BASIC METALLURGY :

6000 SERIES EXTRUSION ALLOYS

CONTENTS

INTRODUCTION

The extrusion of 6000 series alloys is a complex combination of thermal processes that requires a basic understanding of the process metallurgy in order to produce a high quality product efficiently. This document is designed to provide the reader with some background information on the metallurgy of 6000 series extrusion alloys. To assist comprehension, a section defining terms used in the in the extrusion industry is provided at the rear of this document.

THE 6000 SERIES EXTRUSION ALLOYS

Role of Magnesium and Silicon

The 6000 series alloys are typical heat-treatable aluminium (Al) alloys which gain their strength from thermal processing rather than mechanical deformation. The key elements of these alloys are magnesium (Mg) and silicon (Si) which combine to form the Mg_2Si precipitates. These precipitates occur in several forms which may be divided into the following three categories;

- β” (beta double prime) Mg_2Si, the smallest type of Mg_2Si precipitate that is rod-shaped and contributes most to mechanical properties when densely dispersed.
- β’ (beta prime) Mg_2Si, a larger version of rod-shaped precipitate that grows from the β” category. The β’ precipitates have a negligible contribution to mechanical properties.
- β (beta) Mg_2Si, the largest Mg_2Si precipitate that is cube-like in shape and due to its size contributes nothing to mechanical properties.

The role of these precipitates will be explained further in a following subsection ‘Thermal Cycle of 6000 Series Alloys'. Some 6000 series alloys and the corresponding Mg and Si contents can be seen in Figure 1.

Most alloys are designed to have either balanced Mg and Si levels or an excess of Si. Figure 1 shows a dividing line for a balanced composition, assuming that the iron content in these alloys is 0.16%. (Variation in iron content would vary the gradient of this line). Excess Si alloys are preferred over excess Mg alloys because:

- Excess Mg does not add to the final mechanical properties of the product.
- Excess Mg increases the flow stress of the alloy and makes it difficult to extrude.
- Excess Si aids the artificial ageing response and so increases the strength of the final product.

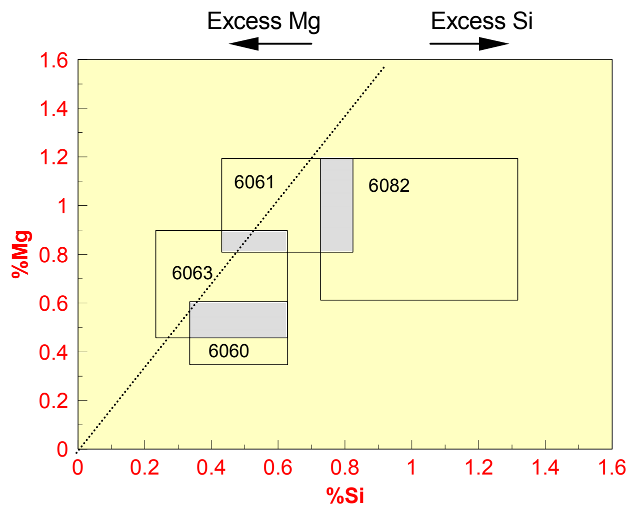


Figure 1: Graph of %Mg and %Si contents for various 6000 series extrusion alloys.

Role of Other Elements

Iron

Iron (Fe) is also present in the alloys and combines with silicon (Si) and aluminium (Al) to form AlFeSi intermetallics. These intermetallics do not contribute to the strength of the alloy but, if they are not correctly processed, they will have a detrimental effect on the extrudability of the alloy. Accurate control of Fe contents in 6000 series alloys is important for surface finishing applications. Different levels of Fe will cause variations in colour response during anodising. Fe is also known to reduce conductivity.

Manganese

Manganese (Mn) is used in a number of ways in 6000 series alloys. This includes reducing homogenisation times by promoting the transformation of β AlFeSi to α AlFeSi and preventing coarse grain growth during post extrusion heat treatments of high strength alloys such as 6061 and 6082. Another benefit is that the fracture toughness can be improved by additions of Mn as it helps to prevent the nucleation of Si at the grain boundaries which embrittles the material. In higher strength 6000 series alloys with significant Mn additions (e.g. >0.10%), the detrimental effects of Mn are an increase in flow stress of the billet which decreases extrudability, as well as increasing quench sensitivity.

Chromium

Chromium (Cr) acts in much the same way as Mn but its effect on quench sensitivity is more pronounced than Mn.

Copper

Copper (Cu) additions may improve conductivity and machinability of the extruded alloy and counteracts the detrimental effect of room temperature storage on the mechanical properties of artificially aged high strength alloys, particularly 6061. The corrosion resistance of 6000 series extrusion is lowered by the presence of Cu once the level exceeds 0.2%

Zinc

Zinc (Zn) is not known to have any detrimental effect on the mechanical properties of the 6000 series alloys. However, in amounts greater than 0.03% Zn may cause a differential etching effect known as 'spangle' during the anodising process.

A summary of the effects of the major and some minor elements is given in Table 1.

Table 1. Effect of alloying elements on properties of 6000 series alloys

ALLOYING ELEMENTS	EXTRUDABILITY	QUENCH SENSITIVITY	STRENGTH / HARDNESS	DUCTILITY AND TOUGHNESS
Mg (Mg_2Si)	↓↓	↑↑	↑↑	↓↓
EXCESS Si	↓ (1)	↑	↑↑	↓↓ (4)
Mn	↓	↑ (5)	(2)	↑↑
Cr	↓↓	↑ (5)	(2)	↑↑
Fe	↓	(3)	(3)	↑
Cu	(3)	↑	↑↑	(3)

↑↑ Major Increase ↑ Minor Increase

↓↓ Major Decrease ↓ Minor Decrease

(1) For constant Mg_2Si contents
(2) No adverse effects or little change providing quench rate is high
(3) Negligible or no adverse effects
(4) In the absence of Mn, Cr and Zr additions
(5) Dependent on addition level and homogenisation practices

THERMAL CYCLE OF 6000 SERIES ALLOYS

The 6000 series extrusion alloys obtain maximum strength from the following heat treatment cycle:

- solutionizing during extrusion or solution heat-treatment,
- followed by quenching at a rate that is alloy dependent and
- then precipitation age hardening.

Maximum mechanical properties cannot be obtained without accurate temperature control which regulates the Mg_2SI characteristics throughout the process. The following temperature/time history is a practical way of identifying the steps in the extrusion process and the roles of Mg and Si in the steps, Figure 2.

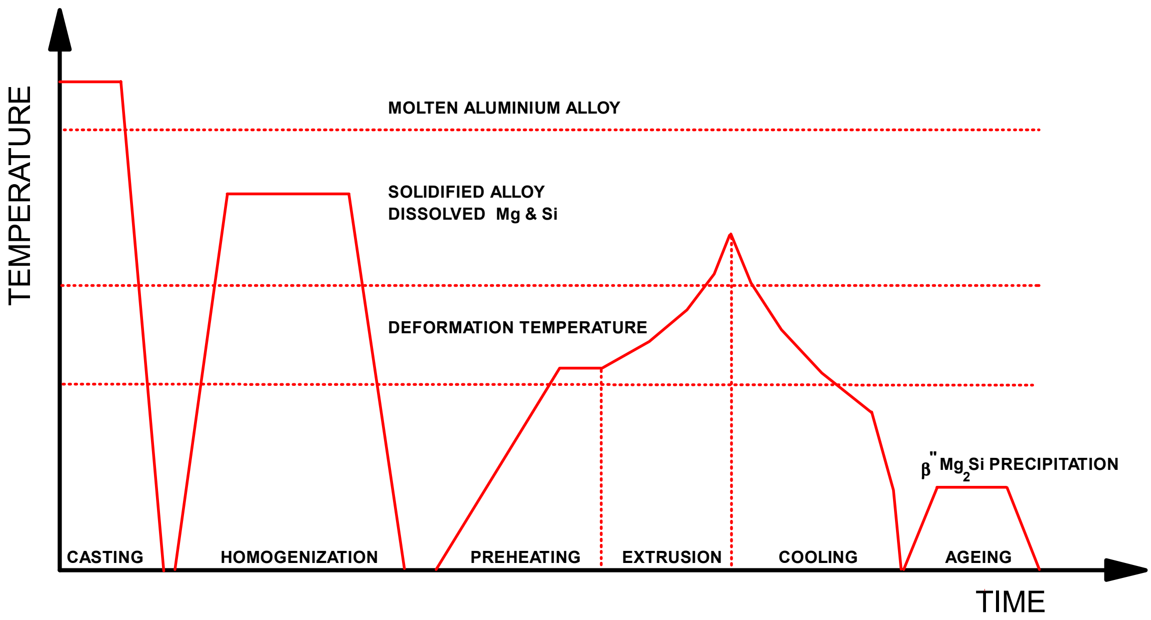


Figure 2: Temperature vs time history.

