

Materials – Wrought materials production

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5 Wrought materials production

See also:

- ⤴ AAM – Materials – 6 Special materials production > Longitudinally welded tubes
- ⤴ AAM – Materials – 6 Special materials production > Metal Matrix Composites
- ⤴ AAM – Materials – 6 Special materials production > Laminates / Sandwiches
- ⤴ AAM – Materials – 6 Special materials production > Foam
- ⤴ AAM – Materials – 6 Special materials production > Tailored blanks

5.1 What to find in this section

This section describes the processes for production of major semi-finished automotive products, i.e. for sheet, extrusions, forgings and impact extrusions. (Special materials' production, such as welded tubes, MMC, Laminates, Foam and Tailored Blanks, are treated in a subsequent section.)

The purpose is to illustrate the production processes, which lead to special qualities and shapes and to a variety of surface finishes, as background for material selection and fabrication. When specifying or designing such products, it is important - for economic reasons - to consider the characteristics of the production processes.

Semi-finished automotive products are specialty materials with closely controlled properties and tolerances for specific customer requirements and are to be distinguished generally from standard mill products and stock materials for general purpose applications.



Right figure: Run-out table of an extrusion press with cooling/quenching equipment for in-line heat treatment of extrusions.

Left figure: Coiling of hot rolled strip.

5.2 Automotive sheet

5.2.1 Automotive sheet production

– Rolled material with special property profile

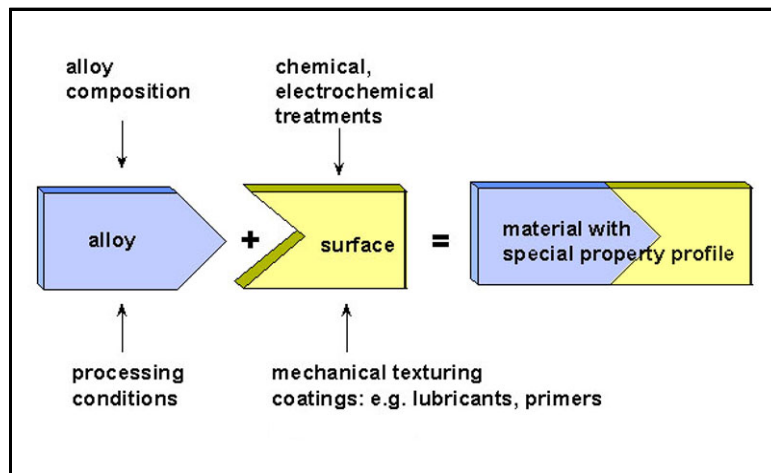
Literature:

- ⤴ Furrer, P. and Bloeck, M.: Aluminium-Karosseriebleche. Landsber: Verl. Moderne Industrie, 2001, (Die Bibliothek der Technik; Bd. 220) ISBN 3-478-93250-5

Automotive sheet material is a specialty material

In order to comply with the requirements of the car manufacturer aluminium automotive sheet materials have been developed with special property profiles, which are the result of combined characteristics of

- ⤴ the base material and
- ⤴ the sheet surface (*s. figure below*).



Source: M. Bloeck and G. Marshall, Alcan

Sheet production comprises several discrete steps:

- ⤴ ingot casting,
- ⤴ hot rolling,
- ⤴ cold rolling and
- ⤴ finishing (heat treatment, surface preparation and/or cutting).

5.2.2 Automotive sheet production

– Process steps influence microstructure and properties

Base material properties are directly related to microstructure which is strictly controlled by alloy composition and the processing parameters. Examples of key processing parameters are given in the accompanying table.

The sheet **surface characteristics** have a significant influence on:

- △ friction behaviour, i.e. during
 - transport of the panels,
 - forming,
 - mechanical joining,
- △ joining performance, e.g. during welding, bonding,
- △ adhesion of coatings and lacquers,
- △ optical appearance after lacquering,
- △ corrosion resistance

Process step	Influence on microstructure	Influence on sheet properties
Ingot casting	<ul style="list-style-type: none"> • Content of elements in solid solution • Type, size and distribution of primary particles • Grain structure 	Can affect formability and mechanical properties, but this is largely dependent on the subsequent process steps
Ingot preheating	<ul style="list-style-type: none"> • Phase transformation • Shape change of large (>1µm) intermetallic particles • Formation of small (<1µm) particles (dispersoids) • Chemical homogenisation (solute elements) 	Formability, anisotropy of properties, final strength and bake hardening response of AA6xxx alloys.
Hot rolling	<ul style="list-style-type: none"> • Type, size and distribution of all intermetallic particles. Recrystallisation response and crystallographic texture, after hot rolling and during subsequent processing • Formation of particles of soluble elements (e.g. Mg, Si, Cu) 	Formability, anisotropy of properties, final strength and bake hardening response of AA6xxx alloys.
Cold rolling	<ul style="list-style-type: none"> • Increase in dislocation density (control of subsequent recrystallisation behaviour and grain size) • Size and distribution of all intermetallic particles 	Anisotropy of properties, formability
Final heat treatment (soft anneal or solutionising and quenching)	<ul style="list-style-type: none"> • Grain size • Dissolution of soluble particles • Formation of age hardening particles 	Formability, Yield strength of AA5xxx sheet alloys, Yield strength and bake hardening of AA6xxx alloys, Bendin g behaviour of AA6xxx alloys

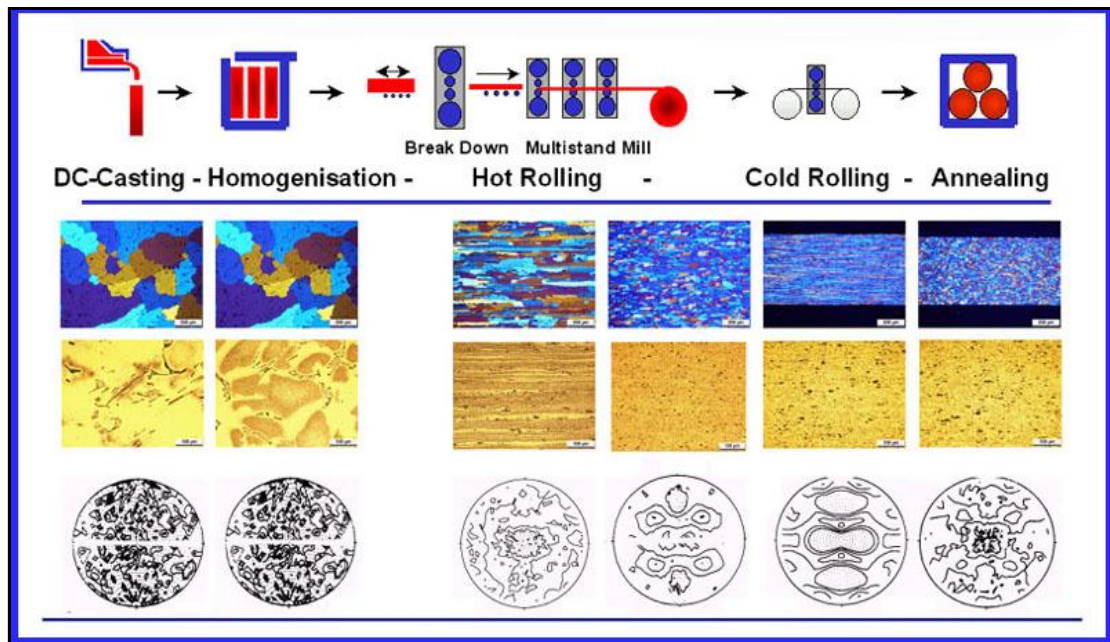
Source: M. Bloeck and G. Marshall, Alcan

Evolution of Microstructure

The essential microstructural features developing during the complete chain of thermo-mechanical processing steps from ingot casting through ingot homogenisation, hot rolling, cold rolling and intermediate or final annealing are

- △ grain structure
- △ constituent phase particles
- △ precipitations and
- △ textures.

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Typical process chain for rolled products

Source: L. Löchte, VAW aluminium AG Bonn

5.2.3 From ingot to strip and panel

Cast House

Raw metal for production of ingots:

- ⤴ Mixture of primary aluminium and sorted fabrication scrap or secondary aluminium gained by melting of scrap from recycled products.

Casting:

- ⤴ Alloying elements are added (when needed) to the melt to attain precise composition control.
- ⤴ The molten Aluminium is filtered and degassed immediately before casting.
- ⤴ DC casting stands for Direct Chill casting.

For example an aluminium smelter or cast house will produce between 100-600 kt of sheet ingots annually with an individual ingot weighing up to 27 t. A casting centre will cast up to five ingots in a single operation



Casting of aluminium ingots

Source: M. Bloeck, Alcan, 87331

From ingot to rolling slab

The cast ingots are typically sawn at head and foot to remove head shrinkage and start of cast foot region. The cast surface imperfections and metallurgical inhomogeneities are also removed by scalping the rolling faces to a predefined depth that depends on alloy and product requirements.

Strip casting

It is also possible to produce a coil of aluminium by a semi-continuous route using a block, belt or roll caster. The semi-fabricated product is a coil in the 3 to 10 mm range which would subsequently be cold rolled to final gauge. Casting a thin strip product can have economic advantages but there are metallurgical drawbacks associated with rolling a cast surface, lack of homogenisation and chemical segregation linked to some alloys. For these reasons continuous casters have yet not been adopted for automotive sheet.



