MME 345
Lecture **B:08**

The Design of Feeding System

2. Feeding calculations 1: Optimizing size of feeder

Ref:

[1] P. Beeley, Foundry Technology, Butterworth-Heinemann, 2001
[2] J. Campbell, Castings, Butterworth-Heinemann, 2001
[3] Heine, Loper, Rosenthal, Principles of Metal Casting, Tata McGraw-Hill, 1976

Topics to discuss....

1. Introduction
2. Optimizing size of feeder

1. Introduction

- 7 rules of feeding
  1. Do not feed (unless necessary)
  2. Heat transfer requirement
  3. Volume requirement
  4. Junction requirement
  5. Feed path requirement
  6. Pressure differential requirement
  7. Pressure requirement

- It is essential to understand that all six rules (no. 2 to 7) must be fulfilled if sound castings are to be produced
  - the breaking of only one of the rules may result in ineffective feeding, and a porous casting
  - the wide prevalence of porosity in castings is a sobering reminder that solutions are often not straightforward.

- The optimum feeder size is so burdened with complications
  - dangerous if calculated wrongly; costs money to cast on, and more money to cut off
  - the casting engineer is strongly recommended to consider whether a feeder is really necessary at all (rule 1 applies !!)

- The feeder and the casting should be considered an integral system because a casting cannot be made sound without adequate feed metal, no matter how much we pay attention to other details.

- Table shows that only a relatively small amount of feed metal is necessary.

- So one might think that feeding is fairly simple and that only a small reservoir is necessary to compensate for shrinkage.

Metal	Crystal Structure	Volume Change, %
Al	fcc	7.14
Cu	fcc	5.30
Mg	hcp	4.10
Zn	hcp	4.08
Fe	bcc	3.16
Li	bcc	2.74
Si	diam	-2.90
Bi	rhom	-3.32

- But the metal in the feeder is subject to the same laws of solidification as the metal in the casting and, to be effective,

  (1) a feeder must stay fluid at least as long as the casting, and
  (2) must be able to feed the casting during this time.

- Consequently, the problem of providing this feed metal during the entire solidification period of the casting involves quite a few variables!

- The key criteria that should be considered in feeder design:
  1. **Feeder size and shape**
  2. **Feeder number and feeder dimensions**
  3. **Location of feeder**
  4. **Feeder connections to the casting**
  5. **Increase in efficiency of feeder**
  6. **Special conditions arising from joining sections (junction problem)**

2. Optimizing Feeder Size

- Methods for determining feeder head size must be based upon meeting the separate requirements for

  freezing time criterion, which indicates that the head must freeze sufficiently slowly to ensure that the liquid metal will be available throughout the freezing period, so enabling directional solidification from the casting to the feeder, and

  feed volume criterion, which ensure that the head must be capable of supplying sufficient volume of liquid to compensate for liquid and solidification shrinkage

- In each individual case either one or the other of these requirements will be the critical factor controlling the minimum size of head.

- When head size is governed by the freezing time criterion,
  - **the freezing times of head and casting are not estimated**
  - **a purely 2D geometric comparison** (based on comparison of the ruling sections of casting and head; method of inscribe circle, for example) **is adopted to ensure that the head will solidify last**

2.1 Determination of feeder size

Caine's Method

- If a cylindrical casting is fed by a top feeder, the diameter of the feeder should be at least equal to the diameter of the casting.
- One the other hand, a plate casting of the same volume and thickness smaller than the diameter of the cylinder need not require a feeder of the same volume, because it will not have to remain molten as long as the feeder on the cylinder.
- So, obviously then, the **A/V** ratio of feeder can be related to the **A/V** ratio of the casting.
- Caine developed an equation for steel which expressed the relative freezing time of feeder and casting in terms of the relative volumes of feeder and casting:

$$X = \frac{a}{Y - b} + c$$

X = freezing ratio, or relative freezing time = $\frac{(A/V)_{casting}}{(A/V)_{feeder}}$

Y = $V_{feeder} / V_{casting}$

For identical freezing rates of feeder and casting, feeder volume requirement becomes infinite

