Process stability for Rheocasting process

Abstract

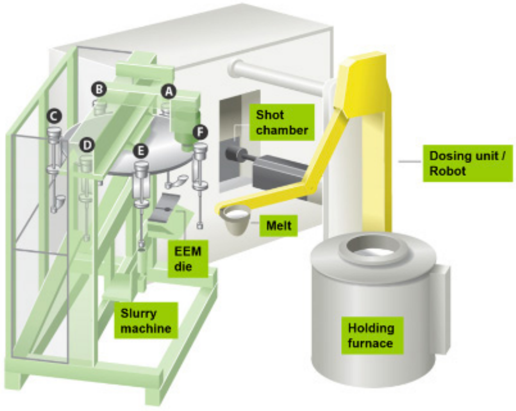
This white paper describes the parameters influencing the casting process using Rheocasting with the RheoMetal process [1-2]. The aim with this paper is to describe how each parameter influences stability of the process and which parameter that must be under control and under which tolerances and min / max values to ensure process stability and robustness.

Short process description

Rheocasting is a melt preparation process. Thus, most of the casting process is very similar to traditional High Pressure Die Casting (HPDC). The difference is an additional step between the holding furnace and the shot chamber of the casting machine. The basic process steps are the following:

- *Produce a solid piece of aluminium. This is what we call the EEM; Enthalpy Exchange Material. The EEM should be attached to a stirring rod.*
- *Insert the EEM, while being rotated, into the pouring cup containing liquid aluminium.*
- *After a certain time, the EEM has melted away and in that way cooled the liquid into the semi-solid state. The so-called slurry, having a certain solid fraction, is then poured into the shot sleeve of a normal HPDC machine.*

A schematic illustration of the process, when integrated into the foundry, is shown in Figure 1.



Picture 1. The slurry machine; the heart of the rheocasting process.

The different steps including slurry preparation are shown in Figure 2.

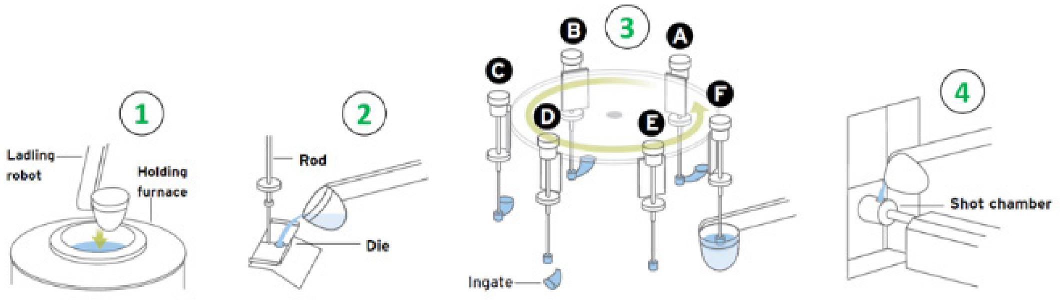


Figure 2. From holding furnace to casting.

1. Melt is taken from the holding furnace.
2. Some of the melt is poured into the die to produce the EEM. Alternatively, the EEM can be casted with a separate linear dosing device.
3. The different actions in the slurry machine are as follows: The EEM is casted (A), cooled in two steps (B and C), the ingate is removed (D) and inspected (E). Finally, the slurry is prepared using the rotating EEM (F).
4. The produced slurry is poured into the shot chamber of the HPDC machine.

Since there are 6 stations in the slurry machine, there is always an EEM ready for slurry preparation, and hence the slurry preparation will not prolong the cycle time.

Influencing parameters

The simplicity of the RheoMetal process is the reason for its ease of industrialization. As for any casting process, there are several parameters which should be kept within reasonable limits to maintain process robustness. In comparison to traditional HPDC, only a few additional parameters must be strictly controlled. Below, the influencing parameters for rheocasting are listed in order of decreasing importance.