CASTING

Two types of direct chill (DC) casting are used to produce extrusion billets, vertical and horizontal. The most common method of producing extrusion billet is vertical direct chill (VDC) casting. VDC casting can produce larger quantities of large diameter extrusion billet with a more uniform microstructure than horizontal direct chill casting (HDC). HDC casters are more typically used in smaller scale operations to produce small diameter material (e.g. forging stock or small diameter extrusion billet, 75-200mm). Schematics of the processes are shown in Figure 3.

During VDC casting the molten aluminium is poured into one or more moulds which are mounted on a table fitted to a hydraulically operated ram. As the metal passes into these moulds it is solidified in two stages. The first stage, known as primary cooling, involves the solidification of the aluminium at the cooled mould wall. This forms a solid shell of aluminium around a semi-molten core. As the solid shell is formed the ram lowers the base of the mould and the shell comes into contact with a curtain of water which initiates the secondary stage of solidification. During secondary cooling, the metal is completely solidified throughout the billet cross-section. This process can produce multiple billets in continuous lengths (for example 7m) depending on specifications and melt capacity.

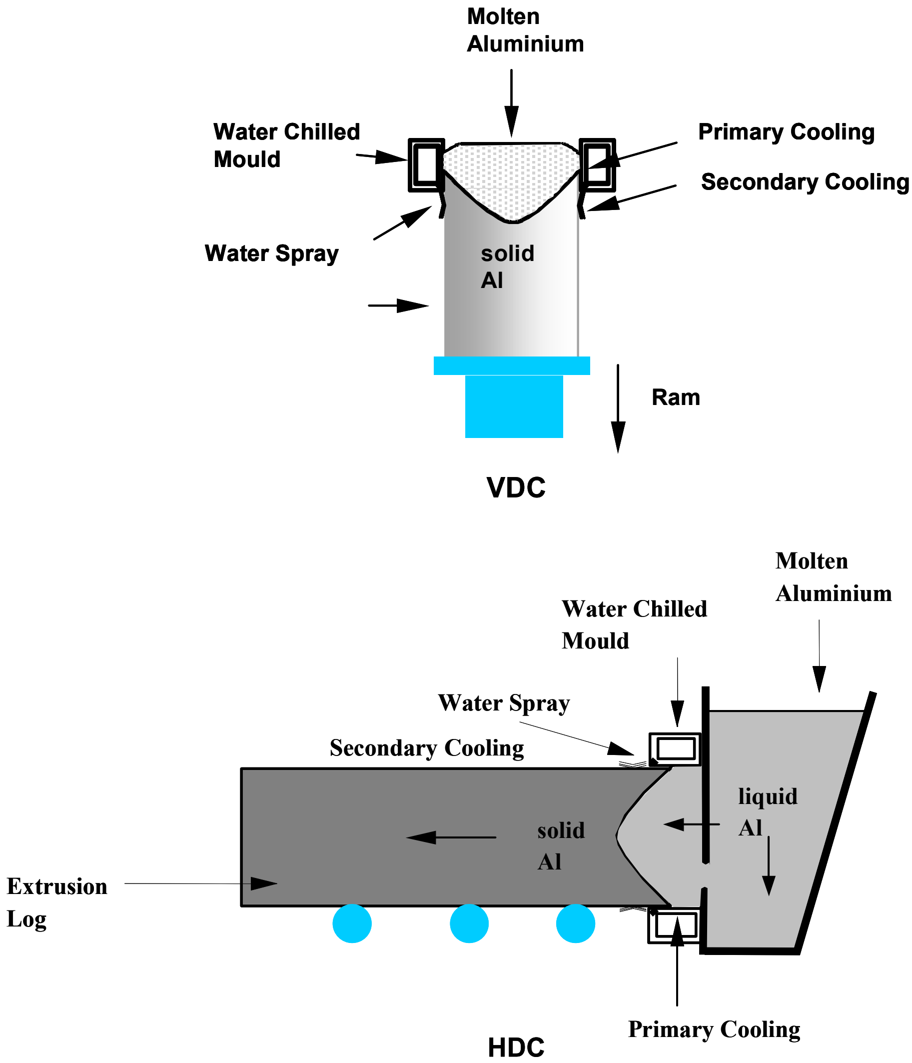


Figure 3: Schematics of VDC and HDC casting.

Several types of VDC moulds are commonly used: the conventional float cast, air pressurised and, in between, there are moulds that use neither floats nor air. The float cast technique uses a ceramic float to control the metal level in the mould and the metal comes into direct contact with the mould wall. Mould wall contact also occurs in hot top operations that do not use floats. Air pressurised methods do not use a float and have an air cushion that restricts metal contact with the mould wall.

This method has several advantages. Surface finish of the casting is smoother, primary cooling is more tightly controlled to give narrower segregation zones that are beneficial to extrusion operations, and the second cooling results in a finer, more uniform grain structure and distribution of intermetallics phases, Figure 4.