Rolling ingots are retracted from casting pit

Source: M. Bloeck, Alcan, 87333

Hot Rolling

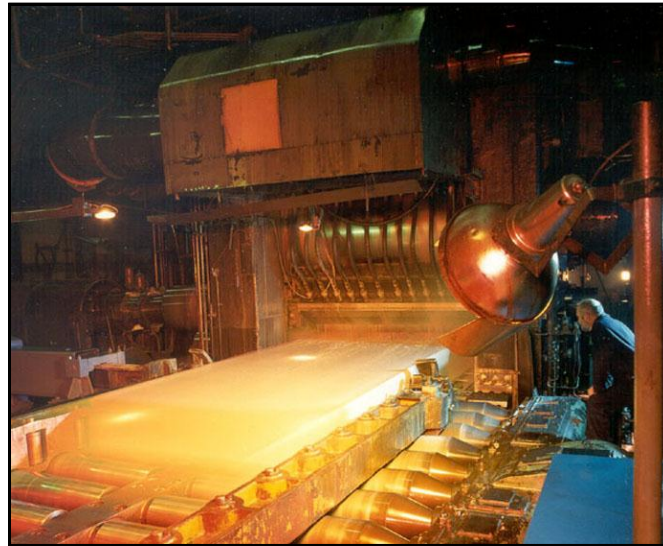
Preheating: the slabs are preheated at 480-580°C for several hours for homogenization of the microstructure.

Hot rolling: the preheated slabs are hot rolled using exactly defined pass reductions and controlled temperature conditions.

In most rolling plants hot rolling is done on a reversing mill (up to ~ 25 mm strip gauge) followed by rolling on a tandem mill.

In some rolling plants hot rolling is performed on a reversing mill only. Depending on the hot rolling concept, the gauge of the hot rolled strip can vary between 3-12 mm. The hot rolled strip is hot coiled and cooled down to RT.

Cold rolling: The hot rolled strip is cold rolled to final gauge in several passes. Cold deformation leads to an increase of the material strength. Therefore, for some alloys an interanneal is performed to allow further rolling.



Hot rolling on a reversing mill



Coiling of the hot rolled strip

Annealing of cold rolled strip

At final gauge the strip is annealed to adjust the required material properties:

- ⤴ heat treatable alloys, such as AlMgSi alloys, are subjected to an anneal in a **continuous annealing furnace** with rapid heating to the required metal temperature (MT), short hold at MT followed by quenching. By this solution anneal the main alloying elements Mg and Si are dissolved leading to a good formability of the material (T4 temper).
- ⤴ AlMg alloys are soft annealed at inter- mediate or final gauge depending on the required temper. Usually the coils are annealed in **batch type furnaces** for several hours at 300 to 400 °C.



Source: M. Bloeck, Alcan, No. 87 357

(above): **Continuous anneal of aluminium strip**: surface quality inspection at the exit of the annealing furnace.



Source: M. Bloeck, Alcan, 2001

(above): **Batch type annealing furnace for coils** under protective gas. Typical technical details of a batch furnace →

number of coils:	max. 5-6 coils
max. strip width:	2050 mm
coil OD:	max. 2200 mm
coil weight:	max. 12000 kg
protective gas:	nitrogen
max. gas temperature:	600 °C
heating system:	electric

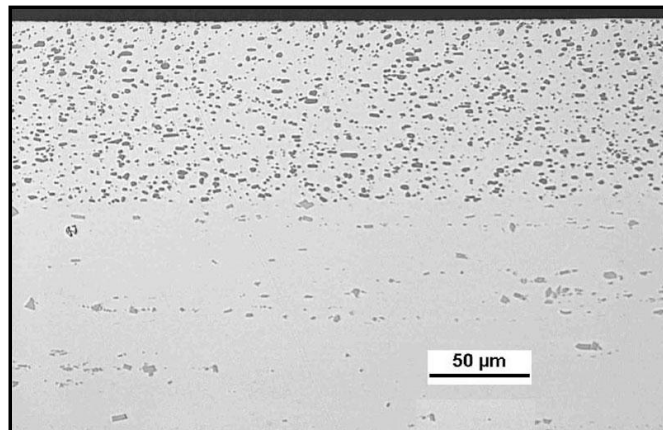
Production of Brazing Sheet

See also:

- ▲ AAM – Products – 1 Rolled products
- ▲ AAM – Joining – 4 Brazing

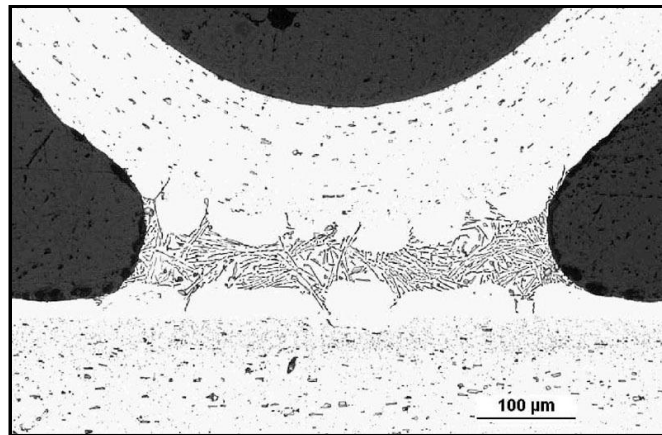


Roll Bonding – Brazing packs are normally hot roll bonded following an appropriate preheat/homogenisation cycle (460 to 620°C). Bonding is normally complete after 2-3 defined reductions. Thereafter, hot rolling is similar to that of standard sheet products. Gauge of the hot rolled strip is typically 2.5 to 4.5 mm



Clad Packs – Clad thickness can range from 5 to 20% of the total pack thickness and can be single or double sided clad, sometimes with differential % cladding. For some applications, it is also required to produce brazing sheet with a corrosion resistant cladding (AA1050 or AA7072).

Multi-clad products are also available.



Brazing Sheet Coil – Material is supplied typically in H14/H24 tempers for radiator tubestock products and in fully soft temper for high formability products.

Cutting of panels

See also:

▲ AAM – Manufacturing – 2 Cutting > Shear cutting > Blanking

Annealed strip is supplied in **coil** or is **cut longitudinally** or into **individual panels** depending on customer needs.

Flatness tolerances for hot rolled and cold rolled strip, sheet and plate: see EN 485-3 and 485-4.



For certain parts, e.g. hoods, the strip is cut into **panels with special shape**. This offers the advantage that production costs and scrap can be saved.



5.2.4 Special sheet surfaces

Surface topographies

The **sheet surface topography** affects

- △ the formability of the material and
- △ the appearance of the panels after lacquering.

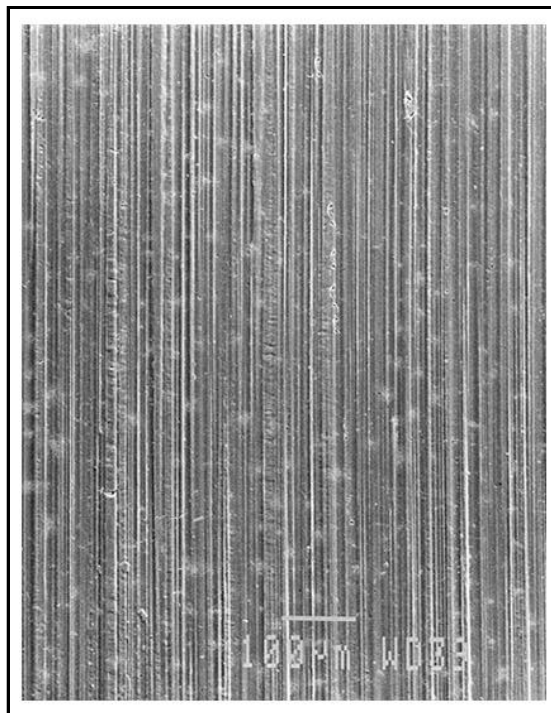
Special topographies have been developed for **automotive sheet**.

The required topography usually is transferred during the last cold rolling pass from carefully prepared work rolls to the strip surface using controlled rolling conditions.

In Europe the established surface quality is **EDT** (Electric Discharge Texturing). To produce this topography the roll surface is textured by means of electric discharge. Transfer to the strip requires a special rolling practice.

In North America the established surface is **mill finish** which is achieved without special work roll topographies and using standard rolling practices.

