TALAT Lecture 3206

The Feeding of Castings

24 pages, 23 figures

Basic Level

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Objectives:

- To provide an introduction to the techniques used to compensate for the solidification shrinkage of castings.
- The student will be able to understand the basic principles of how to design a feeder system to produce a shrinkage-free casting

Prerequisites:

- Basic knowledge of castings production
- Basic knowledge of physics and metallurgy

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3206 The Feeding of Castings

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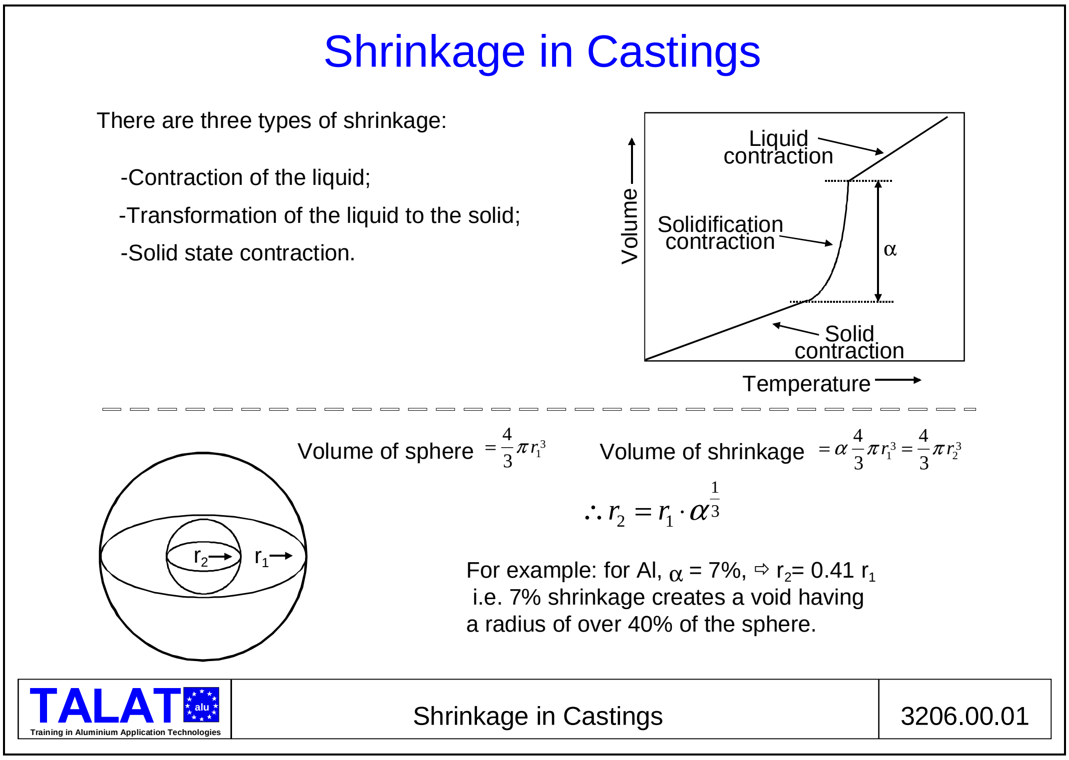
Shrinkage Problems

The primary objective of this lecture is to consider how to produce castings that are free from defects caused by shrinkage of the metal.

It is important to appreciate that there are three types of shrinkage. Firstly, any liquid metal will contract in volume as it cools from its initial temperature down to its freezing point. This contraction is linear with temperature and can be compensated for without much difficulty. Secondly, there is always a volume change as the liquid metal transforms to a solid due to the change in the arrangement of the atoms from the rather open, random close-packed manner in a liquid to a regular close-packed form in a solid. Examples of the latter are face-centered cubic (f.c.c.) and body-centered cubic (b.c.c.). Finally, there is the contraction of the solid metal as it cools down to room temperature (see **Figure 3206.00.01**).



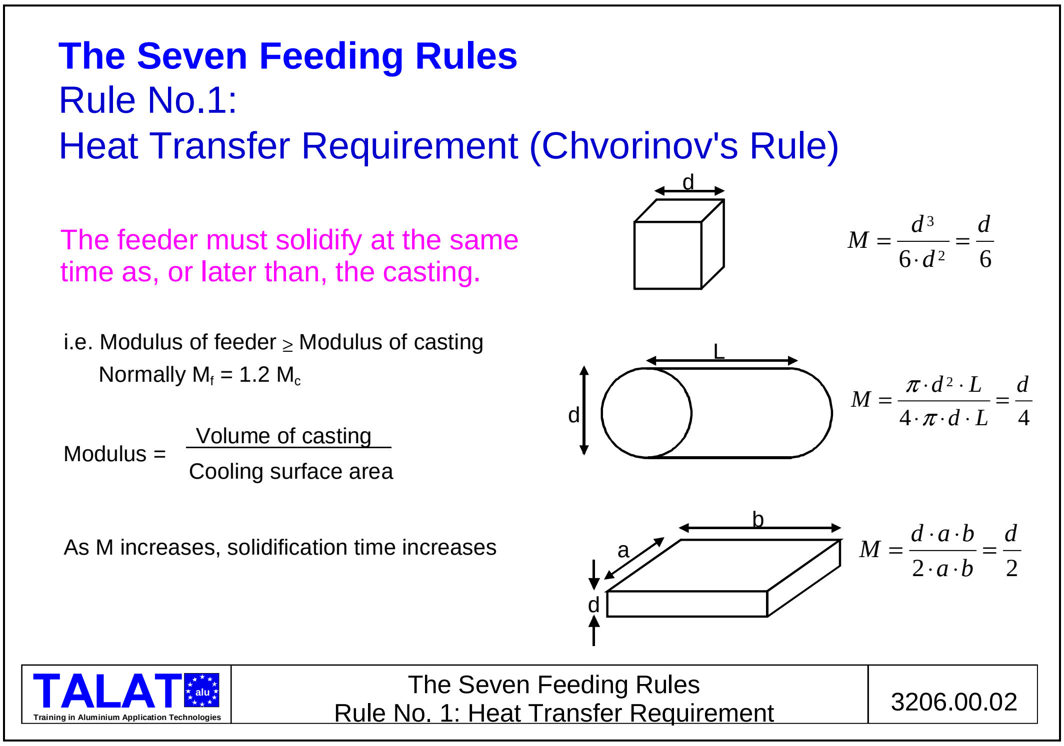
Of these, the transformation from liquid to solid is the most critical. Normally this is a contraction i.e. the metal undergoes shrinkage as it solidifies. Typical values of a are 7% for aluminium and 3.2% for iron. (However, it should be noted that some metals expand on freezing, examples being bismuth and silicon.)

Although 7% shrinkage may not sound very much, it is instructive to consider a simple mathematical treatment of the solidification of a sphere. This shows that it creates a void in the centre of a sphere having a diameter which is 41% of the original sphere diameter. This void must be filled up if the casting is to be sound, but this often causes a real problem in practice. This lecture considers how such shrinkage defects are prevented by the use of a reservoir of molten metal, normally called a feeder in English, but often referred to as a riser in American English.

The Seven Feeding Rules

1) Heat Transfer Requirement

Although much has been written about the feeding of castings, it can be summarised in the form of a set of relatively simple rules, which we shall now consider in detail.



The first rule (see **Figure 3206.00.02**) is a heat transfer requirement known as Chvorinov's Rule. It can be stated as:

"the freezing time of the feeder must be at least as long as the freezing time of the casting".

It can be re-stated in simple terms as:

"the modulus of the feeder must be equal to or greater than the modulus of the casting".

More often, it is written as:

"the modulus of the feeder (M_f) equals 1.2 times the modulus of the casting (M_c)".
The extra 20% given by this expression is a safety factor to allow for errors and difficulties in calculating the moduli.

The modulus is, of course, defined as the solidifying volume divided by the surface area of the casting which is losing heat. It is important to include *only* those surfaces which lose heat. As the modulus increases, so the solidification time ts increases, and the modulus is therefore a useful means of predicting solidification times.

