

TALAT Lecture 1401

Aluminium Powder Metallurgy

26 pages, 25 figures

Advanced Level 1

prepared by

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Objectives:

- to understand the differences between conventionally produced and powder metallurgy aluminium with respect to potential uses
- to learn about the various processes to produce and to consolidate alloy powders
- to illustrate the extension of the useful property range beyond that of limits of conventionally processed aluminium alloys
- to learn the advantages and disadvantages of aluminium produced by powder metallurgy
- to understand the potential of aluminium produced by the route of powder metallurgy.

Prerequisites/Target Group:

Students: Graduate education in metallurgy materials science, materials engineering

Trainers: Research or teaching experience in metallurgy, materials science, materials engineering

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1401 Aluminium Powder Metallurgy

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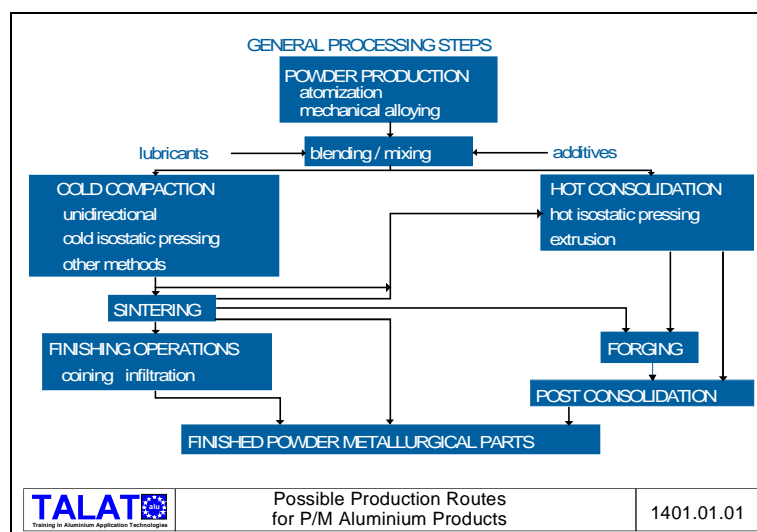
1401.01 Introduction

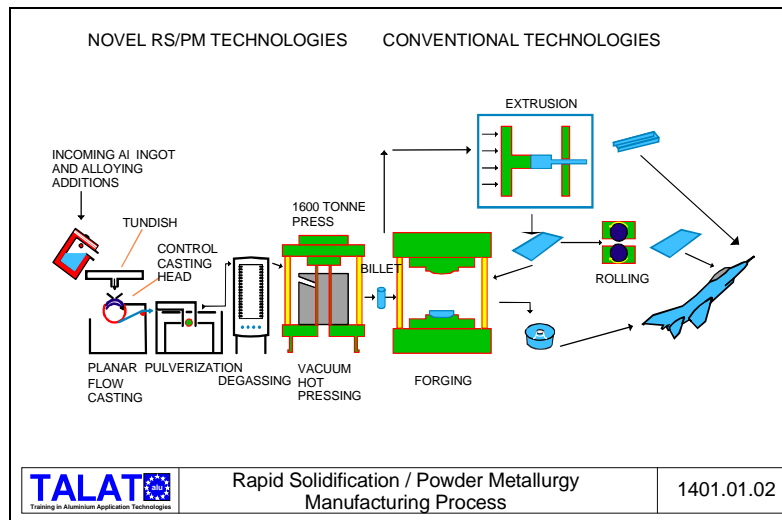
An improvement of the properties of available aluminium alloys would help the aluminium industry to conquer new markets for their products. The alloys obtained by the classical ingot route have been optimised by a careful choice of composition, the alloying elements, the fabrication techniques, and the thermal and thermomechanical treatments. Improved mechanical, physical and chemical properties would, however, be possible if alloys with compositions unattainable by the classical ingot route could be produced or if new processing techniques could be developed. The powder metallurgical (P/M) route creates some possibilities in this respect. The use of P/M has the following **general objectives**:

Due to a rapid cooling refined and more homogeneous microstructures can be obtained. The wider choice of alloy compositions makes it possible to obtain tailored properties concerning density, thermal expansion etc. The P/M technique is suitable for near net shaped products and better thermal stability as well as increased corrosion and tribological properties are possible.

The **production** of P/M aluminium alloys is mainly done by two methods. For compositions with alloying elements with a high solubility in the liquid state, a rapid solidification technique is used. For alloying elements with low solubility in the liquid state, mixture in the solid state is preferred.

Powder metallurgical products can be manufactured along different production routes, but in general the following steps can be mentioned : powder production, blending and mixing of powders with the addition of lubricants and binders, cold compaction eventually followed by degassing, sintering or hot consolidation and finally some post consolidation treatments. A survey of some production routes is presented in **Figure 1401.01.01**. An example of one particular manufacturing process is given in **Figure 1401.01.02**.





Most of the P/M alloys can be divided into three main **application fields**: low density applications, high strength at room temperature and high temperature applications. The reduction in density is obtained by the addition of lithium. Although some commercial Al-Li alloys (e.g. AA2090, AA8090) are produced by the classical ingot route, a higher Li-content can be obtained with the P/M route through supersaturation beyond the equilibrium solubility limit and an increase in strength can be achieved via dispersion strengthening of fine second phase particles. The Al-Li alloys are mend for the replacement of the classical AA2024T3, AA7075T6 and AA7075T3. The high strength alloys are produced by rapid solidification of AA7xxx alloyed with transition elements like Co, Zr or Ni or by mechanical alloying of Al or Al-Mg alloys with Al-carbides or Al-oxides. These alloys are mend for the replacement of the AA7075T6. Alloys for elevated temperature applications are obtained by rapid solidification of Al alloys with rare-earth or transition metals or by mechanical alloying.

In spite of the interesting technical possibilities, the actual economical interest of P/M in the aluminium industry is almost negligible. The main barrier for an extensive use of P/M products is the high cost (roughly 1.5 to 2 times that of ingot parts) which is due to the need of some special equipment and to the safety precautions with powder handling.

Another constraint is the small size of the billets which can be processed into wrought products and their limited availability. Some resistance to the use of P/M components in critical load-bearing applications is due to the restricted availability of reliable non-destructive testing techniques for detecting small pores or other defects. Commercial application of P/M products seems for the near future to be restricted to high strength alloys for (military) aircraft components, wear resistant alloys for automotive engines, high modulus alloys for stiffness and high temperature alloys for engine and airframe applications.

1401.02 Powder Fabrication

- Main fabrication methods for Al powder
- Rapid solidification
- Characterisation of metal powders
- Safety considerations

Main Fabrication Methods for Al Powder

Powder metallurgical aluminium materials can be produced by a variety of manufacturing routes. The main production routes, i.e. those for which materials are commercially available are: atomisation, melt spinning and subsequent pulverisation of the ribbons into flakes, and mechanical alloying.

Atomisation involves the formation of powder from a molten metal stream which is broken into droplets. Both elemental and pre-alloyed powders can be formed. Actually, it provides the majority of all powders. An important aspect of this technique is the rapid solidification of the powder from the melt. The main techniques for the production of aluminium powders are water and gas atomisation. Much less important are vacuum and air atomisation and centrifugal atomisation. Another method consists of the production of a rapidly solidified ribbon (e.g. by **melt spinning**) and a subsequent **pulverisation** of the ribbon into flakes which can be compacted and extruded. An attractive method for the production of oxide dispersion strengthened material for high temperature applications is **mechanical alloying** where powder is repeatedly welded, broken and rewelded in an attritor.