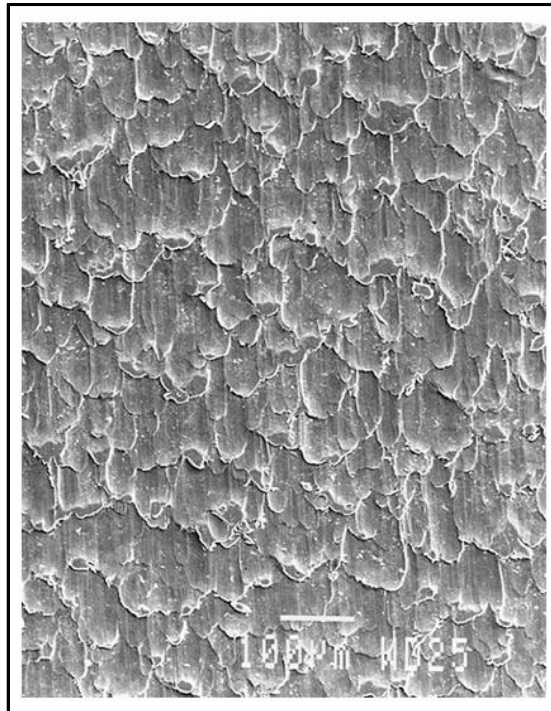
Millfinish surface of strip



SEM micrograph of the surface structure of automotive sheet with Millfinish topography

Source: Alcan

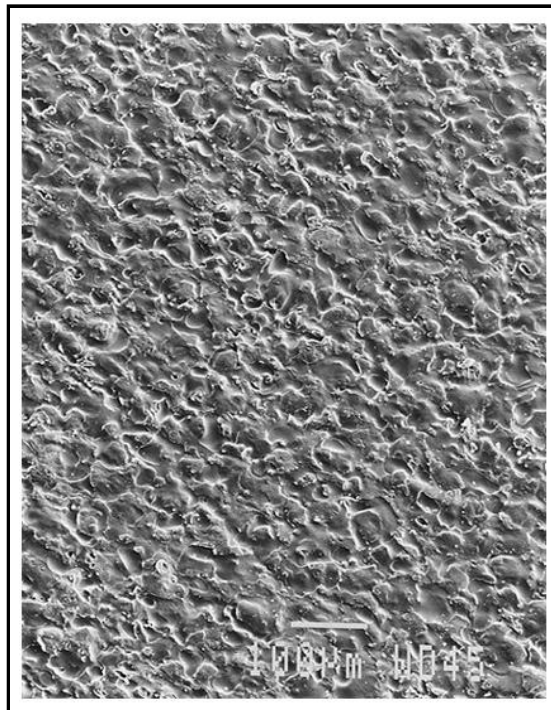
EDT surface of strip



SEM micrograph of the surface structure of automotive sheet with EDT topography

Source: Alcan

EDT surface of dressing rolls



SEM micrograph of the surface structure of dressing rolls with EDT topography

Source: Alcan

Chemical & electrochemical pre-treatment

Reasons for pre-treatment of strip:

Following are the main reasons for chemical and electro-chemical pre-treatment:

- △ remove residues from rolling: oils and aluminium debris
→ **Degreasing**
- △ generate an oxide layer with homogeneous properties
→ **Etch cleaning** (pickling)
- △ pre-treatment and corrosion protection of adhesive bonds
→ **Conversion or anodising layer**
- △ interlayer before application of a primer or lacquer
→ **Conversion or anodising layer**

These pre-treatment are performed in **coil coating lines**.

The contact with the chemical agents can be achieved by means of spray or immersion. The conversion treatment is, mainly due to environmental reasons, preferably performed in a **No Rinse** process, i.e. without rinsing after treatment.

The conversion treatment can be done by means of a roll coater or by means of spraying or immersion followed by squeezing of excess chemical agents.

Degreasing

Degreasing of aluminium strip is preferably performed using **mild alkaline** agents that do not attack aluminium.

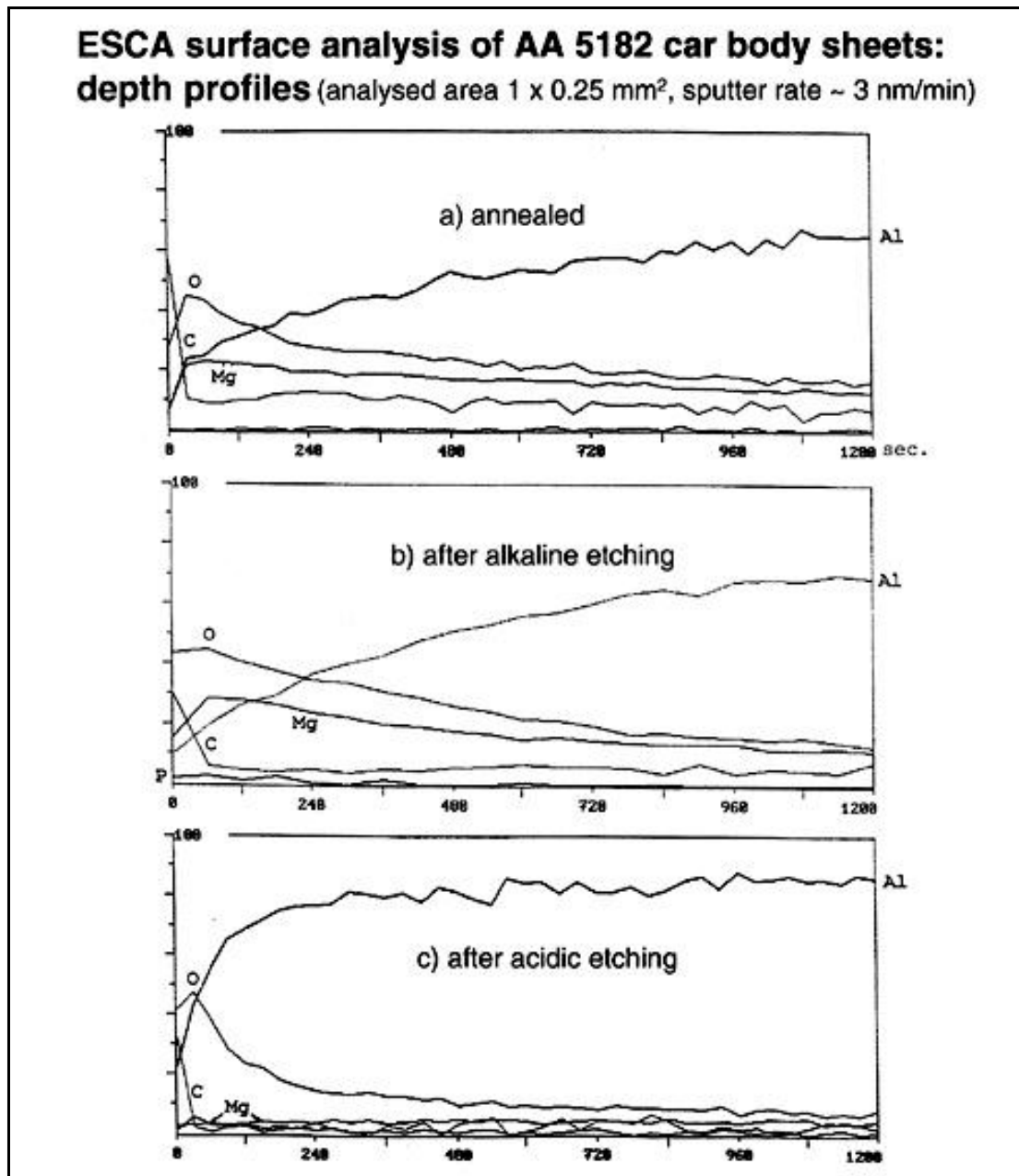
Etch Cleaning (Pickling)

Aluminium is covered by a natural oxide layer that can vary in thickness and composition depending on the alloy type and processing conditions. The oxide layer protects the aluminium against corrosion, because it is passive over pH ~4.5 to ~8.5.

The surface properties of the material are strongly influenced by its oxide layer, e.g.:

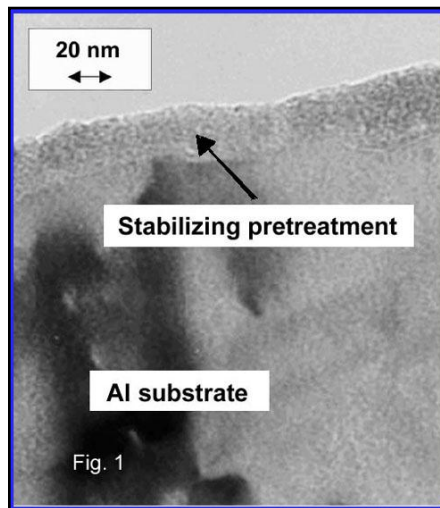
- △ the surface resistance has a considerable effect on the spot weldability; a low, homogeneous surface resistance is of advantage
- △ the chemical composition of the oxide layer influences the performance of adhesive bonds and the adhesion of primers and lacquers.

In order to achieve homogeneous surface characteristics a pickling process is done usually by means of **acidic** agents.

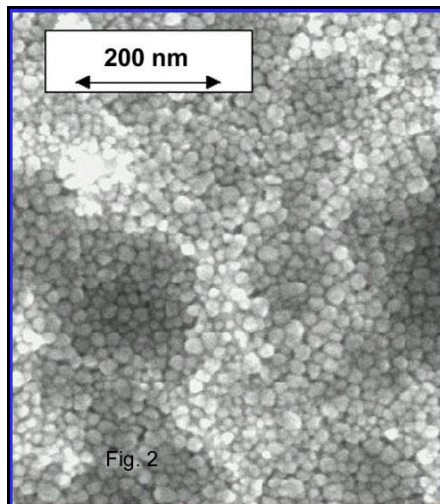


Conversion treatments

Presently two main types of **conversion treatment** are applied, a thin stabilising pre-treatment used mainly for closure sheets and a structural layer used when adhesive bonding is required. For a stabilising pre-treatment the natural oxide layer is removed and replaced by a chemically modified layer (<10 nm thick) (s. *fig. 1*) Suitable for this process are e.g. agents based on **titanium-** and/or **zirconium-fluoride** or on **silicates**. For environmental reasons chromating is not used any more. Thicker layers can be used for aluminium sheet where structural bonding is required. An example of this type is a silicate based system with a 50 nm layer (s. *fig. 2*).



TEM x-section of chemical conversion layer on Al sheet



Pre-coatings

Lubricant application

In order to protect the relatively soft aluminium surface for transport, the strip surface is usually covered with a thin film of a corrosion protection or deep drawing oil or alternatively with a dry lubricant film.

Panels that are supplied for exterior applications sometimes still are covered for surface protection with interleave paper instead of a lubricant.

The oil and dry lubricant usually are applied by means of roll coating or spraying.

The use of dry lubricated sheet has the main advantage that automation is facilitated during pressing of panels in the press shop.