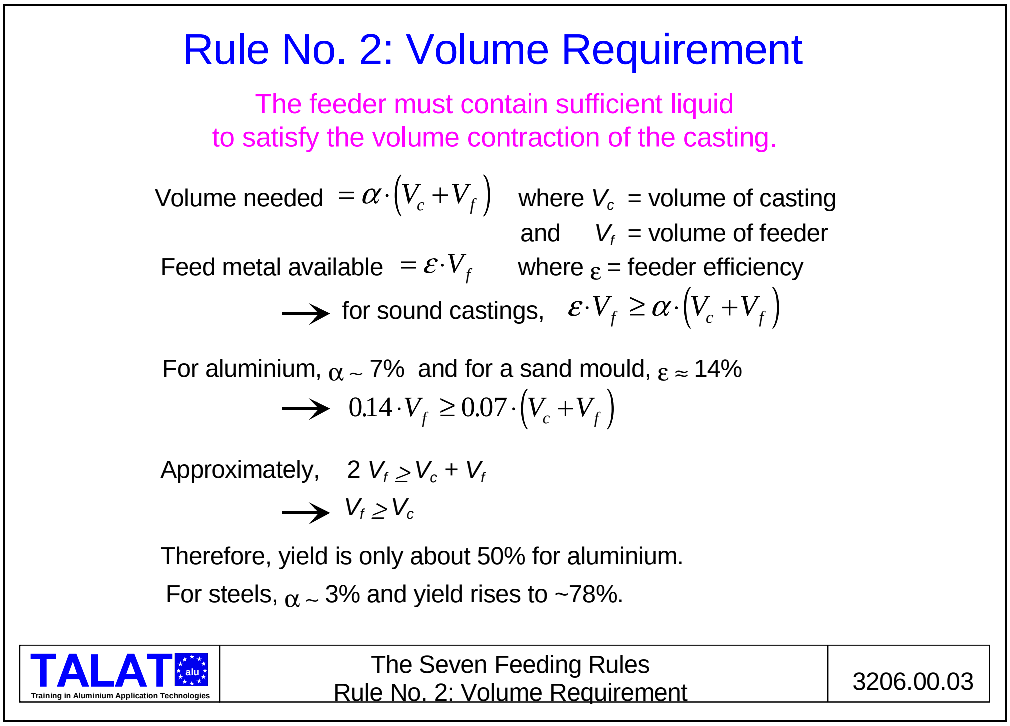
Some modulus calculations for simple shapes are shown here:

- The modulus of a cube having a side of d is d/6.
- For a very long cylinder of diameter d and length L, the volume is $\pi \cdot d^2 \cdot L/4$ and the cooling surface area is $\pi \cdot d \cdot L$ which gives a modulus of d/4. In this case it has been assumed that no heat is lost from the two end surfaces which is a good approximation if L is much greater than d.

– The volume of a thin plate is d·a·b and the cooling surface area is 2·a·b to give a modulus of d/2. In this case, it has been assumed that the thickness, d, is much smaller than a or b, so that the amount of heat lost through the side faces is negligible. When a and b are not negligible, then the heat lost through the side faces is easily taken into account.

When working out the modulus of a complex casting, it is normal to consider those parts that are in good thermal communication as a whole. Thus an aluminium casting can often be treated as a whole because of its high thermal conductivity. Conversely, a steel casting is often dealt with as a series of separate primitive shapes. It should be noted that the modulus always has the dimensions of length.

2) Volume Requirement



The second feeding rule is normally known as the Volume Requirement (**Figure 3206.00.03**). It can be stated as:

"The feeder must contain sufficient liquid to satisfy the volume contraction requirements of the casting".

Even if Rule 1 has been closely followed to give $M_f >> M_c$, it is still possible that there may not be enough liquid metal to feed the casting, with the result that the feeder would be emptied and a shrinkage cavity would extend into the casting. An example of when this could occur would be a long thin casting.

The volume required can be calculated from the volumetric contraction, α, and the volumes of the casting (V_c) and feeder (V_f), so that

$$\text{Volume required} = \alpha (V_c + V_f)$$

This has to supplied by the feeder, which only works with a certain efficiency, ε, so that sound castings will be produced if:

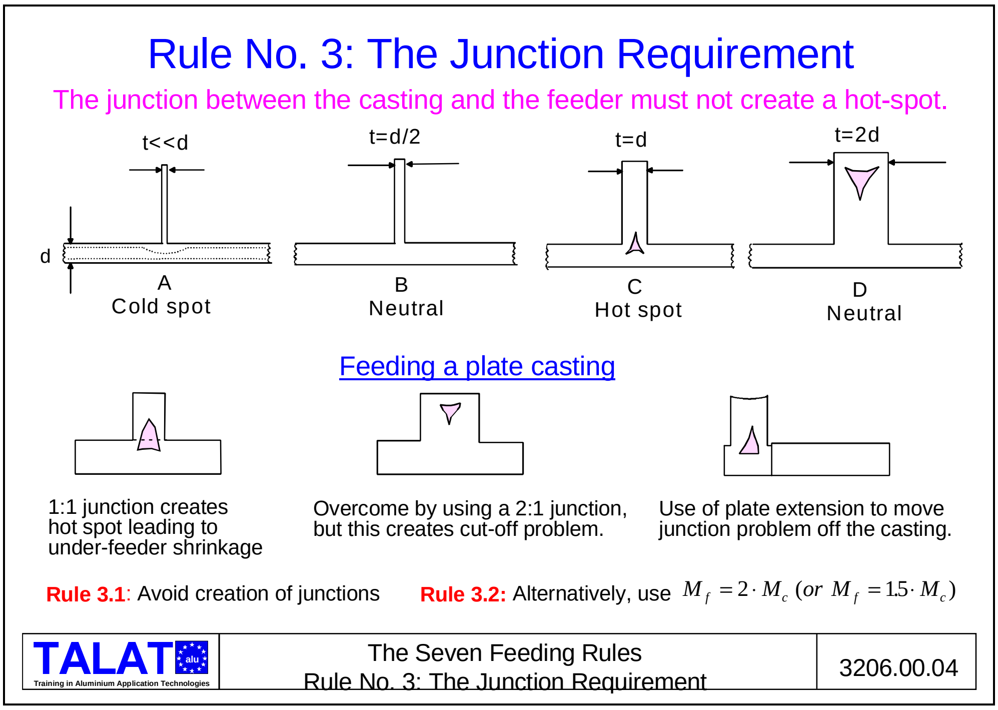
$$\varepsilon \cdot V_f \geq \alpha (V_c + V_f)$$

As an example, α for aluminium is about 7% and ε for a typical feeder moulded in a sand mould is 14%. Substituting these values into this expression shows that, as an absolute minimum, the volume of the feeder must equal that of the casting. It can therefore be seen that aluminium has a very high feed metal requirement since the yield (i.e. weight of casting as a proportion of the weight of the casting plus feeder) is only 50%. For steels with a typical α value of 3%, a feeder of the same efficiency would provide a yield of over 78%.

It should also be pointed out that it is possible to improve the yield by insulating the feeder which can increase ε to 50% or higher.

Before moving onto Rule 3, it can be commented that many text books only consider Rules 1 and 2, yet there are additional rules which must be followed if sound castings are to be made.

3) Junction Requirement



The next rule is known as the Junction Requirement (**Figure 3206.00.04**). This states that the junction between the casting and the feeder must not create a hot spot.

This shows a series of T-junctions between a plate of thickness *d* and an adjoining plate of varying thickness *t*. Junction A consists of a thin fin of thickness $t << d$ joined to the plate. It does not take too much imagination to see that the fin will act as it would on a radiator: it will extract heat rapidly, leading to a change in the thermal profiles and the solidification front. In effect, Junction A acts as a cold junction. This effect is sometimes exploited when it is necessary to achieve more rapid cooling locally, as an alternative to chills placed in the mould. It is especially useful when wishing to provide local cooling in aluminium alloys because of their high thermal conductivity. Such junctions are much less effective in steel castings.

If we now jump to junction C where we have two legs of equal thickness ($d = t$) joined together. This creates a hot spot, a fact which is well known to all foundrymen!

Solidification proceeds less rapidly at the junction of the T because the sand gets very hot in this area. As a result, the fragile solidified skin collapses in this area, leading to a 'wormhole' into the casting. This type of junction must always be avoided.

Moving to junction B, logic allows us to guess that when one plate of thickness d is joined to a plate of half of that thickness, the cold and hot junction effects are balanced to give a neutral junction. This means that junction B can be used as an ingate since it has no effect on the casting.

Moving to junction D, this can be seen to have a 2:1 ratio and its geometry is therefore similar to that of junction B. This means that it is also neutral and this arrangement is useful as a feeder.

