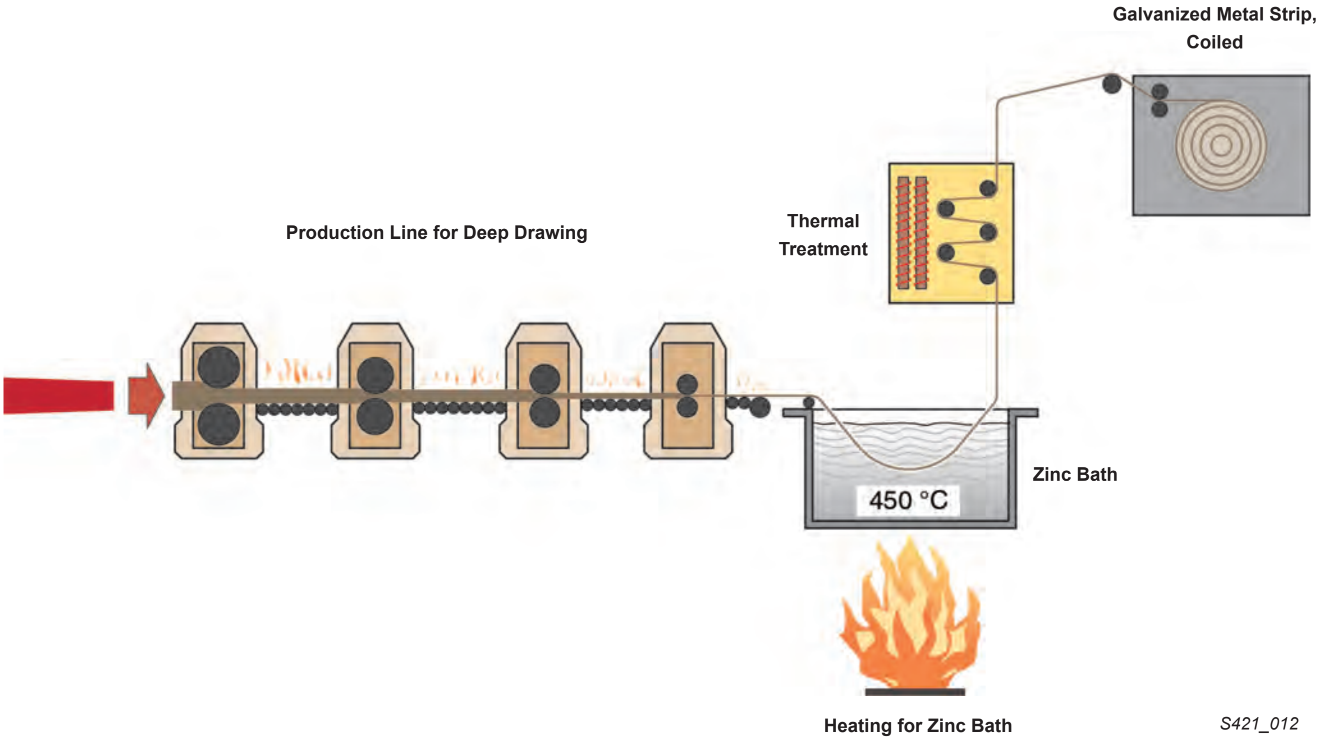
Note

Hot dip galvanizing cannot be used for outer body panels due to the high process temperatures and the risk of the metal becoming warped.

“Galvanealed” Method



The coating formed in “galvanealing” is added after rolling and before deep drawing of the sheet metal.

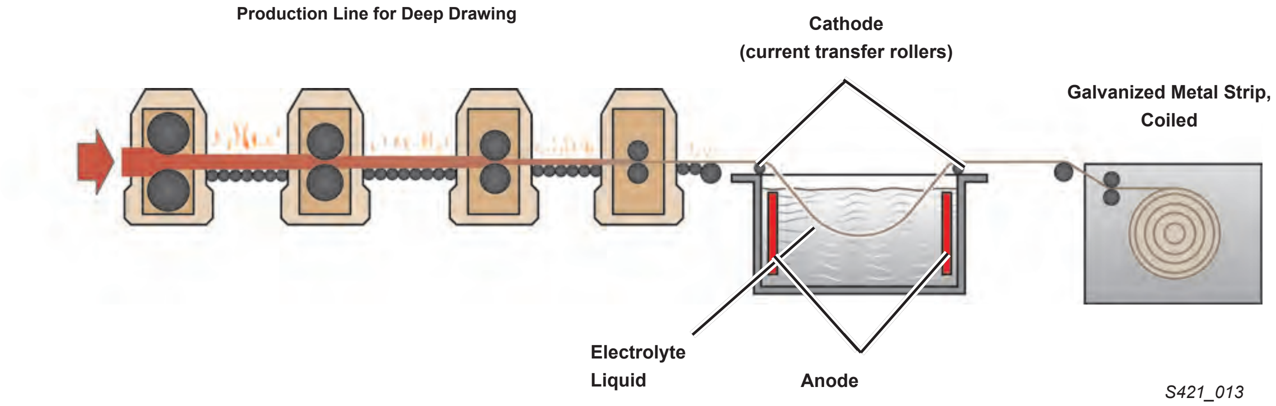
The “galvanealed” method is a variant of hot dip galvanizing. In contrast to hot dip galvanizing, the steel is treated thermally (annealed) at 430°C (806°F) for an additional 30 seconds after the bath.

In this thermal treatment, the iron present in the steel is diffused into the zinc coating. An ALLOY of zinc and iron is formed. The zinc coating contains around 10% iron and is known as a galvanealed coating.

Galvanealing provides greater corrosion resistance compared with hot dip galvanizing. This method has the following advantages:

- Optimization of coating weldability
- Good surface quality without irregularities
- Good basis for subsequent coatings

Zinc Electroplating



Zinc electroplating is performed after rolling and before deep drawing of the sheet metal. This method is based on an electrochemical process.

The metal strip is guided over so-called current transfer rollers, which act as the negative pole (cathode). An electrical field between the metal strip (which now also acts as the cathode) and the anodes acting as the positive pole causes zinc released from the electrolyte liquid to be deposited on the sheet.

This creates a very fine, uniform zinc coating with a thickness of about 8 micrometers. Subsequent processes, like stamping, welding and painting, can then be performed without losing the corrosion protection.

Due to the good final quality, this technique is used for visible parts of the body.

The final appearance of the zinc electroplating depends on the coating thickness and the surface quality of the steel.

!

Note
Zinc electroplating can be used for outer body panels due to the low warpage.