Primers

Aluminium sheet can be coated with an organic primer before supply to the OEM. The primers fall into two categories, electrical **conducting primers** that are electro-coat compatible and **non-conductive primers** that are electro-coat replacements with multiple layers up to the clear coat. The application of a primer offers a number of advantages:

- △ surface protection during transport and handling
- △ improved formability
- △ in mixed metal constructions a primer coating can protect against galvanic corrosion of the aluminium
- △ good bondability and long term stability of adhesive bonds
- △ appearance after lacquering comparable to that of steel panels

Primers are applied on the strip surface by means of a roll coater process after degreasing and conversion treatment. For curing of the primer the strip has to be heat treated.

Application of Primers to aluminium sheet

Both types of primers require special processing equipment to produce a high quality product. Following the final metallurgical heat treatment, the aluminium strip is first cleaned / degreased, then conversion treated for adhesion promotion and then coated with a primer. The organic based primer is typically roll coated but then has to be heat treated to harden the film. The temperature of bake hardening can be as high as 240°C depending on the system chosen. For multiple coating layers a sequence of roll coating and baking steps is needed. The most efficient processing is achieved using an integrated line to perform all steps in sequence and indeed, when coupled to the metallurgical heat treatment, all finishing operations can be economically completed.

Pre-lacquers are applied on the strip by means of a roll coater after degreasing and conversion treatment.

Each lacquer layer has to be cured by heat treatment.

Technical Details:

strip width:	1000 - 2300 mm
strip gauge:	0.6 - 3.2 mm
line speed:	150 m/min
line length:	268 m
coil weight:	max. 26400 kg
line capacity:	100000 t/year

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Coil Coating Line

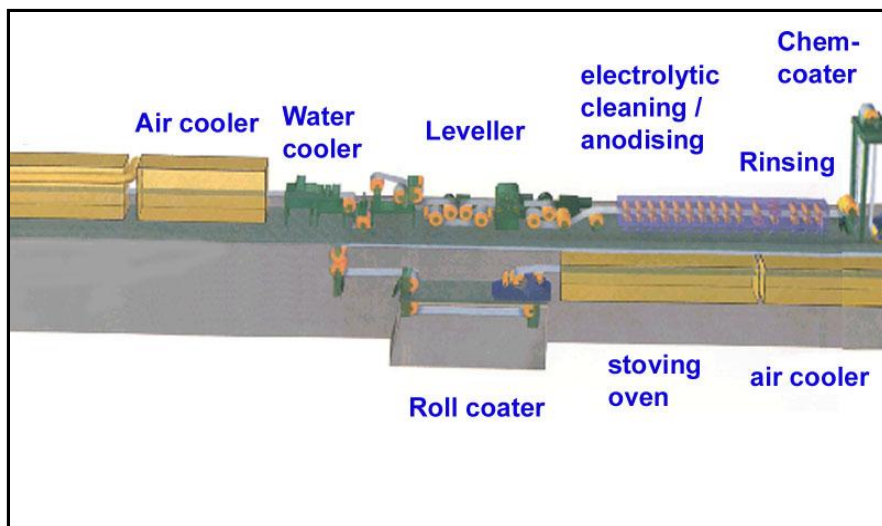
In-line treatment process steps:

- ⤴ levelling
- ⤴ continuous annealing followed by air or soft water quench
- ⤴ electrolytic cleaning/anodising: 0.05-0.20 μm
- ⤴ chemical pre-treatment: roll coater (Chemcoater), No Rinse
- ⤴ pre-coating: primers or pre-lacquers, roll coater, followed by curing
- ⤴ lubrication
- ⤴ lamination with protective films



Part I of treatment line

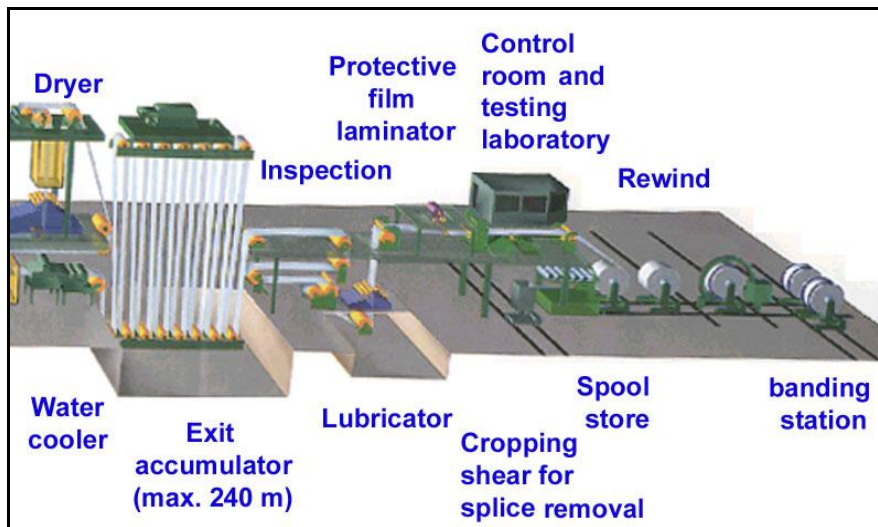
Source: Alcan



Part II of treatment line

Source: Alcan

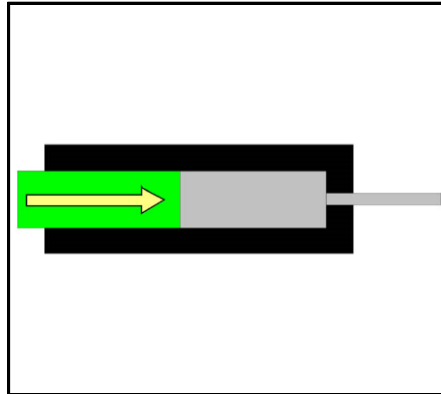
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Part III of treatment line

Source: Alcan

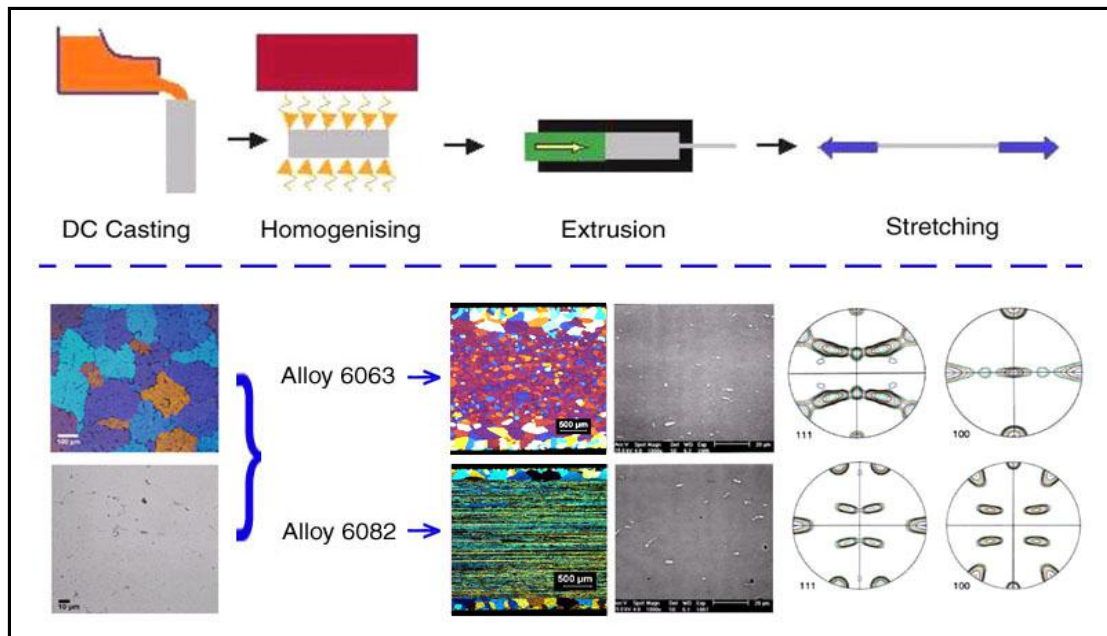
5.3 Extrusion



5.3.1 Automotive extrusions – Process steps and microstructure

For processing steps from melt to section, see figure below. Base material properties are directly related to microstructure, which is controlled by alloy composition and the processing parameters. Generally, the higher the alloying content, the higher will be the profile strength and the lower the extrudability and cold formability. Microstructural features developing during processing steps from ingot casting through homogenising, extrusion, and in some cases solution treatment are:

- ⤴ grain structure,
- ⤴ constituent phase particles,
- ⤴ precipitations and
- ⤴ texture (fig.: texture at 40% depth).



Evolution of microstructure during extrusion

Source: Asboell, Hydro Aluminium

The resulting microstructure and grain structure of the extruded sections will depend on several parameters:

- ⤴ The presence and number of dispersoids

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- ⤴ The alloy content in general
- ⤴ Extrusion conditions; shear deformation rate
- ⤴ Area of reduction ratio

The grain size of the sections shown on the previous page are different in the way

- i. that Alloy 6063 is recrystallised and exhibits the texture shown on p. 1,
- ii. while Alloy 6082 exhibits only a thin recrystallised surface layer and a texture somewhat different from the other.

In contrast to alloy 6063, 6082 contains about 0.5 % Mn, which forms dispersoids which again have effect as a recrystallisation restraining agent.

Alloy 6082 is more highly alloyed than 6063. Without the addition of Mn, this alloy would tend to recrystallise to coarse grains in and near the surface and thus exhibit reduced ductility.

