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Reoxidation Processes Prediction in Gating System by Numerical Simulation for Aluminium Alloys

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Abstract

Pouring of liquid aluminium is typically accompanied by disturbance of the free surface. During these disturbances, the free surface oxide films can be entrained in the bulk of liquid, also pockets of air can be accidentally trapped in this oxide films. The resultant scattering of porosity in castings seems nearly always to originate from the pockets of entrained air in oxide films. Latest version of ProCast software allows to identify the amount of oxides formed at the free surface and where they are most likely to end-up in casts. During a filling calculation, ProCast can calculate different indicators which allow to better quantify the filling pattern. The fluid front tracking indicator " Free surface time exposure" has the units [cm^2*s]. At each point of the free surface, the free surface area is multiplied by the time. This value is cumulated with the value of the previous timestep. In addition, this value is transported with the free surface and with the fluid flow.Experiments to validate this new functions were executed.

Keywords: Aluminium alloys, Oxide films, Numerical simulations

1. Introduction

When the gating system is not properly designed, entraining of air bubbles into melt may occur. The area of melt, which is in contact with air bubbles in gating system, behaves the same way as melt exposed to air in previous phases of pouring – oxidation (reoxidation) processes begin absorbing the surrounding melt. These processes could be the main source of porosity in final castings. One of the most progressive ways to study reactions taking place in gating system is computer simulation of mold cavity filling. Initially this scientific discipline was inaccurate and in practice had limited use possibilities. Over the time, new methods and new programs brings a computer simulation closer to reality. In previous years the popularity in the examination of processes taking place in the gating systems rapidly increased thanks to precise simulation programs. Products of reoxidation are generally associated with the flow of liquid metal into the mold during pouring. However, modeling and verification trials in foundries have failed to indicate how gating systems may be universally improved. Simple rules, such as filling the runner system as quickly as possible, have proven effective to some degree. Still, the fine tuning of gating systems to optimize their performance has been largely unsuccessful. While it is relatively easy to produce dirty castings with a bad gating system, the use of a good gating system does not necessarily lead to clean castings. It is well known that oxidation of the melt due to exposure to the atmosphere during mold filling is the root cause for the formation of a significant portion of the inclusions found in castings. For instance, in low-alloy steel, reoxidation inclusions account for 83% of all inclusions.

The problem with gating systems is directly linked to how the metal is delivered into the gating system, and each part of the delivery system cannot be treated in isolation. Water modeling has shown the highly variable nature of current pouring systems. Studies of the hydraulic issues and analysis have shown that velocity is the largest single contributor to air entrainment in the gating system, and consequently the amount of inclusions is dependent on the air entrained. This is in agreement with the studies performed by Campbell. . A new direction in the observation of reoxidation processes is provided by simulation software ProCast. [1, 2]

ProCast contains feature called "front tracking indicator" which allows to observe the free surface of the melt in gating system (exposed to air) in real-time. The program keeps tracking exposed surface area during the whole filling process, even when surface is entrained to the bulk of the melt by the turbulences. At each point of the free surface, the free surface area is multiplied by the time. This value is cumulated with the value of the previous timestep. In addition, this value is transported with the free surface and with the fluid flow. With the possibilities of visualization, we can observe the reoxidation processes taking place in the gating systems during filling the mold, as well as the distribution of the oxides in the final casting, therefore it is possible to predict the optimal design of the gating system. [3, 4]

2. Experiment Methodology

Horizontal runner and effect of its geometry on melt flow and reoxidation processes during gravity pouring into sand mould was studied with the aid of latest version of ProCast simulation software. ProCasts new function „FLUID FRONT TRACKING“ can calculate different indicators which allow better quantification of the filling pattern. In our experiments was used "Free surface time exposure indicator" which corresponds to the local free surface area multiplied by time (surface * time units) and can be used to quantify the amount of oxides transported by the free surface. This indicator was not used to specifically determine amount of oxides in castings, but to compare differences in two observed variants.