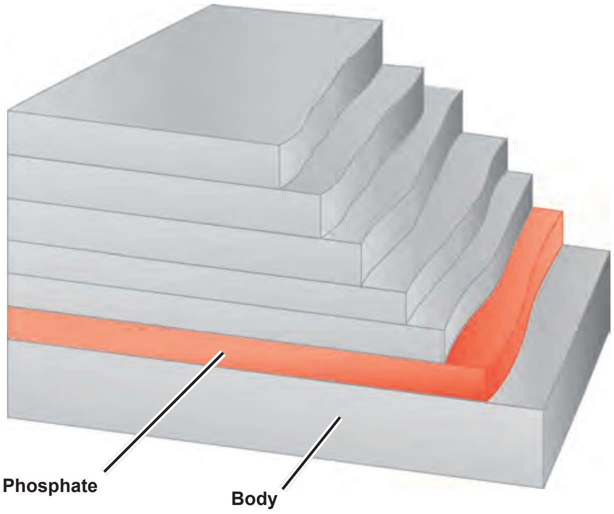
Corrosion Protection

Pre-Treatment

If the body is to be painted, the material must be prepared well. Phosphating is primarily used for body preparation.

Goals of pre-treatment:

- Corrosion protection
- Creation of a good primed surface



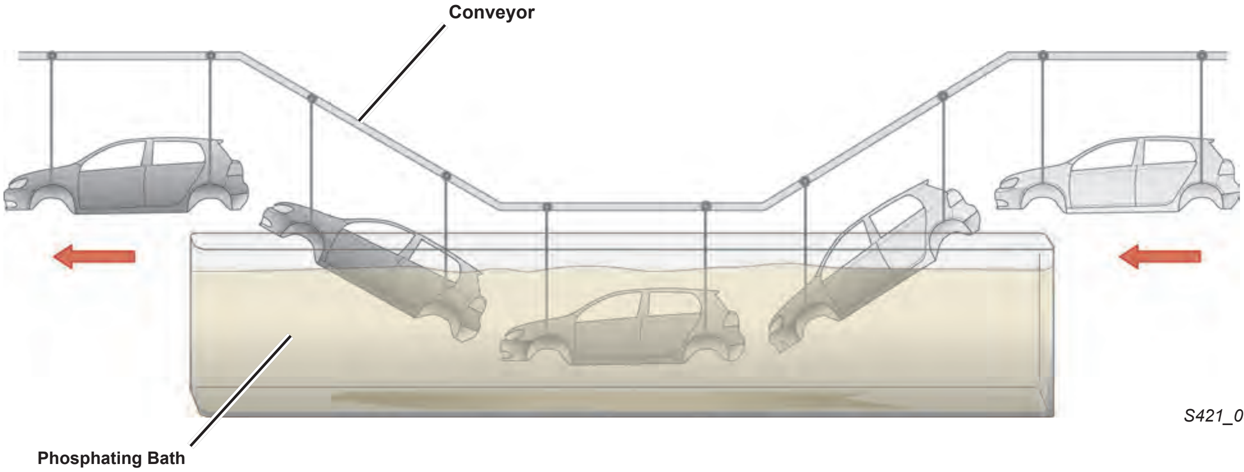
S421_096

Phosphating

Phosphating is chemical/electrochemical process where thin fine crystalline water-insoluble phosphates are deposited on the surface of the metal by dipping it into phosphoric acid solutions (iron, zinc or manganese ions and phosphoric acid).

These phosphates are produced in a chemical reaction with the base metal and form a layer that is securely anchored to the base metal.

Depending on the reacting base metal (this can also be the coating material), a layer of iron, nickel, manganese or zinc phosphate is formed.



S421_036

The coating has numerous hollow spaces and capillaries, which can be used for maximum absorption. This allows good penetration of corrosion protection agents like waxes, oils, color pigments and paints.

Phosphated surfaces ensure a good primed surface for paint and lacquer coatings.

Seam Sealing

Effective seam sealing is equally important for permanent corrosion protection.

It is often presumed that missed spots in the body cavity sealing are the starting points for CORROSION. However, the process of body cavity sealing has been perfected so that hardly any problems can occur in this area.

Seam sealing is used at weld seams with overlaps on:

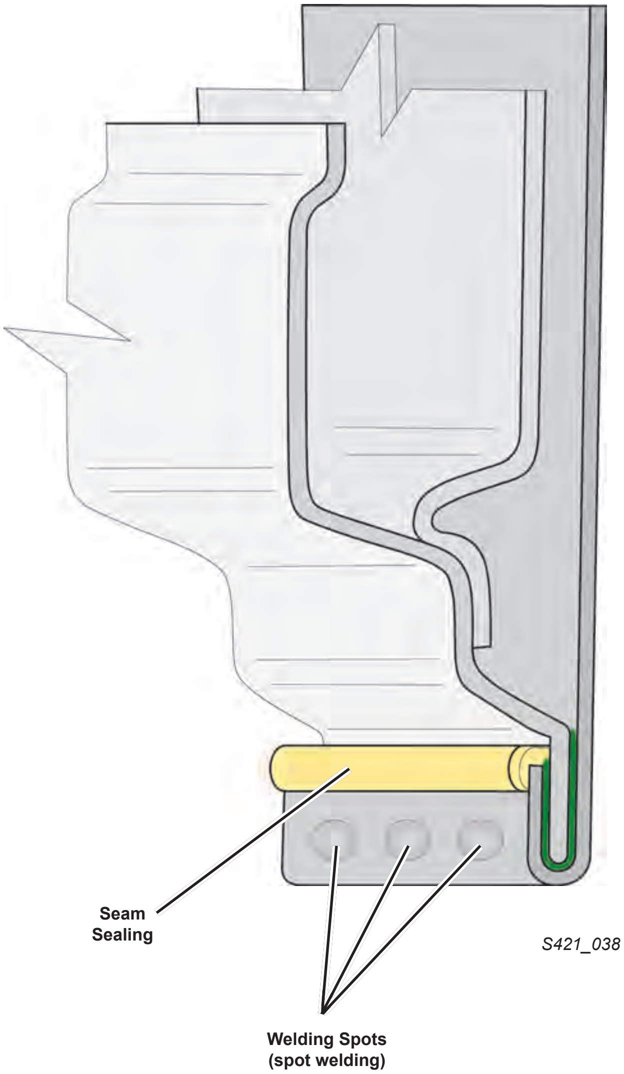
- front and rear skirts
- rear valence
- engine compartment
- luggage compartment floor
- passenger compartment floor
- side panel
- wheel housing
- vehicle underbody
- fenders
- etc.

