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Analysis of Reoxidation Processes with Aid of Computer Simulation

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Abstract

Submitted work deals with the analysis of reoxidation processes for aluminium alloys. Due to the aluminium high affinity to the oxygen, the oxidation and consequently reoxidation will occur. Paper focuses on the gating system design in order to suppress and minimize reoxidation processes. Design of the gating system is considered as one of the most important aspect, which can reduce the presence of reoxidation products - bifilms. The main reason for the reoxidation occurrence is turbulence during filling of the mold. By correctly designing the individual parts of gating system, it is possible to minimize turbulence and to ensure a smooth process of the mold filling. The aim of the work is an innovative approach in the construction of gating system by using unconventional elements, such as a naturally pressurized system or vortex elements. The aim is also to clarify the phenomenon during the gating system filling by visualization with the aid of ProCAST numerical simulation software. ProCAST can calculate different indicators which allow to better quantify the filling pattern.

Keywords: Aluminium alloys, Reoxidation, Gating system

1. Introduction

Based on the previous research it can be implied that 84% of casting defects are due to reoxidation. Reoxidation is the term involving secondary and tercial oxidation of liquid metal during metallurgy operations and the filling process of gating system. Result of liquid metal oxidation is oxide layer created on the surface. Oxide layer essentially protects the melt from external influences, but the problem occurs at the moment when oxides are entrained to the internal volume of molten metal. Formation and entrainment of the oxide layer in the casting process are due to the high velocity of the melt, causing turbulence during the mold filling. Folding the surface oxide layer, dry side to dry side, creates a bifilm (Figure 1). New bifilms have very small and compact shape, so they can penetrate through all the filling components (even filter) and ends in the final mold cavity, where can be considered as a nucleation site during solidification for various defects. Prof. Campbell as the first pointed out the importance of bifilms. He observed that the formation of many defects, like porosity and tears in cast aluminum is associated with the presence of bifilms. [1, 2]

Reducing critical velocity (0,5 $m.s^{-1}$ for many alloys) is possible, among other things, by suitable design of the gating system. By correctly designing the individual parts of the gating system, it is possible to minimize present of turbulence in system.

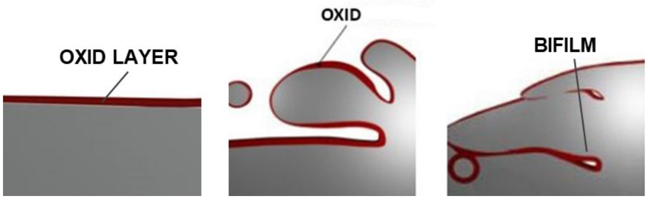

Fig. 1. Process of creation of bifilm

2. Gating system

Construction of the gating system is commonly divided on pressurized and non-pressurized gating system, based on poured alloy. In 1962 was for the first time mentioned the concept of naturally pressurized gating system by Jeancolas and collective. Nowadays, this specific gating system design is subjected to research mainly by prof. Campbell and a group of scientist focusing on reoxidation research.

Naturally pressurized gating system (Figure 2c) is without a mechanism for any reduction of melt velocity. The whole area of liquid metal is in direct contact with the mold walls (except for the front area of flow) by natural back pressure in gating system due to frictional resistance. Oxide layer forming on the front area of flow is pressed on the mold walls. The advantage of a perfectly filled system is lost when the melt passes through the gate to the mold cavity. Due to the smooth transition without the presence of choke elements is the flow velocity too high. Although there is no turbulence during passage through the system, by passing the gates splashes occurs and all benefits of naturally pressurized system is lost. High velocity of melt flow is often the reason, why this type of system is not used in the casting industry. To reduce the melt velocity was in previous research works used the filters, various extensions of the runner or so-called vortex elements. Based on the literary analysis it appears that the satisfactory results will be achieved by ensuring the combination of these elements. [3, 4, 5]

3. Numerical simulation

For analysis in the simulation software ProCAST were designed four types of gating system shown in Figure 2.

First design is concept of the non-pressurized system with ratio 1:4:4, commonly used for aluminum alloys. The second is also a non-pressurized system, but with a modification of the end of runner with chamfer. Another two variants are concepts of the naturally pressurized gating system with ration 1:1:1, the last design have vortex extension of the runner (Figure 2d).