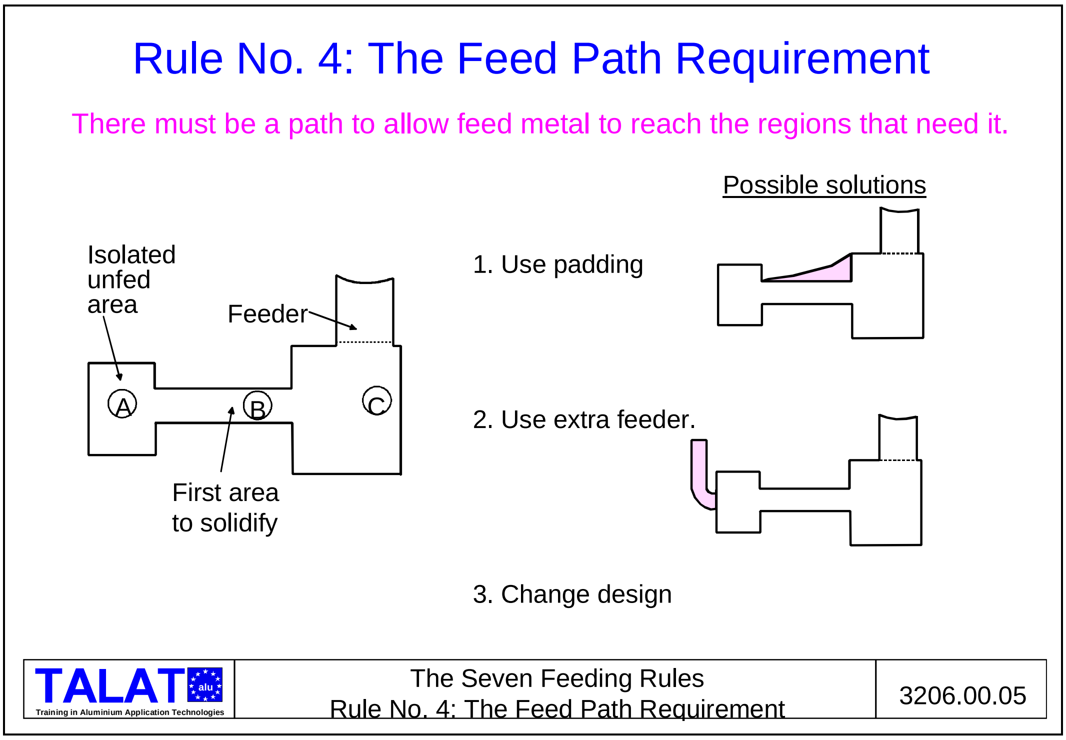
We shall now emphasise the importance of the Junction Requirement by considering how to place a feeder on a plate casting. As we have already seen, Chvorinov's rule would suggest that satisfactory feeding should occur if M_c is equal to M_f. However, if we place the feeder on the casting as shown here, we will create a hot spot because we have overlooked the Junction Requirement. As a result, we will inevitably get shrinkage porosity at the base of the feeder, which is also known as under-riser porosity. From the previous discussion on junction design we can see that this problem can be overcome by enlarging the junction between the plate and the feeder. However, this leads to a large feeder which is difficult to cut off the casting.

This difficulty can be overcome by trying to avoid junctions altogether and one way to achieve this rather contradictory aim is to extend the casting and to put the feeder on that.

Rule 3 can therefore be written in two parts. Rule 3.1 is to avoid the creation of junctions, particularly T junctions. However, if there is no alternative to placing a feeder directly on a casting, then Rule 3.2 is to ensure that the modulus of the feeder is twice that of the casting to prevent a hot spot in the casting. This is a theoretical value and in reality it should be possible to reduce this to perhaps $M_f \sim 1.5\ M_c$ (the research to provide an exact factor has not yet been carried out), but it is important *not* to use $M_f \sim 1.2\ M_c$, which is too close to $M_f \sim M_c$.

4) Feed Path Requirement

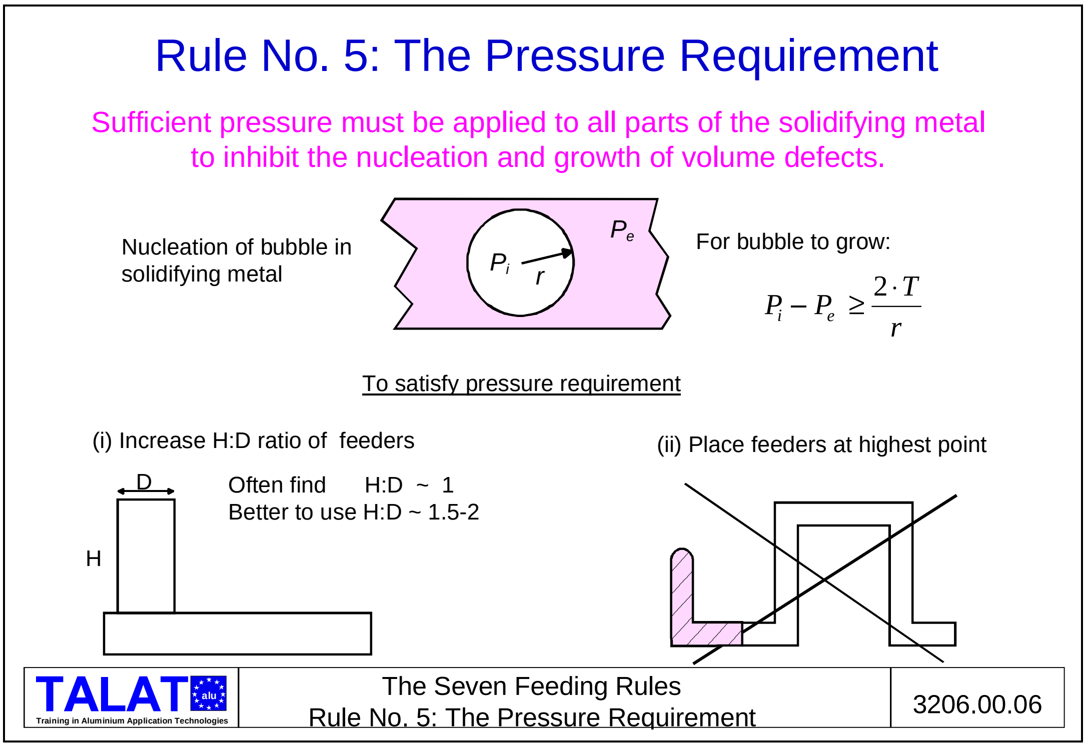
Rule number 4 is known as the Feed Path Requirement (**Figure 3206.00.05**). This states that it is necessary to have communication between the feeder and the feature on the casting which is being fed. This might appear to be rather obvious and trivial, but it is often overlooked and is often difficult to achieve.



This shows a section through a typical flanged wheel casting and we shall assume that the modulus calculations indicate that it should be possible to feed this with a single feeder placed on one of the heavy sections (C). It can easily be seen, however, that the feed path to the other heavy section (A) will be cut when the thinner section B solidifies. One way of overcoming this, which is widely used in steel foundries, is to use 'padding', i.e. to add extra material so that the feed path is kept open. The extra material then has to be removed, which adds to the manufacturing cost. One alternative is to use an extra feeder, although this is not always feasible and may be difficult to remove. A further possibility is to apply a chill or cooling fin to A (not shown on the overhead). A better alternative may be to negotiate a change of design with the customer, although again this may not always be possible.

5) Pressure Requirement

Rule number 5 (**Figure 3206.00.06**) is known as the Pressure Requirement but it is not so obvious as the others. It should firstly be appreciated that most defects - such as porosity or hot tears -are volume defects, that is, they are induced by the volume changes which occur as a casting solidifies. It follows that if a pressure is applied to a solidifying liquid, it is difficult for the defects to nucleate. Rule 5 is therefore that sufficient pressure must be supplied to all parts of the solidifying metal to inhibit the nucleation and growth of volume defects.