The seams require sealing afterwards with suitable sealing materials so that it is impossible for water to get into the spaces between two joined components.

Even if the gaps of weld seams (spot welding) are filled with adhesive, the seams must be sealed. Seam sealing also protects the edges of the sheets.

Sealing seams is important because it is virtually impossible for any moisture that penetrates the seams to dry. CORROSION can start in seams considerably faster compared with open surfaces.

Weld Seam with Seam Sealing

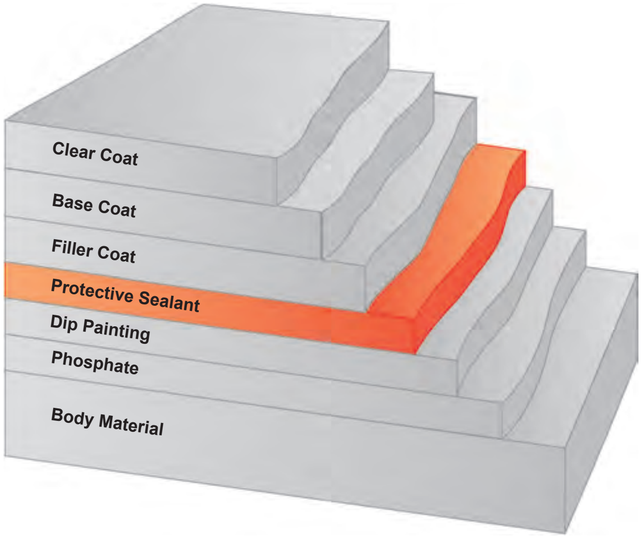


S421_038

Stone Chip Protection

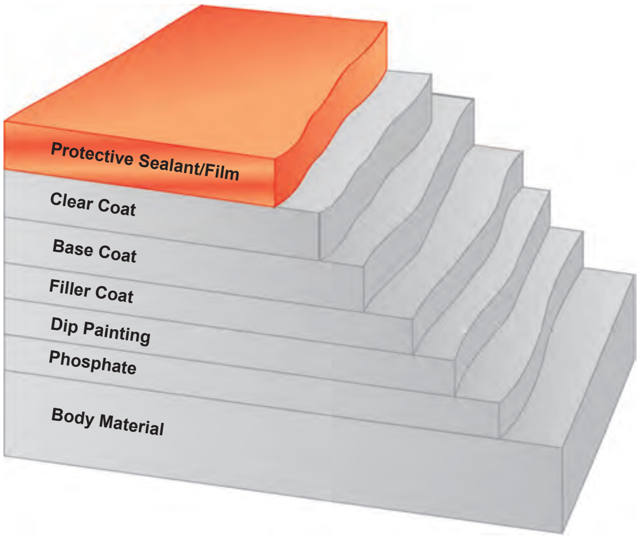
Stone chip protection is one important and very effective measure against CORROSION. The complete body cannot be treated in this way. Instead, coats are applied to the areas of the body that are at risk. This can be done in the following way:

- Applying a protective sealant after priming (dip painting) and before applying the paint – e.g. at front end of body.



S421_073

- Applying protective sealant after painting (clear coat) to non-visible areas, e.g. to the vehicle floor and the wheel housings, or also applying a special protective film.



S421_074

Stone chip protection is normally a tougher, elastic coating. The elastic properties combined with a greater thickness also have an anti-vibration effect.

Stone chip protection can also be achieved by using special materials for body parts, for example, by using special plastics instead of painted metal parts.

Protection Against Galvanic Corrosion

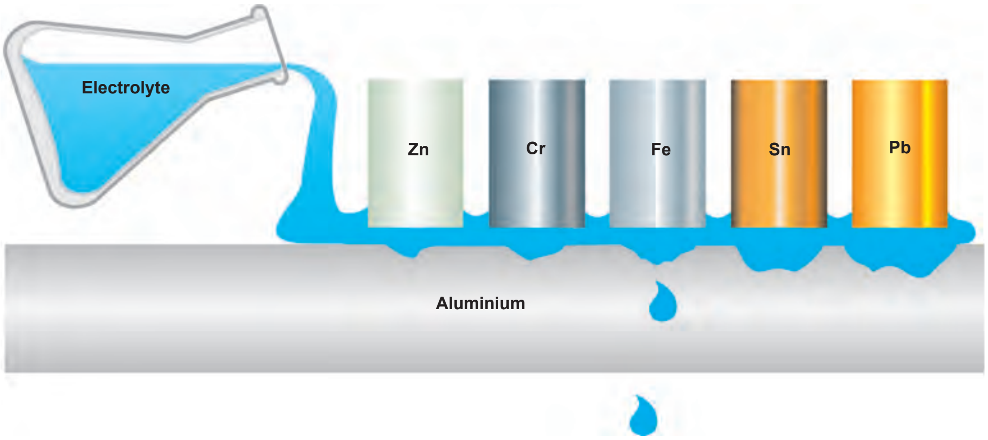
If other metals such as aluminium are used in addition to steel in body construction, particular attention should be paid to the prevention of galvanic corrosion. This also applies to iron/steel. However, due to its particularly low electrical potential value in the electrochemical series, aluminium is considerably more prone to galvanic corrosion. Galvanic corrosion will be explained using aluminium as an example.

Galvanic Corrosion

All metals have a specific ELECTROCHEMICAL POTENTIAL, which differs from the potential of other metals. If an electrolyte (acidic, alkaline or saliferous liquid) is added to two or more materials that are in contact with each other, voltage equalisation can occur between the potential partners. An electric current flows. The metal with the greater negative voltage value always corrodes first.

The electrochemical series of metals is used to illustrate the potential differences.

Figure S421_046 shows an example of a test set-up to illustrate CORROSION.



S421_046

Legend for electrochemical series

(selection from electrochemical series)

Pb – lead (–0.13 V*)

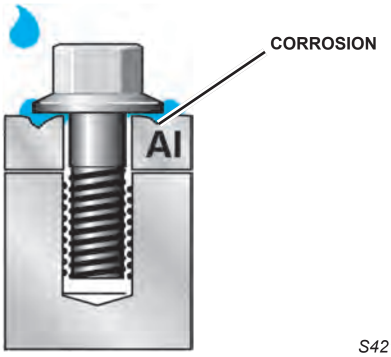
Sn – tin (–0.14 V*)

Fe – iron (–0.44 V*)

Cr – chrome (–0,56 V*)

Zn – zinc (–0.76 V*)

Al – aluminium (–1.67 V*)



S421_047

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* Compared with a standard hydrogen electrode at 25°C. The potential differences between aluminium and the metals (zinc, chrome, iron, tin and lead) shown in the figure (S421_046) can be calculated from the difference between two metals that are in contact with each other.