For the purposes of all the simulations has been used aluminum alloy A356.0. Aluminium alloy AlSi7Mg0,3 was chosen from software database for purposes of all simulations. Pouring temperature was set
to 730 °C. To determine the effect of runner geometry on flow character, all simulations used identical gates
and sprues, also conditions of non-pressurized gating system with ratio 1:4:4 was realized. Filling time was 4 seconds.

Cross section area of sprue – 93 mm^2

Cross section area of runner – 372 mm^2

Cross section area of gate – 372 mm^2

3. Results

Three gate designs were evaluated, attention was focused on four areas:

– The filling condition at the beginning of the runner
– The filling condition at the end of the runner
– Velocity of the melt at the entrance to the casting cavity (subcritical condition speed
– 0.5 ms-1 was observed in all the designs and therefore will not be mentioned further)
– Contamination of the casting with so called "new" oxide films, created during reoxidation process (formation of porosity in castings is greatly influenced by "new" oxide films, also it is neccessary to mention that simulation software is not able to determine the presence of "Old" oxides generated in previous stages of melt treatment).

3.1. Variant 1

The first proposal was based on a frequently used runner concept of runner, where the dominant dimension is height. In practice a lot of runners has an aspect ratio of width to height of 2 : 1 (Figure 1).

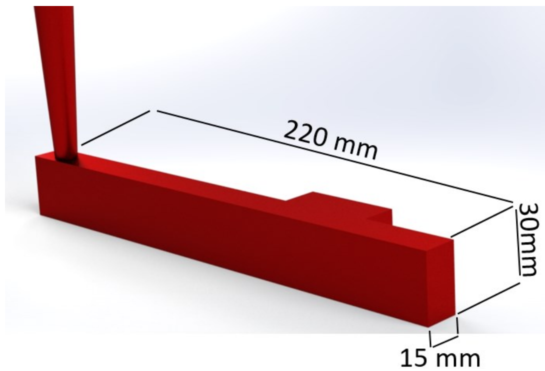

Fig. 1. Runner design for variant 1

Filling at the beginning of the runner is shown on Fig. 2. From this Figure we can see the limits of this concept. Liquid metal entering the runner doesn’t have ability to fill whole cross-section area of the runner and free surface of melt is exposed to air, which leads to extensive reoxidation processes. .

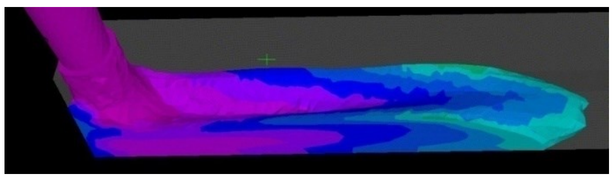

Fig. 2. Filling at the beginning of the runner

This process can be observed by the gradual change of color on the melt surface (Fig.3, purple-area represent least exposed melt to the air gradually through blue, green, yellow and red, the intensity of exposure to air increases).

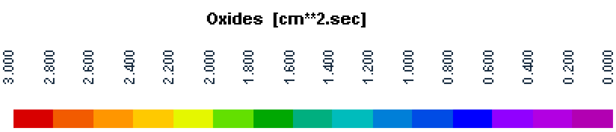

Fig. 3. Colored scale of the simulations

Filling at the end of the runner is shown on Fig. 4. Dominant dimension of the runner is height, which gives the possibility to form massive rebounding waves at the end of the runner. Yellow colour in front of wave indicates the amount of oxides. All these oxides will be consumed into the bulk of melt when the wave collapses into opposing liquid metal flow.

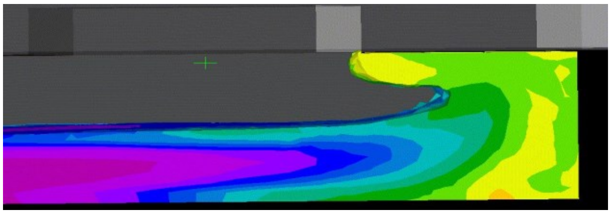

Fig. 4. Filling at the end of the runner

Forming waves represent negative phenomena which cause entraining of surface oxide films (The "old" created during previous stages of the melting process and "New" created because of incorrect dimensioning of gating system) into the internal volume of the melt. This mechanism supports formation of entrained doubled oxide films floating in melt. Schematic representation of mentioned mechanism is shown in Figure 5. [5]