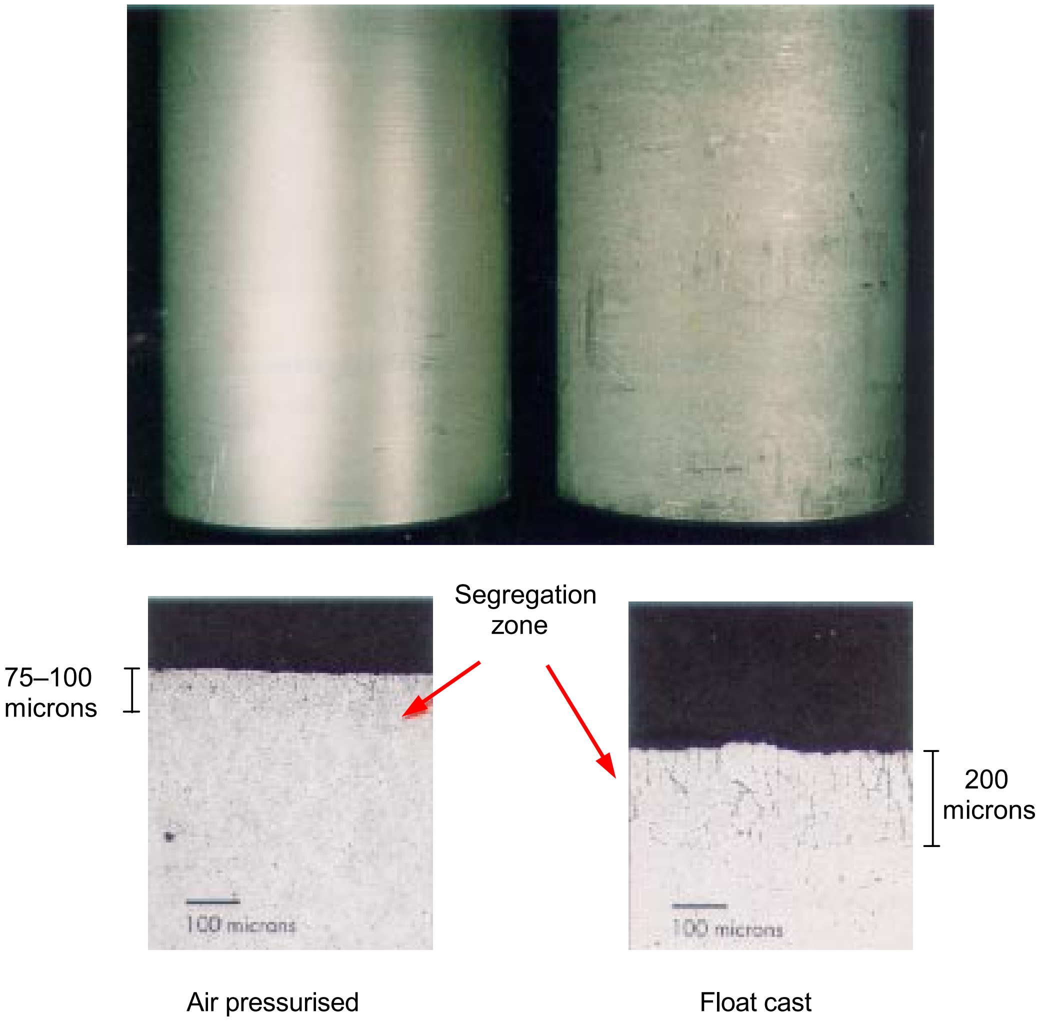


Figure 4: Air pressurised and float cast surface finishes and microstructures.

HOMOGENISATION

The as-cast billet consists of a solid Al matrix containing dissolved Mg and Si as well as a network of β AlFeSi located at the grain boundaries, Figure 5.

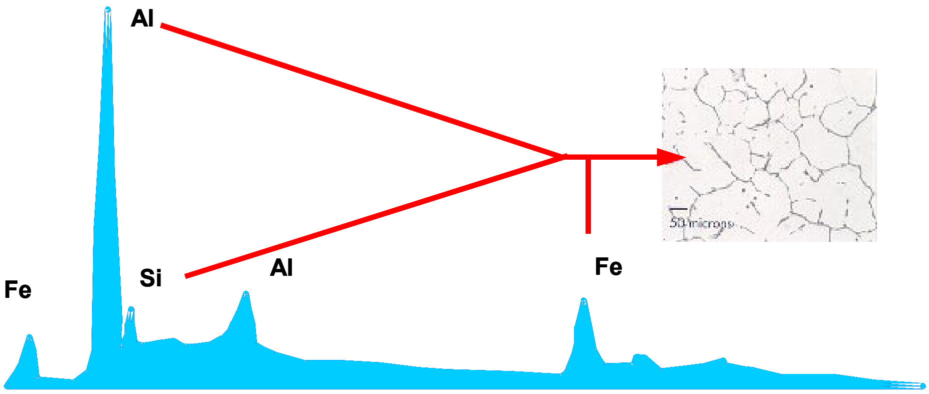


Figure 5: Micrograph of as-cast structure with energy dispersive spectrograph identifying the elements in the intermetallics, (200 mag).

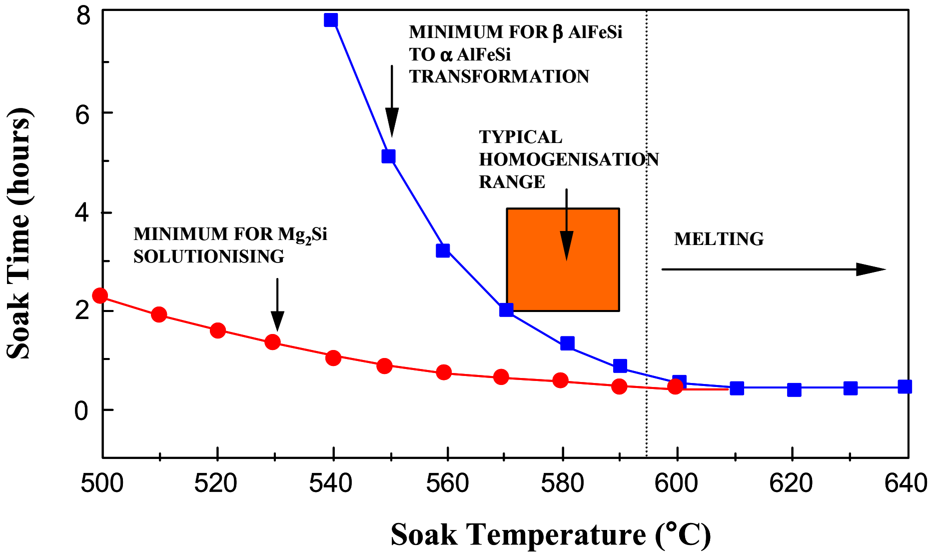


Figure 6: Homogenisation soak temperature versus time.

The homogenisation cycle is specifically designed to modify the as-cast structure to one which can be extruded at high speed while achieving excellent surface finish and optimum mechanical properties.

For low strength 6000 series alloys containing Mn, a typical homogenisation cycle consists of heating the billet to 575°C, holding for 2 to 4 hours and then cooling the billet at a controlled rate through the critical range of 450^{0}C to 200^{0}C, Figure 6. This cooling practice avoids the formation of β Mg_2Si and β' Mg_2Si precipitates in the microstructure which are detrimental to the final mechanical properties of the extrusion. The actual cooling rate used is dependent on type of alloy and billet diameter cast, Figure 7.

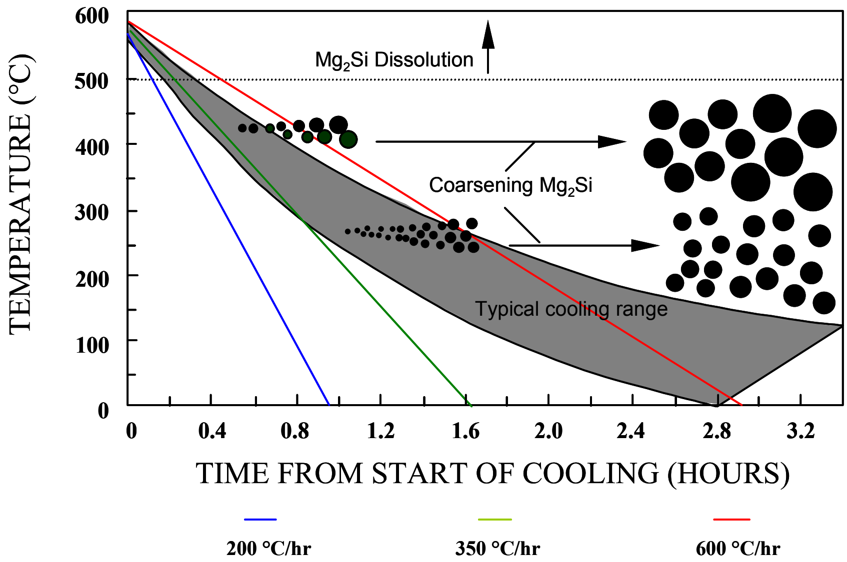


Figure 7: Effect of homogenising cooling rate.

The homogenisation cycle:

- transforms hard, needle-like ß AlFeSi intermetallics (detrimental to extruded surface finish) to more spheroidised α AlFeSi intermetallics,
- ensures an even distribution of chemical elements in the alloy,
- nucleates a large number of fine, evenly dispersed β' and β" Mg_2Si precipitates that are readily dissolved during extrusion, Figure 8.