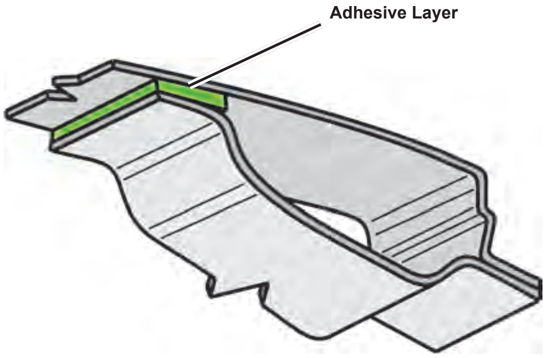
Protection Against Galvanic Corrosion

Direct contact between components made from different metals should be avoided to prevent galvanic corrosion.

The joint must be designed so that an insulating layer is included between the two different metals.

Variants of an insulating layer can be:

- Adhesive layer – The adhesive for bonding is also used for insulation



S421_048

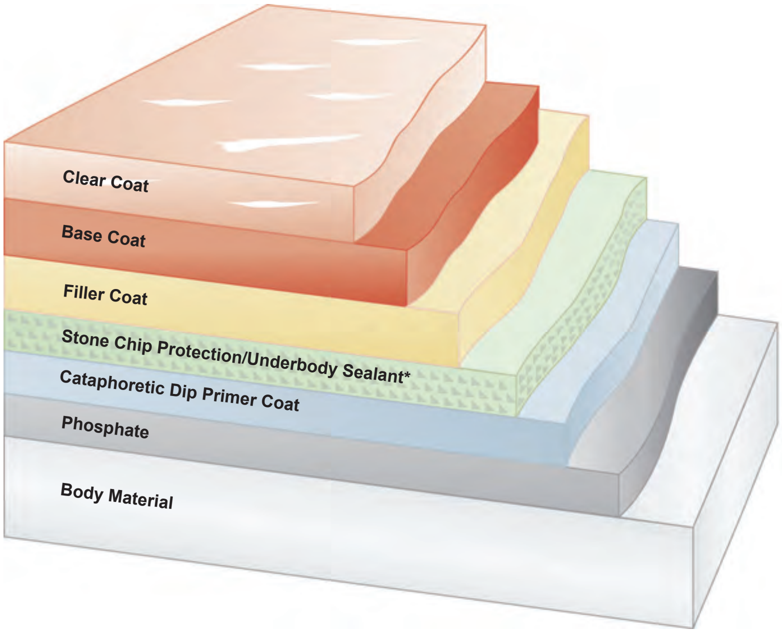
- Surface coating of one part acts as an insulating layer. This may be used where a steel bolt for fastening aluminum body parts is used.

S421_049

Painting

After treatment of the SEMI-FINISHED PRODUCTS or also the complete body, the corrosion protection is finalized using paint. Painting involves the following main steps:

- Before painting, the body is cleaned and degreased so that no binding faults occur during the painting process
- Phosphating then takes place to create a good primed surface and meet the requirements for optimum corrosion protection
- Next, a cataphoretic dip primer coat is applied
- Then the filler coat is applied
- After a rinsing process, the top coat consisting of a base coat and a clear coat is applied



* After the cataphoretic dip primer coat, the underbody sealant and the sealant for cosmetic sealing are sprayed onto the appropriate body areas. A highly viscous elastic paint is applied to the areas prone to stone chips.

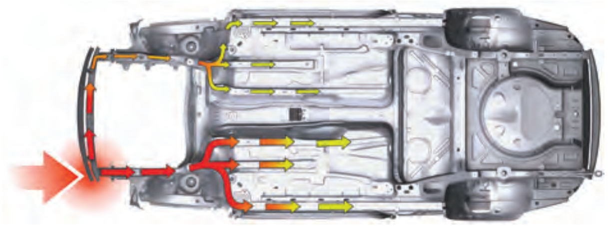
Basics

The damage needs to be assessed before any repair work is started.

Assessment criteria:

- In which direction did deformation take place?
- Are neighboring, concealed parts of the body also damaged?
- Has the structure of the body been deformed?

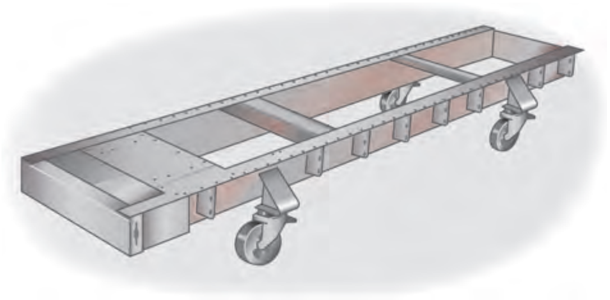
S421_111



S421_112

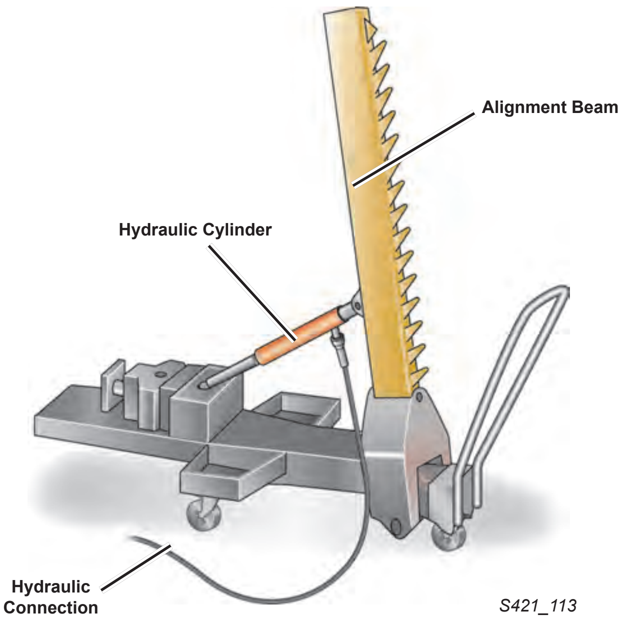
If the body is so badly damaged (deformed) that its structure is also affected, it must be aligned or rectified with the aid of an alignment jig and alignment units.

