TALAT Lecture 3201

Introduction to Casting Technology

29 pages, 44 figures

Basic Level

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Objectives:

- To provide an introduction to the techniques used to produce castings and to the range of castings produced
- To gain an appreciation of the production and application of castings

Prerequisites:

- No prior knowledge is assumed.

Date of Issue: 1994
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3201 Introduction to Casting Technology

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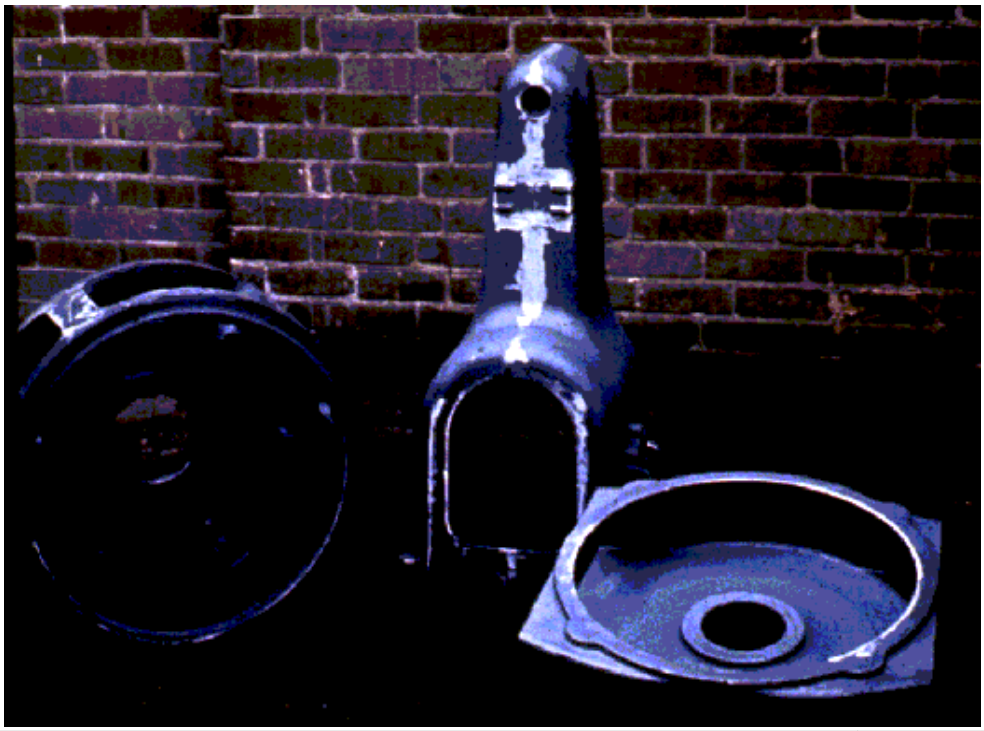
Introduction

This lecture is to set the scene. It plans to answer the questions: what are castings and what does the industry look like? It is worth while spending some time on these initial questions.

The first series of figures will give us an overview of the many varieties of castings which are produced.

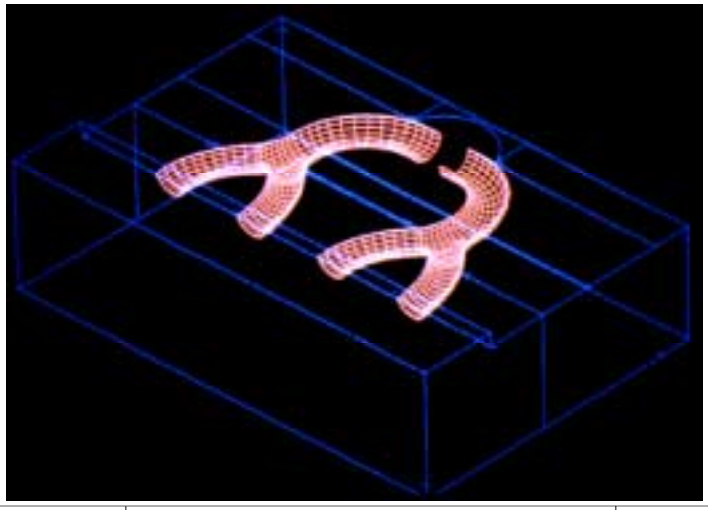
Figure 3201.00.01 may be your image of the casting industry - rough iron castings from a foundry under a railway arch. It is true that some of the industry is still like this, as in many sections of the engineering profession. However, elsewhere, the industry has entered the twentieth century, and is already preparing for the twenty-first!



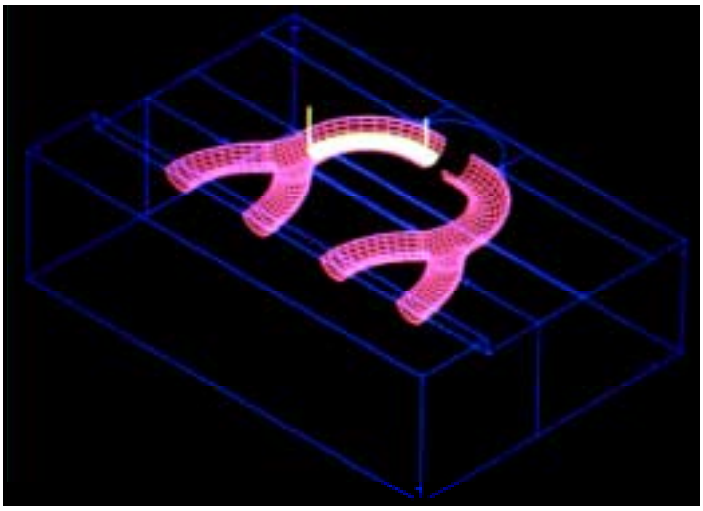
TALAT Training in Aluminium Application Technologies	Image from the "Dark Age" of the Casting Industry	3201.00.01

Low pressure sand casting method (LPS)

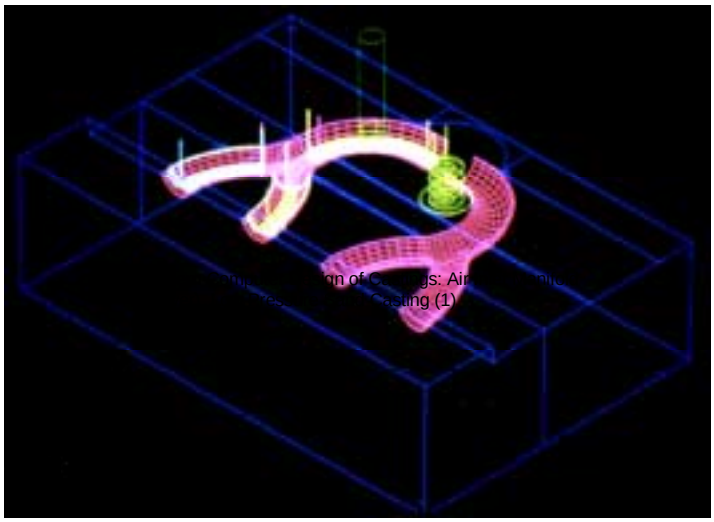
Much modern casting design starts here, on the computer. The series of the following figures (**Figure 3201.00.02, Figure 3201.00.03, Figure 3201.00.04, Figure 3201.00.05** and **Figure 3201.00.06)** shows how the design is built up for an inlet manifold. This was for Rover's highly successful K series engine, based almost entirely on lightweight aluminium alloy castings produced on their Low Pressure Sand (LPS) casting method.



