TALAT Lecture 2202

Structural Aluminium Materials

28 pages, 10 figures

Basic Level

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Objectives:

– To aquaint those using the lectures on the structural use of aluminium with the types of aluminium alloys available and the semi-fabrication processes used in their manufacture. The treatment is not detailed and anyone requiring further information will use other TALAT material or the contained references.

Prerequisites:

– the standard required for the main **TALAT** 2000 series lectures

Date of Issue: 1994

2202 Structural Aluminium Materials

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Aluminium and its Alloys

Pure Aluminium

Pure, unalloyed aluminium, as produced at the primary production stage in electrolytic smelters, is cast into different shapes or forms suitable for manufacturing of semi-finished products. Depending on the level of purity a distinction is made between

- commercial purity (99,5 - 99,8% aluminium) and
- high purity (up to 99,98% aluminium)

The material is relatively soft with low mechanical properties; although the strength can be somewhat increased by forming processes, pure aluminium is normally not used for structural purposes. However, its corrosion resistance in normal atmosphere is excellent, its thermal and electrical conductivities are very high, and so is its formability. Pure, unalloyed aluminium is widely used for electrical, chemical, food packaging, petrochemical and building product applications.

The mechanical properties can not be increased by heat treatment (age hardening), and pure aluminium is, therefore, classified in the group of non-heat treatable alloys.

Aluminium Alloys: the main types

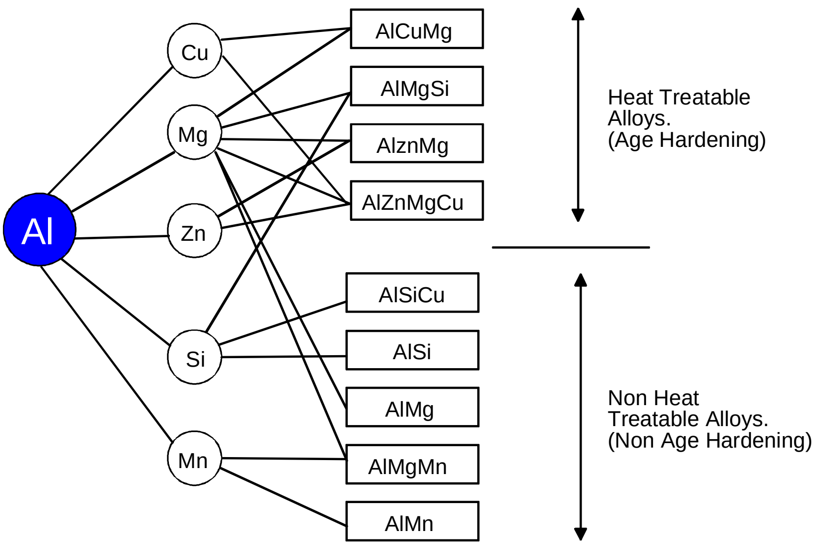
Alloying elements added to pure aluminium improve its strength. Commonly used alloying elements are:

copper (Cu)
magnesium (Mg)
zinc (Zn)
silicon (Si)
manganese (Mn)

Other alloying elements like bismuth (Bi), boron (B), chromium (Cr), lithium (Li), iron (Fe), lead (Pb), nickel (Ni), titanium (Ti), zirconium (Zr), strontium (Sr) and sodium (Na) are added in small quantities to achieve special metallurgical effects or properties, e.g. grain refining, machinability etc.. Adding lithium (Li) in quantities of 3 to 5% improves the elastic modulus and decreases the density. Structural aluminium-lithium alloys are, however, restricted to aerospace applications, since special care and attention must be paid at the casting, fabrication, use and scrap recycling stages.

Figure 2202.01.01 shows the principal alloying elements and the families of alloys derived from them.

Principal Groups of Aluminium Alloys



TALAT	Principal Groups of Aluminium Alloys	2202.01.01

A further distinction is made between **wrought alloys** and **casting alloys**.

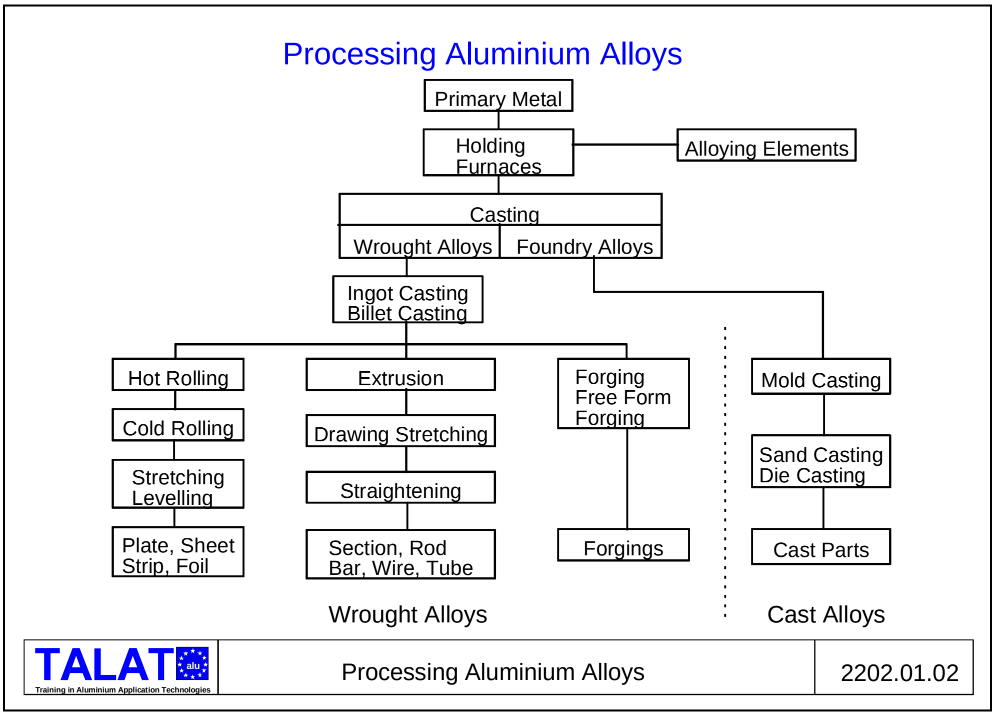
Wrought alloys

Wrought alloys are designed specifically for fabrication by hot and cold forming processes, such as rolling, forging and extrusion. Magnesium and manganese are the principal aloying elements for non-heat treatable, wrought alloys. Magnesium is a very effective solid solution strengthening element, which is added up to 5% by weight. Chemical resistance is improved by adding magnesium, manganese or a combination of magnesium and silicon. If zinc, copper and/or silicon are added in addition to magnesium, very high strength alloys are obtained, which must be subjected to special heat treatments. The machinability is increased by adding lead and bismuth. High temperature strength properties are improved by additions of copper and/or nickel, manganese or iron. It is important to realize that alloying elements added to achieve improvements of specific properties may well reduce other important properties, eg. ductility, stress corrosion resistance, etc. In order to choose the best alloy for the particular use or working conditions, it is therefore important to be aware of all potentially detrimental working conditions. The choice of an alloy will often be a compromise with respect to best possible over-all performance.