Alignment Jig (example)



S421_114

Alignment Unit (example)



S421_113

Repair Methods

Rectification

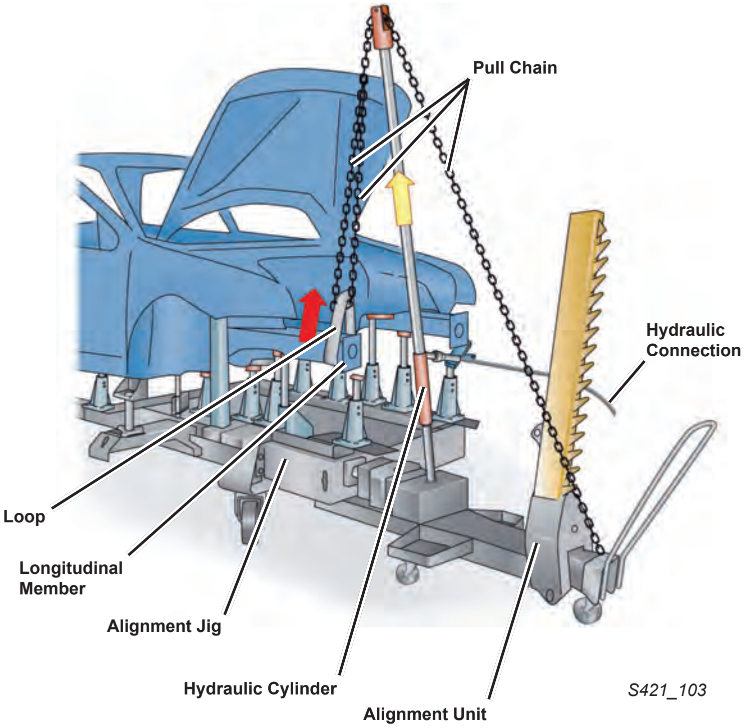
Rectification is the most frequently used repair method for vehicle bodies. Rectification can be done in different ways. Some selected methods are presented briefly below as examples.

Three-point pull directed upwards …

A pull chain is tensioned by a hydraulic cylinder.

One end of the chain is secured to the body part being aligned (in this example using additional loop) and the other end to the alignment unit.

When the hydraulic cylinder is actuated and extended upwards, the chain is tensioned and pulls the deformed body part upwards.



S421_103

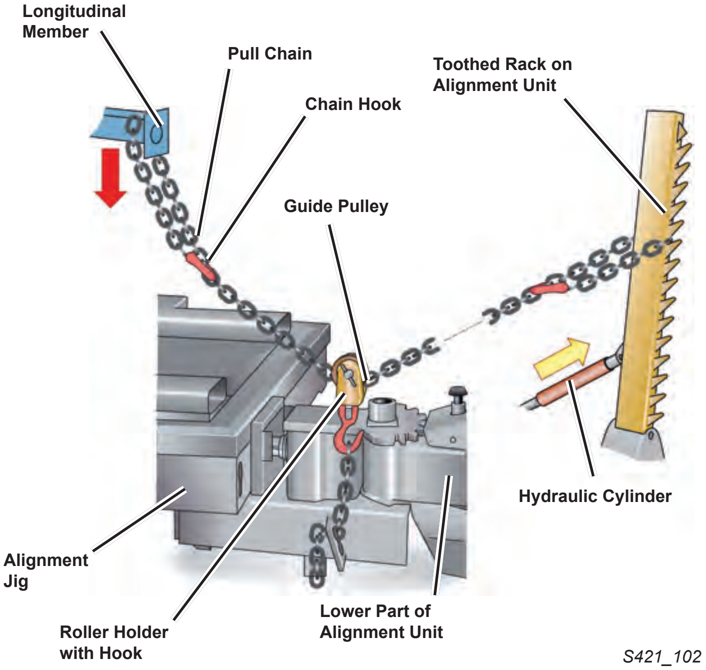
Directed downwards with loose guide pulley …

One end of the pull chain is placed around a body part, e.g. a longitudinal member, and re-attached to the chain using a chain hook.

The other end of the chain is attached to the toothed rack on the alignment unit.

The pull chain passes through a loose guide pulley with roller and fastening hook. This hook is connected to another chain, which is secured to the lower part of the alignment unit.

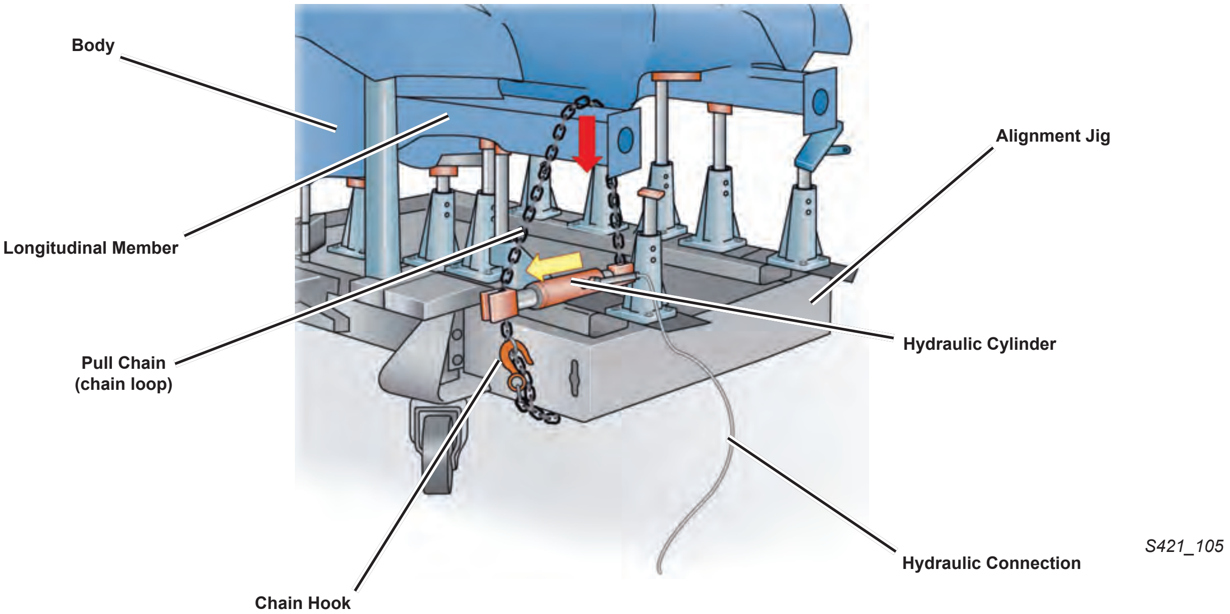
If the pull chain is now tensioned by moving the toothed rack with the hydraulic cylinder, the longitudinal member will be pulled downwards.