When casting freezes increasingly rapidly relative to the feeder, the feeder volume requirement decreases towards a minimum , which is represented by the shrinkage requirement alone

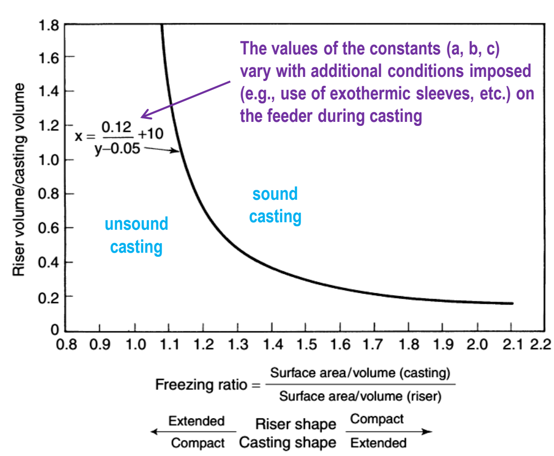


Figure 3.12 Caine's curve for minimum feeder head volume, based on relative freezing rates of casting and head, or freezing ratio (after Reference 41) Basic risering equation: x = a/(y − b) + c, where x = freezing ratio, y = riser volume/casting volume, a = freezing characteristics constant, b = liquid–solid solidification contraction, c = relative freezing rate of riser and casting (courtesy of American Foundrymen's Society)

Provides the basic understanding of feeding principles

- requires trial-and-error calculation to obtain desired feeder size
- nature of shape of shrinkage cavity generated in feeder affects feeder size

Bishop's Method

Simple modification of Caine's method
that considers the shape of casting instead of freezing ratio

Shape factor, $S = \dfrac{L + W}{T}$

With increasing values of S (thin casting), the feeder head diminishes towards the limiting level at which the controlling influence is no longer the shape factor but the volume of feed metal required

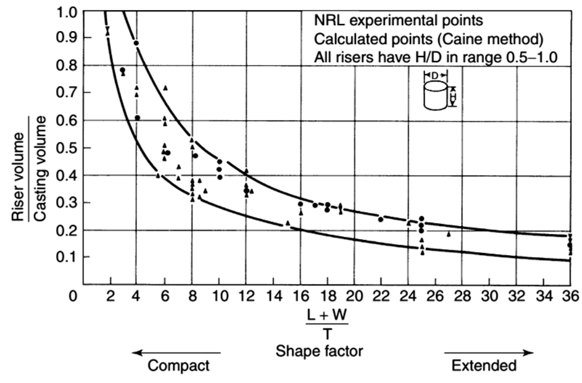


Figure 3.13 Relation of casting shape factor to minimum effective riser volume expressed as a fraction of casting volume. For cylindrical feeder heads with H/D ratios 0.5–1.0 (after Bishop *et al*[43]) (courtesy of American Foundrymen's Society)

Wlodawer's Modulus Method

Based on Chvorinov's method

Deduction of the feeder head requirement

1. Determine the cooling modulus of the casting (cooling surfaces are included only)

$$M = \frac{\text{volume of casting/segment (V)}}{\text{cooled surface area (CSA)}}$$

2. Feeder head is then selected on the principle that it should have a modulus value 1.2 times that for the casting or section concerned.

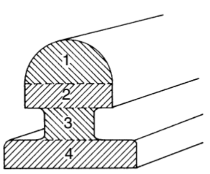
- ❑ Extended to include systematic consideration of exothermic materials, padding, chills and other aids to directional solidification
- ❑ Since the feeder head requirement for a slender, extensive cast shape is governed not by its modulus but by the volume of feed metal, a further check is therefore necessary to verify that the feed volume from the proposed head will be adequate in the particular circumstances.

