Appendix B - Calculation of Ideal and Actual Fill Times for Water Inlet Casting

B.1Calculation of Ideal Fill Times

The following formula can be used to calculate the ideal fill time for a given casting.

$$t = kT\left(\frac{T_i - T_f + SZ}{T_f - T_d}\right) \quad \text{[B1]}$$

where;

t = Ideal filling time, seconds.

k = Empirically derived constant, s/mm.

T_i = Temperature of the molten metal as it enters the die, °C.

T_f = Minimum flow temperature of the metal, °C.

T_d = Temperature of the die cavity surface just before the molten metal hits it, °C.

S = Percentage of solids allowable in the metal at the end of die filling, %.

Z= Constant based on latent heat of casting alloy, °C/%.

T = Typical casting thickness, mm.

In order to solve the equation for fill time we must first determine suitable values for the other parameters. Herman [B1] has provided a list of suggested values for a range of alloy and die material combinations. A selection for aluminium alloys and H13 dies are given in Error: Reference source not found.

Casting Alloy	k, for H13 die (s/mm)	T_i (°C)	T_f (°C)	T_d (°C)	Z (°C/%)
Al 360, 380,384	0.0346	650	570	340	3.8
Al 390	0.0346	720	595	355	3.8

Table B.1 Suggested Values for Parameters in Fill Time Equation. [B1]

We shall now discuss the applicability of these values to our problem and suggest more appropriate values where possible.

***k*, s/mm,** is a function of, among other things, the heat transfer rate between the die and the molten alloy as the cavity fills. Its value will depend upon;

- the alloy being cast,

* the die material,
* the type and amount of lubricant, and
* the condition of the die surface.

This parameter has not been accurately determined for a range of conditions. The values supplied in the text only take into account the die material being used. The same value is used for almost all casting alloys from iron to magnesium. It is suggested that...

“The practical die caster may find it necessary to adjust the constant *k* as much as plus or minus 40% from the value recommended in [Error: Reference source not found] to get a good correlation with practice.” [B1]

It is therefore the job of the die designer to assign a value to *k* based on experience with past dies. When one considers that varying *k* will have a direct effect on the fill time, ie. a 40% increase in *k* will cause a 40% increase in *t*, we can see the importance of correctly determining this parameter. If we can only guess at the value of *k* then much of the fill time calculation is meaningless.

In the current case we will calculate the fill times for a range of *k* values and present the results as a distribution.

T_i, °C, represents the temperature of the molten metal when it reaches the gate. Herman [B1] suggests that the metal will usually lose 8 to 9 °C in the ladle and shot sleeve, so a value about 10 °C lower than the temperature in the holding furnace would be appropriate. This is contradicted by the work of Iwahori et al [B2] who demonstrated an alloy cooling from 640 °C in the holding furnace to around 570 °C by the time it reaches the gate of the cavity in an A384 alloy casting. This value of 570 °C is equal to the minimum flow temperature given in Error: Reference source not found. Clearly there also exists some confusion about what values are appropriate to be used here. The values determined by Iwahori et al [B2] seem to be more realistic and are backed up by sound experiments, for this reason we shall base the values we use upon them.

They represent a drop in holding furnace temperature to injection temperature of 70 °C. We know that for our castings the holding furnace temperature is usually 680 °C so we shall use a T_i value of 610 °C.

***T_f*, °C,** represents the temperature at which we would like the metal to travel through most of the cavity. Herman [B1] recommends a temperature of 570 °C. It is important that this temperature lies above the solidus temperature of the alloy, 540 °C for 380 alloy [B3]. Apart from this requirement it is difficult to see any reason to choose one value over another. With this in mind we shall use a value of 570 °C.

***T_d*, °C,** represents the die surface temperature that the molten metal encounters as it is injected. It is possible to get a fairly good idea of what this is by measuring the surface temperature of the die just before the die closes. In our case we have done this with a thermal imaging camera so we can use average values obtained from these images.

***S*, %,** represents the amount of solidified metal present in the flowing metal at the completion of cavity filling. In theory, for atomised flow, this solid component will consist of small isolated particles amongst the liquid flow. Such solidification will not hinder flow at low percentages. A high percentage solids factor should result in less overall shrinkage porosity in the final casting. However, if the factor is allowed to get too high the casting's surface finish will become worse. We shall use a range of values from 0 to 30 % in our calculations.

***Z*, °C/%,** is a function of the specific and latent heats of the alloy and as such is not subject to change. The value given in Error: Reference source not found will be used.

***T*, mm,** is the representative thickness of the casting. Very few castings have a uniform thickness throughout. In the case of the water inlet casting the thickness varies from 5 mm to 2 mm. We shall use a representative value of 3 mm. In a similar manner to the *k* parameter, this parameter will have a major effect on the resulting fill time so it is important to get it right. We can see that in this case if we used a value of 2 mm instead of 3 mm our ideal fill time would be reduced by 33%. This is another area in which experience must be used to determine an appropriate value.