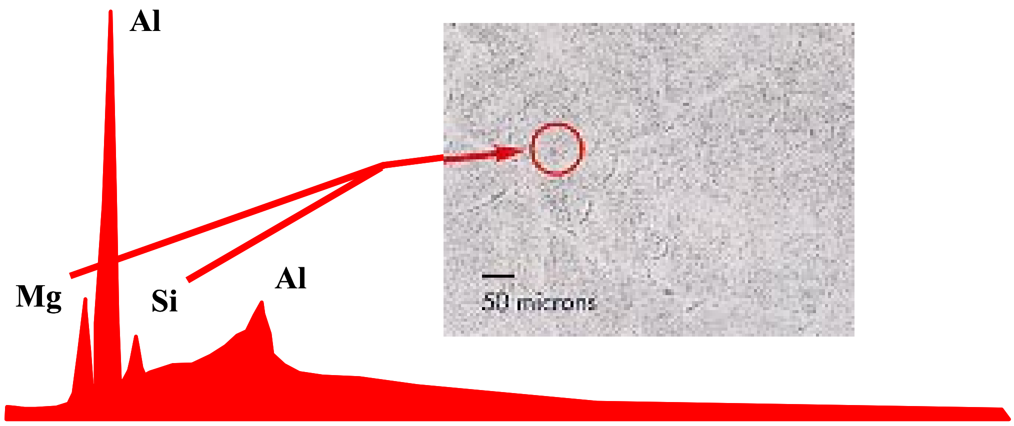


Figure 8: Micrograph of homogenised and cooled microstructure with energy dispersive spectrograph identifying the precipitated elements, (200 mag).

For 6000 series alloys not containing additions of Mn, longer holding times in the homogenisation cycle would be necessary to transform β AlFeSi to α AlFeSi. Typically, a cycle would be 4 to 8 hours at 575°C, followed by similar cooling for Mn containing alloys.

PRE-HEATING

The purpose of preheating billets for extrusion is to lower the flow stress of the alloy to allow extrusion at maximum speed while maintaining an excellent surface finish and mechanical properties.

The preheat temperature used must be sufficient to dissolve β' Mg_2Si precipitates during extrusion. This will ensure that optimum final mechanical properties are obtained subsequently with proper press quenching and artificial ageing. A typical preheat temperature for dilute 6000 series alloys is 450^0C but this may vary depending on how difficult a section is to extrude, the alloy type and the particular mechanical property/surface finish requirements.

Two common type of billet preheaters are gas fired, tunnel type furnaces and electrical induction heaters. The latter type of preheating is very rapid with billets reaching temperature for extrusion in a matter of minutes. The rapid heat up rates in induction heating allow little time for the post homogenised microstructure of the billets to change. Although dependent on post homogenising cooling rate, in general this characteristic can have a detrimental effect on extrusion pressure (which may in turn affect acceleration to maximum extrusion speed) but be of considerable benefit to final mechanical properties. The homogenised microstructure mainly contains β' Mg_2Si precipitates and some Mg and Si in solution, Figure 9.

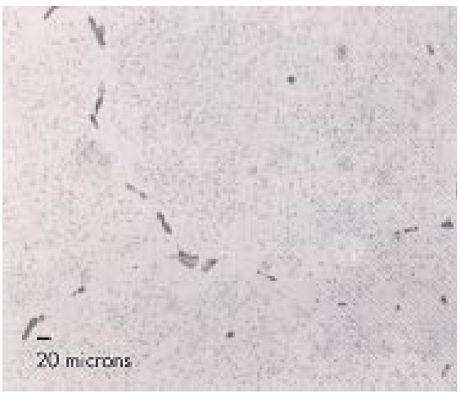


Figure 9: Typical billet microstructure after induction preheating.

Mg and Si retained in solution will increase the hot flow stress of the billet thus decreasing extrusion speeds. However, the rapid heat up through the range 200°C - 450°C is beneficial because it avoids the formation of coarse β Mg_2Si precipitates. Coarse β Mg_2Si is not readily dissolved during extrusion and avoiding this phase enables optimum mechanical properties to be reached. Figure 10 illustrates the relationship between heat up rates and the formation of β Mg_2Si.

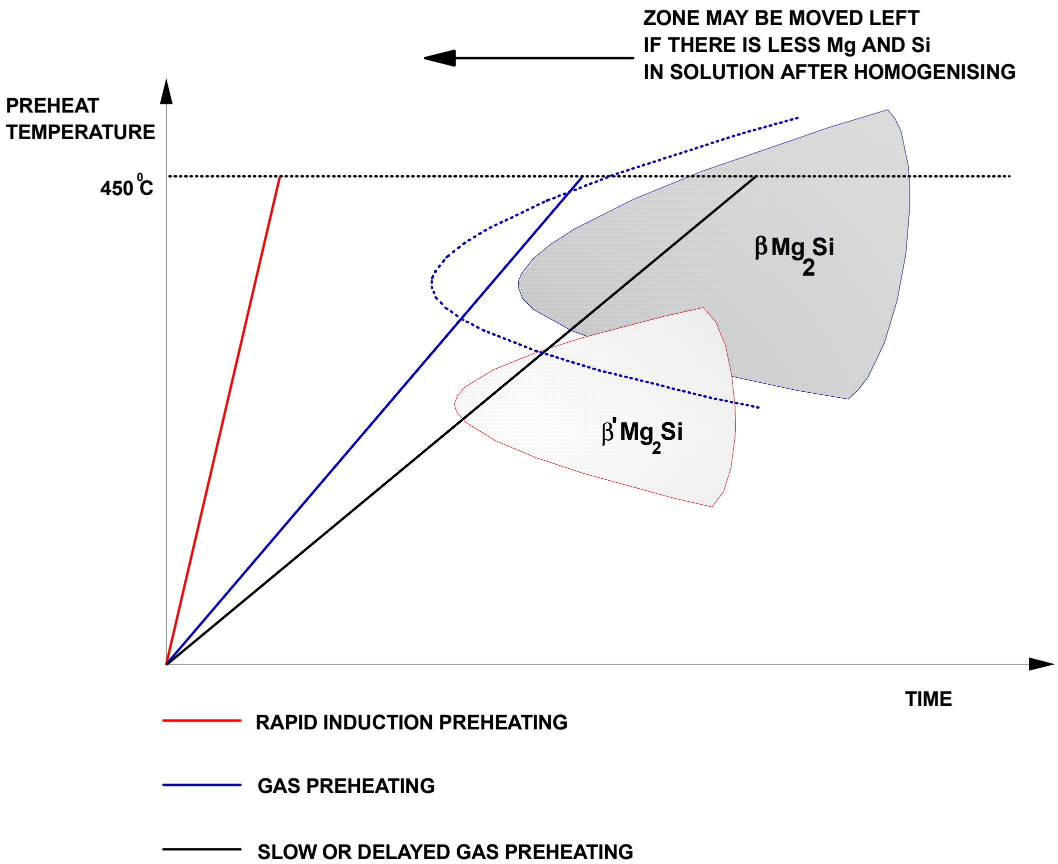


Figure 10. Graph of preheat rates and zones of β' and β Mg_2Si *formation.*

When using gas preheating the situation is almost reversed. The slower heat up times allow the homogenised microstructure to change so that Mg and Si may be precipitated from solution as β' Mg_2Si which lowers the hot flow stress of the billet allowing greater extrusion speeds to be used. The detrimental aspect of gas heating is the possible reduction in final mechanical properties. Slow or delayed preheating can coarsen the β' Mg_2Si as the temperature approaches 400°C. β Mg_2Si begins to form at around 400°C. The coarse β' Mg_2Si requires higher exit temperatures for dissolution and the β Mg_2Si will not dissolve during extrusion. The reduced amount of

Mg_2Si in solution will result in less than optimum mechanical properties after artificial ageing.