Casting alloys

Casting alloys (or foundry allys) are exclusively used for the fabrication of cast parts and have favourable characteristics for this process. They exhibit high fluidity in the liquid state and good resistance to hot cracking during solidification. Castability is improved by the addition of silicon (7 to 13% Si). Increasing the silicon content further up to 25% reduces the thermal expansion down to levels of iron and steel. Such high silicon contents assure the dimensional stability upon heating e.g. for pistons in engines.

The processing scheme in **Figure 2202.01.02** gives a brief overview of the operational steps in the production of semi-finished products of wrought and casting alloys.



For structural applications casting alloys play only a minor role when compared with wrought alloys. Because of the prevailance of wrought alloys in structural engineering applications they are described in some more detail below.

Refering again to **Figure 2202.01.01** the strengthening effect of alloying elements is caused by either solid solution strengthening or precipitation hardening or both. Depending on the prevailing type of strenghtening mechanism aluminium alloys are divided into two groups:

- Non heat treatable (Non-age hardening) alloys and
- Heat treatable (Age hardening) alloys

The non-heat treatable alloys

The **non-heat treatable alloys** (non age-hardening) are based on the following main element groups: see **Figure 2202.01.01**

AlMg
AlMn
AlMgMn
AlSiCu
AlSi

Strengthening is brought about by the combined effects of the alloying elements and work hardening (rolling, forging etc.). Depending on the degree of deformation work hardening reduces ductility, which can be improved again by subsequent annealing (recovery and recrystallisation annealing). However, the concomitant reduction of strength properties cannot be reverted by renewed heat treatment - hence the term “non-heat treatable alloys“.

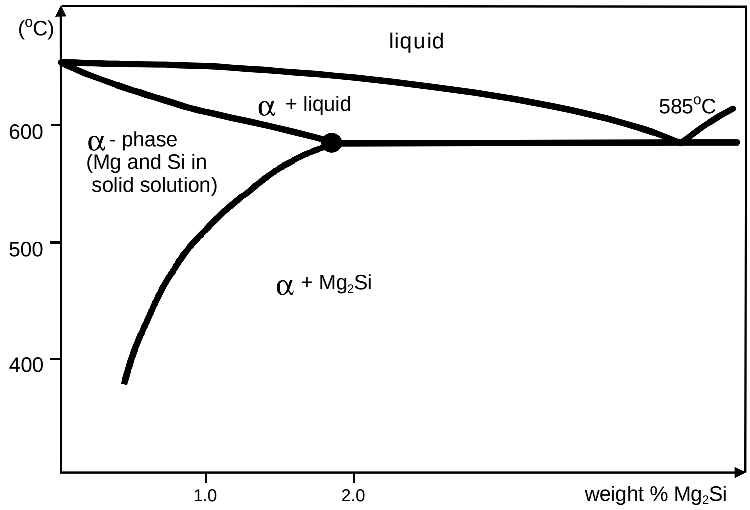
The heat treatable alloys

The **heat treatable alloys** (age-hardening alloys) constitute the following alloy groups:

AlMgSi	(6000 series)
AlZnMg(Cu)	(7000 series)
AlCuMg	(2000 series)
AlLi	(8000 series)

These alloys obtain their strength by **heat treatments**. The mechanism of strengthening depends on finely distributed small particles in the crystal lattice of the grains, which reduce the motion of dislocations, ie. plastic deformation. The strengthening particles are precipitated from a supersaturated solid solution of alloying elements in the aluminium matrix and are coherent or partly coherent with the aluminium lattice. The constitutional requirements for heat treatable alloys are a substantial range of solid solubility of alloying elements at high temperatures and a very low solubility at lower temperatures as is e.g. exhibited by the phase diagram for binary Al-Mg_2Si alloys in **Figure 2202.01.03**. To obtain a fine and even distribution of strengthening precipitates in the aluminium alloy matrix a heat treatment sequence has to be followed which consists of **solution annealing** at temperatures high enough to dissolve the alloying constituents (“α-phase“ region), of **rapid cooling** (“quenching“) to temperatures below 290 °C or lower (supersaturation) and of **ageing** (precipitation) at room temperature (“natural ageing“) or at elevated temperatures in the range of 120° to 200°C (“artificial ageing“). This heat treatment sequence can be repeated several times - hence the term “heat treatable alloys“. **See Appendix for further details on the subject of heat treatment**.

The Heat Treatable Alloys



TALAT	Example of Phase Diagram for Mg_2Si in Aluminium	2202.01.03

The Alloy Designation System

Worldwide, the national standards have been using different designation systems, and in addition many of the metal producers also use their own special alloy trade names.

This multitude of standards and designation systems have confused many aluminium specifiers and designers and have led to misunderstandings and even to occasional product failures.

However, the European countries and their respective aluminium manufacturers have now adopted the use of a common international designation and record system based on U.S. Aluminium Association (AA) standard.

Alloy compositions and their designation system are contained in **EN 573 Pt. 1-4 (1994)** for wrought aluminium and aluminium alloys. The following description is based on this system.

The Four Digit Alloy Designation System

A system of four-digit numerical designations is used to identify wrought aluminium and wrought aluminium alloys.