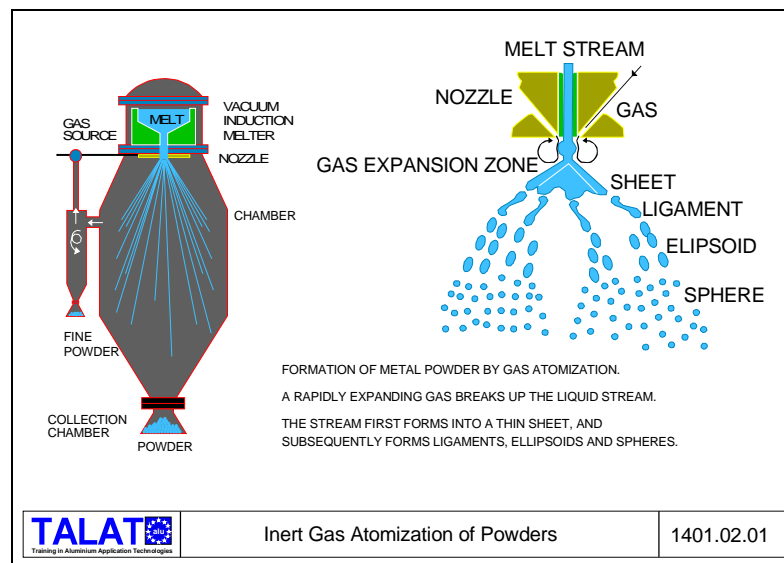
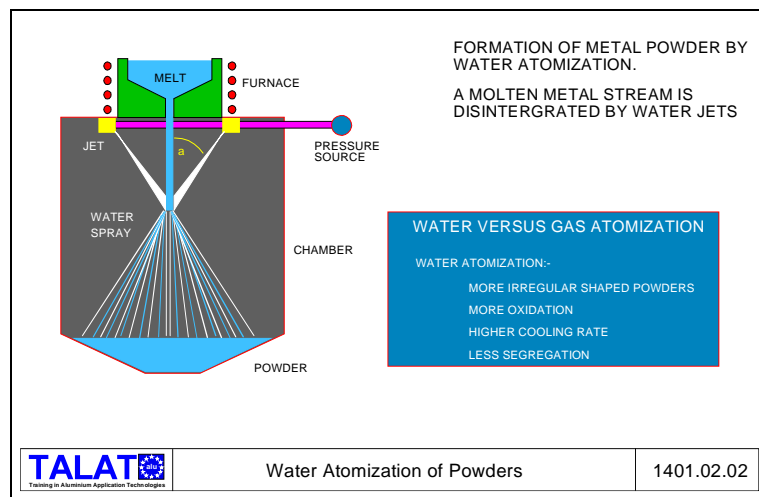


Figure 1401.02.01 shows a schematic diagram of a vertical inert **gas atomiser**. The superheated melt is prepared in a vacuum induction furnace and is poured into one or more nozzles. A rapidly expanding gas breaks up the liquid stream which first forms a thin sheet and subsequently forms ligaments, ellipsoids and spheres. The powder is collected beneath and a cyclone allows gas exit and recycling, leaving the very fine particles behind. The gas atomisation process has a large number of operating variables such as : alloy composition, metal feed rate, melt temperature, melt viscosity, gas pressure and temperature, type of gas, nozzle geometry. The main advantage of gas atomisation is the product homogeneity, the absence of contamination due to totally inert processing conditions and the spherical shape of the produced powder.

A **water atomisation** process is similar to gas atomisation but the molten metal stream is disintegrated by water jets (see **Figure 1401.02.02**). The cooling rate is higher than for gas and consequently the chemical segregation in to powder is smaller. The shape of the powders is more irregular, the powder surface is rougher and more oxidised. A high water velocity causes a decrease in the mean particle size.



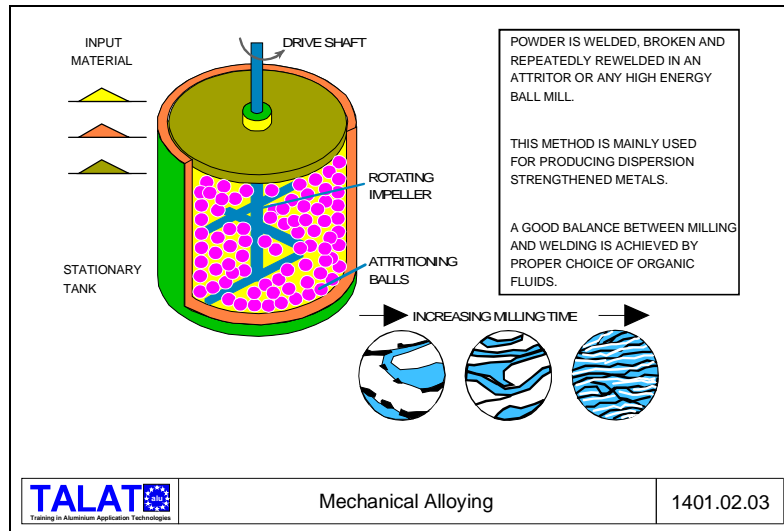
In a simple form the relation can be written as:

$$D = C/V \sin \alpha$$

with V the water velocity, α the angle between melt stream and water jet, D the mean particle size and C a constant incorporating material and atomiser design effects.

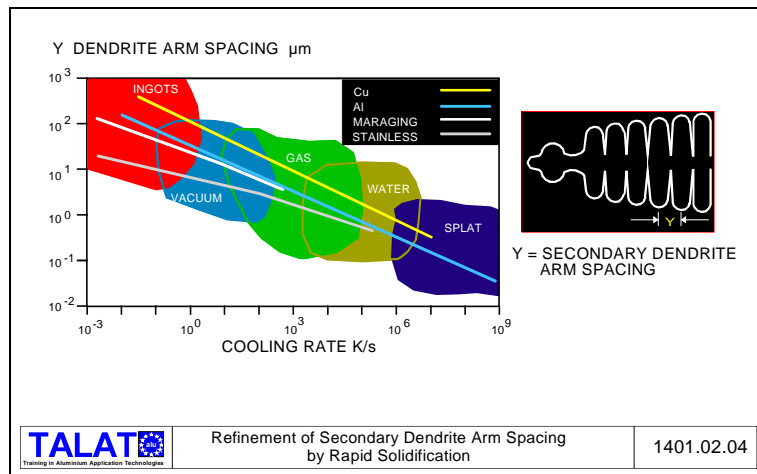
Mechanical alloying uses a mixture of balls and elemental powder to create a micro alloyed composite powder in an attritor or in another high energy ball mill (**Figure 1401.02.03**). The repeated milling, cold welding, fracture and rewelding of the metal powder leads to a homogenized material with a uniform dispersion of inclusions. A good balance between milling and welding is achieved by the proper choice of organic fluids (process controlling agents). Because of the heavy cold work, mechanically

alloyed powders are not easy to consolidate. This technique is not particularly efficient but remains attractive since fairly unique alloys can be prepared, mainly for high temperature applications.