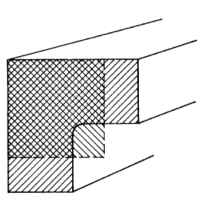
2.2 Modulus determination

Shape	Volume V	Area A	Modulus V/A
Sphere	$\frac{\pi t^3}{6}$	πt^2	$\frac{t}{6}$
Cylinder h = t	$\frac{\pi t^3}{4}$	$\frac{3\pi t^2}{2}$	$\frac{t}{6}$
Cube	t^3	$6t^2$	$\frac{t}{6}$
Bar (square semi infinite)	$t^2 l$	$4tl$	$\frac{t}{4}$
Bar (Cylindrical semi infinite)	$\frac{\pi t^2 l}{4}$	πtl	$\frac{t}{4}$
Plate (semi infinite)	At	$2A$	$\frac{t}{2}$

Modulus of some common shapes

- more complicated shapes should be broken down into simple shapes
- moduli of the individual simple shapes should be determined
- the section having the highest modulus should be considered as the significant section as sensitive for porosity formation





- for more complex shapes, a general formula of the following can be used

$$M = \frac{\text{cross-sectional area}}{\text{perimeter}}$$

Example: For simple rectangular shape

$$M = \frac{a \cdot b}{2\,(a + b)}$$

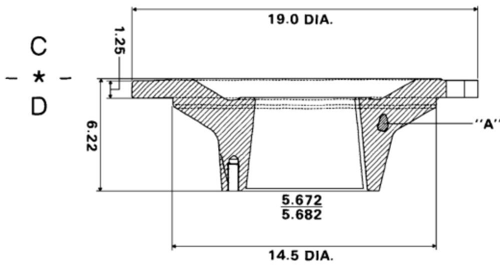
- if any of the sections contain directly non-cooling surface, its dimension (c) should be excluded from the perimeter

Example: For simple rectangular section

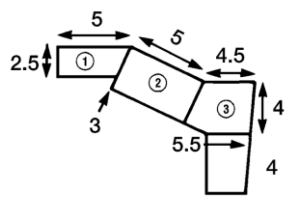
$$M = \frac{a \cdot b}{2\,(a + b) - c}$$

Example:

- Heavy truck wheel hub casting
- Weight = 68 kg
- Very high scrap rate due to shrinkage defect “A” in segment 3



$$M = \frac{a \cdot b}{2(a+b) - c}$$



$$M_1 = \frac{5 * 2.5}{2\,(5 + 2.5) - 2.5} = 1.0$$

$$M_2 = \frac{5 * 3}{2\,(5 + 3) - 3 - 3} = 1.5$$

$$M_3 = \frac{5 * 4}{2\,(5 + 4) - 4 - 3} = 1.8$$

Significant modulus, M_S = 1.8

2.3 Influence of feeding criteria and casting shape on feeder shape

Table 3.3 Moduli and freezing times of bodies of constant volume 1000 cm^3

(a) Variously shaped bodies

Shape	Ruling dimension cm	Modulus $M = V/A$ cm	M^2 cm^2	Freezing time = $2.1\,M^2$ min	Freezing time as percentage of that of the sphere
Sphere	$D = 12.41$	2.068	4.277	9.0	100
Cylinder $H = D$	$D = 10.84$	1.806	3.26	6.8	76
Cube	$T = 10$	1.667	2.78	5.8	65
Cylinder $H = 10D$	$D = 5.03$	1.198	1.44	3.0	38
Square bar $L = 10T$	$T = 4.64$	1.101	1.23	2.6	29
Plate or slab $L = 10T$	$T = 2.15$	0.898	0.81	1.7	19

(b) Plates of varying proportions

	Ruling dimension cm	Modulus $M = V/A$ cm	M^2 cm^2	Freezing time = $2.1\,M^2$ min	Freezing time as percentage of that of the sphere
$L = T$(cube)	$T = 10$	1.667	2.78	5.8	65
$L = 2T$	$T = 6.30$	1.575	2.48	5.2	58
$L = 5T$	$T = 3.42$	1.221	1.49	3.1	35
$L = 10T$	$T = 2.15$	0.898	0.81	1.7	19
$L = 20T$	$T = 1.35$	0.617	0.38	0.8	9

Table 3.4 Comparison of volumes of bodies of a given modulus $M = 1$ (equivalent to a constant freezing time of 2.1 min for steel cast in sand moulds)