Figure 11: Billet microstructure showing coarse β Mg_2Si formed during a delay in gas preheating.

EXTRUSION

The 6000 series heat-treatable alloys are most commonly extruded via the direct extrusion process, Figure 12.

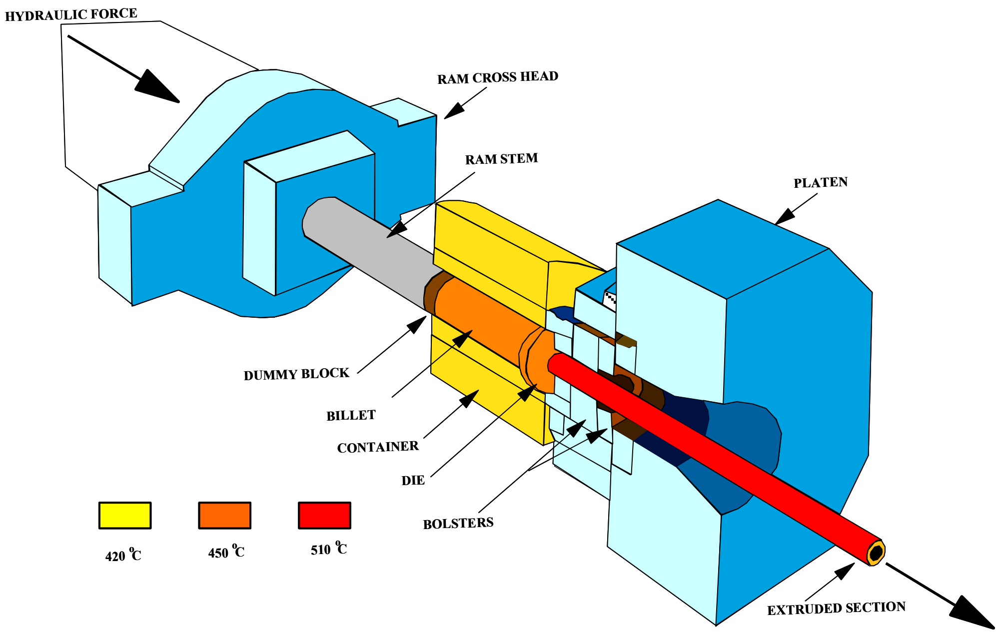


Figure 12: Schematic of direct extrusion process, temperatures for the billet, container, die and extrusion are colour coded.

Direct extrusion is the process of exerting a hydraulic force on a billet in a container through the aperture(s) of a stationary die.

The aluminium billets are heated to 450-500°C, (depending on alloy, extrusion shape and extrusion ratio), and loaded into a pre-heated container (420-470°C). A hydraulic ram pushes the billet through the die aperture(s) at pressures up to 680 MPa. The hot metal flows through the die to produce a continuous extrudate with a cross-section identical to the die aperture. These shapes may vary from complex hollows to simple solids.

Some major factors affecting the extrusion process

1. Press Capacity (or available pressure)

For maximum press productivity, an extrusion press is operated close to the maximum running pressure which usually corresponds to maximum speed.

Figure 13 illustrates the relationship between several extrusion process variables and available extrusion pressure. The solid line is the boundary between sufficient and insufficient pressure to extrude through a given die over a range of extrusion speeds and billet temperatures.

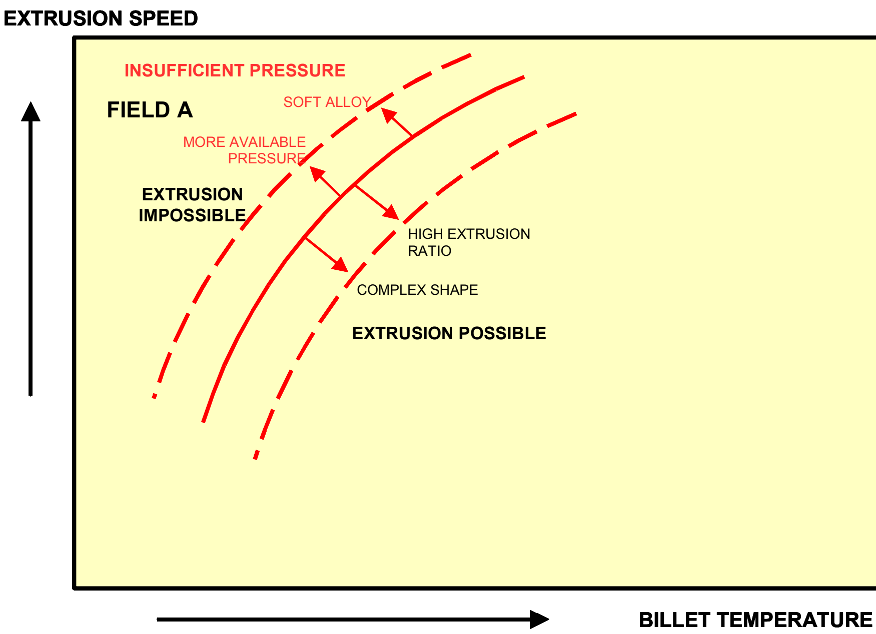


Figure 13: Diagram showing relationship between extrusion pressure and process variables.

This boundary may be moved to the left by using soft (dilute) alloys or by utilising more available pressure in order to maximise productivity. Hard alloys, higher extrusion ratios or more complex shapes will move the boundary to the right. This will expand field A and reduce the extrusion speeds (and productivity) obtained for a particular press capacity (pressure). Using higher billet temperatures may compensate for the reduction in extrusion speed but other variables may limit the temperature increase.

2. Surface Finish

The second diagram (Figure 14) illustrates the relationship between surface finish and process variables in conjunction with the pressure diagram shown in Figure 13.

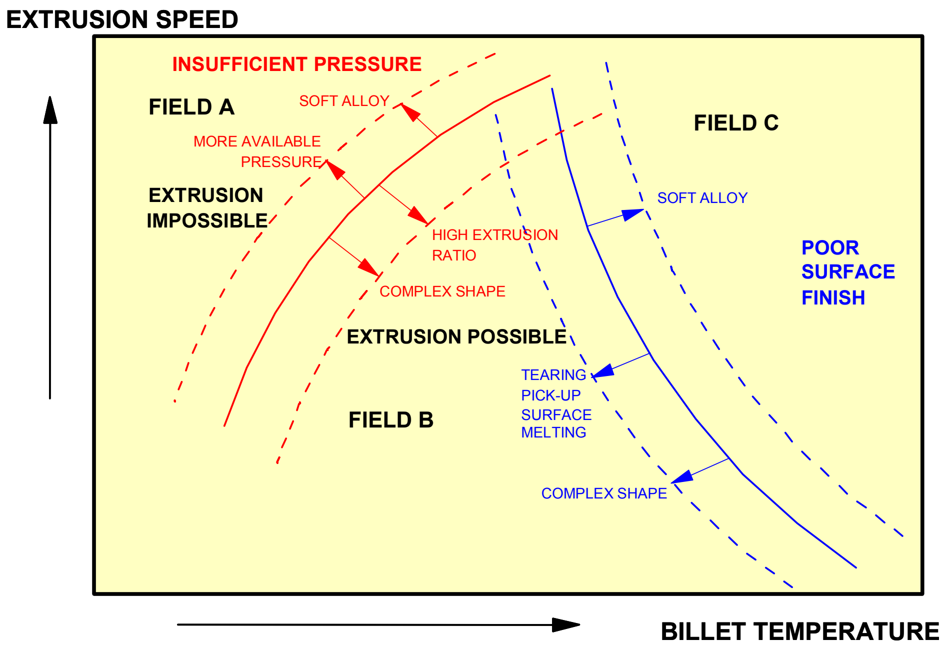


Figure 14: Diagram showing relationship between surface finish, extrusion pressure and process variables.