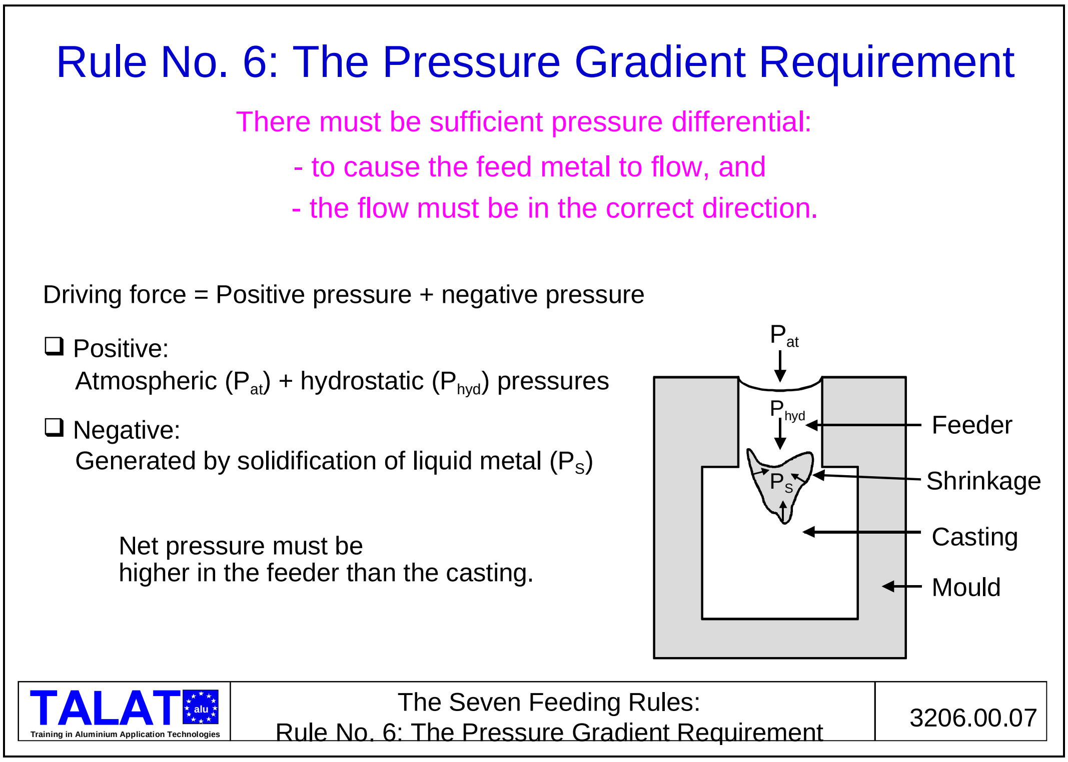
This shows an embryo bubble of radius r having an internal pressure P_i which is trying to grow in an environment which imposes an external pressure P_e. In order for the bubble to grow, it is necessary for the pressure difference to be greater than the restraining force offered by the surface tension, i.e. to satisfy the requirement that:

$$P_i - P_e \geq \frac{2 \cdot T}{r}$$

where T is the surface tension.

This equation shows that if P_e increases, the nucleation and growth of bubbles is suppressed and so bubbles collapse and disappear.
There are two very practical applications of this result:

- One concerns feeder design. It is often found that these are designed so that their height and diameter are approximately equal, whereas it would be better to make feeders thinner and taller to increase their H/D ratio to 1.5 or 2. This provides a slight pressurisation to the solidifying metal, equal to $\rho \cdot g \cdot H$, where ρ is the density, g the acceleration due to gravity and H the head of metal.
- The other is the location of feeders which should always be placed at the highest point on the casting if they are to be most effective.



6) Pressure Gradient Requirement

The sixth rule (**Figure 3206.00.07**) is the Pressure Gradient Requirement and is similar to Rule 5. It can be simply stated as:

> *"There must be sufficient pressure differential to cause the feed metal to flow and the flow must be in the correct direction."*

The driving force for the flow of the feed metal is the sum of two pressures:

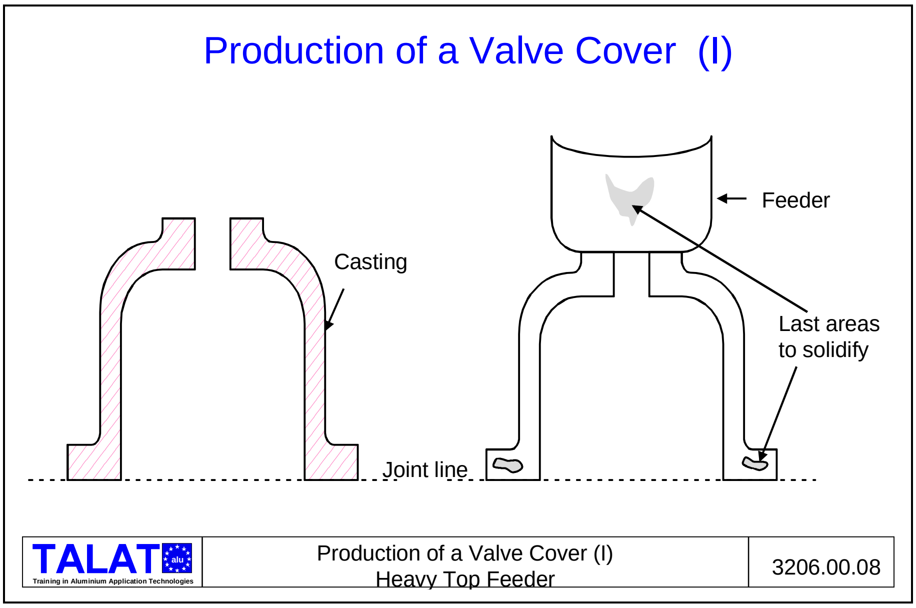
1. A positive pressure - from atmospheric pressure on the metal and the hydrostatic head in the feeder; and
2. A negative pressure - generated within poorly fed regions as the liquid metal contracts within a solid shell.

These driving forces are additive: the feed metal flows as a result of being pushed from the outside and pulled from the inside. It should be clear that the net pressure must be higher in the feeder than in the area of the casting which is being fed.

Valve Cover Example

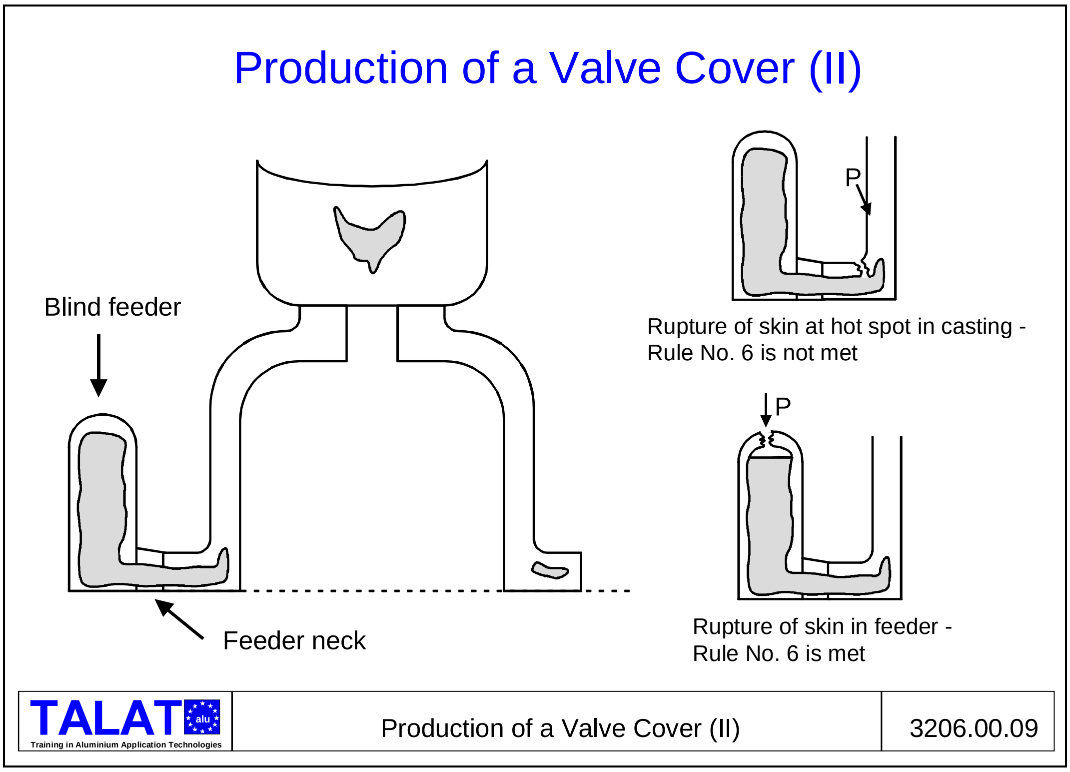
This rule is best illustrated by giving a practical example (**Figure 3206.00.08**). This concerns a valve cover casting (which is shaped rather like a bell jar), with a heavy section at the top, a heavy section flange and a thin wall connecting the two. In other words, there are two isolated heavy sections and it is likely that both will need to be fed if they are to be produced free from shrinkage porosity.

The initial option to be considered would be to place a feeder on the top of the casting. Assuming that this is correctly designed, it should be capable of compensating for the shrinkage in the heavy section at the top of the casting, so that this area of the casting should be quite sound. However, it does not take too much imagination to predict that the thin walls will solidify relatively rapidly, cutting off the path between the feeder and the bottom flange. The last areas to solidify are shown and it can be clearly seen that shrinkage cavities in the bottom flange would be expected. This means that a feeder is also required on this flange.