Melt temperature

The temperature of the melt in the cup before slurry preparation starts is the most important parameter to keep within strict limits for obtaining process stability and robustness. The RheoMetal process is based on the enthalpy exchange between the liquid aluminium and the EEM. For this reason, it is recommended to keep this temperature within +/- 5 DegC. To achieve that, it is necessary to have a holding furnace with a maximum temperature fluctuation of +/- 5 DegC in the area from where melt is taken. Most modern holding furnaces can fulfil this requirement.

The pouring cup and its handling will naturally also have an impact on the melt temperature when the EEM is inserted. It is recommended to keep the cup in the melt for a few seconds before filling it to the desired level, and in that way minimize temperature losses. Provided that the pouring cup is preheated and that the time from filling of the cup until slurry preparation is kept constant, the temperature fluctuations in the cup are the same as those in the holding furnace. Dosing is typically done with a robot, and hence timing will be identical for all shots.

Anyhow, some temperature fluctuations will always exist, and then it is of course important to know its effect of the slurry and the subsequent casting quality. The slurry process has been studied in detail over the years, particularly at Jönköping University in Sweden. If the melt temperature increases, the solid fraction in the slurry will decrease. However, the change in solid fraction is rather small. In Figure 3a, the impact of superheat above the liquidus temperature on the solid fraction as well as the grain size is shown. When increasing the superheat from 17 to 27 DegC, the solid fraction decreases from 32 % to 28 %. At lower superheats (from 7 to 17 DegC), the increased temperature did not change the solid fraction at all. In the studied temperature range the grain size is also very stable; from 68 to 72 µm.

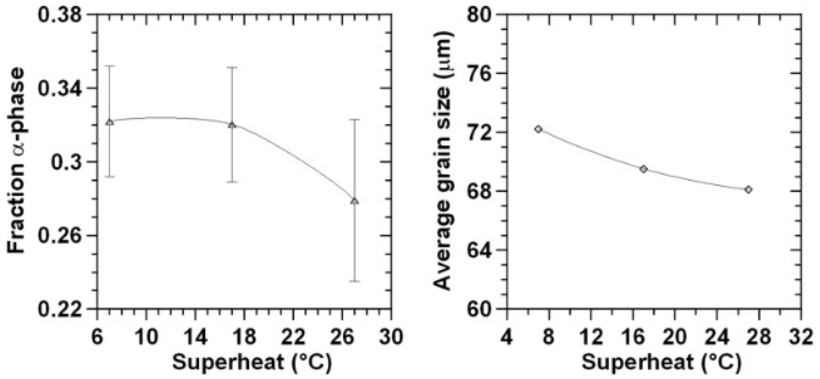


Figure 3. Impact of varying superheat (initial melt temperatures) on solid fraction in the slurry (a) and the average grain size (b) [3].

In summary, if the melt temperature stays within +/- 5 DegC, it can be expected that the solid fraction in the slurry will vary by a maximum of +/- 2 % (absolute values). A change in solid fraction will lead to a change in viscosity. Figure 4 shows the impact of solid fraction on the viscosity for a semi-solid material with globular grains [4]. In the same figure, the red lines illustrate the expected viscosity range when changing the solid fraction from 28 to 32 %. Obviously, the change in viscosity can be considered as negligible. On the other hand, if the solid fraction changes at higher solid fraction ranges (~50 %, as typically used in thixocasting), there is an extremely high sensitivity. The RheoMetal process is typically run in the range of 30-35 % solid fraction. At solid fractions higher than ~40 %, the slurry cannot easily be poured out from the pouring cup.