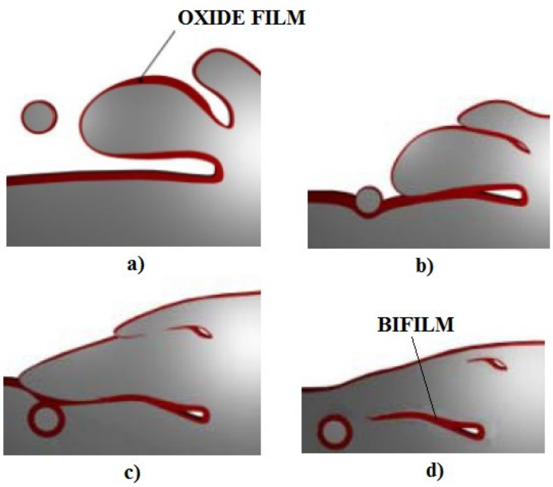

Fig. 5. Bifilm formation

"Front Tracking indicator" was used as a tool to compare rates of reoxidation with other runner designs and not as a tool for specific, accurate determination of the oxide amount in the casting. Therefore, conclusions regarding the rate of reoxidation processes may be concluded only after a comparison of all simulated designs. However, already can be concluded that:

a) due to the extension of the runner behind the gate we managed to prevent the entry of a certain amount of oxides in the casting cavity,

b) Rebounding waves at the end of the runner are created because of the height of the runner.

3.2. Variant 2

The second proposal was based on a concept where the dominant dimension is width. During the experiment we observed changes in behavior of the progressing melt and also amount of surface exposed to air. Proposed runner had a ratio of height to width of 1: 2 (14 mm: 28 mm). Runner design is hown in the Figure 6.

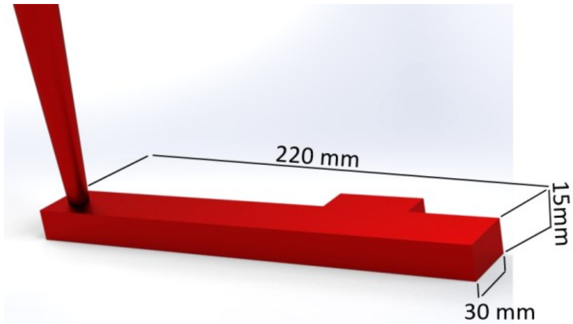

Fig. 6. Runner design for variant 2

From Figure 7 it can be seen that by changing the geometry of the runner, the melt fills most of the cross section area, but immediately after the falling stream can be observed contraction area marked by the red circle. Resulting in tearing of the melt stream from the walls of the mold and the formation of regions with negative pressure. In this area, mixing of the entrained air and the melt occurs - accompanied by re-oxidation processes. Another negative phenomenon is formation of two side-streams (marked by yellow ellipsis) in the runner, which leave the center of the runner relatively empty. In this area with reduced pressure may, again occur reoxidation, also indicated by the color of the melt in the image.

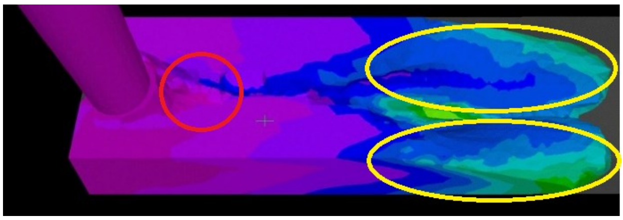

Fig. 7. Filling at the beginning of the runner

Filling process at the end of runner with reduced height does not have sufficient space to create the reflective wave (Figure 8) turbulences and entrainment of oxide films are to some extent suppressed. It is observed that the contraction and tearing the flow to two streams of the melt will produce more oxides at the end of the runner than in variant first variant.