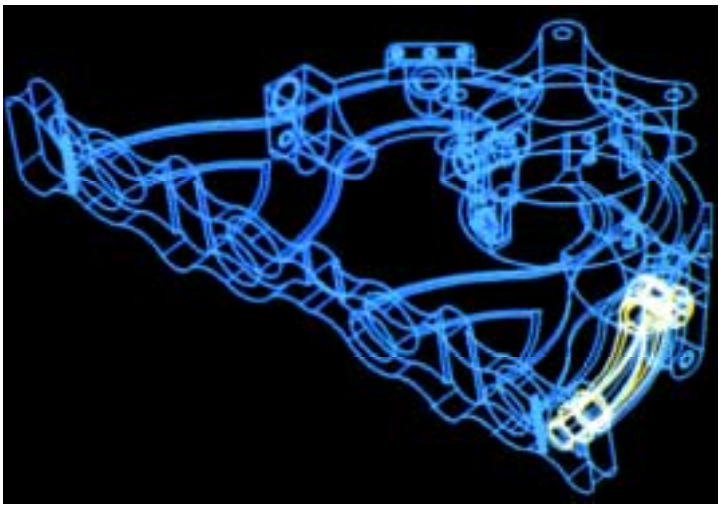
TALAT Training in Aluminium Application Technologies	Modern Computer Design of Castings: Air Inlet Manifold (Rover), Low Pressure Sand Casting (1)	3201.00.02



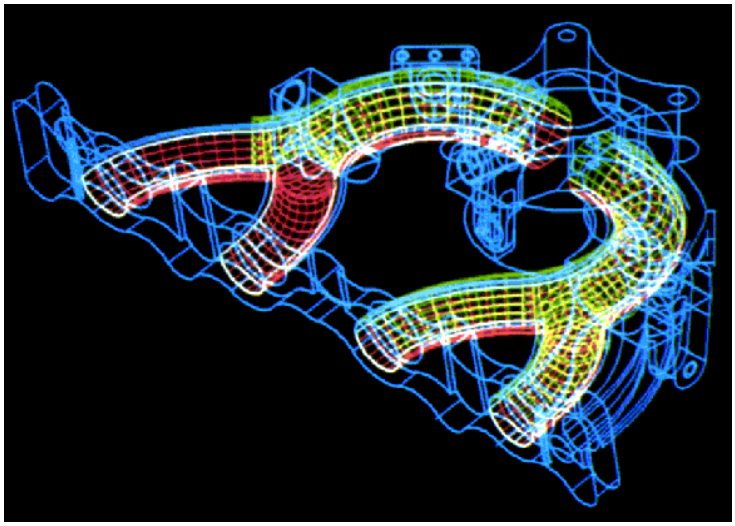
TALAT Training in Aluminium Application Technologies	Modern Computer Design of Castings: Air Inlet Manifold (Rover), Low Pressure Sand Castings (2)	3201.00.03



TALAT Training in Aluminium Application Technologies	Modern Computer Design of Castings: Air Inlet Manifold (Rover), Low Pressure Sand Casting (3)	3201.00.04

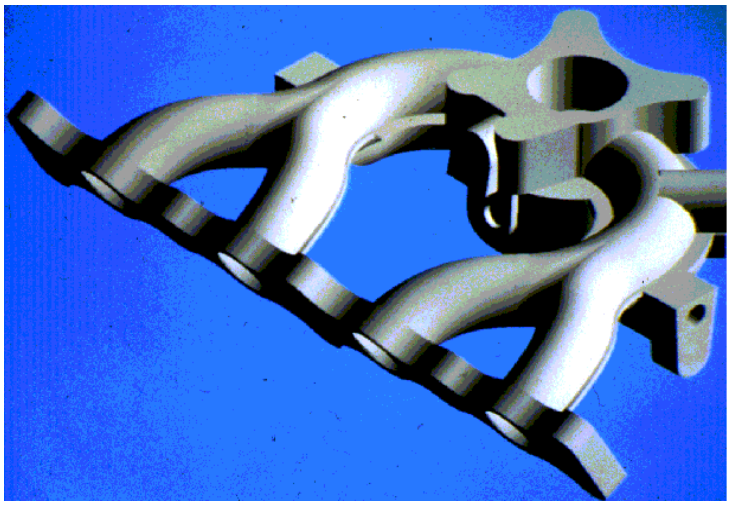


TALAT Training in Aluminium Application Technologies	Modern Computer Design of Castings: Air Inlet Manifold (Rover), Low Pressure Sand Casting (4)	3201.00.05



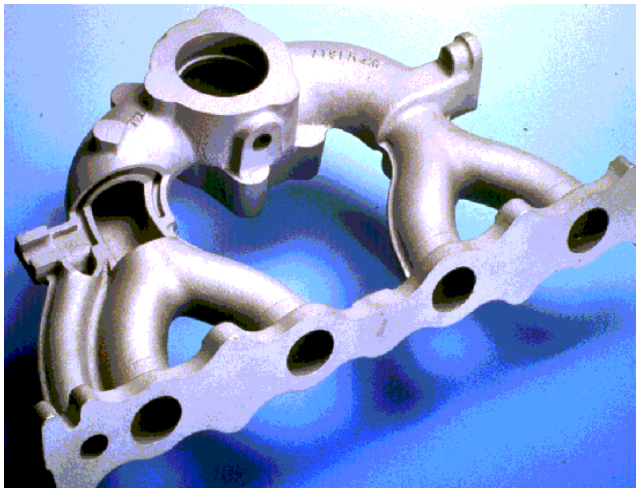
TALAT Training in Aluminium Application Technologies	Modern Computer Design of Castings: Air Inlet Manifold (Rover), Low Pressure Sand Casting (5)	3201.00.06

This was the first inlet manifold which they had designed with a wall thickness of 3 mm. **Figure 3201.00.07** shows the solid model generated on the computer.



TALAT Training in Aluminium Application Technologies	Air Inlet Manifold (Rover), Solid Model Generated by Computer	3201.00.07

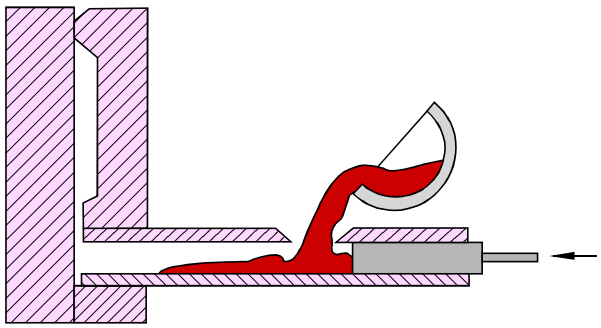
The final casting which the designer received three months later is shown in **Figure 3201.00.08**. It can be commented that three months was a good achievement for a casting having high technical requirements - the competitors did not succeed even after 15 months.



TALAT Training in Aluminium Application Technologies | Final Casting Shipped 3 Months after Receipt of Orders | 3201.00.08

Pressure die casting process

And now for something completely different! Approximately half of all light alloy castings are made by the pressure die casting process, in which the liquid metal is injected at high speed and high pressure into a metal mould which is usually called the die. The principle of the pressure die casting process is shown in **Figure 3201.00.09**.



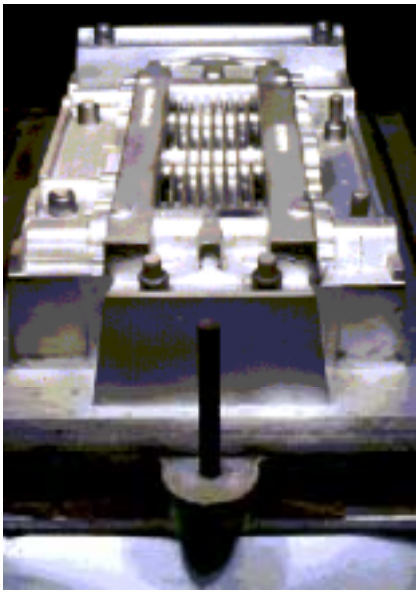
TALAT Training in Aluminium Application Technologies | Principle of the Pressure Die Casting Process | 3201.00.09

Figure 3201.00.10 shows a simple gear for an instrument application and is a pressure die casting. It is characterised by a good quality surface finish which often means that machining is not required. However, we need to take care with pressure die castings because, although the product in this case seems to be perfectly well suited to its application, the lack of internal unsoundness is a cause for concern in other applications where strength and possibly leak tightness are required properties. As we will see in later lectures, turbulence and air bubble entrapment often cause an *Aero Chocolate* structure which has poor metallurgical properties and causes leaks in many castings.

TALAT Training in Aluminium Application Technologies	Example of High-Pressure Die Casting (Gear)	3201.00.10

Pattern for sand castings

I would now like to return to sand castings which, in contrast to pressure die castings, can be made sound and leak tight. The pattern is the starting point for making a mould and **Figure 3201.00.11** illustrates a simple pattern which will form the lower half of a sump casting for a racing engine.