(a) Variously shaped bodies

Shape	Ruling dimension cm	Volume V cm^3	Ratio V/V equivalent sphere	Volume of equivalent sphere as a percentage of V
Sphere	$D = 6$	113	1	100
Cylinder $H = D$	$D = 6$	170	1.5	67
Cube	$T = 6$	216	1.91	52
Cylinder $H = 10D$	$D = 4.2$	582	5.15	19
Square bar $L = 10T$	$T = 4.2$	741	6.56	15
Plate or slab $L = 10T$	$T = 2.4$	1 382	12.23	8

(b) Plates of varying proportions

Shape	Ruling dimension cm	Volume V cm^3	Ratio V/V equivalent sphere	Volume of equivalent sphere as a percentage of V
$L = T$(cube)	$T = 6$	216	1.91	52
$L = 2T$	$T = 4$	256	2.27	44
$L = 5T$	$T = 2.8$	549	4.86	21
$L = 10T$	$T = 2.4$	1 382	12.23	9
$L = 20T$	$T = 2.2$	4 259	37.3	3

- The dimensions of any feeder head must satisfy the two separate criteria: (1) **modulus** (representing freezing time), and (2) **volume feed capacity**.

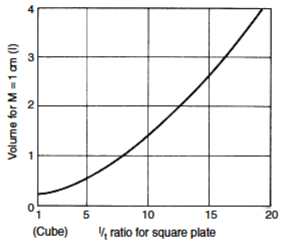


Figure 3.19 Influence of shape of plate castings upon volume associated with identical freezing times (values for M = 1 cm, equivalent to a freezing time of 2.1 min)

- any of the castings represented on this curve could be fed by a spherical head of modulus 1.2

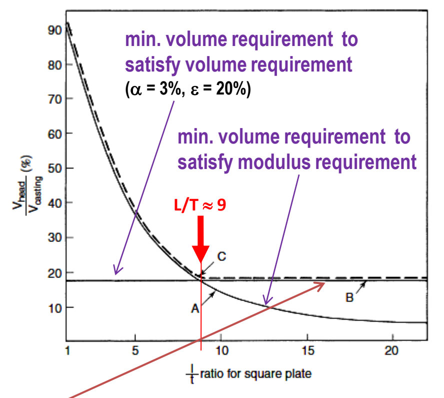


Figure 3.20 Illustration of factors determining feeder head volume. Theoretical feeder head requirements for plates of various proportions (spherical head, ignoring non-cooling interface). Curve A: Minimum head volume percentage to satisfy freezing time criterion (based on relation $M_F = 1.2M_C$). Curve B: Minimum head volume percentage to satisfy volume feed demand criterion (based on 3% specific shrinkage and 20% metal utilization). Curve C: Composite feeding curve

it also demonstrates the increased yield attainable for thin-walled castings

- The ranges of casting dimensions over which freezing time and volume feed capacity respectively control feeder head size **depend upon the specific shrinkage** of the alloy.

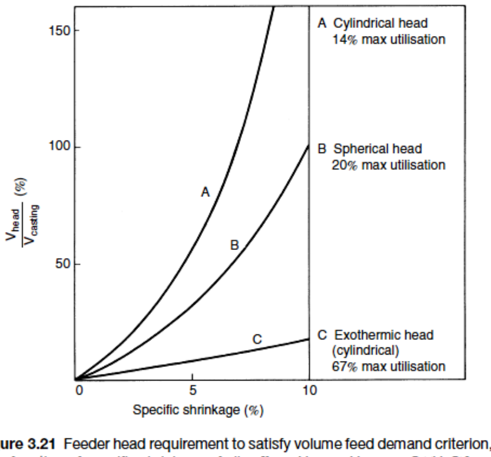
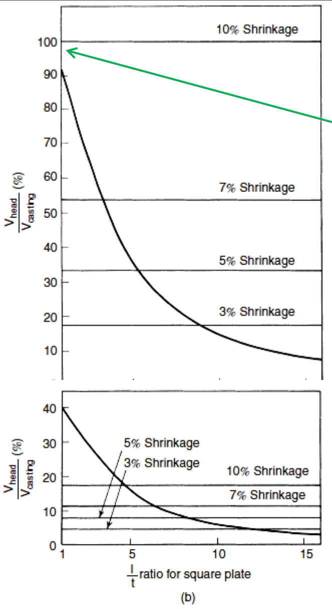