Therefore in general the high strength 6xxx- and 7xxx-series alloys are designed to contain dispersoids, which inhibit or reduce the tendency to recrystallisation during extrusion and thus maintain ductility and toughness.

5.3.2 Casting of extrusion log

See also:

^ AAM – Products – 2 Extruded products > Alloys

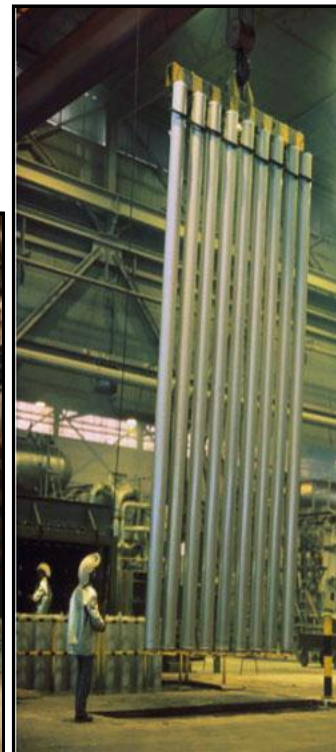
Metal sources

are a mixture of primary aluminium and sorted fabrication scrap or secondary aluminium gained by melting of scrap from recycled products.

Casting

Alloying elements are added to the melt to attain precise composition control. On its way to the casting station, the molten aluminium is filtered and degassed. The casting process, which is a continuous process, (DC casting - Direct Chill casting), cast log lengths of typically about 7 m in length.

One charge is typically 50 t metal, which gives about 50 logs of diameter 250 mm.



5.3.3 Cutting logs to billets / Preheating to extrusion temperature / Extrusion

Cutting

When the logs have been cooled after homogenising, they are cut to appropriate lengths, billets of about 1 m.

Preheating

Before entering the extrusion press, the billets are preheated to a suitable temperature, 450 – 500 °C. Preheating is done in induction- or gas fired furnaces. Some extruders apply taper heating, which means that the front of the ingot is heated to a temperature 50 – 100 °C above the rear part. The aim of the taper heating is to compensate for the heat being generated during the extrusion process.

The extrusion process

The preheated billet is conveyed into the heated press container. The ram pushes the billet forward through the steel die at the end of the container. The finished section, as defined by the shape of the die, runs out of the press exit. At the run-out table a puller holds the section and pulls at a force suitable for keeping it straight. At the same time it is cooled by forced air or in some cases by water.



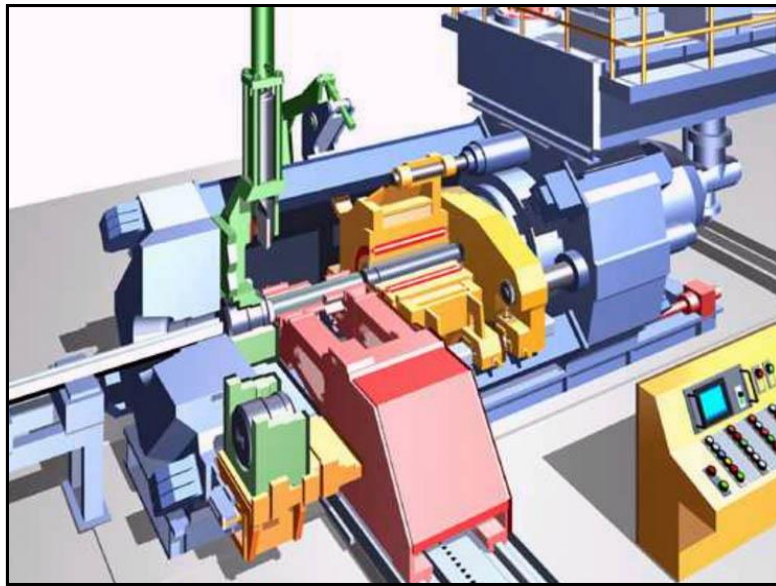
5.3.4 Extrusion presses

See also:

^ AAM – Products – 2 Extruded products > Profile dimensions > Size limitations

Extrusion presses

Extrusion presses for automotive products range in press force from 1600 to 5600 t. A general rule is: the higher the press force is the wider are the ingots and the larger may the profiles be. Billet diameters used range from about 185 mm to about 340 mm. The section dimension is thus limited to circumscribing circle of about 300 mm, but a special spreader technology can be used to extrude some wider sections. See section "Size limitations".



Drawing of an extrusion press showing part of the interior

Source: SMS Eumuco GmbH

5.3.5 Factors influencing on quality of extrusions

Metal quality

Large inclusions (> 50 µm) will make surface defects like die lines, longitudinal lines. Quality of the billet surface will also affect surface quality of the section.

Chemical composition will affect extrudability and thus surface quality and grain size, which again affect properties.

Operating parameters

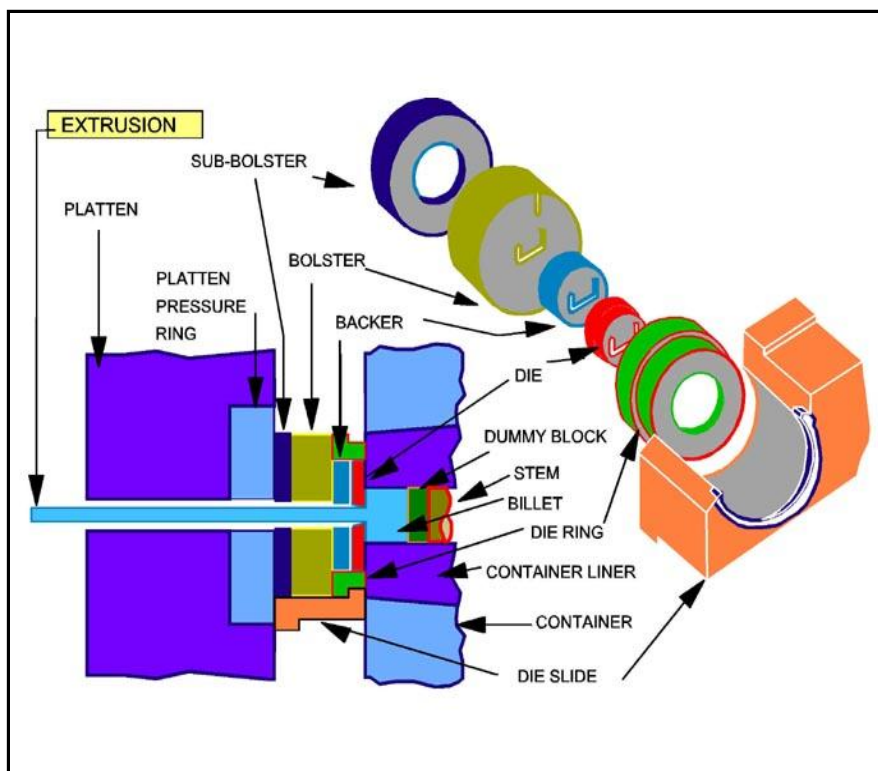
Higher extrusion speed improves output, but a limit exist above which the die and metal surface temperature becomes too high and pick-up, or even worse, local tearing occurs. The container temperature should be somewhat lower than the billet. The aim of this is to reduce metal flow of the billet surface in order to collect the oxide-rich metal in the discard. Also the size of the discard affects quality. Small discards means surface oxide may pass through the die.

When a new billet is charged into the press, metal from the new billet flows into the die welding chamber/ feeder plate and pressure welds to the old metal, producing a charge weld. The charge weld area, which is somewhat enriched with oxides, exhibits visual defects and may show reduced mechanical properties. Therefore a sufficient length of the charge weld zone should be cut discarded.

5.3.6 Die tooling

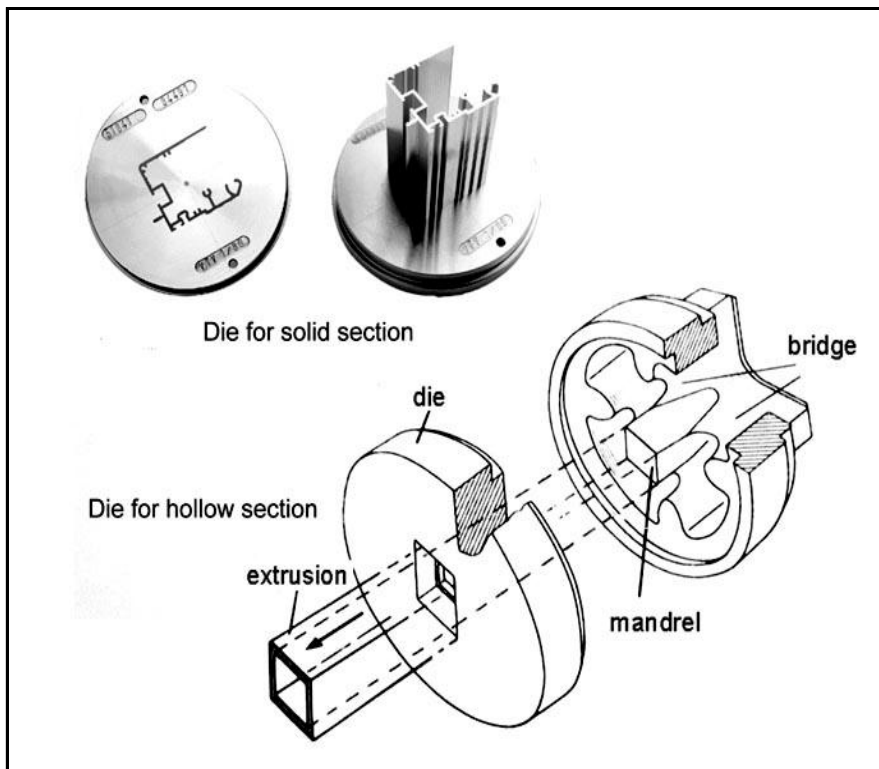
The die tooling is a package consisting of die slide, die ring, die, backer, bolster and sub-bolster. The die itself is for open sections a disk of tooling steel quality with a slit that has the cross sectional shape of the section. The die slit is designed to control metal flow, such that an inlet choke is used to slow metal flow and a relief is applied at the exit side to speed up flow. In addition a back taper and an undercut is used, see figure.