- The first digit indicates the alloy group as follows:

Al. 99,00 % purity and above	1xxx
Copper (Cu)	2xxx
Manganese (Mn)	3xxx
Silicon (Si)	4xxx
Magnesium (Mg)	5xxx
Magnesium and Silicon (MgSi)	6xxx
Zinc (Zn)	7xxx
Other element (eg. Li, Fe)	8xxx
Unused series	9xxx

- The second digit indicates modifications of the original alloy or impurity limits.
- The last two digits identify the aluminium alloy or indicate the aluminium purity.
- A letter used as a prefix indicates an experimental alloy.
- A letter used as a suffix indicates national variations.

Some classification examples of commonly used alloys:

Int. reg. record EN 573	**ISO**
1050A	Al 99,5
1070A	Al 99,7
2017A	AlCu4MgSi
3103	AlMn1
5052	AlMg2,5
5454	AlMg2,7Mn
5083	AlMg4,5Mn
6060	AlMgSi
6063	AlMg0,5Si
6082	AlSiMgMn
7020	AlZn4,5Mg1

Temper Designation

The temper designation system is based on a sequence of treatments used to produce the various tempers. Temper designations consist of letters followed by one or more digits. These digits designate specific treatments which influence the characteristics of the product. Basic temper designation:

F as-fabricated
Applies to as-fabricated products without special control over thermal conditions or strain hardening. For wrought products there are no guaranteed mechanical property limits.

O annealed
Applies to wrought products which are annealed to obtain the lowest strength temper, and to cast products which are annealed to improve ductility and dimensional stability.

H strain hardened
Applies to wrought products which have been cold worked with or without supplementary thermal treatments to produce some reduction in strength. The H is always followed by two or more digits.

W solution heat treated
An unstable temper applicable only to alloys which spontaneously age at room temperature after solution heat treatment.

T thermally treated to produce stable tempers other than F, O, and H
Applies to products which are thermally treated, with or without supplementary strain hardening, to produce stable tempers. The T is always followed by one or more digits.

<u>Subdivisions of basic tempers</u>:

The **H-temper -** strain hardened: The first digit indicates the specific combination of basic operations, as follows:

H1 strain hardened only
The number following this designation indicates the degree of strain hardening.

H2 strain hardened and partially annealed
Applies to products that are strain hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing.

H3 strain hardened and stabilized
Applies to products which are strain hardened and whose mechanical properties are stabilized by a low temperature thermal treatment which results in slightly lower tensile strength and improved ductility. This designation is applicable only to those alloys which, unless stabilized, gradually age-soften at room temperature.
<u>The three-digit temper:</u>

The following three-digit H temper designation have been assigned for wrought products in all alloys:

H111 Applies to products which are strain hardened less than the amount required for a controlled H11 temper.

H112 Applies to products which acquire some temper from shaping processes not having special control over the amount of strain hardening or thermal treatment, but for which there are mechanical property limits.

The following three-digit temper designations have been assigned for wrought products in alloys containing over a nominal 4% magnesium.

H311 Applies to products which are strain hardened less than the amount required for a controlled H31 temper.

H321 Applies to products which are strain-hardened less than the amount required fro a controlled H32 temper.

H323/H343 Apply to products which are specially fabricated to have acceptable resistance to stress corrosion cracking.

Subdivision of T temper - thermally treated

Numerals 1 through 10 following the T indicate specific sequences of basic treatments. Some of the commonly used designations are:

T4 **solution heat treated and naturally aged to a substantially table condition**. Applies to products which are not cold worked after solution heat treatment, or in which the effect of cold work in flattering or straightening may not be recognized as affecting mechanical property limits.

T 5 **cooled from an elevated temperature shaping process and then artificially aged.** Applies to products which are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattering or straightening may not be recognized in mechanical property limits.

T6 **solution heat treated and then artificially aged.** Applies to products which are not cold worked after solution heat treatment, or in which the effect of cold work in flattering or straightening may not be recognized in mechanical property limits.

The complete list of temper designations is given in the new European standards EN 515 (1993).

The Choice of Alloy and Temper

In addition to the general technological properties most suitable for the products' actual working conditions, some other factors must also be considered before making the final alloy choice, such as

- the available semi product range
- delivery time from stock or plant
- prices, etc.

On the technical side, the end user will often find himself in a "give and take" situation. As an example, a special alloy with very high mechanical properties might be very sensitive to certain forms of corrosion, or can be difficult to weld. The availability on the market, minimum order quantities as well as product dimensions may also vary from one alloy to another. This will also be reflected in price.

Tables of alloy properties can be found in applicable standards, handbooks and other publications, and they will give pointers to the most suitable alloys and tempers. The designer is well advised to consider the experience with alloys in similar or related applications. Reference is made to the alloy database ALUSELECT, which contains relevant alloy data and recommended uses.

However, some individual alloys might have very special performance under certain working or environmental conditions, and it will always be useful to check with the producer if anticipated conditions and requirements are critical or if there is any uncertainty about the performance of the alloy in use.

2202.02 Aluminium Product Forms

- Extrusions for structural applications
  - The extrusion process
  - Direct extrusion
  - Indirect and hydrostatic extrusion
  - Extrusions for structural applications

- Sheet and plate for structural applications
  - The cold rolling process
  - Hot rolling
  - Alloys for rolled products

- Casting alloys for structural applications

- Availability - possibilities and limitations
  - Extrusions
  - Rolled products

- Costs
  - Rolled products
  - Extruded profiles

Extrusions for Structural Applications

The Extrusion Process

In the extrusion process, a confined billet is forced by pressure to flow through an opening in a steel die forming the section shape of the extrusion. The shape may be of a simple or intricate form and the cross section may either be solid or hollow. With a suitable die design, aluminium extrusions can be produced in complicated shapes in a single step.

Most commercial extrusion processes are carried out at temperatures in the range of 400° - 500° C using a pre-heated billet. This most frequently used extrusion method is called ″Direct Extrusion″. Other methods in use are the ″Indirect and Hydrostatic Extrusions″. Round billets dominate in use, but sometimes rectangular billets are used to obtain extrusions with large widths.