The additional solid line represents the boundary between poor and acceptable surface finish over a range of extrusion speeds and billet temperatures. This boundary can be moved to the right by the use of soft alloys which allows greater extrusion speeds and billet temperatures to be obtained before the surface finish deteriorates.

Complex shapes, high extrusion ratios and hard alloys move this boundary to the left reducing the extent of field B (extrusion possible). This shift may also correspond to surface deterioration such as surface tearing, pick-up and melting experienced by some extrusions. These factors reduce the extrusion speeds and billet temperatures that can be used before the surface finish breaks down. Coarse Mg_2Si particles formed either due to slow post homogenisation cooling or slow preheat, also move the surface finish boundary to the left (expand field C).

3. Mechanical Properties

Mechanical properties also impose some limits on the extrusion process. The third diagram (Figure 15) shows the relationship between extrusion process variables and mechanical properties over a range of extrusion speeds and billet temperatures, in addition to the effects of press pressure and surface finish.

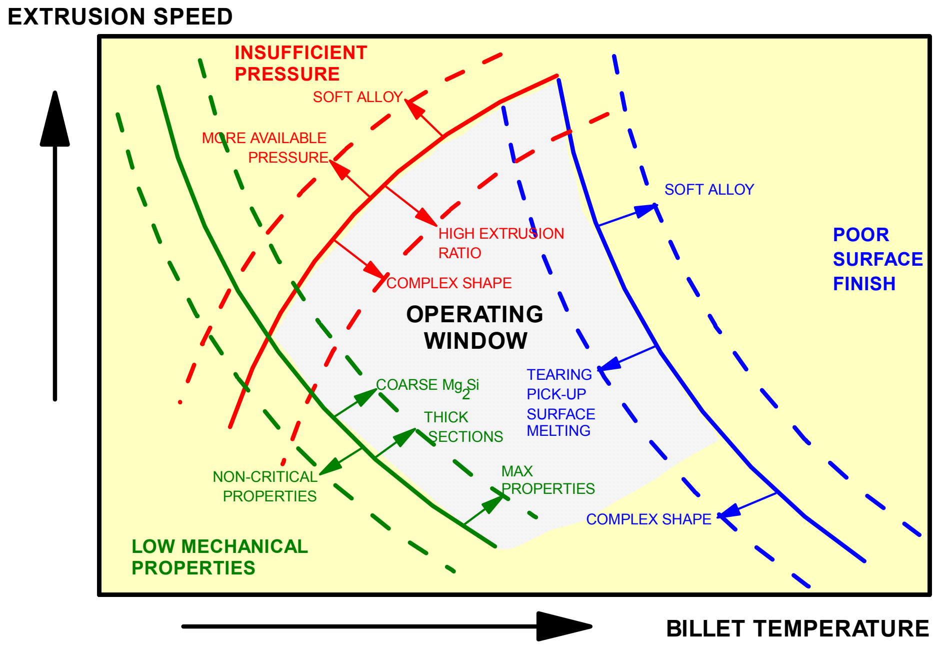


Figure 15: Limit diagram.

The additional solid line represents the boundary between adequate and inadequate final mechanical properties. This boundary may be moved to the right by using billet with coarse β Mg_2Si precipitates, extrusion of thick cross-sections and where higher mechanical property levels are required. Extrusion speeds and billet temperatures must therefore be increased for the extrusion to satisfy final mechanical property requirements. This is to say the energy supplied to the billet to dissolve Mg_2Si must be increased.

Billet containing β" and fine β' Mg_2Si, thin cross-section extrusions and lower mechanical property requirements all move the boundary to the left. Constraints on extrusion speed and billet temperature requirements are reduced and final mechanical properties more easily attained.

The extrusion operation window

Figure 15 is known as a Limit Diagram and illustrates the concept of the operating window to which the extrusion process is restricted. The combination of press capacity (available pressure) surface finish and final mechanical properties act as the boundaries of the operating window for the production of quality product. Where these boundaries are located depends on actual product requirements for surface finish (trim, anodised and structural) and specific mechanical property limits. These boundaries also highlight where maximum press productivity can be achieved. Extrusion speed and billet temperatures are limited to within those boundaries. Other variables, such as alloy type, extrusion ratio/shape and final extrusion properties, may enlarge or reduce the size of the operating window.

PRESS QUENCHING (COOLING)

Post-extrusion cooling rates must be fast enough to retain Mg and Si in solid solution so that mechanical properties are maximised by their precipitation during subsequent age hardening. Cooling rates are determined by section size and cooling type such as still air, fans, water mists or water baths. Figure 16 shows sufficient cooling for 6060-type alloys which will generally be achieved by using still or fan-forced air cooling, although, water mists or baths are desirable for harder alloys such as 6061.

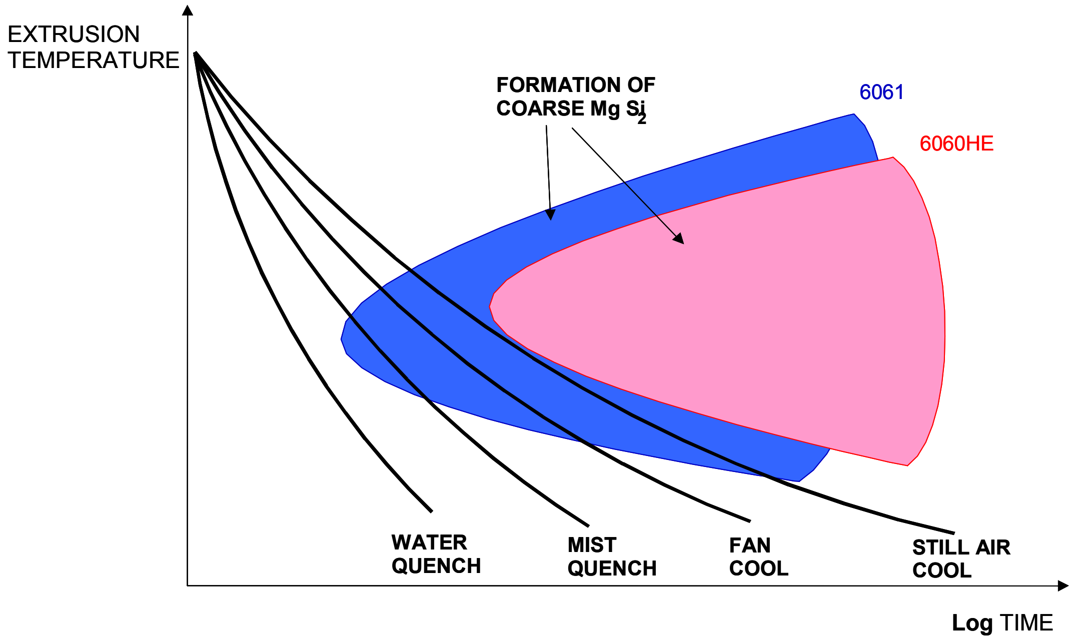


Figure 16: Schematic showing various cooling rates and areas for precipitation of coarse Mg_2Si.

Typical cooling rates required for some 6000 series alloys are given in Table 1.

Table 1. Recommended Quench Rates and Methods for Various 6000 Series Alloys

Alloys	*Minimum Quench Rate °C/min*	*Solid Sections < 10mm Thick.*	*Solid Sections > 10mm Thick*
6060	*50*	*Still Air or Fans*	*Water Mist*
6063	*60*	*Fans*	*Water Mist*
6061	*300*	*Water Mist*	*Water Sprays*
6082 / 6351	*300*	*Water Mist*	*Water Sprays*

AGEING

The ageing of 6000 series extrusions is necessary if an increase in the mechanical properties of the material is desired. The extent of the increase in properties is dependent on the alloy type and the ageing conditions. These conditions range from natural ageing, which occurs at room temperature, to a variety of elevated temperature treatments known as artificial ageing.