Dies for hollow extrusions are built to divide the metal into several streams flowing over bridges. Behind the bridges the streams meet and are welded together by pressure. metal flow and a relief is applied at the exit side to speed up flow. In addition a back taper and an undercut is used, see figure. Dies for hollow extrusions are built to divide the metal into several streams flowing over bridges. Behind the bridges the streams meet and are welded together by pressure.



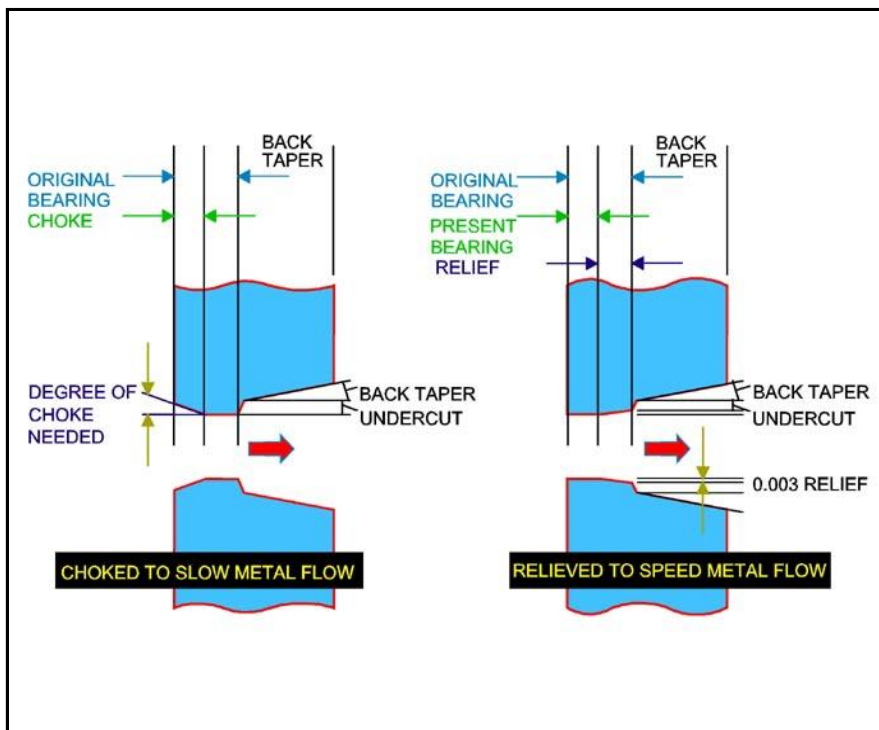
Typical die tooling assembly for forward extrusion

Source: TALAT 1302.01.01



Extrusion dies for solid and hollow sections

Source: SAPA

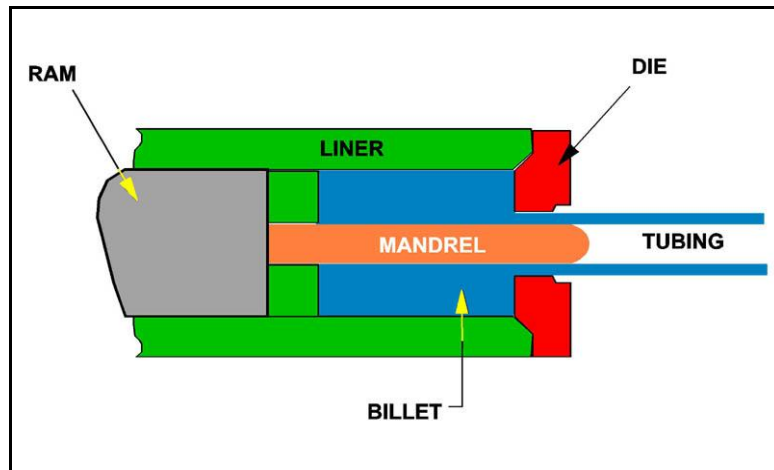


Choking and relieving of metal flow through extrusion die

Source: TALAT 1302.01.03

5.3.7 Extrusion with mandrel

Simple hollow extrusions like tubing can be produced from hollow billet using a mandrel. In this case the extrudate has a uniform metallurgical structure across the section. More complex sections are made using bridge or porthole dies in which the metal flows around shaped bridges and joins again by hot pressure welding in a welding chamber. Extruders working with mandrels are rather few and they are more or less specialised in tubing. For closer tolerances and smoother surface, the tubing is drawn after extrusion.



Extruding seamless tubing with die and mandrel

Source: TALAT 1302.01.09

5.3.8 Post extrusion operations

See also:

- ⤴ AAM – Materials – 2 Alloy constitution > Heat treatment
- ⤴ AAM – Materials – 2 Alloy constitution > Heat treatment > Solution treatment and ageing

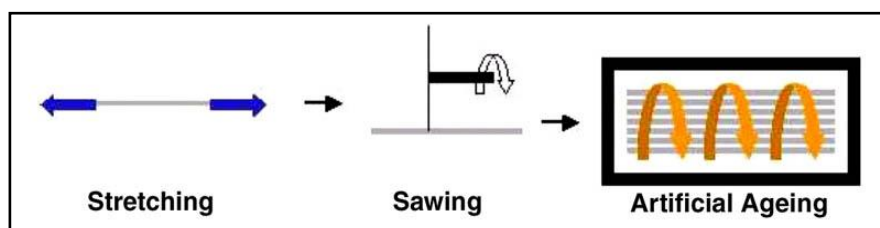
Cooling and stretching

At the run-out table the section is quenched by blowing air, or for some alloys and thicknesses, by water-cooling. This provides solution heat treatment for heat treatable alloys. On reaching room temperature is reached, the long extrusions are stretched to ensure straightness and relieve residual stresses. After stretching, the sections are cut to appropriate length, which may be standard lengths of 4m, 6m or lengths suitable for the finished product.

Artificial ageing

In case of heat treatable alloys and where no or limited forming operations are involved for the final product, the sections are artificially aged to stabilize their mechanical properties. When subsequent forming operations are required and high formability is needed, a separate solution treatment or a retrogression heat treatment is required for the more high strength 6xxx- and 7xxx-series alloys.

The lower alloyed 6xxx-series alloys are frequently formed in T4 or W temper.

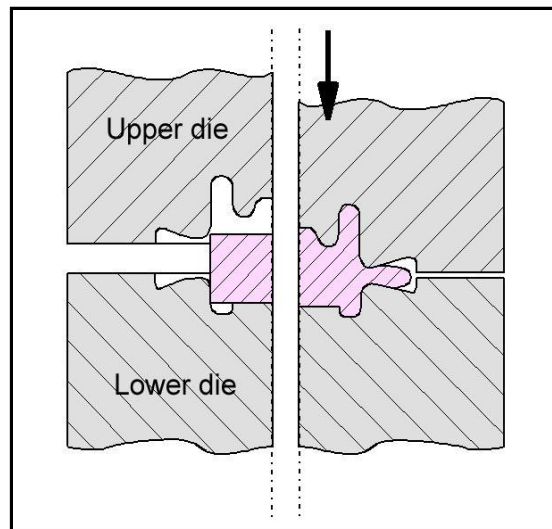


5.4 Forging

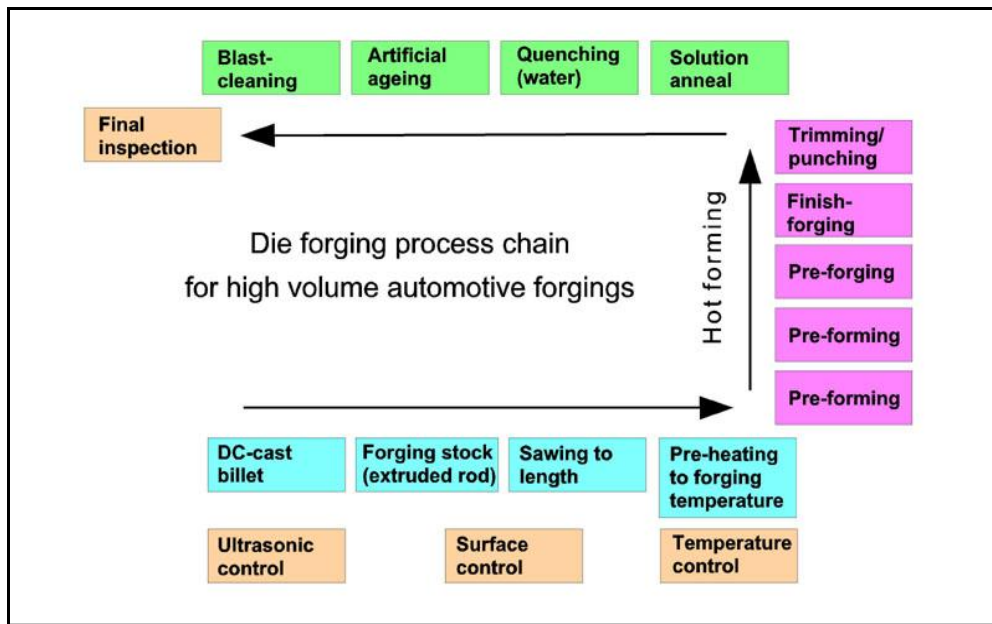
5.4.1 Automotive die forging – Characteristics of the closed-die forging process

Literature:

- ▲ Bittrich, A.: Wirtschaftlicher Leichtbau mit Aluminium-Schmiedestücken. Proceedings, 1st Landshuter Leichtbaukolloquium, 19/20 February 2003



- ▲ Die forging is a bulk metal hot forming process. The initial forging stock is a cast or extruded bar or shaped section depending on the final shape of the component.
- ▲ On the other hand, the cross section usually varies considerably over the extent of the envisaged forged part.
- ▲ Thus, starting with the simple geometrical shape of the forging stock, a sequence of consecutive pre-forming steps (stretching, upsetting, bending) is required before the redundant material is squeezed out into the flash during finish-forging and trimmed off.
- ▲ Prior to final inspection the raw forging is heat treated and blast cleaned with aluminium pellets.
- ▲ The high production volume of automotive forgings permits the set-up of continuous automatic forging lines integrating all necessary process steps.
- ▲ Part and tool design, quality of the forging stock and close control of the processing parameters are responsible to ensure a high quality level of the forged products.
- ▲ Quality forgings are produced in a continuous process closely monitoring material and process parameters.