B.1.1Calculation for Water Inlet Casting

Die temperature was determined by taking an average of the temperatures for the fixed and moving half and the sliding cores from a thermal image taken during experiments in the foundry. The resulting value used was 195 °C. The values of *k* and *s* were varied between high, medium, and low values. All other parameters were given fixed values. The results are presented as a 3 × 3 matrix along with the maximum and minimum values. The average of the nine calculated values is also given.

1Parameter Values

k = 0.02076, 0.0346, 0.04844 s/mm.

T_i = 610 ˚C.

T_f = 570 ˚C.

T_d = 195 ˚C.

S = 0, 15, 30 %.

Z = 3.8 ˚C.

T = 3 mm.

2Results

		k (s/mm)		
		0.02076	0.0346	0.04844
	0	7	11	16
S(%)	15	16	27	38
	30	26	43	60

Table B.2 Fill Times in Milliseconds for Different *S* and *K* Values.

Maximum Value = 60 milliseconds

Minimum Value = 7 milliseconds

Average Value = 27 milliseconds

B.2Calculation of Actual Fill Times

The first step in the calculation of actual cavity fill times is the determination of the plunger position at the point when the molten alloy is at the gate of the casting. This is done by taking an actual casting and weighing the cavity, overflow, and runner sections separately. The volume of each component can then be determined and thus the movement of the plunger required to fill any given part can be determined. This was done for two water inlet castings.

	Casting 1	Casting 2
Distance to fill Runner and Biscuit (mm)	50	53
Distance to fill Cavity (mm)	39	39
Distance to fill Overflow (mm)	9	9

Table B.3 Shot Displacements for Two Castings.

The point at which the metal is at the gate will occur a distance X before the cavity is full, where X = Distance to fill Cavity + Distance to fill Overflows.

The point at which the cavity and overflows are full is best determined by examining the shot trace for the given casting and looking for the pressure peak that will occur upon cavity filling. Once these two points are found the cavity fill time can be read off the time axis of the shot trace. This process is shown in Figure B .1.

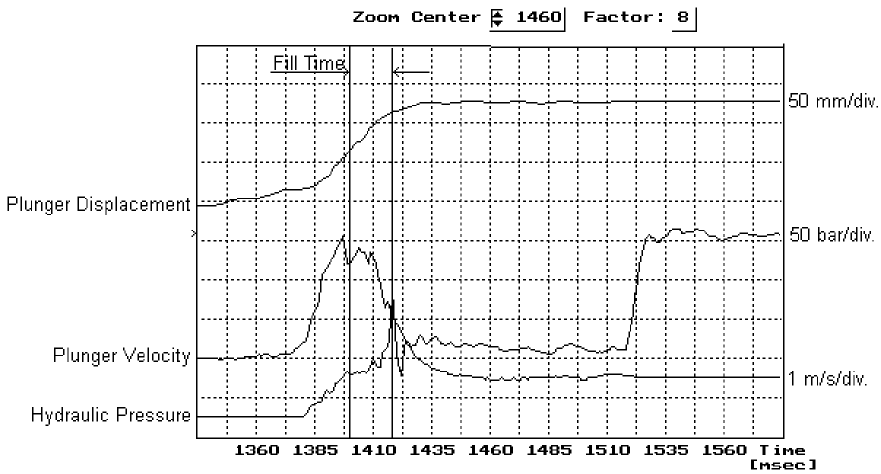

Figure B.1 Enlarged Shot Trace for Water Inlet Casting.

For both castings the actual fill times were determined to be 18 ms.

B.3 Comparison of Actual Fill Times with Ideal Fill Times

It can be seen that actual fill times for the water inlet are of the order of 20 ms. Values in the range of 7 to 60 ms with means around 30 ms were recommended by the ideal fill time equation.

The actual fill times are less than the average calculated fill times. This indicates that most castings will be free from flow defects such as cold shuts. There is room for variation in ideal and actual fill times and this will result in a number of castings that will have flow defects present. This variation may be due to changes in lubricant application, die temperatures, and metal temperature. It is likely that due to the poor fill pattern in the die a very low value of percentage solids is required to make good castings.

B.4References

B1 Herman, *'Die Casting Technology - Calculations'*, Die Casting Education Project RMIT University, 1995.

B2 Iwahori, Nakamura, Tozawa, Yamamoto, *'Metal Flowing Behavior in Die Castings and Defects in Aluminium Die Castings'*, 13th SDCE International Die Casting Congress and Exposition, 1985.

B3 ASM International, *'Metals Handbook - Volume 2, Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, 10th Edition'*, ASM International, 1990.