TALAT Training in Aluminium Application Technologies	Pattern for a Racing Engine Sump (Sand Casting)	3201.00.11

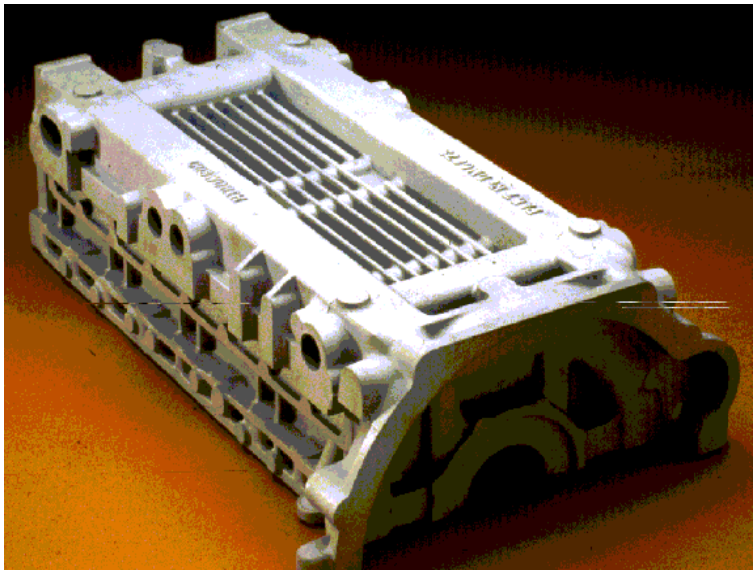
Figure 3201.00.12 shows the lower half-mould which now also contains a number of cores which will form some of the waterways and oil passageways in the sump. It should be noticed that one of the cores is painted with a white ceramic wash. This is an oil passageway core and the customer was insistent that no grains of sand remain in this

interior part of the casting which is difficult to clean. The upper half of the mould can also be seen assembled ready to be closed over. Other cylinder heads are discernible in the distance.

TALAT Training in Aluminium Application Technologies	Half-Mould with Cores (White Core for Oil Passageway); Upper Half-Mould in Back	3201.00.12

Example of cast component

Figure 3201.00.13 is a view of the finished casting. This was the lower crankcase for the Cosworth DFV Formula 1 engine.



TALAT Training in Aluminium Application Technologies	Finished Casting (lower Crankcase of the Cosworth DFV Formula 1 Engine)	3201.00.13

Cores and moulds

You remember that it is necessary to start with a pattern to make a mould and we shall see some examples of patterns in the next slides. However, you should also remember that the hollow inside part of a casting is formed by a core - this can be remembered by analogy with an apple core. Such shapes in sand are formed in a special sort of pattern called a core box. We shall see some examples of cores being produced from core boxes in this section. As a final note before we start these slides, you should notice in places that the distinction between moulds and cores becomes hazy in the core assembly process, in which large blocks of sand are formed in boxes, as a core, but are assembled together to form a mould.

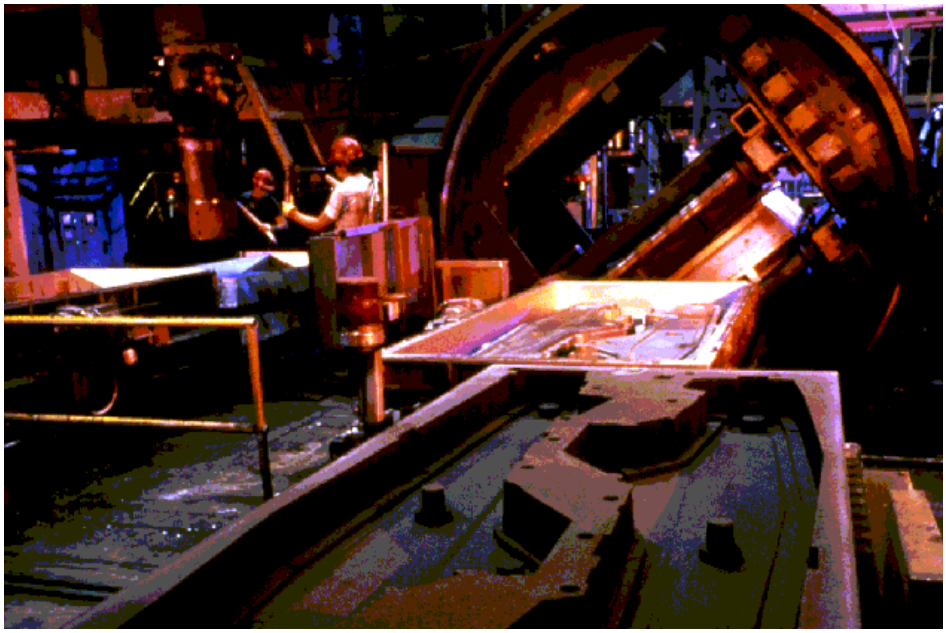
The making of sand shapes in hard, chemically-bonded sands is an important area of foundry technology. In **Figure 3201.00.14 w**e see here a core-making machine in the Caterpillar Foundry in Peoria, Illinois, using the Ashland Isoset process. This allows core sand (silica sand mixed with a two-part binder consisting of a phenol formaldehyde resin and a reactive isocyanate) to be blown into a core box and then hardened by passing an amine catalyst in a carrier gas through it. Thus the core is more-or-less fully hardened by the time it is ejected from the box. This provides high productivity and high accuracy.

TALAT Training in Aluminium Application Technologies	Core-Making Machine Using the Ashland Isoset Process (Courtesy: Caterpillar Foundry, Preoria, Illinois)	3201.00.14

Figure 3201.00.15 gives another view of large cores being assembled to make a mould.

TALAT Training in Aluminium Application Technologies	Assembly of Large Cores to Form a Mould	3201.00.15

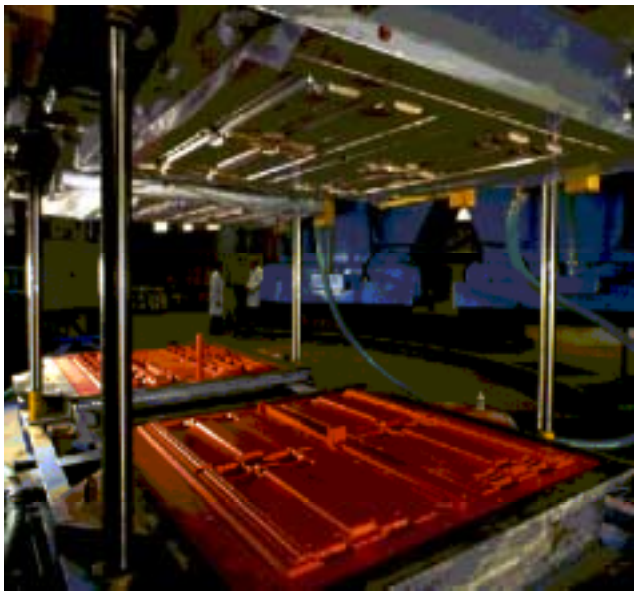
The production of large mould halves in chemically-bonded self-setting sand at the Pryor Foundry, Oklahoma, showing the superb engineering required to turn moulds of this size (**Figure 3201.00.16**).



TALAT Training in Aluminium Application Technologies	Machine for Turning Over Large Moulds	3201.00.16

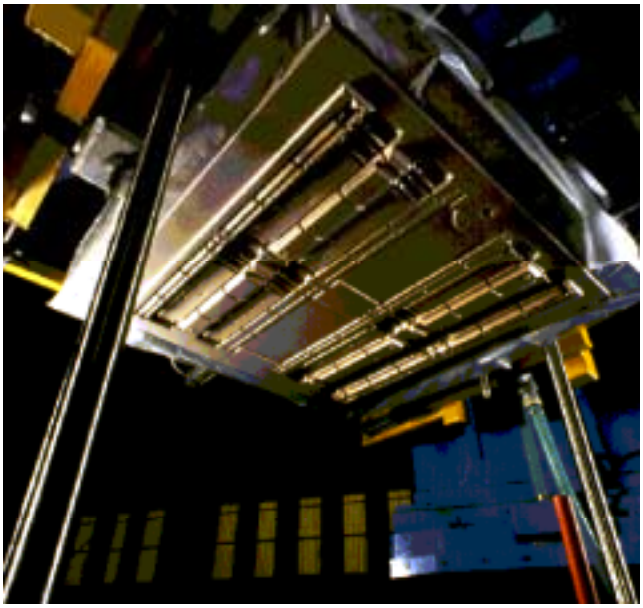
Figure 3201.00.17 shows a process where no binder is used to bond together the sand. The mould is sealed on its front face with a thin film of plastic and a vacuum used to hold the sand grains in place. The mould has just been stripped off the pattern, which can be seen coloured red below. The vacuum moulding process, normally abbreviated to

the V-process, is not widely used in Europe, but is popular in Japan where it was invented. The high quality and smoothness of the mould face can just be seen in this view.