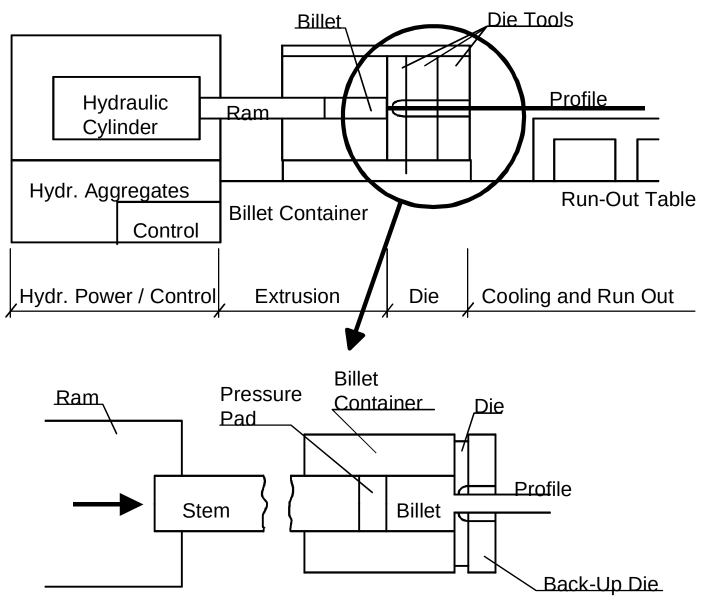
The most widely used extrusion alloys are the 6000-series (AlMgSi), and the extrusion speed for the 6063 alloy is between 20 and 70 m/min. Material with higher alloy content and/or complicated shape is extruded at a slower speed.

Direct Extrusion

In direct extrusion the billet is pre-heated and charged into the press container, and then the aluminium is pushed at a high pressure through a die to form either rod, bar, tube or other special shapes (**Figure 2202.02.01**).

Indirect and Hydrostatic Extrusions

These methods are based on the same principle as the direct extrusion method, and are normally used either for larger tonnages of special products (tube), or for the extrusion of special alloys etc.



TALAT Training in Aluminium Application Technologies | The Direct Extrusion Press Arrangement | 2202.02.01

Extrusions for Various Applications

Most aluminium alloys can be extruded, and the choice of the alloy is often based on special functional, metallurgical or fabricational factors.

<u>A few examples</u>**:**
High purity aluminium (the 1000-series) with very high electrical conductivity is used in extruded bus bars, cables or in other electrical equipment.

AlMn (3000-series) alloys are used for drawn tubes due to very high formability and thereby also excellent dimensional tolerance abilities.

High strength performance can be the reason why the 2000-series or the 7000 series alloys are chosen, although these alloys might have drawbacks such as poor or no weldability (Cu alloys) or potential danger of stress corrosion (Zn alloys).

However, the majority of extrusions are made from the 6000-series alloys (AlMgSi) because of their good overall performance i.e.

- relatively easy to extrude
- medium to high strength in the T6 condition
- good corrosion resistance in marine and industrial environments
- good weldability by all welding methods
- good availability on the market, both as standard and special sections

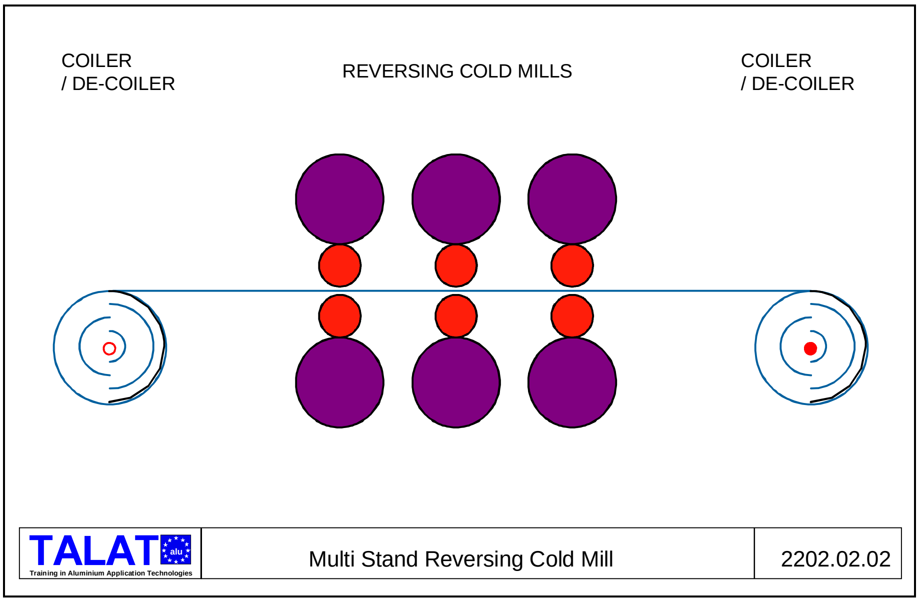
In Europe, the main alloy used in extrusions for structural applications, is the 6082 (AlMgSi1Mn), and the T6 is the normal used temper.

Sheet and Plate for Structural Applications

The Cold Rolling Process

Sheet can be cold rolled directly from continuously cast and coiled re-roll stock, but the majority of sheet is produced by hot rolling of ingots followed by cold rolling. This process is often necessary in order to impart particular properties to the material.

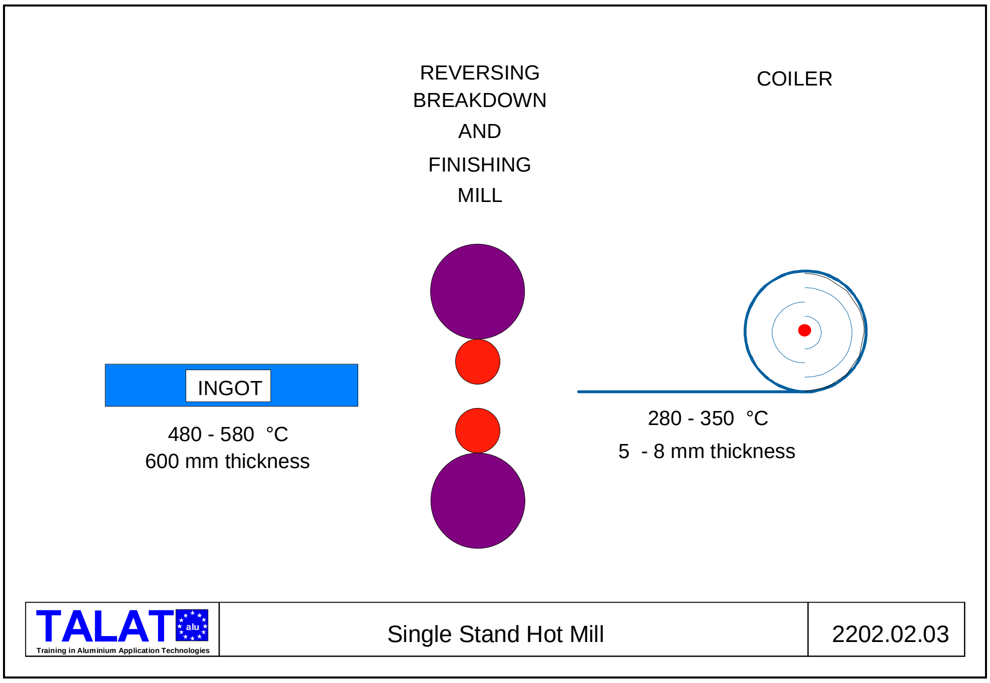
In some cases, cold rolling is carried out continuously on multiple stand mills (tandem rolling mill) (**Figure 2202.02.02**).