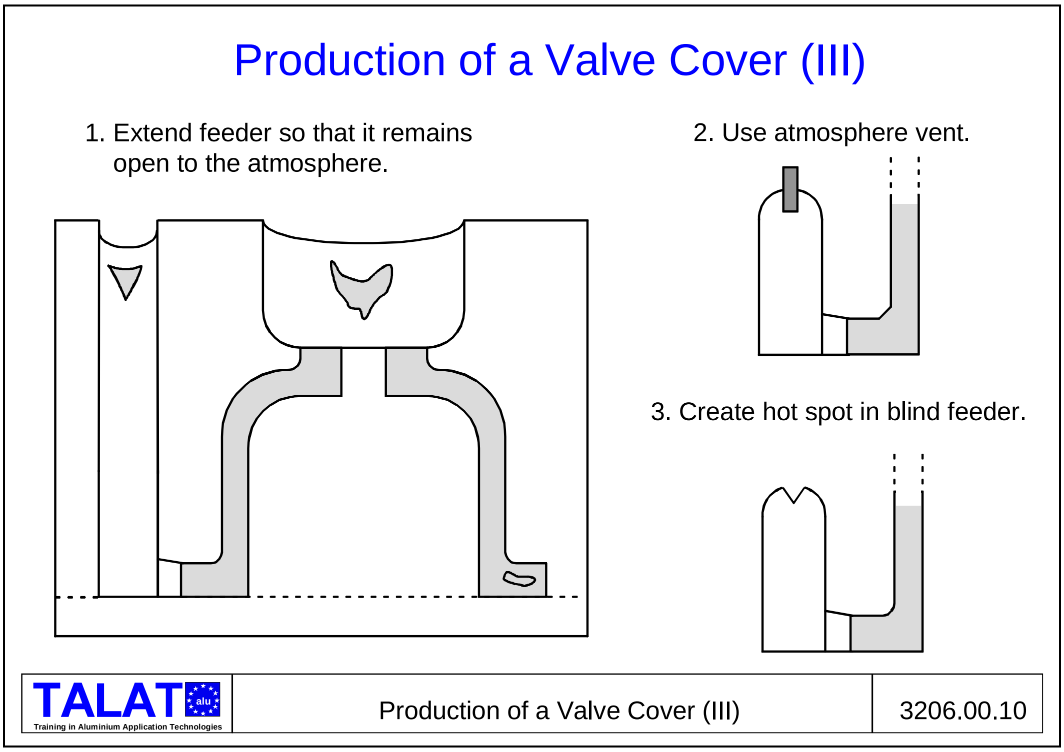


One alternative would be to use a 'blind' feeder as shown in **Figure 3206.00.09**. This is called 'blind' because it is not open to the atmosphere. As the metal in the feeder starts to solidify, a solid skin is first formed which becomes progressively stronger as the temperature falls. As further solid forms, the volumetric contraction results in a hydrostatic tensile stress in the remaining liquid, and the internal suction causes the whole of the solidifying area to start to collapse inwards. This plastic collapse continues for a while, but eventually it is likely that the internal stress will be relieved by either a fracture in the skin or nucleation of an internal pore. This may occur in either the casting or the feeder, with very different results:

- If fracture occurs towards the top of the feeder, atmospheric pressure will be able to act on the molten metal remaining in the feeder. This creates a pressure differential which is in the correct direction to cause molten metal to flow from the feeder to the shrinkage area in the casting, thus satisfying Rule Number 6 - The Pressure Gradient Requirement.
- On the other hand, if the casting design is such that there is a hot spot in the vicinity of the last area to solidify, the hydrostatic tensile stress in the liquid is likely to cause rupture of the casting skin at the hot spot. Hence, atmospheric pressure is now acting on the liquid area in the casting, with the result that the pressure gradient is away from the casting to the feeder, which will cause the metal will flow from the casting into the feeder! In this case, Rule Number 6 is not met. The resulting casting will be more porous than if no side feeder had been used at all.



One way to overcome this problem is to ensure that the feeder remains open to the air so that atmospheric pressure acts on the feeder (**Figure 3206.00.10**). This would require the feeder to be extended upwards, which is not always easy to do. In addition, it reduces the yield.



An alternative approach is to use an atmospheric vent which is a sort of porous plug to let in air and maintain a positive pressure in the feeder. However, one word of caution: in small castings, especially when the metal has low superheat, the porous plug may cool the feeder, leading to solidification around the plug, and thus sealing it closed.

Yet another solution is to create a hot spot in the feeder by placing a notch on its top surface. This serves to delay the formation of a solid skin on the feeder - or if one does form, the notch will ensure that it is more readily ruptured. Nevertheless, care is still needed since although such solutions generally work well for large feeders, they tend to be unreliable in small feeders.

7) The Zeroth Rule

Figure 3206.00.11 summarises the Six Feeding Rules that I have introduced to you so far. Hopefully you will now appreciate that there are many pitfalls in setting up a feeding system for a casting although, if attention is paid to all of these rules, it is normally possible to produce a sound casting.

Summary of the
Seven Feeding Rules

Rule 1: The heat transfer requirement.

Rule 2: The volume requirement.

Rule 3: The junction requirement.

Rule 4: The feed path requirement.

Rule 5: The pressure requirement.

Rule 6: The pressure gradient requirement.

TALAT Training in Aluminium Application Technologies	Summary of the Seven Feeding Rules	3206.00.11

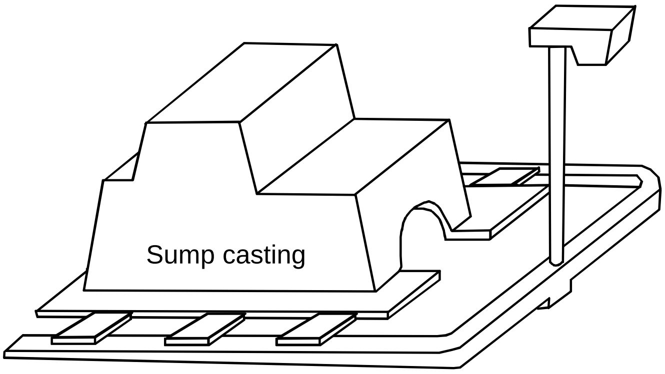
However, the difficulties inherent in devising a good feeding system lead one to suggest that there should be an additional rule - The Zeroth Rule (**Figure 3206.00.12**) - which states that **you should not feed a casting unless it is absolutely necessary**!

This is perhaps rather surprising but it does overcome the otherwise common problem of designing an effective feeding system. Elimination of feeding also brings economic benefits, such as an improved yield and reduced fettling since it is no longer necessary to cut the feeder off the casting. This rule can often be applied when thin castings are concerned and, for example, the sump casting shown here (which you have seen previously) was produced without any feeders.

Rule No. 0: Do not feed

ZEROTH RULE: Do not feed, unless absolutely necessary !!

- gives economic benefits
- applies particularly to thin castings
- example is a sump casting



TALAT (Training in Aluminium Application Technologies) | The Seven Feeding Rules: Rule No. 0: Do Not Feed | 3206.00.12

Summary

Figure 3206.00.13 shows the final list of rules, which number 7 in total. It can be commented that if the Zeroth Rule is not followed, then it is necessary to adhere to **all** of the rest.

Summary of the Seven Feeding Rules

Zeroth Rule: Do not feed unless absolutely necessary!

Rule 1: The heat transfer requirement.

Rule 2: The volume requirement.

Rule 3: The junction requirement.

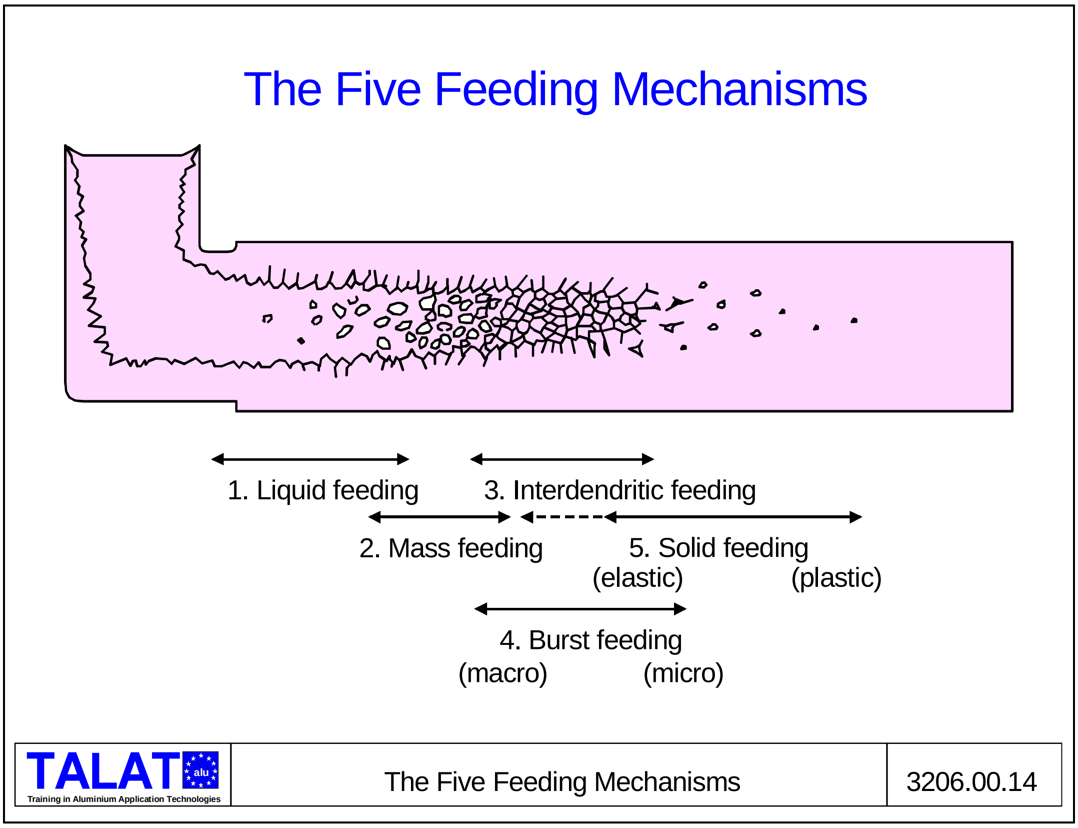
Rule 4: The feed path requirement.