TALAT Training in Aluminium Application Technologies	Vacuum Moulding Process (Japan)	3201.00.17

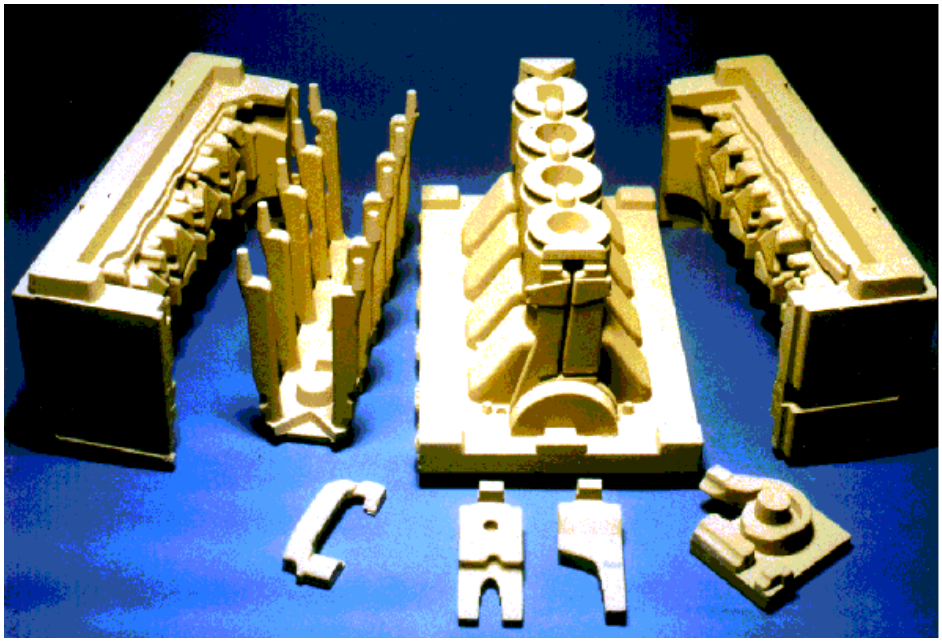
A close-up of the V-process mould is shown in **Figure 3201.00.18** which clearly demonstrates that sand can be used to make complicated shapes.



TALAT Training in Aluminium Application Technologies	Sand Mould Made by the V - Process	3201.00.18

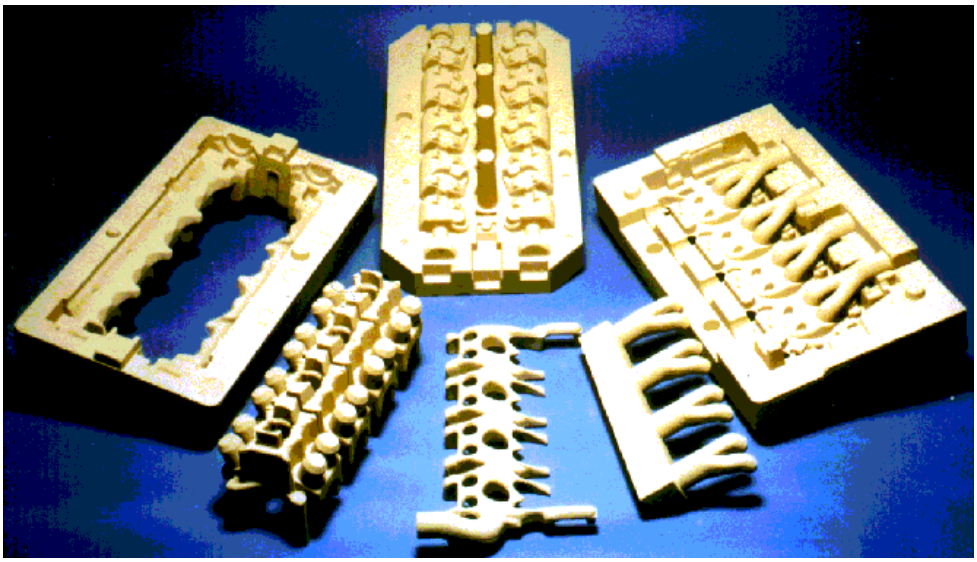
Figure 3201.00.19 shows a set of chemically-bonded sand cores ready for assembly to make a cylinder head mould for the Rover K series engine. The high quality of the cores

is clear and the technique allows the construction of extremely precise moulds. The technique is known as the Core Assembly Process.



TALAT Training in Aluminium Application Technologies	Set of Chemically Bonded Sand Cores for Cylinder Head Mould (Rover, Longbridge)	3201.00.19

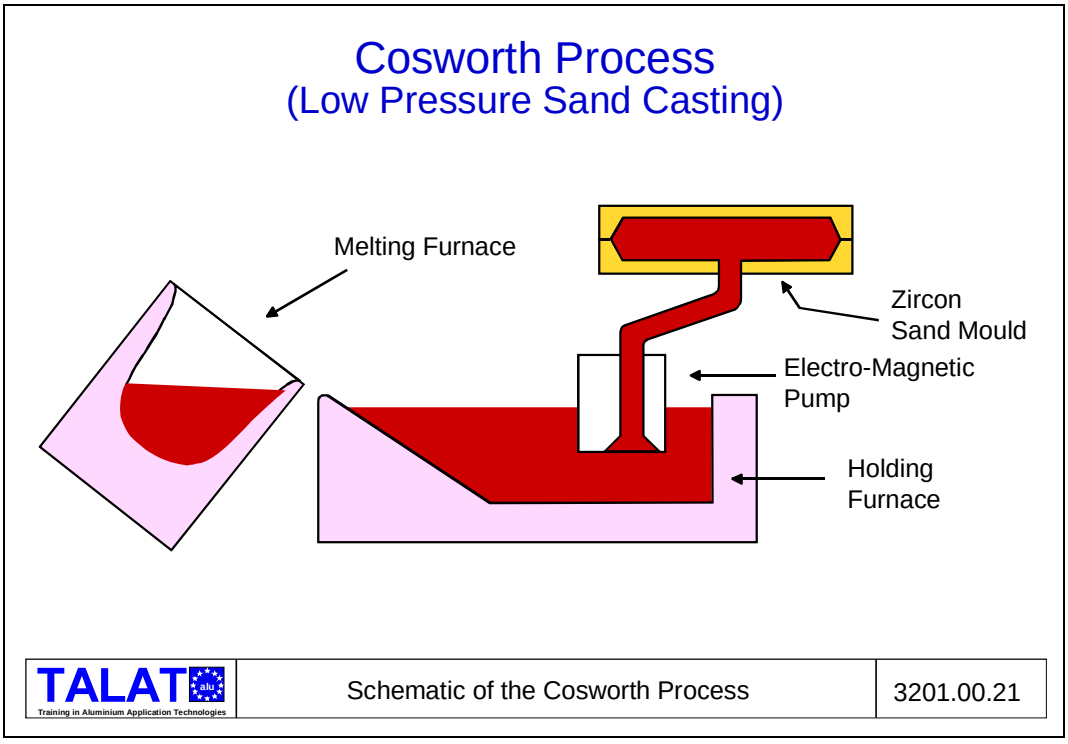
Figure 3201.00.20 shows a similar set of cores for the assembly of the cylinder block for the K series engine, again in the Rover foundry in Longbridge.



TALAT Training in Aluminium Application Technologies	Set of Chemically Bonded Sand Cores for Cylinder Block (Rover, Longbridge)	3201.00.20

The Cosworht Process

The Cosworth Process is a modern development designed specifically for the high volume production of high quality automotive castings. The process illustrates the fact that liquid metal need not be poured to make a casting. In this case, it is pumped uphill against gravity and this enables control to be maintained over the process of filling the mould. The large reservoir of liquid metal in the holding furnace allows time for impurities to sink or float, and the electromagnetic pump (which contains no moving parts) displaces the best quality metal from the mid-depth of the holding furnace up and into the mould, displacing the air ahead of it as it goes (**Figure 3201.00.21**).



The process is capable of a great degree of sophistication with the pump being programmable to fill each type of casting with an optimum filling program. In the latest variant of this process - the Mark II - the metal is introduced through the side wall of the mould which is then rolled over and detached from the filling system. This enables the throughput of moulds to be increased since it is no longer necessary to wait for the metal in one mould to solidify before the next mould is indexed into position at the pouring station.

This process is being adopted by Ford in the USA and Rover have used a similar approach in their LPS Process shown earlier.

Figure 3201.00.22 shows the Cosworth Foundry in Worcester, UK, showing the lightweight engineering approach to the design of the plant, and is in marked contrast to the common image of foundries under the railway arches.