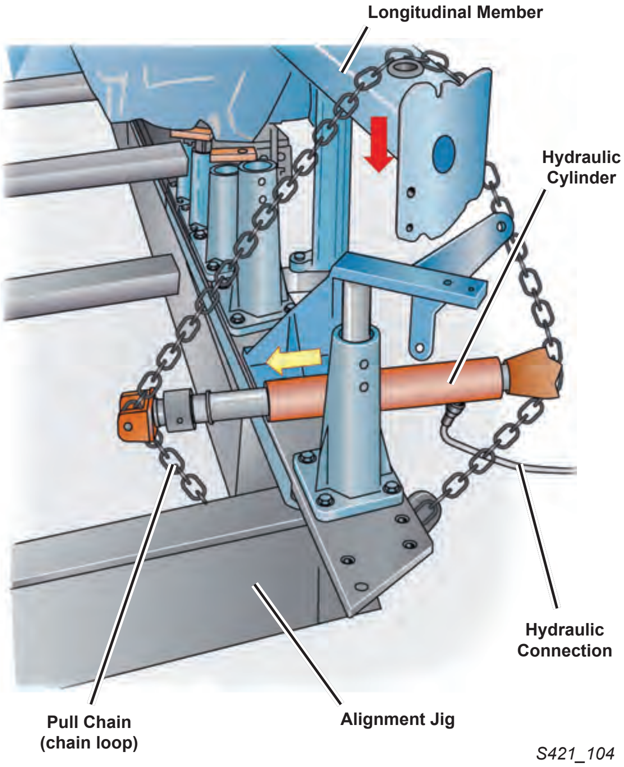
S421_102

Direct pressure on chain to pull assemblies downward

A pull chain is laid around the body part being aligned, e.g. the longitudinal member and a suitable frame part on the alignment jig and attached to itself again using a chain hook. This chain loop is tensioned by a hydraulic cylinder.

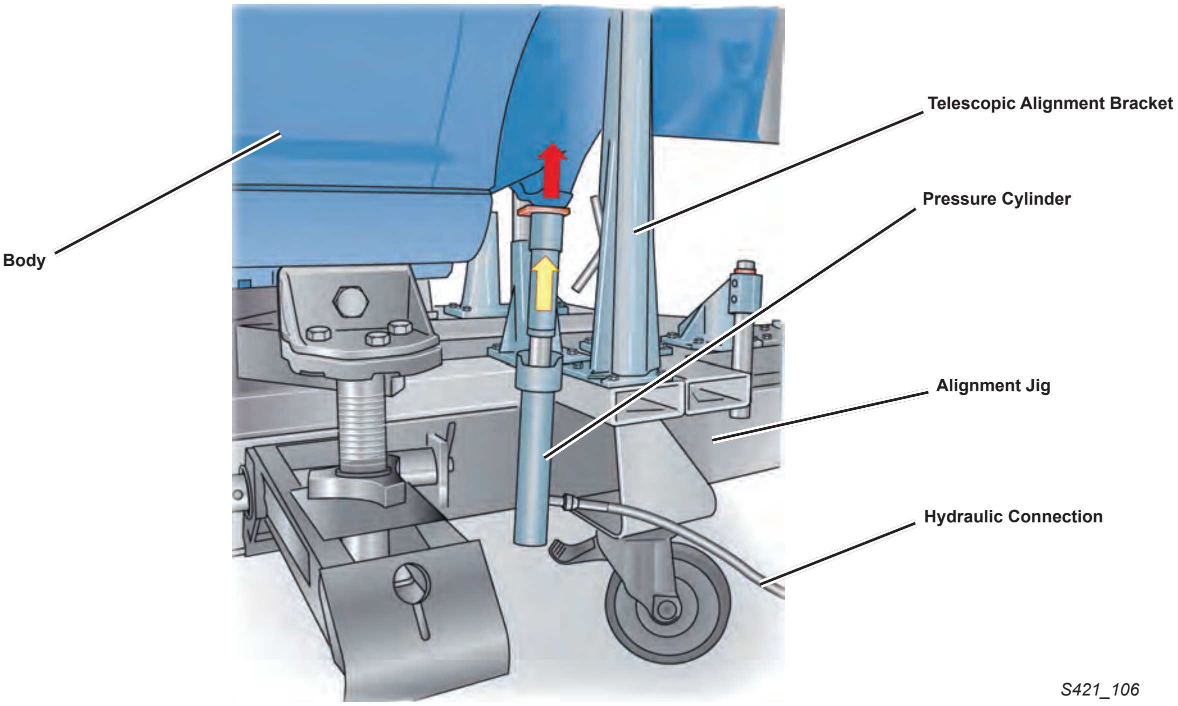


The hydraulic cylinder attached to the chain loop is actuated. It pushes the chain loop apart and the longitudinal member is pulled downwards.



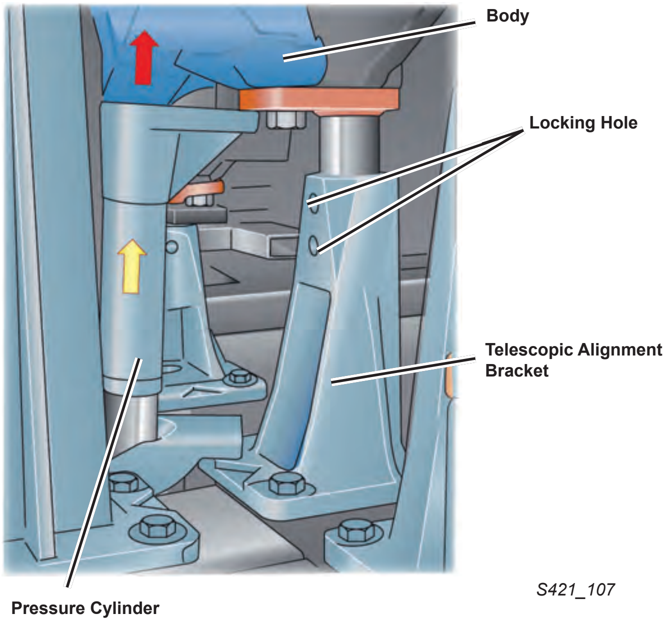
Direct application of force to the body with a pressure cylinder to push assemblies upward

This method of alignment uses the telescopic function of the alignment bracket. To start with, the body part being aligned is raised with a hydraulically operated pressure cylinder by applying direct force.



S421_106

This process is continued until the telescopic alignment bracket fits under the body and can be locked with a bolt that fits into one of the locking holes.



S421_107

Dent Removal with Hammer and Dolly

If a metal panel becomes dented, the material at the transition edge is stretched on the convex edge while the material in the concave portion is stretched on the inside.