Rule 5: The pressure requirement.

Rule 6: The pressure gradient requirement.

TALAT (Training in Aluminium Application Technologies) | Summary of the Seven Feeding Rules | 3206.00.13

The Five Feeding Mechanisms



I would now like to turn to the five feeding mechanisms which are listed in **Figure 3206.00.14** and also shown schematically. As the casting solidifies, the demand for feed liquid in the centre of the casting becomes progressively more difficult to meet, as tangles of dendrites obstruct the feed channels, or regions of liquid become actually cut off from the source of feed metal.

This increasing feeding difficulty causes the pressure in the centre of the casting to fall, possibly falling so far as to become negative in some cases, as a hydrostatic tension. The generation of large hydrostatic tensions in the interior of casting is undesirable, since it constitutes the driving force for the nucleation and growth of pores (either shrinkage or gas) and a driving force for the inward collapse of the casting which might be revealed as a surface sink.

The action of the various feeding mechanisms is to provide material - which can be either liquid or solid - which will flow under the growing pressure gradient, so as to compensate for the volume deficit resulting from the transition from liquid to solid. In so doing, the pressure gradient is reduced thus reducing the driving force for the creation of internal porosity or external sinks.

There are five main mechanisms which can be identified by which feeding can occur. These are dealt with here in the order in which they might occur in a real casting, although not all need occur in any one casting. The order will be seen to progress from 'open' systems to 'closed' feeding systems.

1) Liquid Feeding

Feeding Mechanisms (I): Liquid Feeding

- Most "open" type of feeding mechanism
- Generally occurs first
- Normally the only feeding mechanism in skin-freezing alloys
- Works well with low pressure gradients
- Governed by the Seven Feeding Rules

TALAT Training in Aluminium Application Technologies	Feeding Mechanisms (I): Liquid Feeding	3206.00.15

The first mechanism is *Liquid Feeding* (see **Figure 3206.00.15**). This is the most 'open' of the feeding processes, and generally precedes other forms of feeding. It can be noted that in skin freezing materials - such as pure metals and eutectics - it is the *only* type of feeding process. Since the liquid metal has such low viscosity (near to that of water) this mechanism works effectively at negligibly small pressure gradients. For all practical purposes therefore, if liquid feeding can be ensured in a particular casting, then the stresses which can occur in the liquid will be maintained at such a low level that no practical difficulties will be found. The rules for adequate liquid feeding are the Feeding Rules described at the beginning of this lecture.

The Effects of Inadequate Liquid Feeding

1. Skin-Freezing Alloys
- Smooth solidification front
- Smooth, carrot-shaped pipe

2. Long Freezing-Range Alloys
- Solidifies as dendrite mesh
- Residual liquid drains away leaving "sponge" porosity

TALAT Training in Aluminium Application Technologies	The Effects of Inadequate Liquid Feeding	3206.00.16

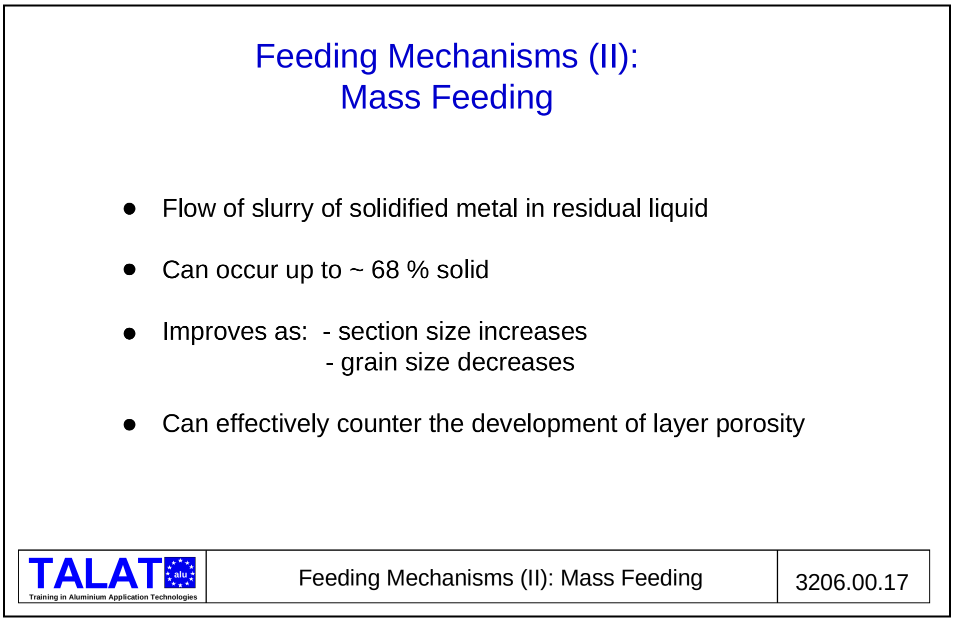
Where inadequate liquid feeding has been applied, i.e. where the feeder has run dry part way through the freezing of the casting, then two types of porosity are found (see also **Figure 3206.00.16**):

1. Smooth-sided shrinkage pipe:
   skin-freezing alloys will solidify with a smooth solidification front, so that a shrinkage cavity will expand, eventually to be constrained by the inward growth of the smooth freezing front. Thus the shrinkage pipe will be the classical smooth carrot-shaped cavity.

2. Shrinkage pipe in the form of sponge porosity:
   long freezing range alloys will normally freeze as a tangled mass of dendrites, so that if the feed liquid is in short supply, then the dendrite mesh can drain of interdendritic liquid, with the result that the shrinkage pipe from the feeder forms an extensive sponge. The shrinkage pipe still is in the form of a single cavity, but its appearance is now complicated by its shape. If a transverse section is made, the porosity appears to be a series of hundreds or thousands of separate minute pores, and is thus often mistaken for microporosity, when it is in fact a single macropore. This type of shrinkage sponge is particularly damaging for castings which are required to be leak-tight after machining.

2) Mass Feeding

The second feeding mechanism is known as *Mass Feeding* (**Figure 3206.00.17**). This is the term used to denote the flow of a slurry of liquid plus solid crystals. It can occur up to about 68 % solid in some alloys. At that stage of freezing the dendrites start to impinge to form a coherent network, as a three dimensional space frame, thus gaining rigidity and resistance to further deformation.



The action of mass feeding is sensitive to the relative size of the grains and to the section thickness of the solidifying casting. For instance mass feeding cannot act in thin section castings which have not been grain refined. Mass feeding improves as section thickness increases and as grain size becomes smaller. Thus is simply because if the section is narrow and if the grains are large, they impinge on each other and are supported on the side walls of the casting, and so are not free to move. Porosity in such sections occurs because of the difficulty of flow of the liquid among the dendrite mesh: this is typically layer porosity - a kind of shrinkage porosity which grows among the fixed network of dendrites (described in more detail in **TALAT Lecture 3207**).

As the section size grows and grains become smaller so this constraint disappears, and the interior semi-solid slurry is free to flow, thus more easily feeding the more distant regions of the casting. Layer porosity effectively disappears in such sections.