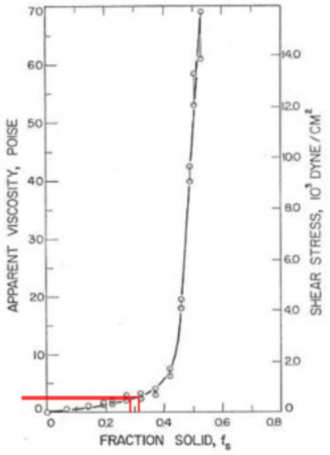


Figure 4. Relationship between solid fraction and viscosity for a semi-solid material with globular grains [4]. The red lines illustrate a typical maximum variation occurring under industrial conditions using the RheoMetal process.

Melt volume in pouring cup

For HPDC, the metal volume poured into the shot sleeve will have an impact on the filling of the cavity and the related part quality. For rheocasting it will additionally have an impact on the solid fraction in the slurry. Typically, the dosing volume stays within +/- 2.5 %.

Assuming a shot weight of 5 kg, and an EEM addition of 6 % based on the shot weight (0.3 kg), an increase in melt volume with 5 % would correspond to a new EEM percentage of 0.3/(4.7*1.05 + 0.3)*100 = 5.73 %. As will be shown below, a change in EEM addition of 1 % (absolute value) has a similar effect on the solid fraction as a change in melt temperature of ~9.3 DegC. Hence, a change from 6 % to 5.73 % in EEM addition amount (0.27 % in absolute value) will have a similar effect as an increased melt temperature of 0.27 *9.3 = 2.5 DegC. Based on the results presented in the previous section it can be expected that an increased dosing volume with 5 % (from 4.7 kg to 4.935 kg) will result in a reduced solid fraction of ~2.5/9.3 *4 □ 1 % (absolute value). The maximum estimated variation in solid fraction will then be +/- 0.5 %.

Size of the EEM

The size of the EEM is controlled by the size of the cavity in the EEM-tool. Provided that the EEM is properly filled, it can be expected that the variation in EEM addition amount will be very small.

Anyhow, if there is a variation in EEM-amount, it would be of interest to estimate how this would affect the solid fraction in the slurry. Based on an energy balance it is possible to derive an expression showing how a change in superheat (□Tmelt) and a change in EEM addition amount (□%EEM) are related to each other for a constant solid fraction in the slurry; see equation below

$$\frac{\Delta T_{melt}}{\Delta \%_{EEM}} = \frac{(1 - f_s^{slurry}) \times \Delta H + C_p^{EEM} \times (T_{slurry} - T_{EEM})}{100 \times C_p^{melt}}$$

Using realistic values, it was shown that a change in EEM addition amount by 1 % (absolute value) has a similar effect as a change in superheat of ~9.3 DegC. For further details, please refer to Ref. [3].

In the same paper [3], the effect of EEM addition on solid fraction of the slurry was studied; see Figure 5.

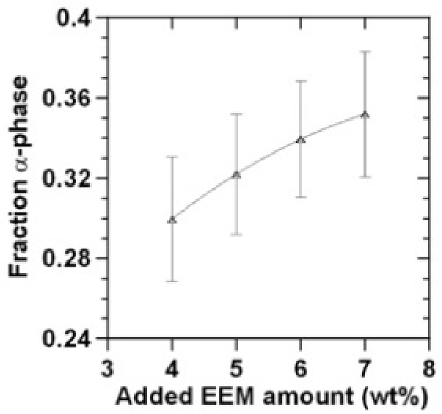


Figure 5. Effect of EEM addition on solid fraction at varying superheats.

It should be noted that the superheat was increased with 5 DegC for every increase in EEM amount with 1 %, as seen in the table below.

Amount of EEM:	4 wt%	5 wt%	6 wt%	7 wt%
Tprocess start	622°C	627°C	632°C	637°C
Superheat used:	2°C	7°C	12°C	17°C

Table 1. The different combinations of superheats and EEM:s used in the experiments.

As an example, it can be observed that the solid fraction increased from 32 to 34 % when increasing the EEM amount from 5 to 6 %. Such a change in EEM amount would correspond to a decreased superheat of 9.3 DegC as shown above. Considering that the used superheat actually was 5 DegC higher, we could expect that the solid fraction would increase in a same way as if decreasing the superheat by 9.3-5= 4.3 DegC. This fits well with the results shown in Figure 3a, where a decreased superheat of 10 DegC increased the solid fraction from 28 to 32 %.