Rapid Solidification

An important feature of atomisation is the rapid solidification of the powder from the melt ($\sim 10^2$ to 10^4 K/s for gas atomisation and 10^4 to 10^6 K/s for water atomisation). One obvious effect of increasing solidification rate is a refinement of the microstructural constituents. There seems to be a linear relation between the cooling rate and the secondary dendritic arm spacing (**Figure 1401.02.04**). This structure refinement has an important beneficial effect on the properties of the P/M products such as increased strength, better fatigue life and improved corrosion resistance. Another effect of increased cooling rate is the extension of the solid solubility limits for alloying elements above the equilibrium values (**Figure 1401.02.05**). This makes it possible to produce metastable alloys with compositions which can not be reached by classical ingot metallurgy.



ADDITIVE	MAX. EQUILIBRIUM SOLUBILITY (at %)	OBSERVED MAXIMUM BY RAPID QUENCHING
Cu	2.5 (at 821 K)	18
Mn	0.7 (at 923 K)	9
Si	1.6 (at 850 K)	16

Extension of Max. Solubility By Rapid Quenching
1401.02.05

Characterisation of Metal Powders

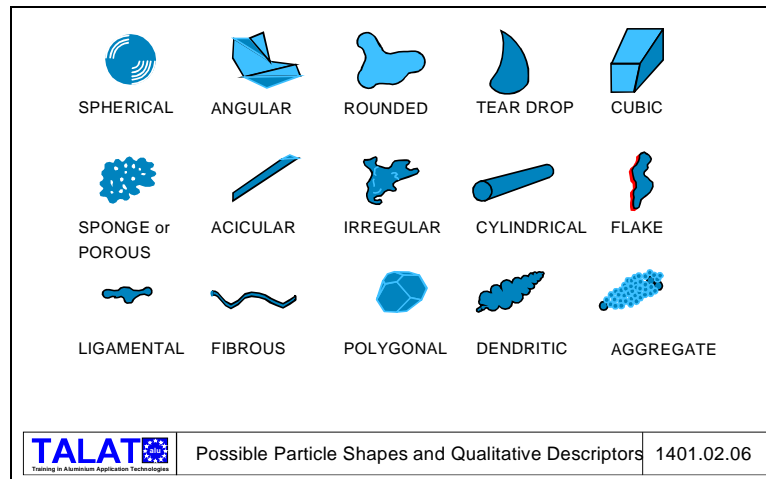
The characteristics of a powder are important because they often determine the choice of a particular processing route. Powder characterisation is a rather complex procedure since not only the properties of individual particles (size, shape, etc.) must be determined, but also the characteristics of the powder mass (particle size distribution, apparent density, etc.) and of the porosity in the powder mass (average pore size, pore volume, etc.). In general the following characteristics should be determined :

chemical composition : the chemical composition as well as the impurity content can be determined with normal analytical chemistry methods; beyond the bulk chemical information, there is often a need to know the surface conditions of the powder (oxidation, observed organic films, surface coatings, etc.); hydrogen weight loss measurements (ASTM E159) can give an idea about the surface oxidation, while the inclusion concentration can be measured by acid dissolution; in some special cases Auger electron spectroscopy can be needed;

internal particle structure : micro segregation, internal pores and precipitates can be studied with conventional microscopic techniques such as light optical microscopy and electron microscopy;

mean particle size and particle size distribution : a large variety of methods to measure the particle size distribution is available; one method uses the ability of the eye to rapidly size dispersed particles in a microscope (ASTM E20); another popular method is sieving (screening) : the powder is tapped through a set of sieves with increasing mesh size and the amount of powder in each sieve is weighed; other techniques are based on the measurement of sedimentation, electrical conductivity, light scattering or even X-ray techniques for very fine powders;

particle shape : a view of possible particle shapes is presented in **Figure 1401.02.06**; the shape of a particle is very important and must be considered together with the size distribution; it can be determined by a scanning electron microscope;



surface area : the specific surface area is expressed as the area per unit mass (m^2/g) and is closely related to the shape of the powder; it can be determined by a gas absorption technique;

apparent density : the apparent density of a powder is defined as the weight per unit volume of powder after pouring through a Hall flow meter (ASTM B212 and ASTM B213) or a Scott volume meter (ASTM B329);

tap density : the tap density is the weight divided by the volume after vibrating the powder (ASTM B527);

flow rate : the flow rate of metal powder is not influencing the final properties of a P/M product but is important for a good die filling during compaction; the flow rate can be measured with a Hall flow meter.

Safety Considerations

Certain powders of metals and metallic compounds can have harmful effects on users exposed to these powders. Powder handling requires proper safety precautions and cleanliness. Persons exposed to metallic dust can be affected by respiratory diseases or other dysfunctions. The particle size and the specific gravity of the material largely determine the deposition site for a respirated particle. Coarse particles are trapped on the precious membranes and do not reach the lungs; fine particles, however, can reach the lungs and may be dissolved into the body. At the present, there are no major indications for recognised hazard effects connected with normal handling of the common grades of aluminium or its alloys. However, special care is needed when using elemental powders as alloying elements (e.g. Cr, Ni, As, Cd).

Another hazard with aluminium based powders is their thermal instability in the presence of oxygen. Aluminium powders in a finely divided state are pyrophoric (burn in air) and potentially explosive. Aluminium powders require very little oxygen content in the atmosphere (less than 3 %), have a low ignition temperature (less than 600 °C) and very low explosive limit (20-50 g/m³). Explosion and fire prevention is based on the evaluation of :

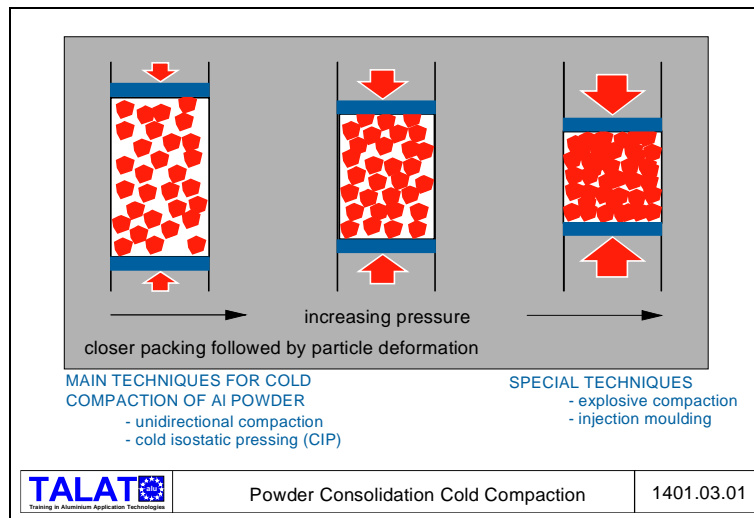
- potential ignition sources (e.g. electrostatic discharge);
- dust cloud generators;
- gaseous atmosphere composition.

Because the mechanisms of pyrophoricity and autogenous ignition are not definitively known, these characteristics should be evaluated relative to the processing, chemical treating and handling of each powder type.

If a fire occurs in a aluminium powder, the fire should be approached with extreme caution. The best way to attack burning metal powder is with special dry-type fire extinguishing agents. Water should never be applied to fires of aluminium.