Process chain for automotive forgings

Courtesy: Otto-Fuchs Metallwerke

5.4.2 Automotive die forging – Process and microstructure

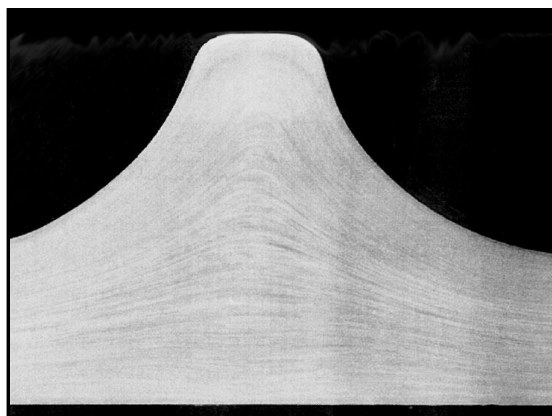


Control arm, alloy 6082-T6

Courtesy: Otto-Fuchs Metallwerke

The characteristic feature of aluminium alloy forgings is a fibrous microstructure.

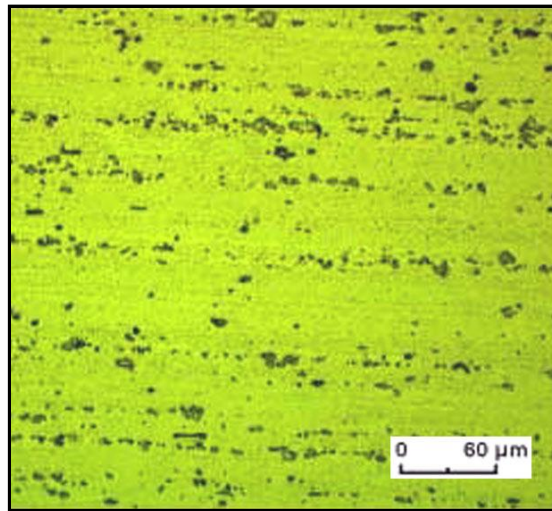
- ⤴ Optimum mechanical properties, i.e. strength, ductility, toughness and fatigue, are obtained in the fiber direction.
- ⤴ Appropriate fiber orientation with respect to the service requirements is the result of judicious choice of starting material, die design and process parameters.
- ⤴ A dense, fibrous microstructure is achieved by properly designed material flow characteristics which are governed by degree and rate of deformation and process temperature scheme.
- ⤴ Friction and high shear strains in the contact zone between work piece and die can lead to a recrystallised surface layer of material which is - up to a certain level - normal and does not affect the service properties of the component.



Fiber structure of a die forging

Source: Otto-Fuchs Metallwerke

5.4.3 Automotive die forging – Composition and microstructure



Alloy 6082-T6 forging

Note linear orientation of constituent particle along fibrous structure

From the wide range of wrought aluminium alloys only a small group of alloys have become of primary importance for automotive applications. The most extensively used forging alloy is the age-hardening **EN AW-6082 (AlSi1MgMn)** because of its excellent combination of mechanical properties and corrosion resistance.

The chemical composition of aluminium forging alloys conforms to the relevant European standard EN 573-3. As a result of the limited solubility of certain impurities (mainly Fe), primary constituent particles are present in the microstructure. It is apparent that volume fraction, size distribution and arrangement of constituent particles in the microstructure are determining factors for ductility and toughness.

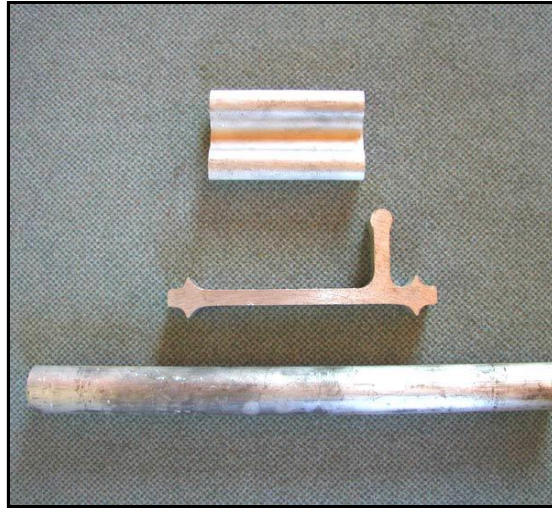
As seen in the micrograph (above) constituent particles are broken down and aligned in the fiber direction during forging. The particle distance perpendicular to the fiber direction is largest and explains the excellent ductility along the fiber direction. The fact that ductility is inferior in the transverse direction is usually of little practical importance in automotive forging applications.

The density of constituent particles is highest along the flash line. Therefore, the flash line should not be placed in a highly stressed area of the component, specifically when it is subjected to alternating loading conditions.

5.4.4 Automotive die forging – Forging stock

See also:

- ▲ AAM – Applications – 2 Chassis > Wheels > Forged wheels > Manufacturing processes

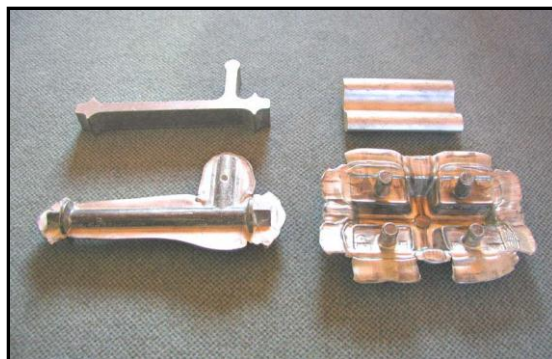


Extruded forging stock: bar and various shapes

Depending on the size, type and shape of the forged part the starting material is produced either as bar stock or as extruded shapes designed to fill the cavities of the die with minimum flash, see figures below.



Forging stock (upper), forging (middle), sheared-off flash (lower)



Forging stock (upper) and forging (lower) with flash still left in place

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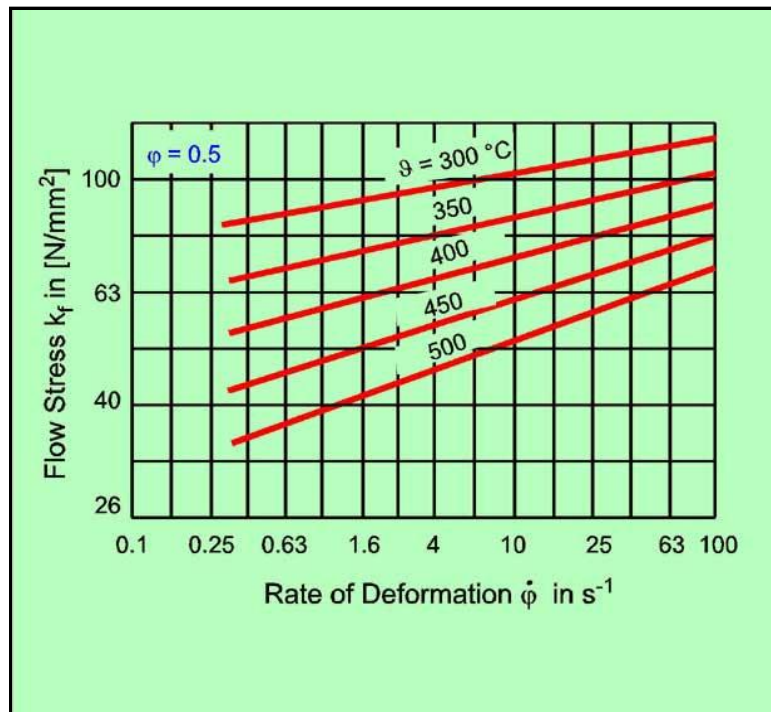
For larger forgings, particularly with circular symmetries, sections of DC-cast ingots are used as forging stock.

The type and quality of the forging stock has a significant effect on quality and properties of the forged part.

For longitudinal parts like control arms the fibrous microstructure of the extruded bar stock determines the microstructure of the forged part.

Other parts may not require unidirectional fibrous structure and can be forged from sections of shaped profiles reducing the number of forging steps.

5.4.5 Automotive die forging – Forging temperatures and rate of deformation



Effect of temperature and deformation rate on flow stress (alloy 6082)

Source: TALAT 3401

Material flow is governed by the degree and rate of deformation and by the processing temperature.