Alloys may be cold rolled to thicknesses of around 0,05 mm, and pure aluminium can be cold rolled to foil down to 0,006 mm. As the degree of cold working increases, the amount of power required for further deformation increases. Intermediate thermal treatments can then be necessary to soften the material for further cold rolling.

Hot Rolling

The starting material is normally a rectangular rolling ingot approximately 200 to 600 mm thick, with a weight from 500 to 30 000 kg. Depending on the dimensions and alloy composition, the ingot is rolled to the final thickness in 10 to 25 passes (**Figure 2202.02.03**).



Alloys for Rolled Products

Although almost all wrought aluminium alloys can be fabricated into rolled semi products, the most frequently used rolled alloys for structural applications are:

Non heat treatable alloys**:**	5052 (AlMg2.5)
	5083 (AlMg4.5Mn)
	5054 (AlMg2.7Mn)
Heat treatable alloys**:**	6082 (AlMgSi1)
	7020 (AlZn4.5Mg1)

Casting Alloys for Structural Applications

The use of cast products for structural applications is mostly concentrated on engine and motor parts, automotive space frame nodes and bumper parts, aircraft components and components used in railway transport vehicles.

The typical alloys for such products are AlSiMg, AlSiCu, AlMg, AlCuTi and AlZnMg, among which the AlSi-alloys are preferred with respect to castability.

The main cast methods are:	Sand casting
	Permanent mold (gravity) casting
	High-pressure die casting

These methods usually require special variations of the different casting alloys for optimum casting performance.

The definitions of products made by these methods are:

Sand casting: produced by pouring molten metal into a sand mold and allowing it to solidify.
Permanent mold casting: produced by feeding molten metal by force of gravity or low pressure into a mold constructed of durable material (iron or steel), and allowing it to solidify.
Die casting: produced by injecting molten metal under high pressure into a metal mold or die and allowing it to solidify.

The choice of method and alloy is very much dependent on the number of cast parts, the complexity of geometry and wall thicknesses, the material structure and strength and the product working conditions.

Availability - Possibilities and Limitations

Extrusions

Although the extrusion process gives the designer a very wide range of profile shaping possibilities, it is also important to note that it does have limitations as far as shape, dimensions, maximum profile length etc.are concerned.

Each extrusion press has its upper and lower limits on profile wall thicknesses, specific weight and outer circumscribing profile circle diameter (OD), and the tooling sizes and costs are usually also increasing with the increasing profile size amd complexity.

It can sometimes seem advantageous to use the largest possible profiles in heavy constructions to save fabrication costs, but before any such decision is taken, it should always be a good rule to evaluate the alternative possibility of using profiles with smaller dimensions which are then joined together to form a larger section.

The main cost parameters to be checked for both alternatives are:

Fabrication costs (welding, handling, etc.)
Die tooling costs
Transport costs

There are relatively few big extrusion presses available to produce profiles of the largest sizes, and delivery time from these plants should also be part of the calculation as should potential extra costs, such as keeping stocks of profiles for the case of unforeseen extra needs during the fabrication phase, and also for any need of spare parts.

The designer should also be aware that while standard and special shape profiles might be available from the stockist, in general, the choice from stock is less extensive than that for standard steel products. However, to buy relatively small quantities of one type of profile directly from the extrusion plant can occasionally be expensive, due to the total overhead costs, and it can often be less costly to use the same profile dimensions to the largest possible extension in the construction, even if some of the structural members should be somewhat overdimensioned.

When compared with a similar construction, in which minimum dimensional shapes are used, the weight saving might be reduced but the overall experience shows that there should be still a weight saving potential of 40 - 50 % and that the last and often marginal weight saving, might be very expensive.

Figure 2202.02.04 describes the relationship between the size of the press, profile circumscribing circle, type of alloy and minimum wall thickness. It should be noted that each extrusion plant will have variations on these figures, and the table should only be used as a guideline.

Lowest Wall Thickness Related to Press Capacity

Min. possible wall thickness for extrusion presses 10 - 80 MN.