1401.03 Powder Consolidation

- Precompaction
- Cold compaction
- Sintering
- Hot consolidation
- Post consolidation
- Spray forming



It has been mentioned in the introduction and illustrated in **Figure 1401.03.01** that a variety of processing routes are available to consolidate the powder. After production, the powders are generally blended and mixed with addition of lubricants and binders. In most cases a cold compaction is carried out, often followed by a degassing treatment. The next step is a hot consolidation. This can be a sintering process or a classical hot deformation (or both). Finally, some post consolidation treatments (machining, surface treatment, secondary pressing, etc.) can be carried out.

Precompaction

Mixing and blending are the two most common precompaction steps in powder metallurgy. Blending means the combination of different sized powders of the same chemistry. It is carried out to obtain a desired powder size distribution. Coarse powders are easy to compact but difficult to sinter; they are often combined with finer powders to enhance the sintering. Mixing of powder is carried out to obtain new alloy compositions. Theoretically, any composition can be prepared starting from elemental powders. It is also common practice to mix a lubricant with the powder to minimize the wear and facilitate the ejection from the die after compaction. With some powders a binder is added to achieve a high green strength (strength before hot consolidation). During sintering the binder and the lubricants are burned out of the compacts.

Cold Compaction

Cold compaction is the first step in the shaping of loose powders into a product of desired form and sufficient strength for further handling. It is mostly done by unidirectional compaction in a die or to a lesser extent by cold isostatic pressing (CIP). More specialised techniques are injection molding and explosive compaction.

A schematic of **unidirectional compaction** is given in **Figure 1401.03.01**. In a first stage the particles are rearranged leading to a better packing. Increasing pressure provides better packing and decreasing porosity. At high pressure the individual particles are deformed and some cold welding between the particles occurs which gives some strength to the green compact. Because of the wall friction the densification of the compact is not uniform. The problem can be minimised by using lubricants and by applying a load from top and bottom simultaneously. The design of the dies is very important because it must take into account that the green product must be ejected after compaction. This limits the geometry that can be obtained by unidirectional compaction.

An alternative method is **cold isostatic pressing (CIP)**. Sealed molds of powder are loaded in a liquid inside a high pressure tank and a hydrostatic pressure is applied by pressurizing the liquid. Typical pressure are between 300 to 400 MPa. This method is useful for large, homogeneous compacts. At a given pressure, higher densities than in die compressions are reached. CIP is very useful for complex shapes but suffers from poor dimensional control.

Explosive compaction is a technique which is mainly used in laboratory conditions but with some possibilities for limited industrial scale applications. A shock wave is used to achieve a rapid consolidation of the powder. Minimal heating is observed while high densities are obtained (up to 99 % of the theoretical density). With this technique negative consequences of sintering or hot consolidation can be avoided; amorphous structures can be preserved during compaction.

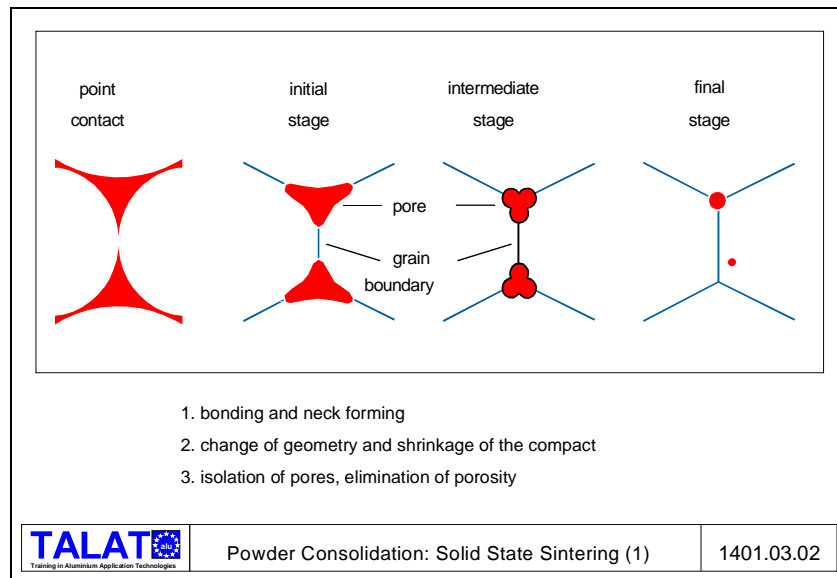
Injection moulding provides another method of consolidating powders. The method is similar to the moulding of plastics and conventional moulding equipment can be used. Powders are mixed with thermoplastic binders and injection moulded to a required shape. Before sintering the binder is removed by thermal degradation or by solvent extraction. The method is useful for small but complex parts.

Sintering

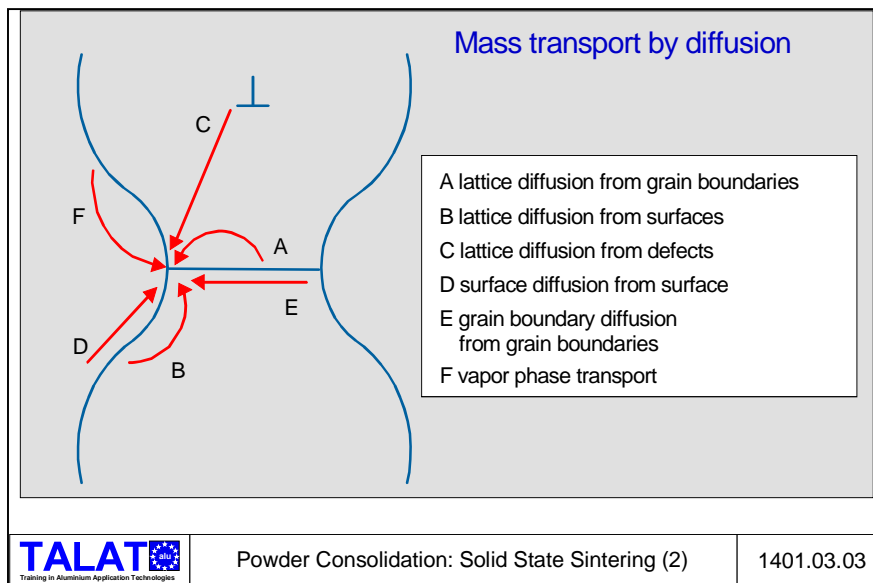
When a powder compact is heated in a protective atmosphere to a temperature below the melting point of the major component, a densification of the powder occurs by eliminating pores and a sintered product of increased mechanical strength is formed. On a microscopic scale, cohesion takes place as necks form and grow at the points of particle contact. The sintering temperature is typically around 600 °C. The driving force for sintering is the reduction in surface energy of the powder and is rather small. To increase this driving force, sintering can be carried out with the addition of reactive elements or with additional components that become liquid at the sintering temperature (liquid phase sintering). Another alternative is to apply an external pressure during sintering (pressure sintering). The efficiency of a sintering process is mainly influenced by the temperature, the time, the properties of the protective atmosphere, the density of the compact, the particle size and the particle shape.