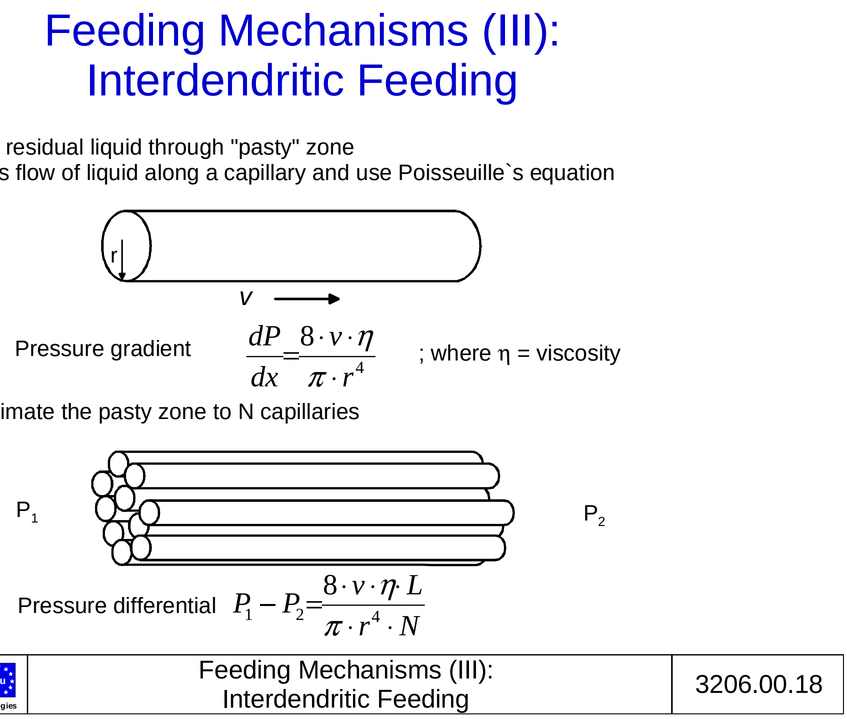
From the point of view of the casting technologist, grain refinement is clearly an important way of facilitating this feeding mechanism.

3) Interdendritic Feeding

The third Feeding Mechanism is *Interdendritic Feeding* (**Figure 3206.00.18**). As the dendrite mesh thickens, the interdendritic channels become progressively narrower, and progressively more resistant to the flow of the residual liquid. We can gain a useful insight into the mechanism by assuming that the channels can be treated as capillaries.
Assuming Poisseuille's famous equation for the flow of liquid along a capillary we have:

$$\frac{dP}{dx} = \frac{8\,\eta\,v}{\pi\,r^4}$$

where dP/dx is the pressure gradient required to cause the flow,
η is the viscosity,
ν is the volume flowing per second,
and r is the radius of the channel.



Feeding Mechanisms (III): Interdendritic Feeding | 3206.00.18

If now we can assume that the pasty zone can be approximated to a bunch of N capillaries of length L, then the pressure differential across the pasty zone required for flow through the zone is reduced to:

$$P_1 - P_2 = \frac{8\,\eta\,v\,L}{\pi\,r^4\;N}$$

For a particular radius, which corresponds roughly to a given size of final pore, the increase of N by grain refinement is seen to be useful in reducing the pressure requirement. Thus grain refinement seems useful for the improvement of interdendritic feeding also. However, this is a relatively insignificant effect compared to the influence of r, which is raised to the fourth power. Clearly, as solidification continues and as the mesh is finally closing, r becomes extremely small and so the pressure differential required to cause interdendritic flow becomes extremely high: this is when the greatest problems of feeding through the interdendritic mesh occur.

The effect of capillary size on the required pressure differential explains the enormous effect of a small amount of eutectic liquid (**Figure 3206.00.19**).

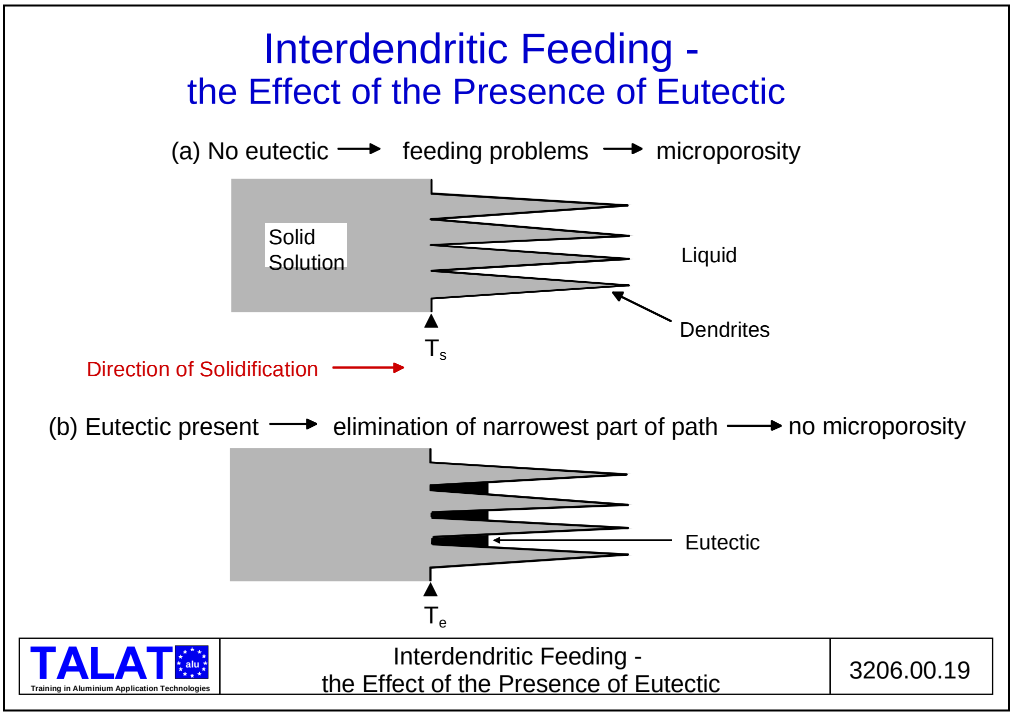


Diagram (a) shows schematically that if there is no eutectic present, then the tapering interdendritic path (towards the root of the dendrites) increases the difficulty of the final stage of interdendritic feeding, where r becomes vanishingly small causing high viscous restraint to flow.

Diagram (b) shows that the presence of a per cent or so of eutectic liquid at the roots of the dendrites, as a result of interdendritic segregation, effectively truncates the final, narrowest parts of the channels by solidifying on a planar front when the eutectic isotherm is reached during cooling. The pressure is typically reduced by orders of magnitude by the arrival of just one per cent of eutectic liquid and therefore the last stages of feeding are much easier.

As the percentage of an alloying element increases in a alloy, a stage is reached at which the solid solution region is exceeded and eutectic liquid first appears. This point is usually markedly below the composition at which eutectic would be predicted from the equilibrium diagram, and is, of course, the result of non-equilibrium freezing, with solute concentrated into the remaining liquid between the dendrite arms - the interdendritic liquid.

Before the eutectic liquid first appears, the long tapering feeding channels cause a maximum problem for feeding, and so microporosity is the result in such (non-equilibrium) long freezing range compositions. When the alloy content has risen to allow eutectic liquid to appear, then the porosity disappears, to be replaced initially by a maximum in the susceptibility to hot tearing. This rapidly reduces as the alloy content is increased, increasing the percentage of eutectic phase.

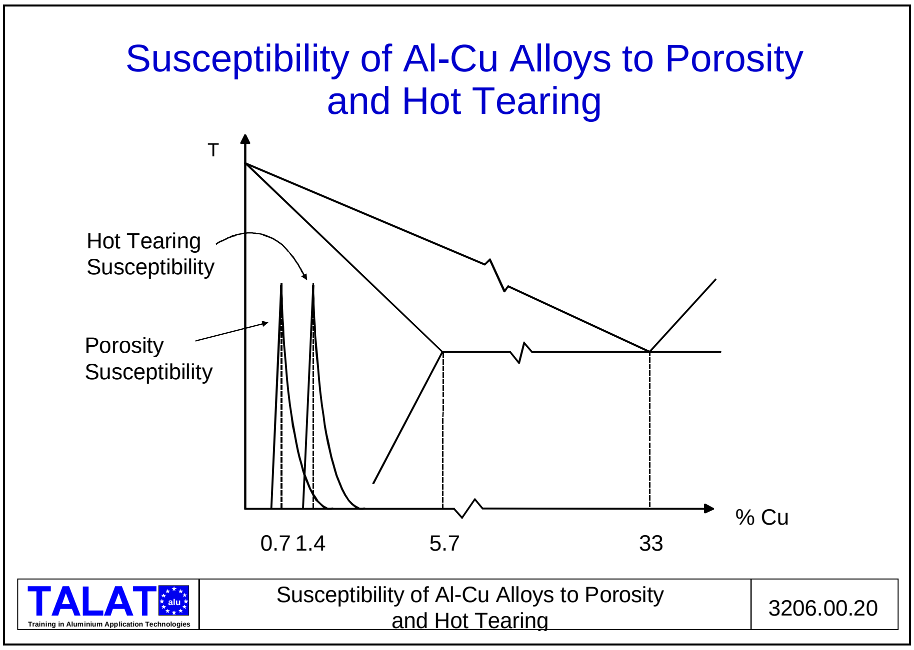


Figure 3206.00.20 shows an example of this effect in the Al-Cu alloy system and indicates the separate maxima in the susceptibility of these alloys to the formation of porosity and hot tears. It can be seen that as the tendency to porosity decreases at ~ 0.7% Cu due to the appearance of non-equilibrium eutectic, so the tendency to hot tearing increases, reaching a maximum at ~ 1.4% Cu.