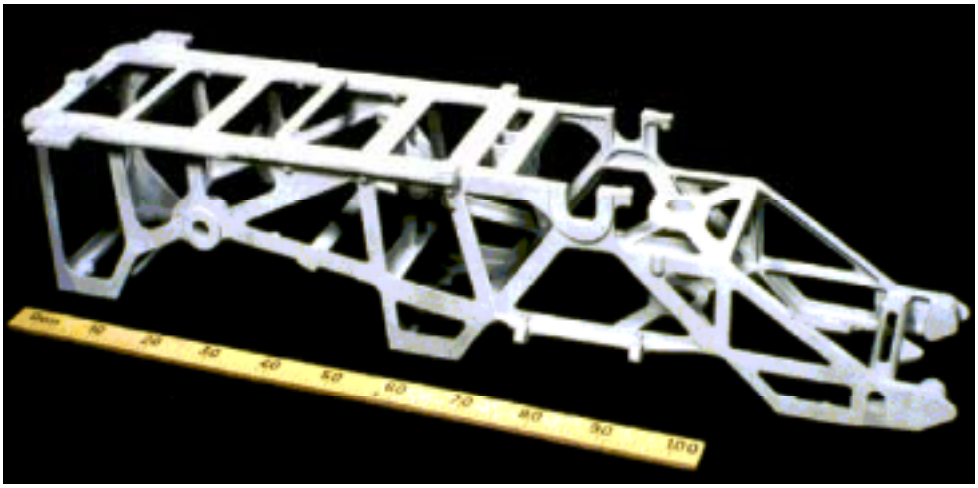
TALAT Training in Aluminium Application Technologies	Cosworth Foundry in Worcester, UK, Showing the Lightweight Foundry Equipment Design	3201.00.22

Examples of sand cast components

Figure 3201.00.23 is a housing for a rotary engine developed by Norton Engineering for motorbikes and has both thick (15 mm) and thin (2 mm outer shroud) sections. This is a sand casting, but filled under gravity, showing that simple filling systems can be made to work well for many castings and that an uphill filling system is not always necessary (even though it would nearly always produce a good casting).

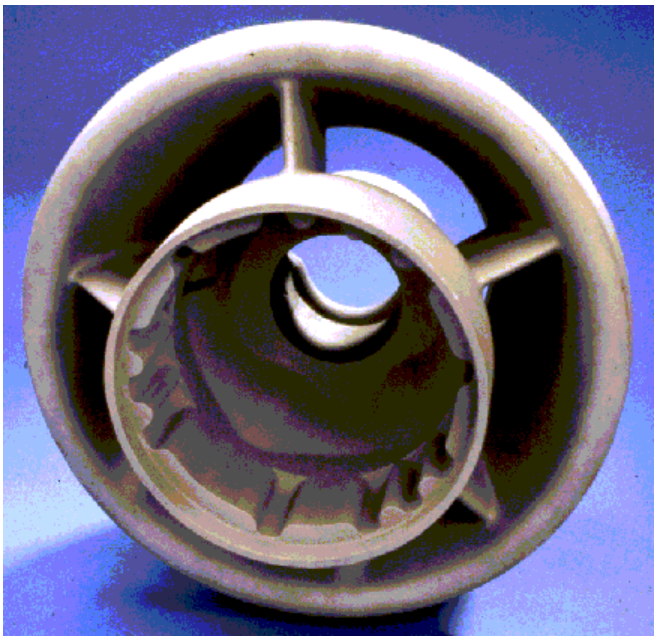
TALAT Training in Aluminium Application Technologies	Rotary Engine Housing with Thick (15 mm) and Thin (2 mm) Sections	3201.00.23

In **Figure 3201.00.24** we now have a series of three sand castings used by the aerospace industry. This is a lightweight space frame for a pilot's ejector seat.

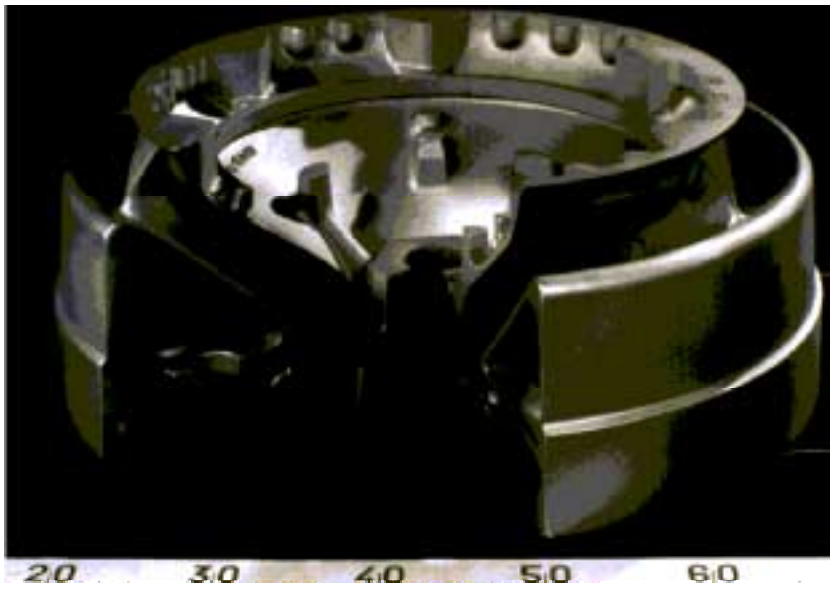


TALAT Training in Aluminium Application Technologies	Aerospace Sand Casting: Pilot`s Ejector Seat Frame	3201.00.24

Figure 3201.00.25 shows an air intake for the Rolls Royce Gem engine which powers the Lynx helicopter, and **Figure 3201.00.26** an even more complex air intake for an aerospace engine produced in France.



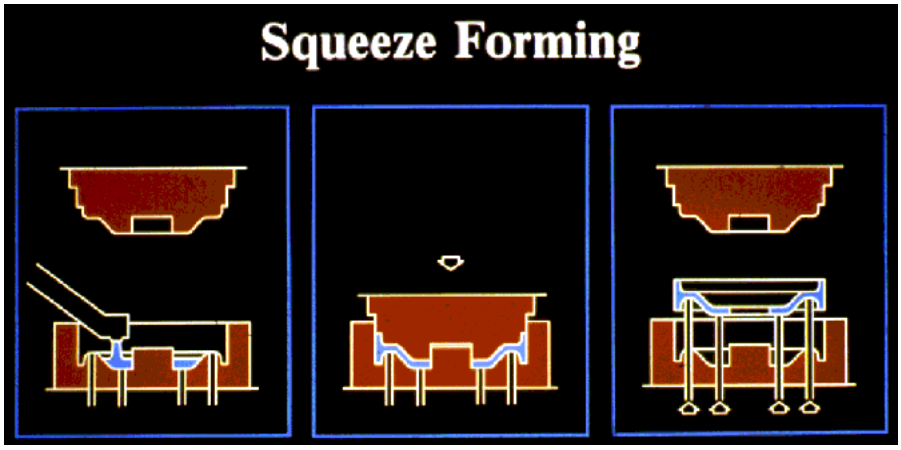
TALAT Training in Aluminium Application Technologies	Aerospace Sand Casting: Air Intake for a Turbo-Engine (Rolls Royce)	3201.00.25



TALAT Training in Aluminium Application Technologies	Aerospace Sand Casting: Air Intake for a Turbo-Engine (France)	3201.00.26

Squeeze Casting Process

We shall now turn to a completely different kind of casting technology. You will recall that we introduced the current topic with a picture of a pressure die casting, but with a warning of its probable unsoundness. The Squeeze Casting Process was developed to counter unsoundness in die castings and is shown in the next slide (**Figure 3201.00.27**).



TALAT Training in Aluminium Application Technologies	Schematic of the Squeeze Casting Process (Sometimes Also Called Squeeze Forming)	3201.00.27

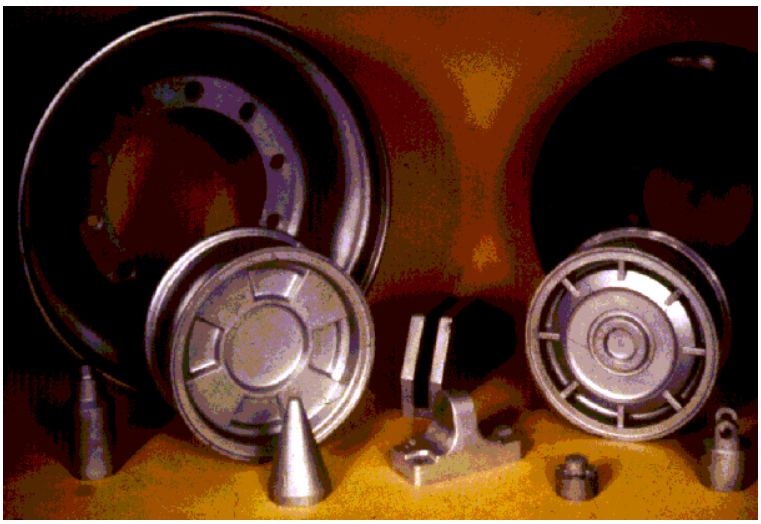
Metal is introduced into an open die, just as in a closed die forging process. The dies are then closed. During the final stages of closure, the liquid is displaced into the further parts of the die. No great fluidity requirements are demanded of the liquid, since the

displacements are small. Thus forging alloys, which generally have poor fluidities which normally precludes the casting route, can be cast by this process. This is a unique advantage enjoyed by Squeeze Casting. For this reason, it is sometimes known as Squeeze Forming, to emphasize its similarity to forging processes. The other great advantage of Squeeze Casting is of course the potential of the process to produce products which are effectively perfectly sound. In practice this is not always so easy, but the process has to be recognised as having unique potential in this respect.