Solid state sintering can be divided into three (overlapping) steps (**Figure 1401.03.02**):

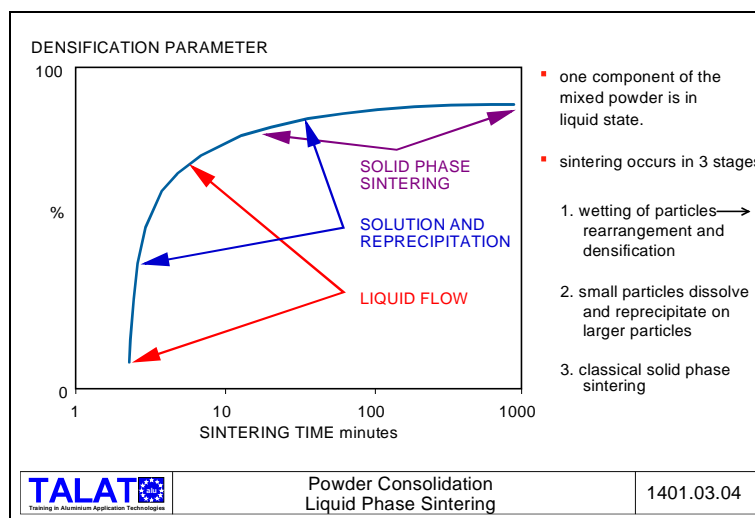
1. bonding of powder particles forming necks;
2. change of pore geometry and shrinkage of the compact;
3. isolation of pores by grain growth, elimination of residual porosity.



This sintering process involves some mass transport. At least six different diffusion paths can be identified (**Figure 1401.03.03**): lattice diffusion from grain boundaries, surfaces and defects, boundary diffusion from grain boundaries, surface diffusion from surfaces and vapour phase transport from surfaces. Many models have already been proposed to describe the growth of necks and the shrinkage of pores, but due to the complexity of the pores a general accepted quantitative model remains to be developed. Ashby has developed a system of graphs (sintering mechanism maps) in which neck size, shrinkage and relative density are plotted as function of the temperature and where the predominant sintering mechanisms are indicated.



Activated sintering is mainly achieved by adding some activators to the powder. Their presence on the grain boundaries enhances the grain boundary diffusion and lowers the activation energy for sintering. Activated sintering allows for lower sintering temperature, shorter sintering time and better properties.



In multicomponent systems (involving mixed powders) one component can be in the liquid state during sintering, thereby accelerating the sintering because rapid mass transport is now possible. **Liquid phase sintering** takes place in three stages (**Figure 1401.03.04**). Initially the liquid phase wets the particles, leading to rearrangements of the particles and to a fast densification. In a second stage the small particles dissolve and reprecipitate on the large particles. In the third stage, classical solid phase sintering occurs.

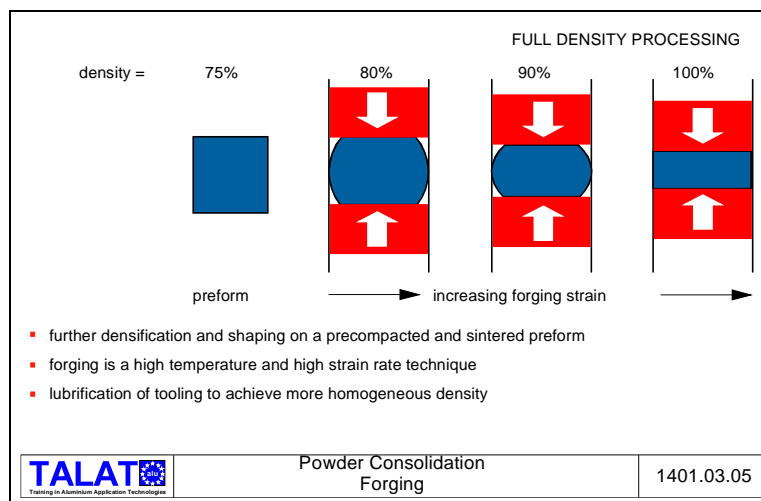
A third method of enhanced sintering is **pressure sintering**. Sintering is carried out under an external stress field. In a first stage a rapid consolidation to high density occurs by plastic (hot) deformation. In a second stage of densification, creep mechanisms become operative. In a final stage, diffusion as in normal sintering becomes dominant.

Hot Consolidation (Full Density Processing)

By a simultaneous action of heat and pressure it is possible to obtain a P/M product without residual pores (full dense compacts). It is difficult to achieve this with a simple sintering process because some residual pores become stabilised and are difficult to remove, especially when they are filled with gas. The elimination of residual pores can improve the mechanical properties of the product, but on the other hand, a prolonged heating can also deteriorate some properties, due to structure coarsening. Hot consolidation increases the price of the final product, therefore one should evaluate its necessity in view of the required product performances. Beneath further densification hot deformation can also achieve a further shaping of the product.

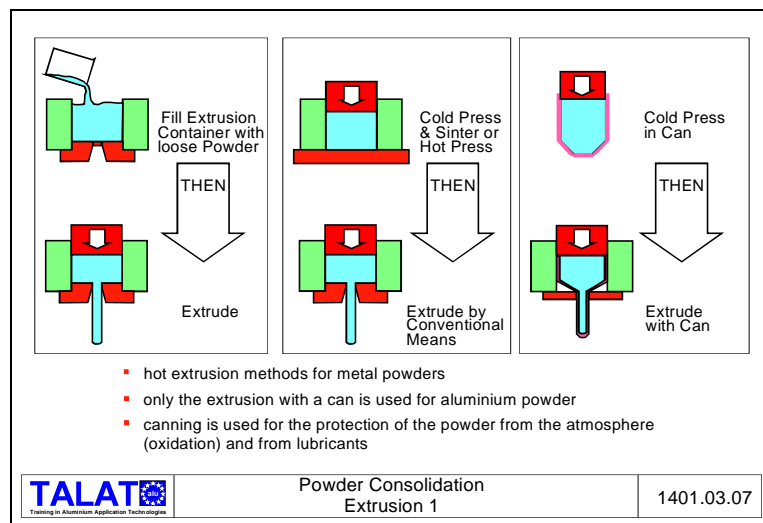
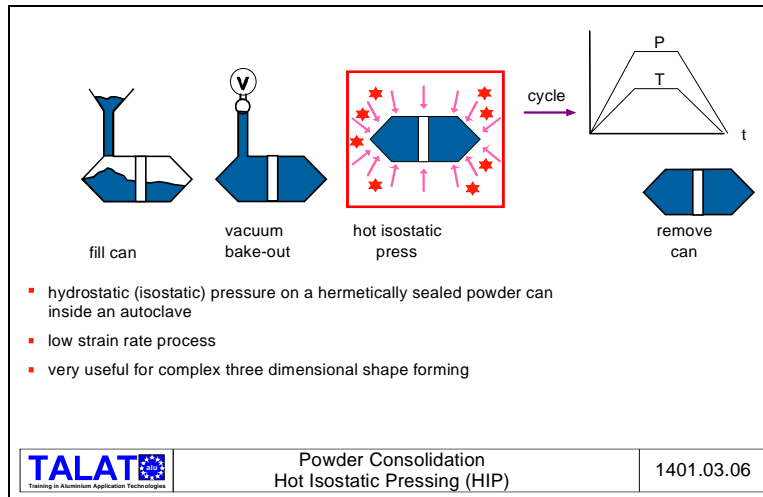
Hot consolidation can be performed on sintered products or directly on cold compacted products. In many cases the product will first be degassed before hot consolidation. The most important techniques of hot consolidation are : forging, extrusion and hot isostatic pressing.