In contrast, the highly castable Al-Si alloys with Si contents in the region of 5 to 10 weight per cent silicon are well outside of these danger regions (which occur at about 0.5 to 1 wt. % Si), and explain the generally forgiving characteristics of these alloys which permit a tolerable casting quality to be achieved.

4) Burst Feeding

Our fourth mechanism is *Burst Feeding* (**Figure 3206.00.21**). This has been predicted as being possible, but very little evidence has been obtained for it to date. This is perhaps not surprising, since it will be difficult to observe, and difficult to predict since computer models are not yet sufficiently sophisticated.

It was proposed to allow for the condition where the build-up of pressure across a barrier to feeding causes the barrier to collapse, allowing an in-rush of feed liquid. Such barriers are envisaged to be meshes of dendrites, perhaps heaped up as a result of mass feeding, especially if this pile-up chokes a narrow feed path into a larger section requiring feed metal.

Feeding Mechanisms (IV): Burst Feeding

- Predicted as being possible, but little evidence to date.
- Assume sudden yielding of barrier to feed metal
  → in-rush of liquid.
- Barrier could be meshes of dendrites.

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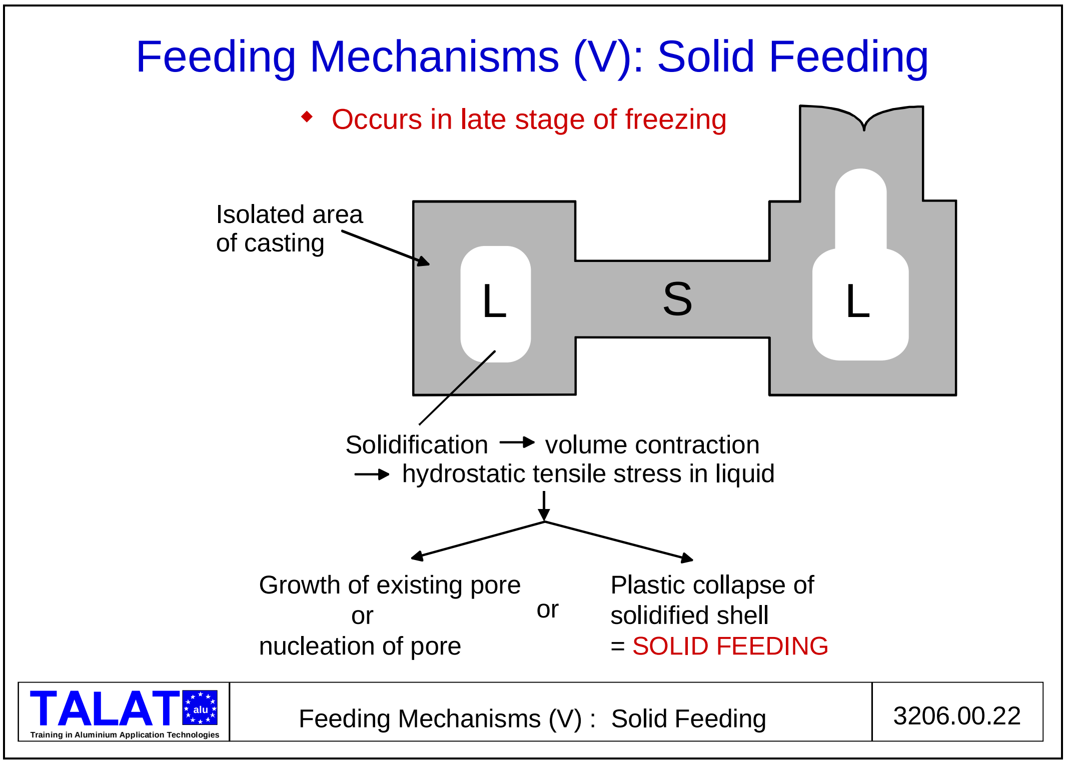
In practice it may be that the collapse of such structures will be more gentle than dramatic, as a result of the plasticity of the dendrites at temperatures near their melting point.

However, the curved appearance of some types of layer porosity may be the result of such deformation of the dendrite mesh prior to, or perhaps during, the ingress of feed liquid to underfed regions.

Burst feeding is perhaps something to be kept in mind as a logical possibility rather than viewed as a mechanism of great importance, or so it seems at this time.

5) Solid Feeding



The final mechanism is *Solid Feeding* (**Figure 3206.00.22**) . In contrast to burst feeding, solid feeding is a mechanism of great importance, and for which there is a great deal of evidence. It is essential to understand this mechanism thoroughly to be able to understand the feeding of real castings.

This is the most 'closed' type of feeding. It describes the situation where a region of the casting has become isolated (or effectively isolated) from the supply of feed liquid. As the residual liquid in this region continues to freeze it progressively occupies less space. This space has to be accounted for somehow. One option is for it to grow as a shrinkage or gas pore, although this requires either a pore to be already in place somehow, or a suitable nucleus to be in place to allow a pore to be created. The other option is for the solid shell of the casting to collapse inwards under the internal reduced pressure, so making up the volume deficit. Solid feeding therefore relieves the hydrostatic tensile stress built up in the liquid by the inward flow of the solid.

Figure 3206.00.23: If the yield stress of the solid shell is low, then solid feeding occurs so easily that only limited internal tension can build up. This happens in aluminium alloys, but less readily in steels and high temperature alloys where the poor thermal conductivity of the metal results in a cool and hence strong shell of solidified metal. Solid feeding is also enhanced by the use of high mould temperatures as in investment casting, where moulds are sometimes preheated to temperatures approaching the freezing point of the metal. The solidified shell is especially plastic in such conditions, and, automatically it seems, isolated bosses feed themselves!

Feeding Mechanisms (V): Solid Feeding (Continued)

◆ **Solid Feeding enhanced by:**

- Low yield strength at high temperature (e.g. aluminium alloys)
- High mould temperature (e.g. investment castings)

◆ **Solid Feeding can cause:**

- Surface sinks
- Uniform (unnoticeable) contraction

Example

Aluminium ~ 6% total solidification shrinkage = 3% liquid / mass feeding + 3% solid feeding

3% solid feeding = ~1% in 3 perpendicular directions = 0.5 % per surface

For 4 mm thick sections, this is equivalent to 0.5% of a 2 mm dimension, or 10 µm.

This can be compared with the typical surface finish of a casting of 25 µm (R_a value).

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Collapse of the solid shell to feed internal shrinkage is often seen as sinks on the surface of castings adjacent to a heavy section. However, such undesirable shape deformations need not always accompany solid feeding. If the general plasticity of the solid shell can be kept reasonably uniform then collapse can be so uniform as to be unnoticed. For instance, if we assume that the solidification shrinkage of an aluminium alloy is 6%. The first 3% or more is easily provided by liquid and/or mass feeding. The remaining 3%, if isolated from outside supplies of feed metal, now has to be spread over 3 perpendicular directions, i.e. 1% in each direction. If this is further spread over opposite surfaces, then this is 0.5% per surface. For a 4 mm cast section this is 0.5% of a 2 mm dimension, or 0.01 mm, which is effectively unmeasurable on most castings, being smaller than the surface roughness of most sand and gravity die castings.

It is important to note that solid feeding is assisted by atmospheric pressure, but not necessarily dependent on it. For instance it can work effectively in vacuum castings.

Finally, solid feeding will also operate at a late stage of freezing even if the region is not entirely isolated from the liquid supply. The gradual build up of hydrostatic tensile stress in the residual liquid as interdendritic feeding occurs can rise to such a level that the stress becomes limited by the collapse of the surrounding solid. In this case it is clear that interdendritic feeding can take place at the same time as solid feeding - both are cooperating in an attempt to reduce the internal stress in the poorly-fed region.

In conclusion, this lecture has examined how the shrinkage inherent in making a casting is compensated for by the use of feeding. We have considered both the mechanisms by which feeding takes place and the rules that need to be followed if we are to produce sound castings. Feeding is not always easy to get right and failure inevitably leads to the initiation of shrinkage porosity, which will be covered in more detail in **TALAT Lecture 3207**.

Literature

Campbell, J.: Castings, Butterworth Heinemann, 1991.

List of figures