Figure 3201.00.28 shows the massive presses at GKN Sankey, Telford, UK on which the Squeeze Casting dies are mounted. This is very much heavy engineering and the high costs of the castings produced by this process reflect this.

TALAT Training in Aluminium Application Technologies	GKN Sankey Squeeze Casting Machine (Telford, UK)	3201.00.28

Typical products produced by Squeeze Casting are necessarily simple, produced if possible from simple two-part dies (**Figure 3201.00.29**). This is the usual geometrical limitation of all of the die casting processes. However, although *side pulls* can be used on die casting moulds to produce cored holes, they are especially vulnerable to being sheared off in a Squeeze Casting press!



TALAT Training in Aluminium Application Technologies	Typical Examples of Squeeze Casting Product Forms	3201.00.29

Investment Casting

I would now like to turn to yet another totally different area of foundry technology: investment casting. This is of course widely known as lost wax casting, because of the use of wax patterns which are coated with a refractory (i.e. the patterns are invested in alternate layers of slurry and stucco), with the wax patterns subsequently melted out to leave a hollow shell into which the metal is cast.

The elegant die from Deritend Precision Castings, Droitwich, UK makes impeller patterns in wax (**Figure 3201.00.30**). The centre is made from steel, with bronze being used for the sliding inserts.

TALAT Training in Aluminium Application Technologies	Investment (Lost Wax) Casting: Die Assembly for Production of Wax Patterns (here: Impeller Wheels)	3201.00.30

In **Figure 3201.00.31** a series of wax patterns is assembled onto a common running system known as a tree and dipped by hand into the ceramic slurry.

TALAT Training in Aluminium Application Technologies	A "Tree" of Wax Patterns being Coated with Ceramic Slurry	3201.00.31

Figure 3201.00.32: the coated pattern is removed, coated in refractory stucco and allowed to dry. The dipping process is repeated many times until a shell of sufficient thickness is built up, typically a minimum of ~7 mm. Until recently, the size of investment castings was limited by the size of shell which could be manhandled.

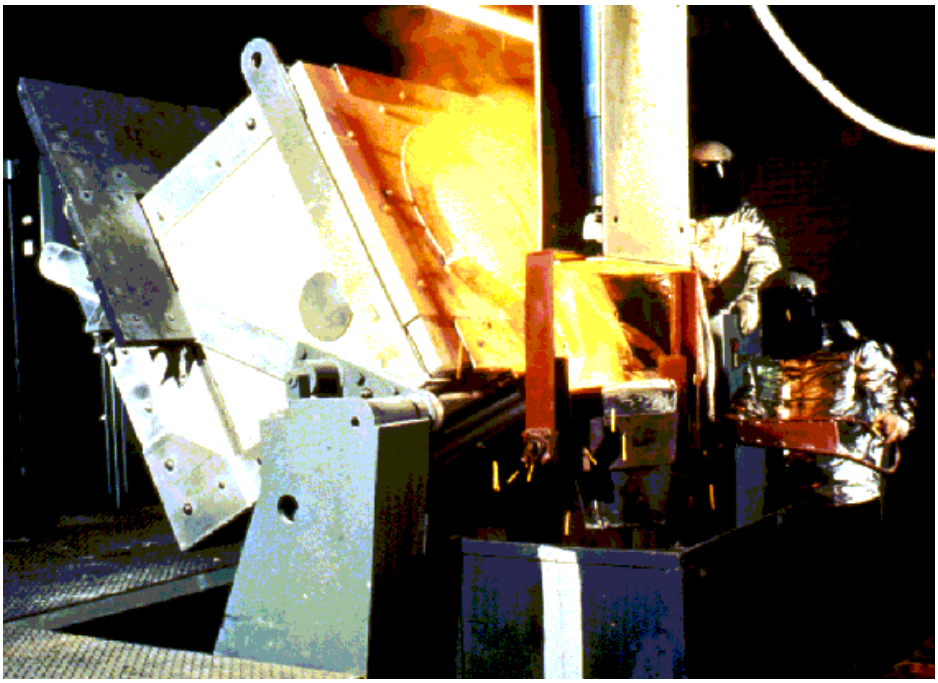
TALAT Training in Aluminium Application Technologies	Dipping Process is Repeated until Sufficient Coating Thickness is Achieved (~7 mm)	3201.00.32

An overall view of a modern facility for making ceramic shells is shown in **Figure 3201.00.33**. A series of slurry tanks and fluidised beds for the stucco are arranged around a robot. The increased weight carrying capacity offered by a robot has

revolutionised the investment casting industry, since castings can now be made with overall dimensions of a metre or more.

TALAT Training in Aluminium Application Technologies	Overall View of a Modern Ceramic Coating Plant	3201.00.33

Figure 3201.00.34 shows a steel investment casting being cast.

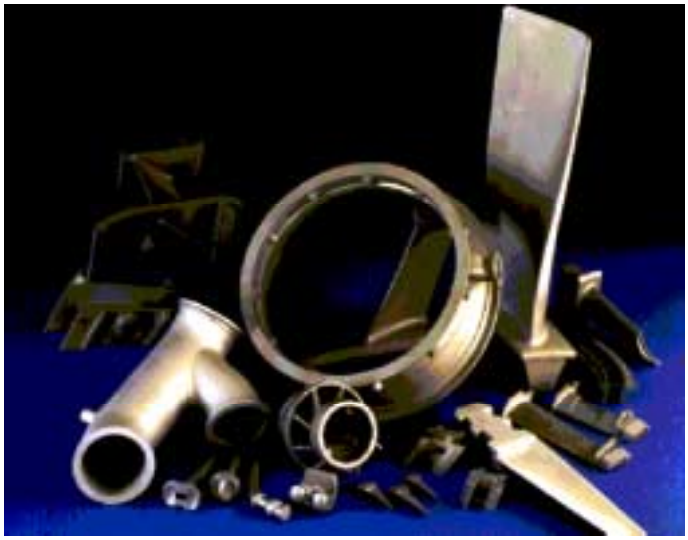


TALAT Training in Aluminium Application Technologies	A Steel Investment being Cast	3201.00.34

The shell has to be removed from the casting which is then cut off from its running and feeding system (**Figure 3201.00.35**).

TALAT Training in Aluminium Application Technologies	Cutting off Runners and Feeders from the Casting	3201.00.35

In **Figure 3201.00.36** lost wax castings have noticeably different forms from other cast shapes. Clearly, the process is versatile in the complexity of shapes which can be formed.



TALAT Training in Aluminium Application Technologies	Examples for Lost Wax Castings: Versatility of Form	3201.00.36

Cast Metal Production

I would now like to move on to give you an overview of the light metals casting industry.

The table in **Figure 3201.00.37** shows the world-wide annual production of castings, from which it can be seen that ferrous castings remain a long way ahead of non-ferrous metals. The majority of non-ferrous castings are made in a wide variety of aluminium alloys and this is followed in importance by zinc alloys. Only relatively limited tonnages of castings are made in magnesium alloys because of their cost. We shall concentrate on the aluminium alloys. These are mainly produced using die casting, sand casting and investment casting, with smaller tonnages being cast using squeeze casting and the *lost foam* process. We shall look at each of these in turn.