Forging is a high strain rate, hot deformation method which is used for the shaping and further densification of a precompact and sintered preform (**Figure 1401.03.05**). Lubrication of tooling is used to achieve a more homogeneous density.



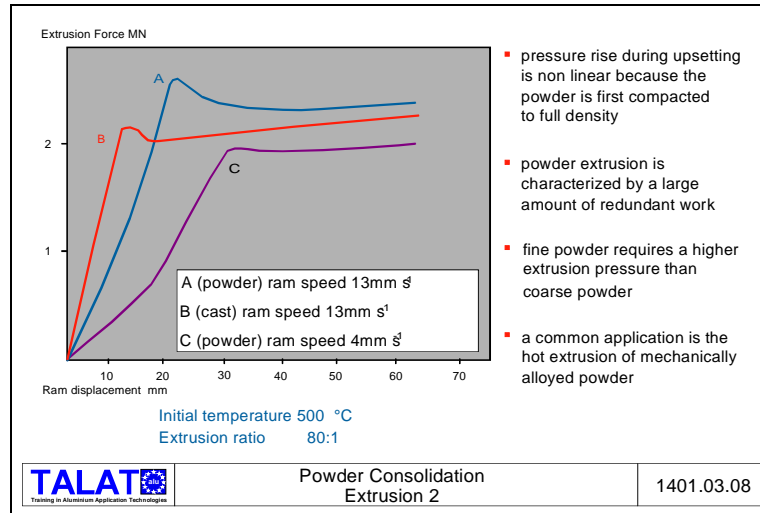
In a **hot isostatic pressing (HIP)** process a can is filled with powder, heated and degassed and then hermetically sealed. This powder container is hydrostatically (often

referred to as isostatically) compressed at elevated temperatures (**Figure 1401.03.06**). Afterwards the pressure is released and the can material is stripped off. It is a low strain rate process which is extremely useful for the forming of complex shapes.



Extrusion is another method to achieve full density. Theoretically there are three methods for the extrusion of metal powders (**Figure 1401.03.07**): the container can be filled with loose powder which is extruded; the powder can be cold pressed to a "green" billet which can be sintered if necessary, or the powder can be densified in a can, degassed and extruded. For aluminium powders only the third method is normally used. Canning is mainly used for the isolation of the powder from the atmosphere (oxidation) and from the extrusion lubricants. By proper choice of the can material an improved lubrication and a better metal flow at the die interface can be obtained. The extrusion of a can is not much different from the extrusion of a classical billet but the initial pressure build up is considerably different as shown in (**Figure 1401.03.08**). For a solid billet the pressure increases linearly as it upsets to fill the container. For a powder

billet the pressure rise during upsetting is non linear because the powder is first being compacted to nearly full density. Although the densification is completed before the onset of extrusion, the powder particles remain poorly bonded and the mechanical strength is low. Only after extrusion the material has been subjected to a sufficient level of shear deformation resulting in sound bonds between the particles.



The pressure P needed to extrude a billet can be expressed by

$$P = a' + b' \ln R$$

with R the extrusion ratio, a' a measure for redundant work and b' a measure for homogeneous work. As can be seen (**Figure 1401.03.09**), the redundant work is much more significant in powder extrusion than in the extrusion of an as cast billet. This is because the redundant work term includes the process of forming cold welds, breaking the weld and rewelding.

Fine powder requires a higher extrusion pressure than coarse powders because more welds are subsequently formed and broken. One of the most common applications for hot extrusion of powders is the consolidation of mechanically alloyed powders.

Post Consolidation

After consolidation of the metal powder a **secondary cold pressing** operation can be applied, especially on sintered products. This can be needed to improve the dimensional accuracy (sizing) and/or to increase the density (repressing). In some cases a coining operation is carried out to give top and bottom of the product a desired surface configuration. Also a number of standard metal finishing operations like machining, heat treatments, surface treatments, etc. can be carried out.

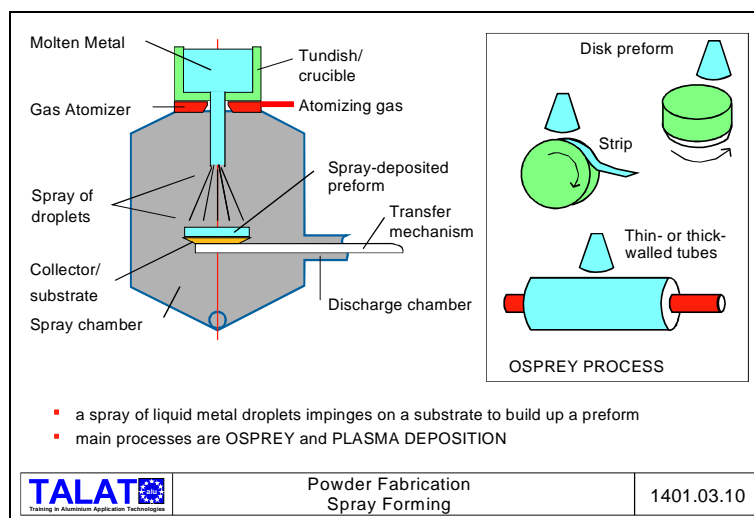
Powder, wt%	Extrusion Relationship	a'/ b'
Al- 3.6Mn 0.95Al ₂ O ₃	P= 555 + 252.5 ln R	2.2
Al- 2.4Mn 1.09Al ₂ O ₃	P= 475.5 + 252.5 ln R	1.9
Al- 1.9Al ₂ O ₃	P= 277.5 + 252 ln R	1.1
Al- 0.26Al ₂ O ₃	P= 187.5 + 252.5 ln R	0.74
99.5 Al (cast)	P= 20 + 287.5 ln R	0.07

TALAT Training in Aluminium Application Technologies	Extrusion Pressure - Reduction Ratio Relationships P = a' + b' ln R	1401.03.09
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Spray Forming

Spray forming is an emerging P/M technology. The material, in the form of a spray of liquid metal droplets, impinges on a substrate to build up a preform. These preforms can subsequently be consolidated into various mill shapes. Two main spray forming processes are Osprey and plasma deposition.

In Osprey, the alloy charge is induction melted in a sealed crucible located atop the spray chamber (**Figure 1401.03.10**). In the atomisation zone below the crucible, the liquid metal stream is comminuted into a spray of droplets by the atomising gas (usually nitrogen or argon). After atomisation, the droplets cool and accelerate toward the substrate, on which they consolidate to form a dense deposit. Composites can be produced by injecting second phase particles or by an in situ reaction with a gas. The resulting microstructure is fine grained, without macroscopic segregation of alloying elements and eventually with a uniform distribution of second phases.



Materials that have been successfully formed by the Osprey process include several aluminium alloys (7075, PM alloy 7090, AlSi alloys) and aluminium matrix composites. Newer aluminium with a high Si-content (exceeding 20 %) has also been sprayed, showing properties exceeding the corresponding wrought alloy.

Plasma spray forming is similar to the Osprey process, but uses a plasma torch in order to produce liquid droplets. Although this process is more suited for high melting materials, interesting Al-based components have been manufactured on laboratory scale.