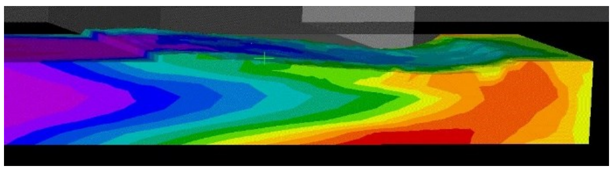

Fig. 8. Filling at the end of the runner

We may conclude that there was a slight decrease in contamination of casting by new oxide films. While at the beginning of the runner, conditions were channel has a plurality of oxide formation, suppression of turbulence at the end of the manifold channel appears to be a positive factor. The decrease in the oxides of the casting may be caused by trapping large amounts of oxides of entry of the melt into the notch.

3.3 Variant 3

Third design of runner is based on a concept, where the dominant dimension is the width. Value of cross-sectional area remained the same as in the second variant, but sprue base was added as shown on Fig. 9.

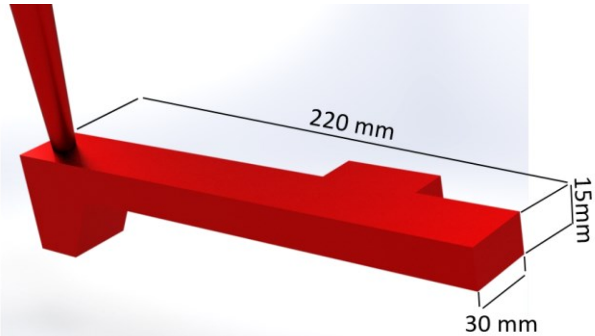

Fig. 9. Runner design for variant 3

Filling at the beginning of the runner – Modified design of runner and process of filling is shown on Figure 10. Simulation demonstrated advantages of this concept. Sprue base is immediately filled with melt, leaving little space for reoxidation processes. The cross-sectional area of runner is completely filled and so only small amount of melt is exposed to air.

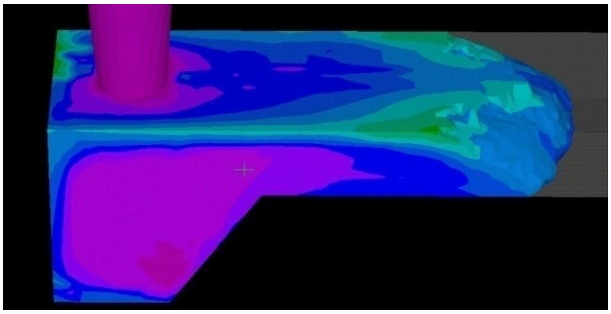

Fig. 10. Filling at the beginning of the runner

Filling at the end of the runner – Advantages of the modified design are also obvious from Figure 11. Spectrum of colours demontrates, that only minimum amount of melt is contaminated with oxides, also formation of rebounding wave was supressed.

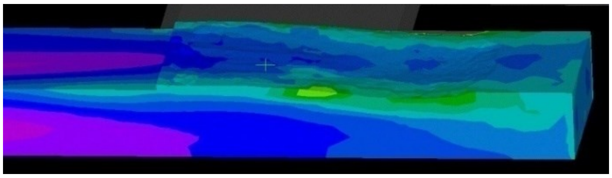

Fig. 11. Filling at the end of the runner

4. Conclusion

The concept of runner with dominant height was evaluated as inadequate alternative during the course of our experiments (focusing on amount of "new" oxides penetrating the mould cavity). By changing the orientation of the runner from height to width and by keeping the same cross section area ratio, only a slight decrease of the new oxide films occurs. By adding of an sprue well has been shown that the runner can provide a substantially lower risk of oxide films formation due to reaxoidation. This modification allowed the melt to completely fill the cross-section area of the runner, leaving little space for reoxidation processes. This factor is very important for alloys strongly reacting with air to form oxide films (mainly aluminum alloys). In some literary sources [new Campbell] is stated that the use of an impact sprue well can be counterproductive. Mainly because the well can be a place for new turbulences to occur and contaminated metal will continue to flow to the mold cavity. Circulation and turbulence of the melt in the well has also the potential to where is a reduction of friction of the melt passing through the fold in the direction of the runner, causing the acceleration of the melt. During the simulations carried out for the purpose of this work is an alternative to an impact hole appears to be more favorable than the alternative without an impact well.

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