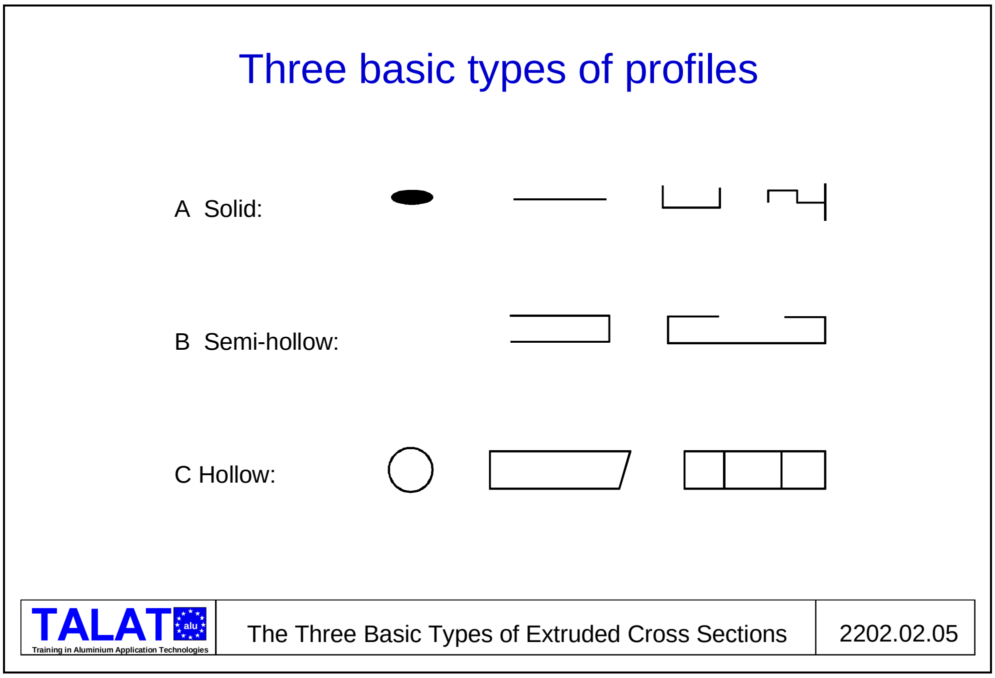
Alloy	Profile type	25	50	75	100	150	200	250	300	350	400	450
Al 99-99,9	a	0,8	1	1,2	1,5	2	2,5	2,5	3	4	4	5
AlMgSi 0,5	b	0,8	1	1,2	1,5	2	2,5	2,5	3	4	4	5
AlMn 1	c	1	1	1,5	2	2,5	2,5	2,5	4	5	5	6
AlMg 1												
AlMgSi 1	a	1	1,2	1,2	1,5	2	2,5	3	4	4	5	6
	b	1	1,2	1,5	2	2	2,5	3	4	4	5	6
	c	2	1,5	2	2	3	4	4	5	5	6	6
AlMg 3	a	1	1	1,2	1,5	2	2,5	3	4	4	5	6
AlMg 5	b	1	1	1,2	1,5	2	2,5	3	4	4	5	6
AlCuMg 1	a	1,2	1,2	1,2	1,5	2	3	5	5	6	7	8
AlCuMg 2												
ALZnMgCu	a	2	2	2,5	3	3	5	6	8	12	12	14
Press capacity (MN)				10 →		25 →	35 →		50 →		80 →	

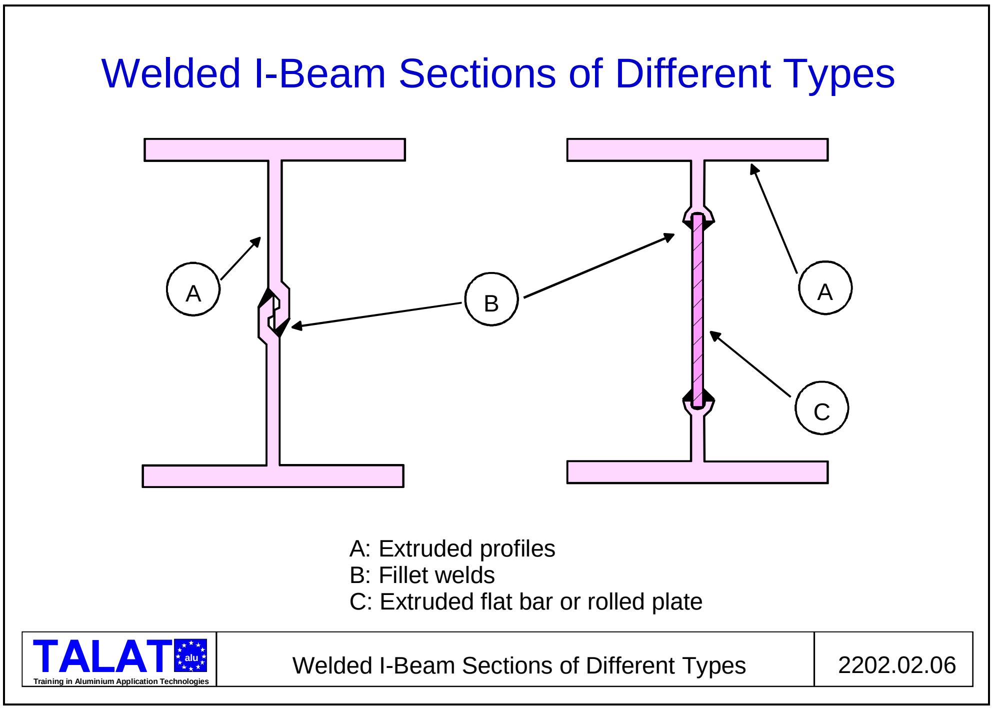
a: Solid / semi-hollow sections
b: Hollow sections with equal wall thicknesses
c: Hollow sections with unequal wall thicknesses

TALAT Training in Aluminium Application Technologies | Minimum Wall Thickness for Extrusion Presses 10-80 MN | 2202.02.04

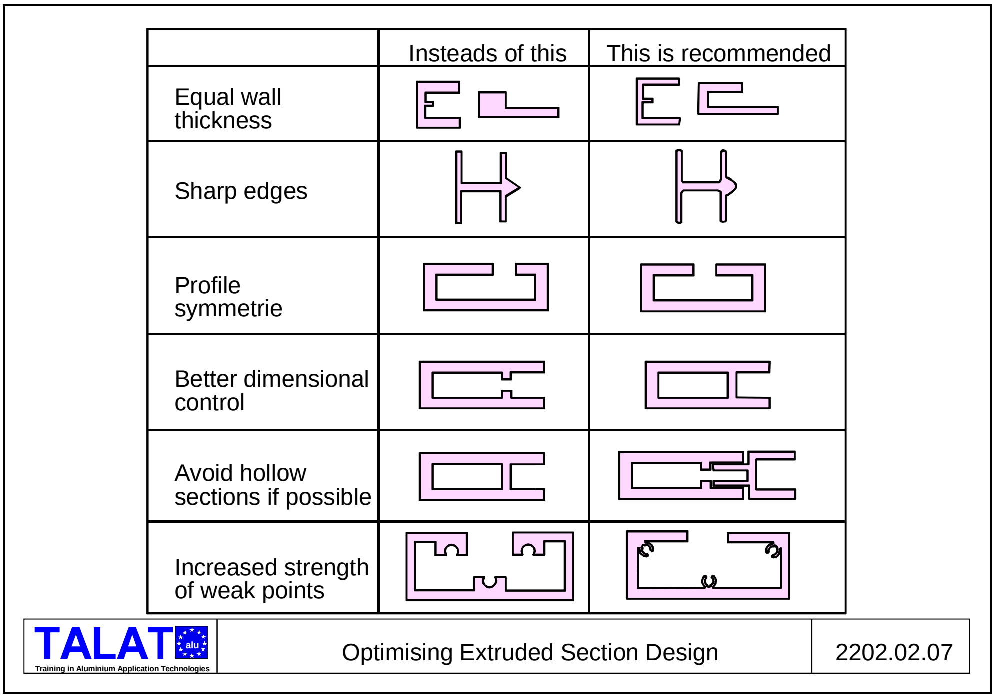
Three basic profile types (**Figure 2202.02.05**) are defined which require different tool design: **solid**, **semi-hollow** and **hollow profiles**.