The strength of 6000 series alloys is directly related to the ability of the material to resist the movement of dislocations during deformation. Dislocations form and travel through a material when a stress is applied to it. As the stress increases the number and intensity of the dislocations travelling in the material increases until eventually the material fails. Dislocation travel is hampered by the presence of Mg_2Si precipitates and the material strength is therefore increased. The size and density of these precipitates is controlled by the ageing conditions. A few fine β" Mg_2Si precipitates can do little to stop dislocations travelling through the material but when in greater numbers the precipitates inhibit the dislocation movement thus increasing the strength of the material. If the precipitates grow too large (β' and β Mg_2Si) they will become fewer in number due to the finite amount of Mg and Si available. Dislocations may easily by-pass these precipitates and the material strength will be reduced.

This may be summarised in the typical artificial ageing curve for 6000 series alloys, Figure 17.

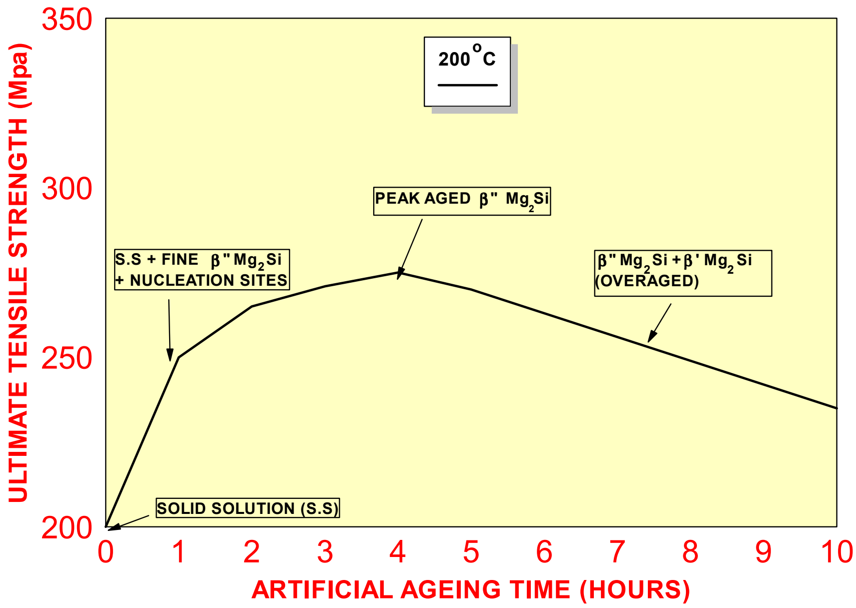


Figure 17: Typical ageing curve for 6000 series alloy.

For peak mechanical properties artificial ageing conditions must be set to achieve a large number of β" Mg_2Si precipitates. For 6000 series alloys typical conditions are 170°C for 8 hours and 185°C for 6 hours. Shown in Figure 18 are transmission electron micrographs (TEM) of Mg_2Si precipitates in the under aged, peak aged and over aged conditions.

Figure 18(a): TEM photo of under aged 6063 alloy showing a small number of fine β" Mg_2Si precipitates that do not contribute greatly to mechanical strength, (115,000 mag).

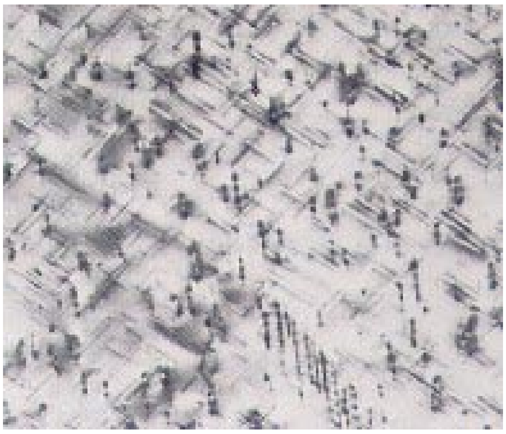


Figure 18 (b): TEM photo of peak aged 6063 alloy showing large number of β" Mg_2Si precipitates that prevent dislocation travel and thus increase strength.

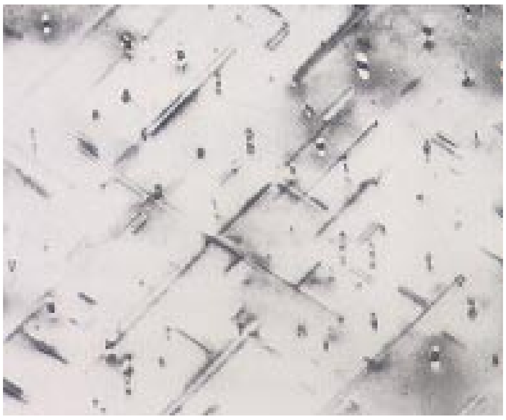


Figure 18 (c): TEM photo of over aged 6063 alloy showing small number of large β' and β Mg_2Si precipitates easily by-passed by dislocations.

There are standard temper designations for the various aged conditions, for example:

- T1 cooled after extrusion to room temperature and naturally aged,
- T4 solution treated after extrusion, quenched, and naturally aged,
- T5 cooled after extrusion to room temperature and artificially aged to peak mechanical properties,
- T6 solution treated after extrusion, quenched, and artificially aged to peak mechanical properties.

Other designations exist for ageing treatments specifically designed to give properties different to peak mechanical properties. Such as, the under aged tempers T52 and T591 used for bending applications or an over aged temper T7 for extrusions that may have end uses at elevated temperature.

It is general practice for extruders to stretch extrusions around 0.5% and then delay ageing of dilute 6000 series alloys (< 0.9% Mg_2Si e.g 6060 and 6063) for 24 hours to promote optimum mechanical properties after ageing. However, delays in ageing high strength alloys (>0.9% Mg_2Si) such as 6061, can result in reduced mechanical properties after ageing. This is due to the premature precipitation of Mg_2Si which results in over aged rather than peak aged properties. The addition of copper (>0.1%) to these alloys counteracts the effect of a delay before artificial ageing.

Common Terms Used in the Extrusion Industry

Alloy
A metallic material comprised of two or more chemical elements one of which must be a metal. The properties of an alloy differ from those of the components.

Anodising
An electrochemical process that produces a protective oxide coating on an aluminium surface.

Ageing, Artificial
Precipitation hardening; producing precipitates from solid solution at elevated temperatures to harden and strengthen an alloy. The process usually follows a rapid quench from solution heat-treatment temperatures.

Ageing, Natural
The ageing process of an alloy occurring at room temperature.

Backer
A steel disk two to three times thicker than the die, with an aperture larger than the die. The function of the backer is to locate and support the die during extrusion.

Bearing
The portion of the die aperture at right angles to the die face that, to some extent, controls metal flow, speed and extrusion surface finish.

Bearing Length
Measurement of the depth of the bearing surface at any point around the die aperture.

Billet
A length of aluminium alloy with circular cross-section suitable for extrusion. May be cast or cut from aluminium alloy logs.

Blister
A dome-shaped defect on the extrusion surface caused by the expansion of gas trapped in the metal. The blister may become obvious during extrusion or after its heat-treatment.

Bolster
Steel disk with aperture larger than backer and die, designed to support die and backer and minimise die deflections.

Break-out Pressure
Initial pressure required to start metal flow through the die.

Butt
Unextruded part of billet left in container when extrusion is complete. The butt is discarded and may vary in thickness, depending on alloy type, original billet length and extrusion conditions.