1401.04 Properties and Applications

- Example 1: The development of the P/M 7xxx alloys
- Example 2: High strength alloys for elevated temperatures
- Example 3: A high modulus, elevated temperature experimental alloy Al-Ti by mechanical alloying.
- Conclusions

Aluminium P/M parts are used for their improved material characteristics or in some cases (e.g. complex shapes) because of their lower production cost. In most of the applications the P/M parts are used because of one (or more) of the following properties: higher Young's modulus, lower density, higher room temperature strength, better high temperature strength, better wear resistance. The greatest variety of P/M parts are currently used by the business machine constructors: lighter weight components reduce inertia on startup and stopping. Aluminium P/M parts have been used for drive belt pulleys, hubs, and caps and connection collars. Other applications are found in automotive components. The need for light, corrosion resistant materials and for strong higher temperature materials promote the interest for P/M aluminium parts.


The strong point of P/M aluminium parts is probably the wide variety of alloy compositions which can be prepared, offering in principle the possibility of achieving a desired combination of properties. A lot of these alloys are currently still under investigation. In the next paragraph we will discuss a selected number of these alloys to give an idea of their (potential) applications.

Example 1: The Development of the P/M 7 XXX Alloys

Powder metallurgical alloys of the 7000 series produced from atomised powders have been investigated since the 1950s. High strengths were achieved but the ductility of extruded bars was very low (typically less than 1 % elongation). From this early work it

appeared that these P/M alloys had better corrosion resistance and a better fatigue limit than the classical ingot alloys. In the early seventies it was demonstrated that good combination of strength (654 MPa), elongation (8 %), exfoliation resistance, fatigue limit (207 MPa.m) and fracture toughness (21 MPa.m^{1/2}) could be obtained. The improvement of toughness by degassing was discovered and efforts were made to scale up the powder billet size to allow the fabrication of plates and sheets. In the 1980s several commercial high strength alloys were developed and registered (see **Figure1401.04.01**). The chemical compositions of the classical 7000 series, were modified by additions of transition elements like Co, Zr or Ni.

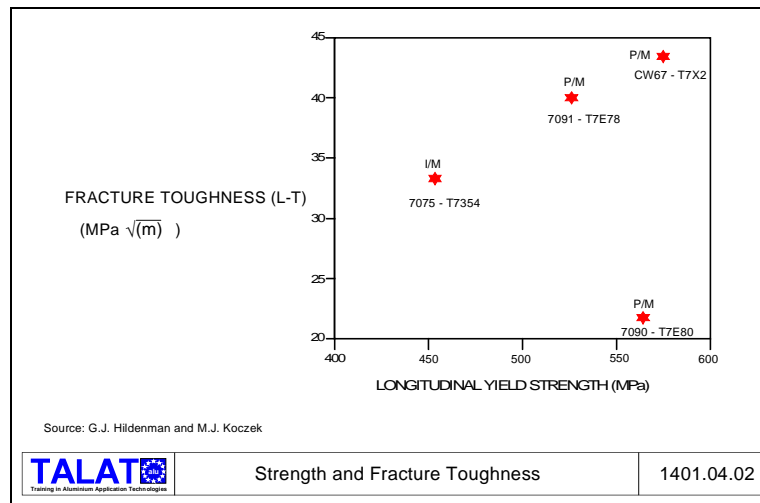
ALLOY	Zn	Mg	Cu	Co	Cr	Zr	Ni	O	COMPANY
7064	7.1	2.3	2.0	0.2	0.1	0.2	-	0.2	KAISER ALUMINIUM
PM 61	8.5	2.5	1.5	0.6	-	0.2	-	0.2	KAISER ALUMINIUM
7090	8.0	2.5	1.0	1.5	-	-	-	0.35	ALCOA
7091	6.5	2.5	1.5	0.4	-	-	-	0.35	ALCOA
CW 67	9.0	2.5	1.5	-	-	0.14	0.1	0.35	ALCOA


Training in Aluminium Application Technologies

Composition of Commercial High-Strength P/M Alloys

1401.04.01

Composition of commercial high strength P/M alloys in order to precipitate thin intermetallic phases. The rapidly solidified 7000 P/M alloys exhibit a better corrosion resistance than the ingot alloys. Stress corrosion in the classical alloys increases with iron content but in the rapidly solidified alloys Fe is trapped in small precipitates and the crack initiation is delayed. For conventional alloys the crack grows along the smooth elongated grain boundaries while for P/M alloys the small grain size imposes a wavy path to the crack propagation and thus an increase in the fracture energy. **Figure 1401.04.02** illustrates that for commercial P/M alloys an excellent combination of strength and toughness in die forging is achieved.

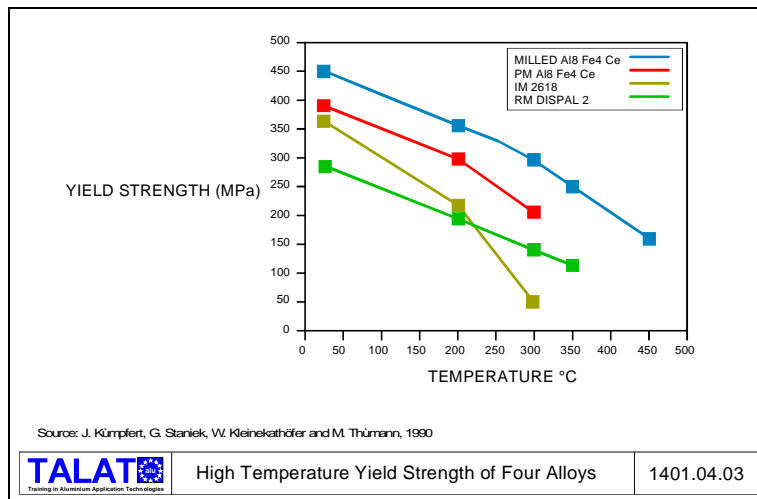


Example 2: High Strength Alloys for Elevated Temperatures

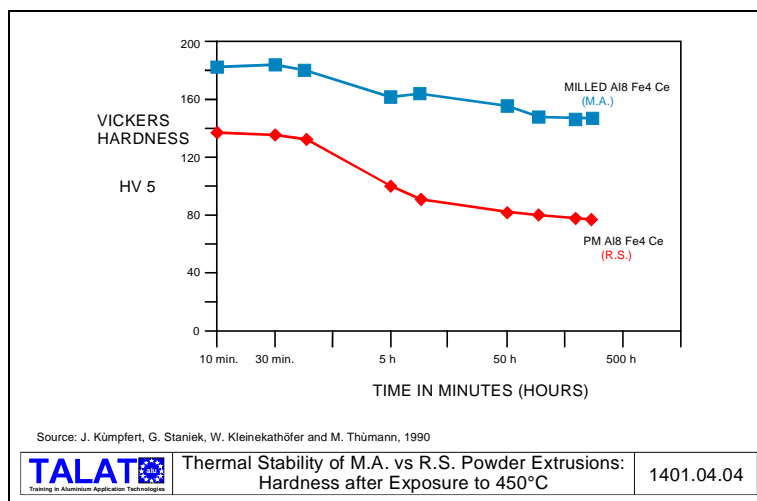
Conventional high strength aluminium alloys such as AA 2618, AA 2219 or AA 2024 lose their strength at temperatures above about 200 °C, mainly because of a rapid coarsening of their precipitates. For certain applications such as jet engine compressors, automotive gas turbines and combustion engine components, aluminium alloys which retain their strength in the range of 300 °C to 450 °C could replace steels or titanium alloys.