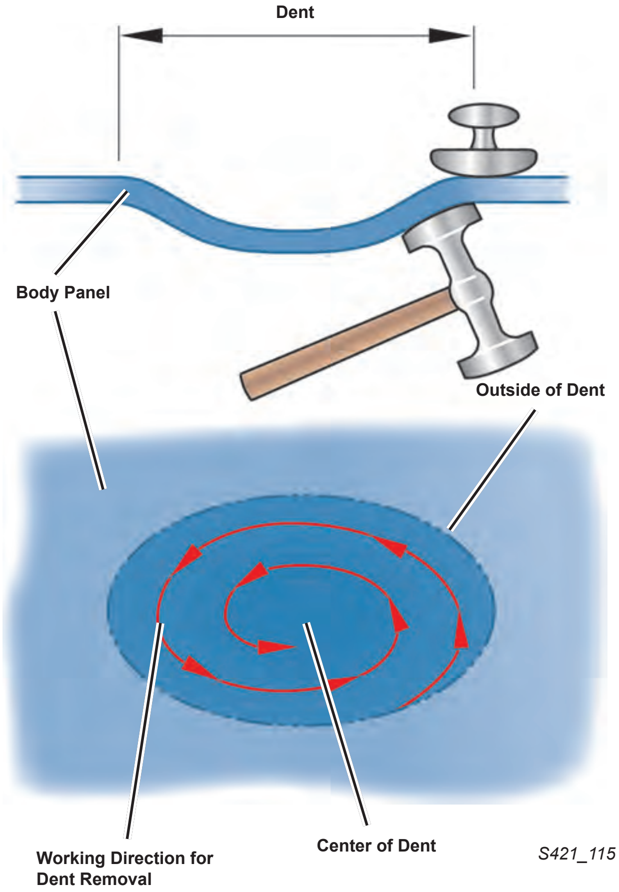
If you hammer back a dent at the center, the material in the compressed areas will immediately pop up. This means that new stretched and compressed areas will form with each strike of the hammer.

As more of these areas are formed, the harder it will become to make the surface smooth.

During dent removal, you should make sure that existing stretched and compressed areas are reduced and no new ones are created. As a result, the dent removal work should be from the outside to the center of the dent.

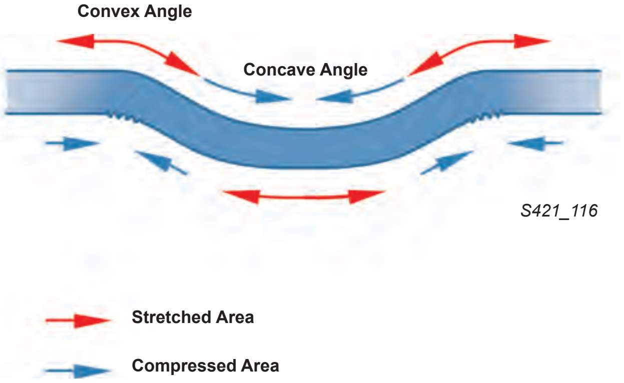
Frequently the metal around the indentation rebounds so greatly that the hammer strike hardly has any effect. “The hammer’s not working!”

It is only when a suitable dolly is held against the back of the metal that measured and effective force can be applied.



S421_115

There is always a compressed area opposite a stretched area.



S421_116

Thermal Dent Removal Method

The thermal dent removal method is ideal for dents with a maximum diameter of 10cm and a depth of 1–2mm.

The following principle is used:

Metal expands when heated and contracts upon cooling.

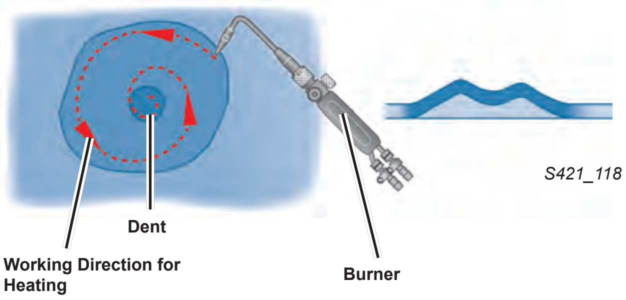
If a dent is heated in a spiral starting at the edge towards the center, the heat will be concentrated in the center of the dent. This also causes the surrounding body surface to rise slightly.

Now a special body file, which has a convex blade, is used to file over the center of the dent. The file rests on the edge of the dent and draws off the most heat there. As a result, the deeper material contracts towards the edges and raises the center of the dent.

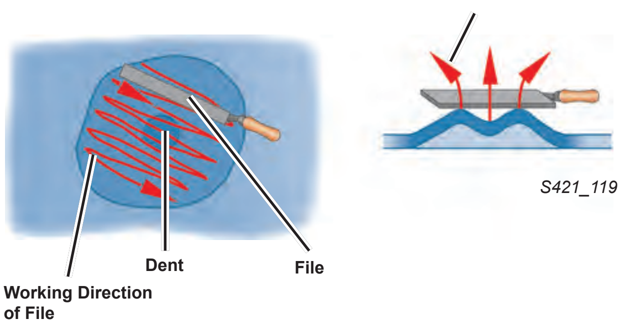
The file heats up very quickly during the process and needs to be exchanged for a cold file after several back and forth movements.

Initial condition of a panel section with a dent

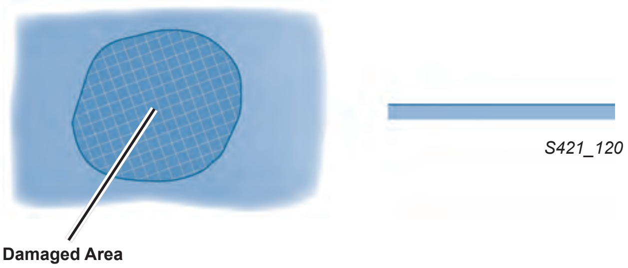
Heating with burner …



Heat withdrawal using a file …



Damaged area after repair …



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Note

Important: The file is used for faster heat dissipation, not for removing material!

Drawing in an “Oil Can“ Dent with the Carbon Electrode

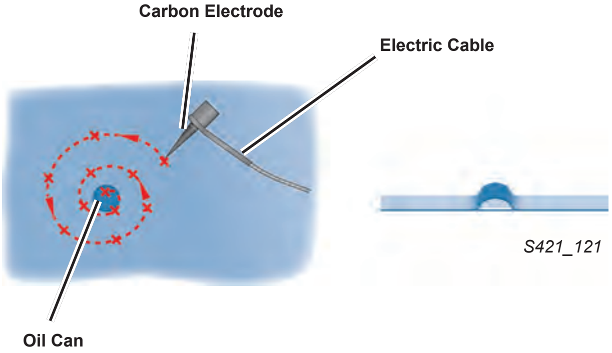
The indented metal surface is heated at certain points with a carbon electrode until it is cherry red. The heating points should follow a spiral from the outside to the inside like when working with a welding torch.