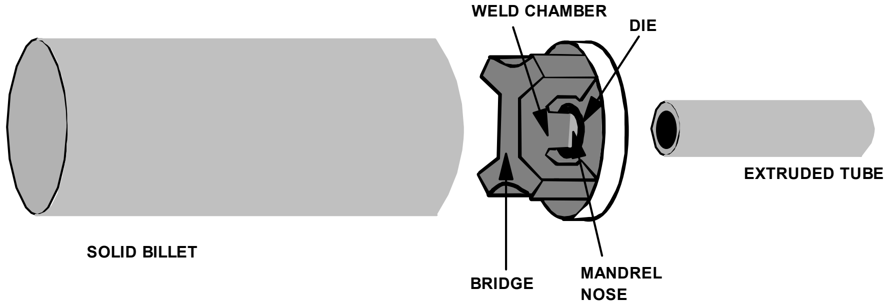
Cold Work
Mechanical deformation of an alloy below the recrystallisation temperature. Hardness and strength can be improved by this process.

Container
Extrusion press tooling that confines the billet during extrusion. It is comprised of a heated steel cylinder with inner diameter slightly larger than billet diameter.

Defect
Any abnormality on or in the extrusion that may cause a rejection of the extrusion.

Die
Extrusion tooling with one or more machined openings designed to produce the extrusion shape.

Die, Hollow
Hollow extrusions such as tubes are produced with hollow dies. Hollow dies are similar in construction to the type shown below.



Hollow extrusions produced by these dies have longitudinal welds caused by metal flow around the supports for the mandrel nose or stub. The metal flows around the supports and is fused in the weld chamber before passing through the die.

Die Face
Die surface facing the billet.

Die Line
A scratch or line on the extrusion surface in the extrusion direction. These lines may be caused by rough die bearings or particles trapped between extrudate and bearing.

Die Ring
A steel cylinder that holds the die and backer together.

Dislocation
A defect in the microstructure of a metal that may take the form of a loop or a line connected at its ends to other dislocations, grain boundaries or other microstructural features.

Ductility
The property of an alloy that allows it to be deformed without fracture. The measure of this property is usually given a % Elongation.

Dummy Block
A steel disk fitted to the ram to prevent backflow of the billet over the ram. The clearance between dummy block and container is kept to a minimum.

Etching
Applying a chemical solution to the extrusion to change its surface for the purpose of cleaning, examination or finishing.

Extrusion
The reduction of a billet to a desired cross-section by forcing it through a similarly shaped die aperture.

Extrusion Pressure
The force needed to produce metal flow through the die.

Extrusion Ratio
Reduction ratio; the ratio of cross-sectional area of the container to that of the extruded section or sections.

Extrusion Speed
Rate at which the extrudate exits the die.

Frictional Heat
Heat component of extrusion attributed to friction between container and billet surfaces.

Funnelling
Back-end defect; caused by billet surface entering extrusion from rear of the billet during extrusion, usually occurring when the butt length is too thin.

Gas Heater
Gas-fired, tunnel type furnace used to preheat billets for extrusion.

Grain
An individual crystal making up part of the metal's crystalline structure.

Grain Refiner
Addition to the liquid alloy that produces a uniform finer grain size in the billet.

Grain Size
A standard measurement of crystal or grain size expressed as either grains per unit area or volume.

Hardness
Resistance of metal to plastic deformation.

Heat-treatment
A series of heating and cooling steps used to change the properties of aluminium (e.g. artificial ageing).

Homogenisation
The heat-treatment of as-cast billet designed to change its microstructure for optimum extrusion performance and post-extruded mechanical properties.

Inclusions
Impurities found in the extrusion or billet such as oxides, flux or refractories. Most inclusions are trapped in the billet during casting but some, such as tool steels, may be embedded during extrusion.

Intermetallic
A particle in an alloy that is a compound of two or more metals with the chemical composition, physical properties and crystal structure differing from the bulk material.

Linishing
A mechanical surface preparation technique undertaken with a motor driven grinding belt.

Log
A long cylindrical casting produced by the direct chill method that is cut into billets for extrusion.

Lubricant
Any type of oil or grease-like substance used to reduce friction during the extrusion operation.

Mandrel
The protruding section of a hollow die that directs metal flow through the die. See Die, Hollow.

Maximum Speed
The fastest speed possible to extrude a particular material and shape without producing defects.

Mechanical Properties
The properties of an alloy associated with an applied force and the resulting relationship of stress and strain in a given material.

Metal Flow
The type of plastic movement of metal both in the container and through the die.

Nitriding
The case hardening of a die in an atmosphere containing nitrogen and ammonia.

Phase
A physically distinct constituent of an alloy with a homogeneous chemical composition. For example α AlFeSi may be written Al_8Fe_2Si and β AlFeSi can be shown as Al_5FeSi, in this case the α and β symbols represent two distinct phases of the AlFeSi compound.

Physical Properties
Those physics-related properties of an alloy other than the mechanical properties, such as density, conductivity and thermal expansion.

Pick-up
Small particles of an alloy deposited on the extrudate's surface during extrusion.

Pitting
Corrosion resulting in pits or craters on the metal surface.

Plastic
The ability of an alloy to deform non-elastically without failure.

Precipitate
A particle that separates from a super saturated solid solution in an alloy. The separation may be either chemically or physically induced. Occurs in both artificial and natural ageing processes.

Pre-heating
The heating of billets to temperatures that lower the flow stress of the billet for extrusion and at the same time promoting solutionizing of precipitates.

Primary Metal
Metal usually cast onsite at a smelter using molten metal direct from the smelting operation as its supply.

Proof Stress
The maximum tensile stress an alloy can withstand before it permanently deforms under a uniform load.

Productivity
The amount of saleable extrusions produced per unit time.

Quench
The rapid cooling of an alloy below a critical temperature using air, water or oil.

Ram
The extension of the main extrusion press cylinder that applies force to the extrusion billet.

Recovery
The amount of saleable extrusion produced from the original billet.

Remelt Metal
Metal cast in remelt operations that use scrap aluminium as its chief source.

Scalping
Removing the outer oxide layer of an as-cast billet by machining.

Segregation Zone
The concentration of alloying elements at the billet edge inconsistent with that found in the remaining billet. It is a product of the solidification during casting.

Shape, Extruded
A shape brought to final dimensions by extruding.

Shear, Butt
The shear removes the butt from the die face at the end of the extrusion cycle.

Shear, Log
As part of a continuous extrusion process this shear divides hot logs from the log/billet heater into billets of suitable length for extrusion.

Solidus
The temperatures at which the alloying constituents begin to melt during heating or freeze during cooling.

Solution
A solid matrix of an alloy containing dissolved chemical elements which may be precipitated to change the properties of the alloy.

Solutionizing

Using applied heat and/or mechanical deformation to raise the temperature of an alloy to the point where precipitates are driven into solid solution and then rapidly cooling the alloy to retain the constituents in the solid solution.

Solution Heat-Treatment
As per solutionizing, except that a heat application separate to other thermo-mechanical processes is used to raise the alloy temperature.

Strain
A measure of the change in dimensions of a shape of an extrusion produced by an applied force. It is usually measured as tensile strain, the percentage change in length per unit of original length.

Stress
The resistance of a material to a change in shape produced by an applied force. It is measured in force per unit area. (SI unit N/m^2 = pascal).

Stretch Straightening
Stretching an extrudate in the extrusion direction beyond its yield strength to achieve straightness along its length.

Taper Heating
Producing a temperature gradient along the billet length so that a constant extrusion exit temperature may be maintained through the cycle.

Temper
Stable mechanical property condition induced in an alloy by thermal or mechanical processing.

Ultimate Tensile Strength
The maximum tensile stress an alloy can withstand before it fails under a uniform load.

Water Stain
Surface oxidation of an extrusion due to a reaction with water.

Welds
The regions of extrusion alloy fused together by the extrusion process. See Die, Hollow.