If for any reason the fabricator finds it appropriate to build together two or more profiles to form a larger section, there are many possibilities for doing this. For structural members (**Figure 2202.02.06**), the normal joining method in such cases will be welding, but other methods or combinations of methods might also be appropriate, e.g. adhesive bonding.





General profile design principles: although almost any kind of profile geometry is possible, there are some basic issues that should be considered in order to reduce the chances of production problems, such as die tool breakages and dimension as well as tolerance problems. **Figure 2202.02.07** gives some basic recommendations that always will lead to better production results.



Rolled Products

There are some variations concerning the definitions of sheet and plate which are caused by traditions of the metric and other system. In most European countries it is common to call ″sheet″ flat-rolled products with thicknesses of less than 6 mm. Thicker flat-rolled material is called ″plate″.

As mentioned above pure aluminium can be cold rolled down to foil of 0,005 mm thickness. Minimum rolled thickness of alloyed material is 0,05 mm. Most of the sheet and plate dimensions used in structural engineering lie in the thickness range of 1 to 150 mm, with a majority in the range of 3 - 25 mm. The standard width and length dimensions of sheet and plate are 1000 x 2000 mm or 1250 x 2500 mm but both coldrolled and hot rolled materials can be produced as coil in different widths or plate with dimensions of 1500 x 3000 mm or even more. Available dimensions for sheet and plate vary from country to country. Manufacturers and stockists will supply relevant details.

Sheet and Plate for Structural Applications:

It is normal to look to the highest tensile properties, but additional factors must be considered when choosing the optimal alloy and temper. The desired tensile strength should always be matched with requirements for

Ductility
Corrosion behaviour under the actual working conditions
Weldability
Fabrication requirements, such as cold forming (bending) etc.
Thermal working conditions

Some of the high-strength alloys might be sensitive to stress corrosion or intergranular corrosion under certain conditions, others can be difficult to weld. The general corrosion resistance in marine atmospheres may also be different from one alloy to another.

Some alloys and tempers are also more available from market stock than others; depending on type and size of the construction, or quantity needed, this factor should also be considered together with price and delivery time.

As a result of all this, a widely used alloy for structural applications is alloy 5052 (AlMg2,5) in tempers from soft (H111) to medium hard as well as in stabilized condition (H32/H34).

The tensile properties for this alloy are not the highest possible, but the corrosion resistance in most environments is very good and so is its weldability. There are no special restrictions with respect to bending or thermal working conditions. The availability on the market is very good.

Another alloy increasingly used for structural applications is alloy 5083 (AlMg4,5Mn). This alloy has higher tensile properties than alloy 5052, but there are restrictions concerning the limits of continuous exposure temperatures (< 65 °C) and also with respect to cold forming requirements in fabrication (e.g. bending). The ready availability is generally somewhat less than for alloy 5052. Alloy 5083 has an excellent, high general corrosion resistance and very good weldability.

Another important factor to be considered is the dependence of tensile properties on plate thickness for the 5000-series alloys. Alloys 5052 or 5083 are not available in work-hardened tempers beyond thicknesses of 100 mm. If higher strength is needed at larger thicknesses, it is necessary to change to heat treatable alloys such as 6082-T6. It has similar good general corrosion resistance and very good weldability.

Some other alloys used as rolled products for structural applications are:

2014	(AlCuSiMn)
2017A	(AlCuMg1)
2024	(AlCuMg2)
7020	(AlZn4,5Mg1)
7075	(AlZnMgCu1,5)

These are high strength alloys with either reduced or poor weldability and corrosion resistance and they are mostly used in special products or constructions, e.g. aircraft and military industries. Alloy 7020 is also used for general structural applications with requirements of high strength and good weldability, although its sensitivity to stress corrosion (in the short transverse direction) and to exfoliation corrosion in the heat affected zone of welds must be taken into account. Its particular advantage is the high strength of welded joints compared to all other weldable aluminium alloys.

Costs

Rolled Products

Considering costs, it is necessary to evaluate the main relevant factors, such as

- type of alloy
- quantity and price
- material dimensions
- delivery time/eventual need for own internal stock
- demands for special material control/certificates and traceability

Type of Alloy

Prices generally increase with the choice of alloy as follows:

AlMn1 < AlMg2,5 < AlMg4,5Mn < AlMgSi1

Quantity and Price

Prices will naturally vary with ordered quantity both from stockists and from the rolling mill if delivered directly. The prices from the rolling mill will normally be somewhat lower, but it is usual to set a minimum production quantity, and the customer must accept eventual overdelivery up to a limit.

Material Dimensions

There will also be a variation in price related to the product dimensions. From stockist, standard products will always be both easier to find and also cheaper than products with special thicknesses, lengths and widths. The prices from the rolling mill will usually not be influenced by dimensions in the same degree. On the other hand, the product spectrum from stock might be limited depending on the geographic location in Europe.

Delivery Time

The delivery time from most stockists is short. It can, however, be influenced by transportation, handling time of customs paper work, etc. The delivery time from the rolling mill will naturally be longer, 10 to16 weeks being normal. In a situation like this, the end user might be in the situation where internal stock-keeping is necessary to secure his own production continuity. Such additional costs should also be considered.

Demands for Special Material Control, Certificates and Traceability.
These factors will normally mean additional costs and - except for standard material certificates - it is often difficult to get extra material control services when buying direct from stock. From some parts of Europe and the Far East it can even be difficult to get a standard certificate for the material. These issues are easier to handle when buying directly from the rolling mill, but the general understanding and requirements of modern industrial demands for quality assurance vary strongly from plant to plant.