If the areas to be drawn in are larger, each point must be cooled immediately after heating (with a wet sponge).

Smaller areas are heated in a spiral in a single operation so that they cool down again in a spiral shape. Quenching with water also has a drawing-in effect in this case.

This drawing-in effect means that something is “pulled in”. In this procedure, it means that the stretched material in the dent area is pulled back to its original smaller dimensions - i.e. “drawn in”.

The material can not be compressed as much by heating and cooling as with direct beating.

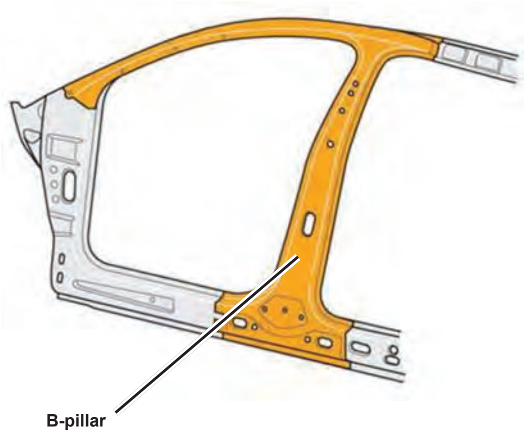


Cutting

Cutting out damaged parts

The job of cutting out damaged parts can only begin once the body has been aligned sufficiently for the alignment brackets to fit the mounting points on the body.

One exception to this rule is the thermoformed B-pillar and the neighboring body area towards the A-pillar on many vehicles. It is virtually impossible to rectify these parts due to the high STRENGTH.



S421_108

Hand tools (e.g. hammers and panel cutters), electrical equipment (e.g. one-hand angle grinders) and pneumatic equipment (e.g. body saws and spot weld removers) can be used to cut out panel sections.

Body Saw

S421_109

Spot Weld Remover

S421_110

Glossary

Alloy

An alloy is a solid solution with metallic properties. The term alloy originates from the Latin word ligare/later legare, which means bind, tie or combine. Alloying is very important in engineering because adding certain alloying elements to metals, such as steel, allows specific material properties to be obtained.

Atom

An atom is the smallest chemical particle of an element that cannot be split. It consists of the positively charged atomic nucleus and negatively charges electrons.

The atomic nucleus contains positively charged subatomic particles, called protons, and electrically neutral particles, called neutrons. The protons are responsible for the positive charging of the atomic nucleus.

Corrosion

In engineering, corrosion refers to the reaction of a metallic material with the surrounding media that causes a measurable change in the material and, at the same time, impairs the function of the component (the term corrosion is also used in other fields, for example, medicine …)

Electrochemical Potential

First of all, the term potential as used in this context should be explained. When we generally talk about a potential, we mean the difference in values between two compared items.

In electrochemistry, the term electrochemical potential is used. This term means that all metals have a specific electrochemical potential that differs from the potential of another metal.

The potential values of the respective metals, which can be found in the electrochemical series, are calculated using a standard hydrogen electrode at 25°C.

Electron

Electrons are negatively charged subatomic particles. A single electron has the smallest negative charge unit - the elementary charge.

Depending on the type of element, an atom can contain one or more electrons. This depends on the number of positively charged protons in the atomic nucleus. A balance of opposite charges, i.e. a balance between the positive and negative subatomic particles, is always sought within an atom.

Hardness

Hardness is a material parameter that describes the mechanical resistance of a material against a mechanical influence.

Hardness is only related to the strength of a material to a limited extent. A high level of hardness is, however, mostly linked to a high level of brittleness (i.e. risk of fracture …).

A good ratio of hardness and strength must be ensured so that the material can fulfill its task.

Hardness is also important when looking at the individual structural components of steels (e.g. hard phases). Corresponding solid solutions with specially created hard components also contribute to increasing the strength of a steel.

Laser

The word laser is made up from the first letters from “Light Amplification by Stimulated Emission of Radiation”. In a laser, a medium such as a helium/neon gas mixture is raised to a higher energy state by “exciting” its electrons. This energy is then emitted as an electromagnetic wave (e.g. as red light) in a highly bundled form, the so-called laser beam.

Metal Ion

Metal atoms have electrons that are bound to the atomic nucleus and one or more “free” electrons on the outer electron shell. The atomic nucleus including the bound electrons is also known as the metal ion. Without the “free” electrons, it has a positive charge. The electrical force of attraction between the negatively charged free electrons and the positively charged metal ions are responsible for the firm cohesion and the strength of the metallic material.

This kind of bond is also called a metallic bond because it is a characteristic of all metals.

Recrystallisation

Recrystallisation is a process by which the crystalline structure of a metal, which has been altered by cold forming is reformed and the previous change in properties is reversed.

Semi-Finished Product

As the name says, these are parts that do not represent the final state of a product. The semifinished product is prepared in terms of geometry, treatment and, if necessary, coating so that as little reworking as possible is required during further processing or fitting in the finished product.

Solid Solution

A solid solution is a mixture of two crystalline solids from at least two different chemical elements. The foreign atoms or ions are randomly distributed. They can occupy interstitial sites (interstitial solid solution) or replace atoms belonging to the other element (substitutional solid solution). The foreign atoms are dissolved in a crystal, hence the term solid solution.

Strength

Strength is a material parameter that describes the mechanical resistance of a material against plastic deformation or fracture.

Tensile, compressive, bending, buckling and shear strength can be distinguished depending on the type of load.

Normally the ultimate strength is calculated for metallic materials used in vehicle construction and is employed for the categorization in different strength classes. However, the yield point can also serve as a basis for certain other steel applications such as construction steel.

The ultimate strength is defined as the greatest tension that occurs in a material. The tension values are calculated in tensile testing using a sample rod.

Notes

Knowledge Assessment

An online Knowledge Assessment (exam) is available for this Self-Study Workbook.

The Knowledge Assessment is required for Certification.

You can find this Knowledge Assessment at:

www.accessaudi.com

From the accessaudi.com Homepage:

- Click on the “ACADEMY” tab
- Click on the “Academy Site” link
- Click on the “CRC/Certification” link
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Thank you for reading this Self-Study Workbook and taking the assessment.

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