Forging aluminium alloys is different from forging steels in that the temperature interval between forging temperature and solidus temperature is rather narrow:

Example AISi1MgMn (6082):

Forging temperature: 430 to 500 °C

Solidus temperature: 575°C

The pre-heating temperature has to be chosen in view of additional heating due to deformation and friction such that reaching the solidus temperature is avoided, otherwise the microstructure is irreversibly damaged.

Temperature rise due to plastic deformation depends on the degree of deformation and the characteristic of the flow curve:

$$k_f = f(\phi, \dot{\phi}, T)$$

with

ϕ = degree of deformation

$\dot{\phi}$ = rate of deformation

T = forging temperature

High rates of deformation produce a larger temperature rise. Mechanical presses have ram speeds of ~0.5 m/s.

At a constant ram travel different deformation rates are generated in the bulk part depending on the varying size of the cross section.

Formability and rate sensitivity of flow stress increases with temperature, s. figure above. Too low forging temperatures may lead to cracks and partially unfilled die cavities.

In theory cost effectiveness is improved when the forging heat is used simultaneously for

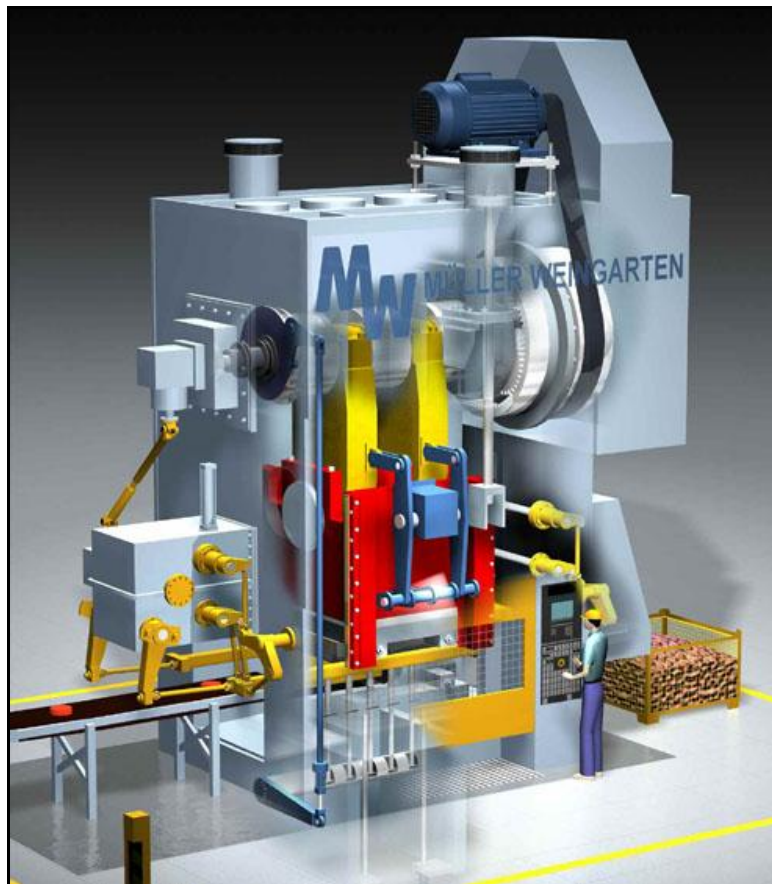
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solution annealing, permitting direct in-line quenching of the part when leaving the finishing die. In practice, however, the exact temperature for solution annealing necessary to achieve optimum mechanical properties can only be guaranteed by a subsequent separate solution heat treatment of the forged part.

5.4.6 Automotive die forging – Forging presses

A fully automatic forging line consists of all the peripheral and operating equipment of the process chain including stock feeder, pre-heating furnace, forging press, heat treatment equipment, shot blasting, etc., all in-line connected by robotic manipulators.

The heart of a fully automatic forging line is a fast, multi-step mechanical forging press. Press capacity, tool dimensions and number of forming steps are tailored to a specific category of forged parts. Forgings weighing between 50 g and 1500 g are produced with presses ranging from 16 to 20 MN press capacity. Smaller parts may be produced in multiple-cavities die sets. The annual production volume runs up to roughly 4 million parts per press line.



Mechanical forging press

Source: Müller-Weingarten, Germany

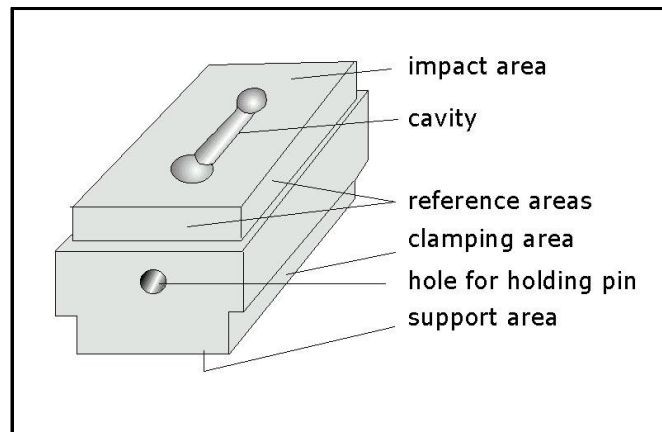
5.4.7 Automotive die forging – Die tooling



Control Arm, alloy 6082-T6

Courtesy: Otto-Fuchs Metallwerke

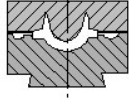
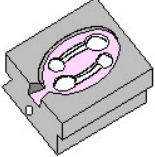
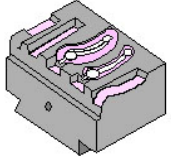
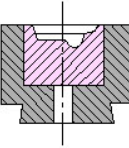
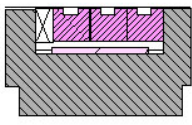
The figure below shows the functional elements of a forging die.



Dies are made of tool steels using high speed machining and CAD modelling. For critical geometries computer simulation is used to demonstrate the feasibility of producing the part.

A variety of dies for closed die forging is schematically shown below:

- ▲ single cavity die,
- ▲ multiple-cavity die (with a number of identical cavities in one die block),
- ▲ multi-stage die (for different steps of operation: e.g. stretching, bending, pre-forming, final forming).

Die with flash			
	single cavity die	multiple-cavity die	multi-stage die
full die			
die insert		insert with a number of identical cavities	

The various functions can also be incorporated in die inserts which adds a further degree of flexibility with respect to die modification and substitution of worn-out forming cavities.

5.4.8 Automotive die forging – Economic aspects

Literature:

- ▲ Bittrich, A.: Wirtschaftlicher Leichtbau mit Aluminium-Schmiedestücken. Proceedings, 1st Landshuter Leichtbaukolloquium, 19/20 February 2003



Control arm with non-planar die parting, alloy 6082-T6

Source: Otto-Fuchs Metallwerke

Die parting

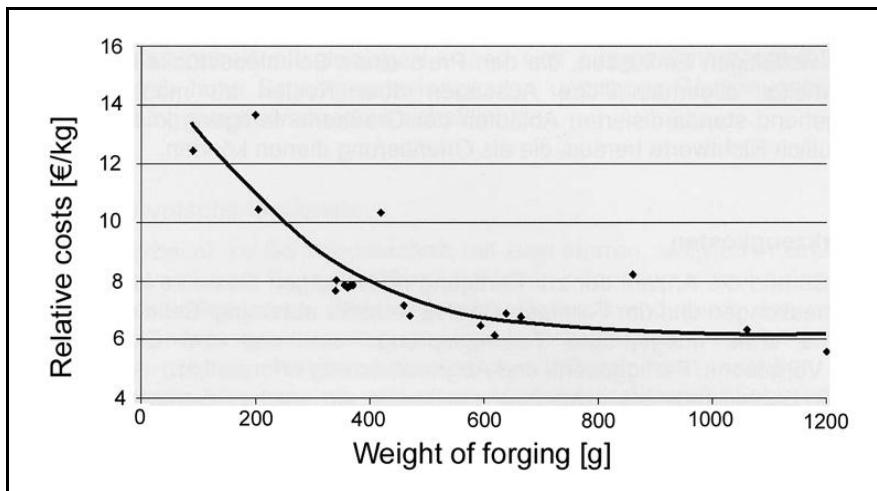
Preferably, the die halves should have plane parting faces. Certain part geometries and envisaged material flow characteristics may require steps in the parting face. These steps should be as small as possible to avoid lateral forces acting on the die set and the need of excessive machining of the die.

Tooling costs

For simple part geometries and plane parting only 3 dies (pre-form, end-form and shear tool) are required. For part lengths up to 360 mm such a tool set may cost Euro 35.000 (s. Lit.). More complicated geometries, e.g. with parting steps in two orientations, require additional dies for bending and sizing. The costs of such a die set may run up to Euro 65.000. For component development, only an end-form die is needed, pre-forming is carried out manually. Generally, prototype tooling costs are ~25% to 40% of the costs of a full die set.

Cost estimate of as-forged components

The cost of forgings depends on a number of factors such as geometric complexity, weight and effective yield. A general estimate cannot be given. Nevertheless, there is a rough relation between cost and weight of the forged part (s. below).



Approximate costs of as-forged parts as a function of part's weight

Source: A. Bittrich, Otto-Fuchs Metallwerke [s. Lit.]

5.5 Impact extrusion

See also:

- ⤴ AAM – Products – 5 Impact extruded products

Literature:

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Work in progress

(see information in chapter "Impact extruded products")