Figure 3.21 Feeder head requirement to satisfy volume feed demand criterion, as a function of specific shrinkage of alloy [from $V_{head} = V_{casting} \times S/(U\text{–}S)$]

Volume feed capacity becomes increasingly significant with higher values of specific shrinkage.



at ~10% shrinkage the volume feed capacity would determine the minimum feeder head size throughout the shape range of the casting

summary of influences of the volume feed and freezing time criteria for various combinations of shrinkage and casting shape

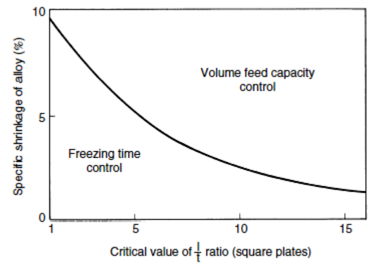


Figure 3.23 Diagram indicating controlling factor in feeder head size (for plate castings of various proportions, fed by spherical head)

Figure 3.22 Feeder head requirement to satisfy volume feed demand criterion for various values of specific shrinkage. (a) For spherical head, (b) for exothermic head (cylindrical, h = 1.5d). Freezing time criterion curves for square plates superimposed. Exothermic curve calculated for residual geometric modulus of 0.7, equivalent to M = 1 without exothermic

2.4 Dimension of feeder neck

- The necessary minimum dimensions of feeder neck vary with the particular casting design and method, but except in special cases, the neck requires a cross sectional area greater than that of the section which it is designed to feed.

- Modulus of the neck commonly controlled to be intermediate between that of the casting and the feeder

  ratio of moduli of casting, neck and feeder are usually taken as **1.0 : 1.1 : 1.2**

- The neck can be reduced significantly **if the neck can be kept hot** for a longer period of time

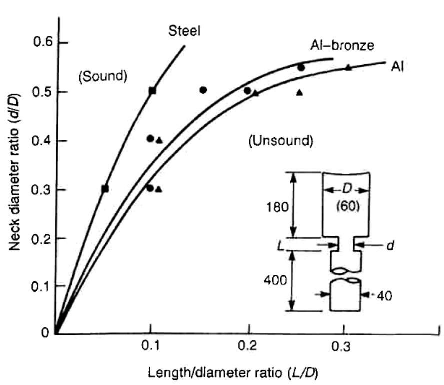


Figure 6.8 *Effect of a constricted feeder neck on soundness of steel, aluminium bronze, and 99.5Al castings. The experimental points by Sciama (1975) denote marginal conditions.*

Restricted neck feeding
(Washburn Core)

- This is an extremely thin wafer with a central aperture, inserted into the mould across the junction of casting and feeder head
- Provided that the core is sufficiently thin in relation to the surrounding mass of metal, its temperature rises rapidly because of its limited thermal capacity
- Solidification thus proceeds extremely slowly adjacent to the core and the aperture remains open for feeding: the net effect is much as though the core were absent
- The successful use depends upon
  - ✓ **maintaining the correct relationship between core thickness, aperture size and metal section**
  - ✓ **adequate mechanical strength**
  - ✓ **resistance to fusion and metal penetration**

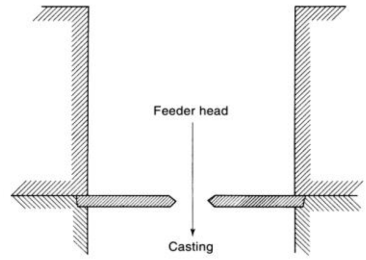


Figure 3.33 Washburn core for restricted neck feeding

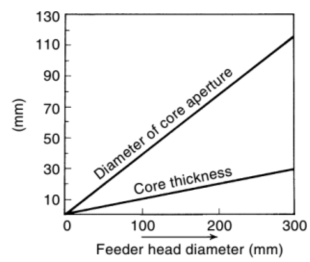


Figure 3.34 Dimensions of Washburn wafer cores

Next Class
MME **345**, Lecture **B:09**

The Design of Feeding System

3. Feeding calculations 2: Optimizing shape and placement of feeder