Extruded profiles

There are numerous extrusion plants in Europe and each plant has its own limited product range, depending on sizes and number of the extrusion presses. Some plants have specialized on specific types of products such as drawn tubes, automotive parts etc., but most plants have a general market related production.

The cost influencing factors are much the same as for rolled products, but some particular factors have to be considered when buying extrusions:

Choice of alloy
Die cost
Profile size
Delivery time

The production plants' quotes for supplying minimum delivery tonnage of each profile is normally considerably smaller than that from the rolling mills. This means that it is much easier to buy both standard and special profiles directly from a plant. For this reason, the stockist keeps mostly standard sections on stock and even then only in a limited range of sizes and alloys.

Choice of Alloy
If the selected alloy is a typical extrusion alloy, such as 6060 (AlMgSi0,5) or 6082 (AlMgSi1), the basic material prices will have only small variations - if any at all.

Die Costs
The extrusion die costs are generally very low compared with die costs for casting moulds or for special punching or bending tools used in sheet forming. However, if a special extrusion die has to be made, costs will vary considerably with the profile size, type and complexity. The die costs for a hollow or semi-hollow section might be up to 5 times more expensive than those for an open section, and the die costs for the largest profiles (350 - 600 mm OD[*)]) can easily be twice or three times those for smaller profiles.

Profile Size
Not only the die costs are related to the profile size. Production factors also contribute to increase the price by 30 - 50 % for the largest profiles compared with profiles with OD less than 300 - 350 mm. Additionally, the minimum wall thickness for a large profile

[*)] OD: Outer circumscribing circle diameter will normally be higher than for smaller profiles. Those factors taken together indicate that it is sometimes necessary to compare the cost of a large profile made from a single, relatively expensive die with that of say two smaller sections made from cheaper dies and joined together - taking into account of course the additional fabrication costs.

<u>Delivery Time</u>
The delivery time for small or medium size profiles directly from the mill is relatively short (2 - 6 weeks), but for large profiles it might be considerably longer, 30 - 75 weeks are not uncommon. This time includes the extrusion die production.

Appendix: The nature of heat treatment

(Extraction from “Properties of Aluminium“ by Aluminium Federation, Birmingham, UK)

An aluminium alloy is said to be in a heat-treated condition when it has been subjected to one or both of the following processes:

a) Heating for a prescribed period at a prescribed temperature, then cooling rapidly from this temperature, usually by quenching (solution heat-treatment).
b) Ageing, either spontaneously at ordinary temperatures (natural ageing) or by heating for a prescribed period at a prescribed low temperature (artificial ageing). The application of both solution heat-treatment and artificial ageing is often termed “full heat treatment“.

The purpose of heat treatment is to increase the strength and hardness of an alloy. Solution heat treatment is an essential preliminary to artificial ageing, although an elevated temperature shaping process, such as casting or extrusion, can to some extent be used instead of normal solution treatment.

Solution heat-treatment on its own initially increases the ductility of alloys and enables a certain amount of cold work to be applied before natural ageing starts to harden the metal. In its own right it increases strength but not to the level achieved by subsequent artificial ageing.

While a metallurgical evaluation of the structural changes that take place in aluminium alloys during heat-treatment is beyond the scope of these notes, a simplified explanation might be useful.

Effectively, heat-treatment is designed to alter the mode of occurence of the soluble alloying elements, particularly copper, magnesium, silicon and zinc, which can combine with one another to form intermetallic compounds. Solution heat-treatment takes these relatively hard constituents into solid solution, thereby softening the alloy: quenching retains the constituents in solid solution at room temperature, so that the alloy is still soft but unstable. The hard constituents gradually precipitate out in a more uniform pattern than they formed in the original un-heat-treated alloy, thereby improving the alloy's mechanical properties. Rates of precipitation vary from alloy to alloy so that the stable condition represented by complete precipitation may take anything from a few days to several years to achieve unless artificial ageing is used. Even with alloys which achieve relatively stable properties by natural ageing it is possible to obtain higher strengths by artificial ageing following solution treatment. In some alloys an additional increase in strength is possible by controlled cold-working of the alloy immediately after quenching from the solution heat-treatment temperature. Because of the complex interactions that take place during the processes of heat-treatment, different alloys have different characteristics that require careful selection and control of the heating operations and specific combinations of temperature and time-at-temperature if the required properties are to be achieved in the heat-treated product.

Solution Treatment

Heating

Maximum improvement in mechanical properties is attained when the solution heat-treatment temperature is within the specified temperature range. If the temperature is too low, mechanical properties will be below requirements. If the temperature is too high there is a risk of cracking due to overheating. Heating periods cannot be given with the same accuracy as temperatures because of variations in the loading and spacing of the workload. The times should be determined by test and, when established, kept to. It is undesirable to solution heat-treat aluminium-clad alloy sheet for prolonged periods, or to re-solution treat clad material which has failed to achieve specification minimum requirements in terms of mechanical properties. This is because the alloying constituents tend to diffuse from the core into the aluminium cladding, thereby reducing resistance to corrosion. In general, cast aluminium alloys need to be solution heat-treated for longer periods than wrought aluminium alloys.

Quenching

Wrought aluminium is quenched by plunging the hot metal into water, but often such rapid cooling may distort the metal. With sheet, distortion can be minimised by vertical immersion and long sections or tubes should be quenched in the same way wherever possible. Plate, extrusions and strip may be discharged from a furnace horizontally and quenched by water sprays which are balanced to minimise distortion. Distortion can also be reduced by decreasing the cooling rate using hot water or oil as a quenching medium and this is often helpful with castings and forgings.

Artificial Ageing

Heat-treatable alloys such as 6082 harden very slowly at normal temperatures; hardening can, however, be accelerated by heating the solution heat-treated alloy in the range 100 - 200 °C for a suitable period. The length of time at the specified temperature, depending on the alloy, can be as short as two hours or as long as thirty hours. Maximum strength is generally achieved by prolonged ageing at low temperature rather than by rapid ageing at high temperature.

Re-heat Treatment

Alloys which have been incorrectly heat-treated, for example by solution treating at a lower temperature than that recommended or by precipitation at too high a temperature for too long a period of time, can be re-solution treated and then precipitation treated again to enable optimum properties to be achieved. If, however, solution-treatment has been carried out at too high a temperature, the condition cannot be remedied by re-heat treatment. Clad material should not be re-heat treated.

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