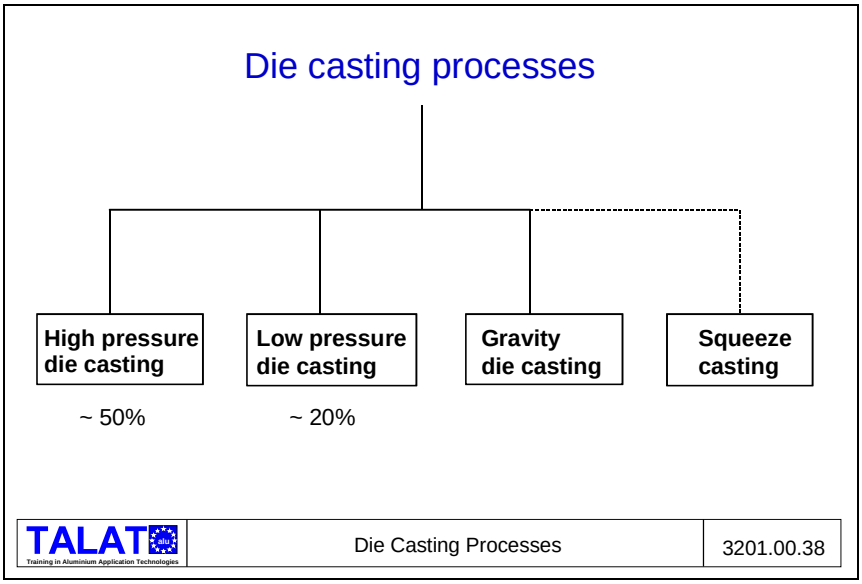
World production of castings 1990

Metal	Production Millions of metric tonnes
Cast irons	54.6
Steels	5.0
Copper-base	0.8
Aluminium	3.4
Magnesium	0.3
Zinc	0.4
Other	0.1
Total	**64.6**

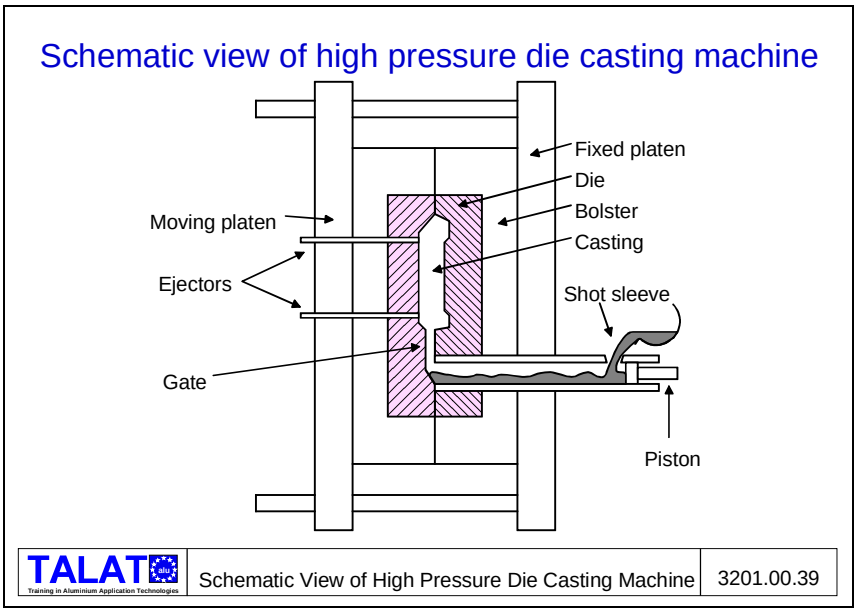
TALAT Training in Aluminium Application Technologies | World Production of Castings 1990 | 3201.00.37

Die Casting Processes

There are a number of die casting processes, as summarised in **Figure 3201.00.38**. High pressure die casting is the most widely used, representing about 50% of all light alloy casting production. Low pressure die casting currently accounts for about 20% of production and its use is increasing, mainly because it is being favoured by the Japanese car companies that have recently been expanding. Gravity die casting accounts for the rest, with the exception of a small but growing contribution from the recently introduced squeeze casting process.



High pressure die casting is carried out using a large, expensive piece of equipment shown schematically in **Figure 3201.00.39**. It consists of two vertical platens on which bolsters are located which hold the die halves. One platen is fixed and the other can move so that the die can be opened and closed. A measured amount of metal is poured into the shot sleeve and then introduced into the mould cavity using a hydraulically-driven piston. Once the metal has solidified, the die is opened and the casting removed.



Low pressure die casting differs in two significant ways (**Figure 3201.00.40**). Firstly, the machine is vertically oriented which gives a horizontal die-parting line. The molten metal is held in a sealed vessel which is then pressurised by gas (usually air) so that metal is displaced ‘’up-hill’’ into the die cavity. In theory, this should be beneficial since it should lead to the controlled filling of the mould. However, in practice, there is often poor control with the result that metal fills the mould in a turbulent manner. This process is mainly used for producing automotive wheels and it is interesting to note that every wheel is X-rayed since these are safety-critical parts.

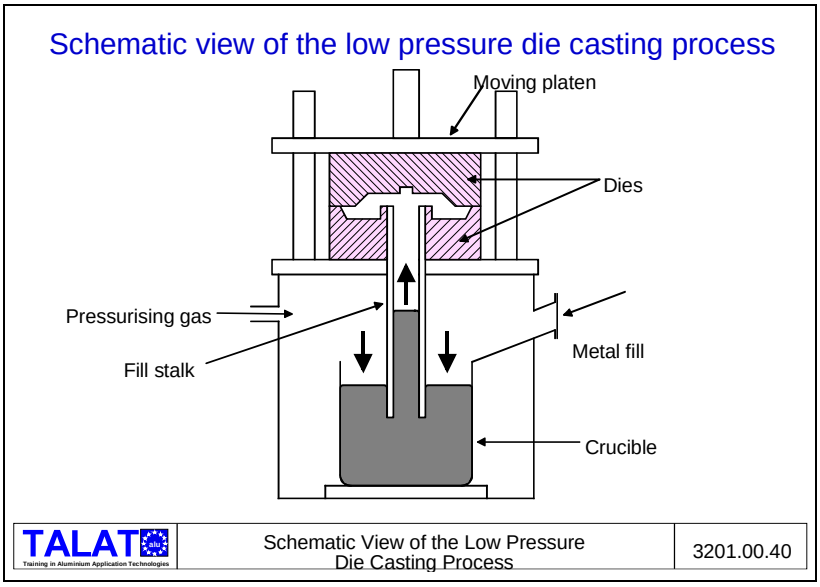
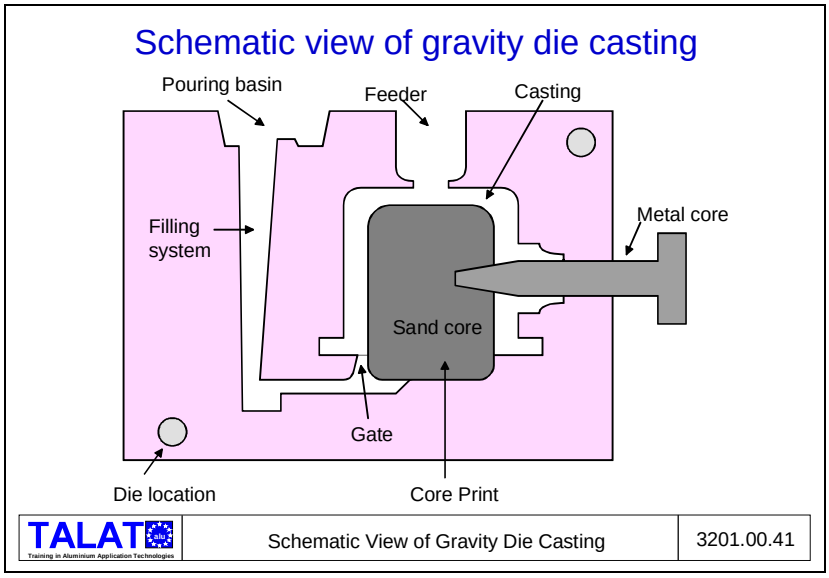


Figure 3201.00.41: Gravity die casting is the simplest die-casting process. It enables castings to be produced with only a very modest capital investment, although plenty of hard physical work is required! However, it can also be automated with either horizontally or vertically-parted dies. Good quality castings can be produced if sufficient care is taken to design running and gating systems which minimise surface turbulence in the metal as it flows into the die.