As mentioned above, the variation in EEM-amount will be very small, and it is estimated to reach an absolute maximum of +/- 0.15 % (absolute value) due to various reasons. **This would then correspond to a maximum change in solid fraction of +/- 0.6 % (absolute value)**.

To conclude, the most important findings discussed in the previous sections are summarized below:

- *An increased superheat of 10 C or a deceased EEM-addition amount of 1 % (absolute value) will lead to a reduced solid fraction of less than 4 % (absolute value); e.g. from 32 % to 28 %.*
- *The estimated variation in solid fraction (absolute values), as caused by permissible process variations, will be as follows:*

o Melt temperature: +/- 2 %
o Melt volume: +/- 0.5 %
o EEM size: +/- 0.6 %

…and consequently, the expected maximum total variations will be ~+/- 3 %; e.g. from 27 to 33 % in the worst case. From Figure 4, it can be seen that this will have a very small/negligible effect on the viscosity, which is a major factor controlling the cavity filling in rheocasting.

EEM temperature

The temperature of the EEM will of course also have an impact on the final solid fraction in the slurry. After the two cooling steps, the EEM typically has a temperature of 150-250 C. Below, an attempt is made to estimate how much it can be expected that the solid fraction decreases if the EEM temperature is raised 100 C.

Again, let's assume a shot weight of 5 kg, and an EEM addition of 6 % based on the shot weight (0.3 kg). An increase of the EEM temperature has a similar effect as a somewhat increased melt temperature; hence an increased energy of the system. Using the following values of the specific heats,

Cp (Liq) = 1150 J/kg,K
Cp(200 C) = 950 J/kg,K

We can estimate the equivalent increase in melt temperature from the following heat balance
0,3 * 950 * 100 = 4.7 * 1150 * □T, which gives that □T is ~5 C.

Hence, increasing the EEM temperature from e.g. 150 C to 250 C, has a similar effect on the solid fraction of the slurry as if increasing the melt temperature by 5 C. From the discussion above, we have learned that this would decrease the solid fraction by ~2 % (absolute value). By keeping the EEM temperature within the range 200 +/- 50 C, we can make sure to keep the solid fraction variation within +/- 1 % (absolute value).

Under normal production conditions, it is no problem to keep the EEM within the above given temperature range. However, after a longer production interruption, it is likely that the temperature of the EEM's have dropped too much, and therefore it is recommended to either produce new EEM's before casting starts or to reject the casted parts until all cold EEM's have been replaced. The EEM temperature is of course also influenced by the temperature of the EEM-tool. Therefore, it is important to always use a tempering device connected to the EEM-tool.

Stirring time and stirring speed

The stirring time and stirring speed should be set sufficiently long/high to provide time for complete melting of the EEM. Typically, the time is set to 10-25 sec's, and the stirring speed to 1000 rpm, depending on the EEM diameter and the alloy used. During stirring there will be some heat losses away from the metal to the surrounding; by heat conduction to the pouring cup and by radiation from the metal to the air. These parameters, which are set in the machine program, will not vary to any measurable extent, and therefore its impact on solid fraction can be considered as negligible.

Pouring cup preheating

To have a smoothly running process it is vital to keep a stable temperature of the pouring cup. This is the reason for the general recommendation to preheat the cup in the holding furnace, or alternatively using a gas torch, before filling up the cup with the requested amount of liquid aluminium. A cold pouring cup will increase the solid fraction in the slurry, but it is difficult to say how much since it so strongly depends on the type of cup used, cup material, dosing volume etc. Based on experience, it is rare that the pouring cup temperature variation causes any disturbances of the process, provided that normal preheating procedures are used (as mentioned above)

References

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