To retain a high strength at elevated temperatures, it is necessary to have a uniform distribution of fine dispersoids which pin the grain boundaries and harden the matrix.

Dispersoids of Al_2O_3 and Al_4C_3 can be introduced in an aluminium matrix by mechanical alloying (MA). An example of such an alloy is the so-called "dispal 2" with 1 wt % O and 2 wt % C leading to 10 to 12 vol % of dispersoids. This alloy has a very good thermal stability but at 300 °C the tensile strength is only half of that measured at room temperature (**Figure 1401.04.03**). Nevertheless, its strength above 250 °C is better than for the conventional I/M 2618 alloy. Another way of introducing a high volume fraction of fine dispersoids in an aluminium matrix is the use of a rapid solidification technique and P/M processing. A variety of alloy systems have been investigated and are still being explored. In general aluminium alloys with transition metals (Mn, Co, Fe, Ni, Cr) and rare earth metals (Ce, La) show interesting possibilities; alloy-systems such as Al-Fe-Ce, Al-Fe-V-Si, Al-Fe-Mn, Al-Cr-Zr or Al-Cr-Zr-Mn have been studied. **Figure 1401.04.03** shows that a P/M Al8Fe4Ce alloy has a somewhat higher room temperature strength than the I/M 2618 alloy and that this strength is better retained at higher temperature.



The mechanical properties of the Al-Fe-Ce alloys can be improved by the dispersion of fine Al_2O_3 and Al_4C_3 . These dispersoids are added by mechanical alloying of the rapidly solidified powders (Figure 1401.04.03). As can be seen from Figure 1401.04.04 the thermal stability after mechanical alloying (measured as Vickers hardness) is better than after simple rapid solidification.



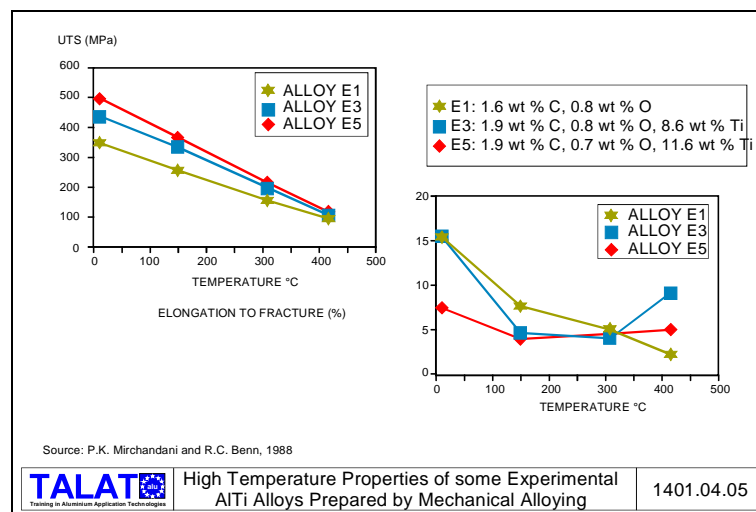
Example 3: A High Modulus, Elevated Temperature Experimental Alloy: Al-Ti by Mechanical Alloying

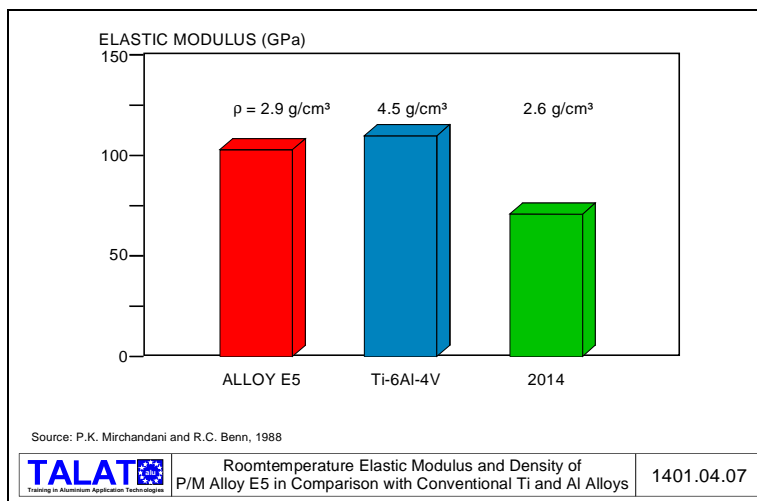
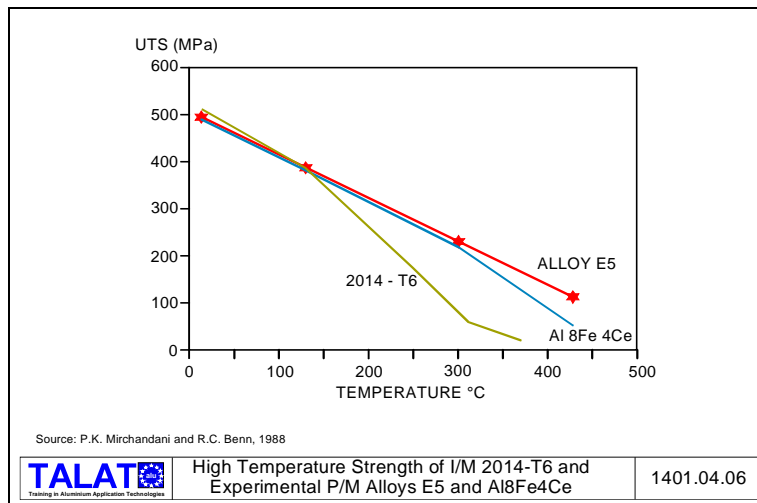
Aluminium alloys with a superior combination of elevated temperature strength, stiffness and thermal stability compared to the conventional ingot alloys, could be a valuable candidate for the replacement of titanium alloys for skin and structural applications in airplanes.

Composites based on conventional aluminium alloys do have the desired high modulus but do not exhibit the useful strength at high temperature and do not have a large ductility. On the other hand many of the available rapidly solidified aluminium alloys for high temperature applications don't have a high elastic modulus (95 to 110 GPa is needed). Since it is generally recognized that the presence of hard, high melting point phases can contribute to both the modulus and the high temperature strength of aluminium alloys, Al-Ti alloys containing up to 35 vol % of submicron size Al_3Ti dispersoids have been prepared. As can be seen from the **Figures 1401.04.05 till .07** the Al-Ti alloys exhibit very attractive combinations of elevated temperature strength, elastic modulus and ductility. Further, these alloys have been found to exhibit good microstructural stability after 500 hrs exposure at 510 °C.

Conclusions

It should be clear from the preceding sections that the P/M processing of aluminium alloys offers the possibility of obtaining alloys with better properties than with conventional ingot metallurgy. Many alloys are still under investigation and regularly new alloy compositions are proposed. Nevertheless an increasing number of P/M alloys are commercially available now. The reason that, compared to the classical alloys, only a small amount of these new alloys is being used for industrial applications is probably due to cost barriers and to the fact that a lot of customers hesitate to use new materials.





1401.05 Literature

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