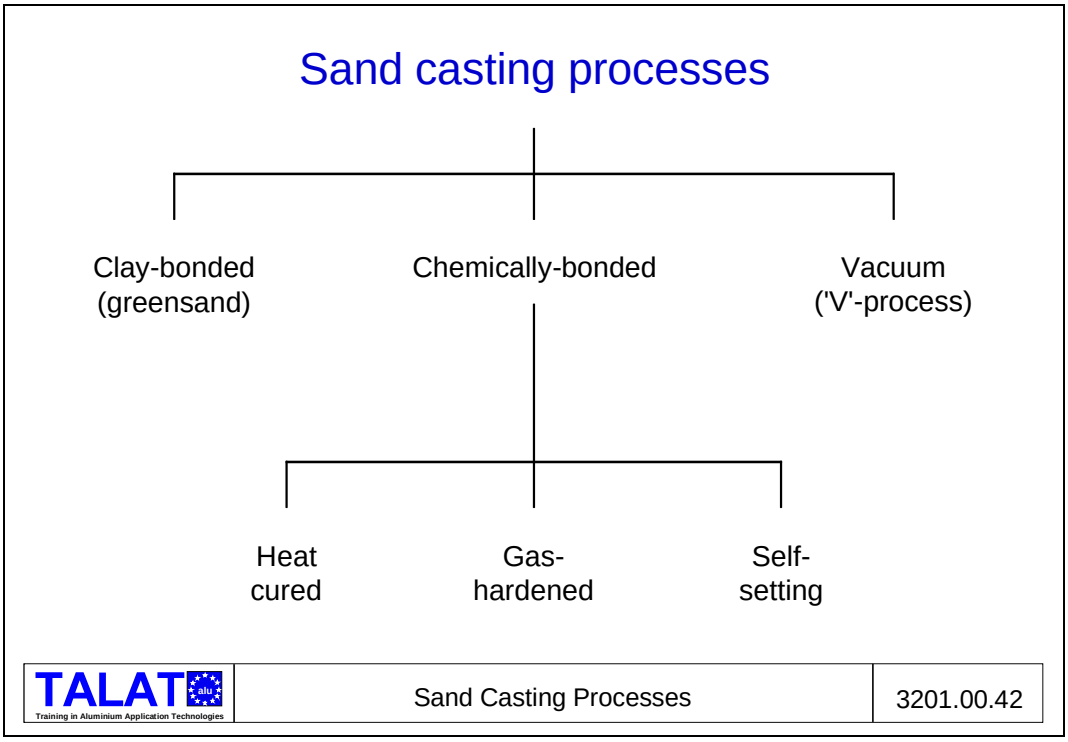


The die casting processes are limited by their poor productivity since it is necessary to wait for the metal to solidify before the die can be opened. [However, at considerable expense, it is sometimes possible to overcome this restriction with gravity die casting by mounting a number of dies on a carousel.] During the solidification time, the very expensive plant is not being used and hence the capital investment is not being recovered. As an example, the cycle time for producing a typical die-cast cylinder head is about 5 - 7 minutes, although this can be as long as 15 minutes for larger variants, such as a Jaguar cylinder head. Ideally, therefore, die casting should be restricted to thin-walled components. The other limitations with all forms of die casting are the high cost

of the dies themselves and their limited lives as a result of thermal fatigue which causes craze-cracking of the working faces.

Sand Casting Processes

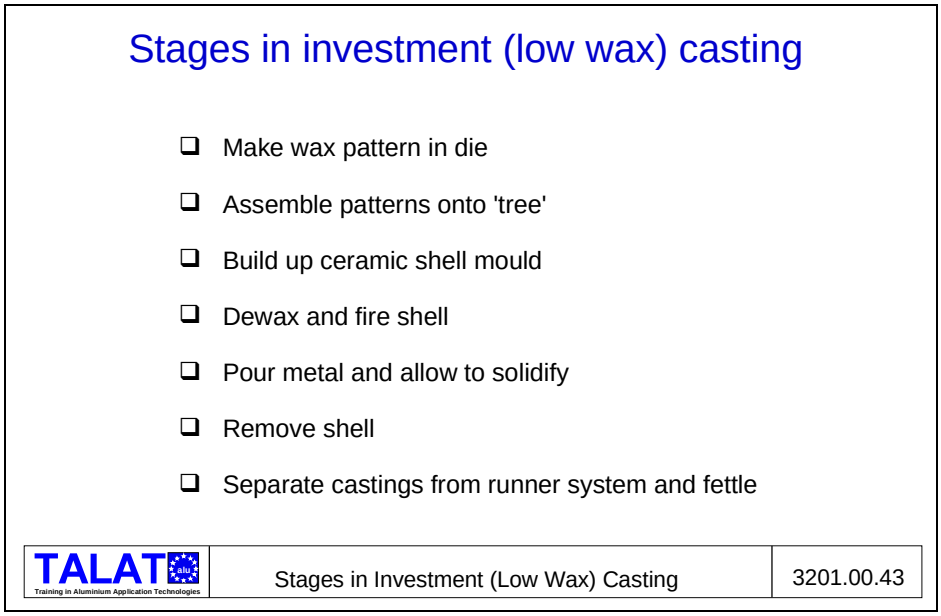
In contrast to the long cycle times inherent in die casting, high production rates can be achieved when casting into sand moulds (**Figure 3201.00.42**). This shows the family of sand-casting processes and in each case, the rate-controlling step is the rate at which the moulds can be produced. The technology has developed to the point where some automatic greensand moulding machines can produce moulds at the very high rate of one every 12 seconds. This process relies on the use of moist clay to bind together the sand grains to produce a *green* (i.e. unfired) mould.

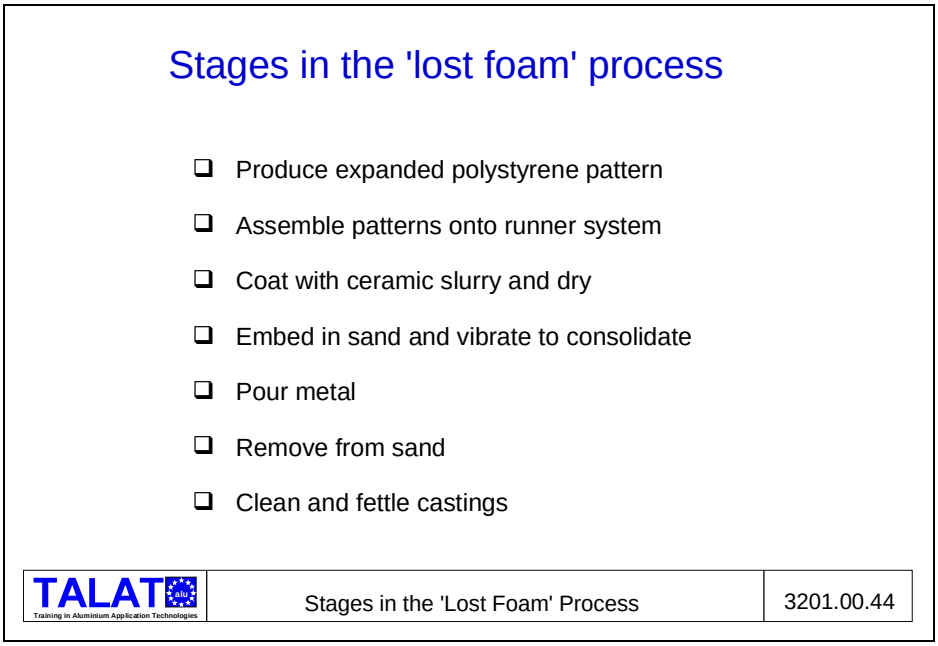


Most of the other sand moulding processes employ a chemical resin to bond together the sand grains. The resin is subsequently cured by using heat or gas; alternatively a number of self-setting resins are available. Although it typically takes 30 - 60 seconds to make a mould and to cure it, this is nevertheless faster than most die casting cycles.

Investment Casting Processes

The steps in the investment casting process are shown in **Figure 3201.00.43**. It is an extremely slow process and the production rate is governed by the time to make the mould. The production of a wax pattern might take only 1 or 2 minutes but most ceramic shell moulds require between 7 and 14 coats and take at least 24 hours and sometimes as long as several days to complete. However, it is now normal practice to make several hundred moulds automatically in one batch and, of course, each mould may comprise several dozen or over a hundred small components.





The *lost foam* or *expanded polystyrene* or *evaporative pattern* casting process again

consists of a number of steps which prevent the achievement of high production rates (**Figure 3201.00.44**):

Polystyrene beads are firstly injected into a metal die which is then heated with steam to expand and fuse the beads. The die is subsequently water-cooled to remove the heat before extracting the pattern. The overall cycle takes at least 1 minute. A number of patterns are then assembled to form a *tree* which is then coated in a ceramic slurry. After drying, the assembly is embedded in loose sand which is vibrated to consolidate it and thereby form a rigid mould. The molten metal is poured onto the polystyrene which is vaporised and replaced by the metal. Although considerable effort has been devoted to this process over recent years, its adoption has been limited by the difficulties of producing defect-free castings and of overcoming dimensional inconsistencies caused by the distortion of the fragile patterns.

The remaining lectures in this course will concentrate on die and sand casting.

This brief view of some selected casting processes forms our introduction to the course. In later lectures we shall see how the metal solidifies to give different metallurgical structures and sometimes to cause defects and we shall see how to control both. The course will conclude with the engineering problems of how casting manufacture can be successfully integrated into an overall manufacturing operation. Thus we shall look into the methods of designing patternwork, castings and machining operations so that they are compatible, each handing over smoothly to the other in a professionally-run relay race. If the baton is dropped, the race is lost whereas, if it is handed on successfully, it is possible to win.

One can guarantee that the race will be exciting!

Literature

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