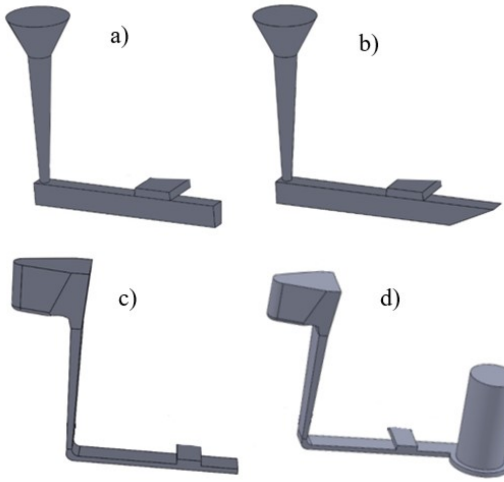

Fig. 2. Design of gating systems used for numerical simulations

3.1. Analysis of turbulence

The tracking indicator for turbulence energy has the units [100 cm^2/s^2]. Based on the obtained results can be stated, that the non-pressurized gating seems to be the least satisfactory in terms of reoxidation processes. Extensive turbulences are caused by increased cross section of the runner. Due to the imperfectly filled runner, there is space for turbulence to occur by corrugating the free surface, and at the end of the runner by the bouncing wave mechanism. In the first variant of unmodified runner, the melt is suddenly braked at its end and thus the melt is folded over onto itself (Figure 3). In the variant with gradual narrowing of the end of the runner, there was a slight suppression of bouncing wave (Figure 4). [6, 7]

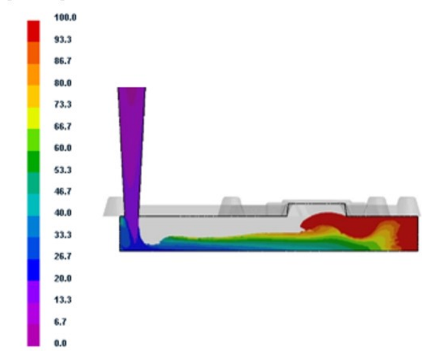

Fig. 3. Turbulence of melt – non-pressurized gating systems

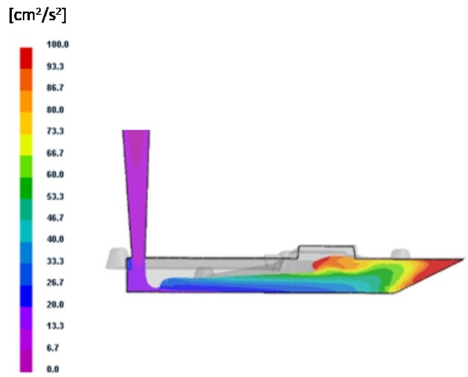

Fig. 4. Turbulence of melt – non-pressurized gating systems with chamfer

In the case of a naturally pressurized gating system, the place for turbulence is eliminated by perfectly filled system in every point as shown in Figure 5. The best result was observed in the concept of naturally pressurized system with the vortex extension of runner at the end (Figure 6). The melt flow was directed to a vortex element, which ensures calm continuity of flow in the runner. Turbulence energy is situated to the vortex element and another parts of system is protected from the negative influence of reoxidation.

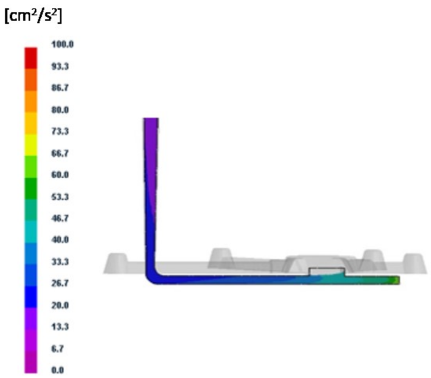

Fig. 5. Turbulence of melt – naturally pressurized gating system

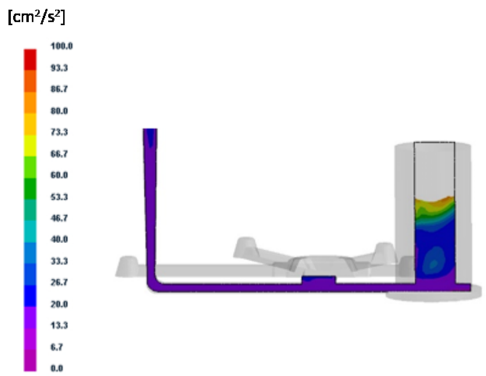

Fig. 6. Turbulence of melt – naturally pressurized gating system with vortex extension

3.2. Analysis of oxide occurrence

The tracking indicator for oxide occurrence was set to [0.5 cm^2.s]. As was mentioned above, the resulting of reoxidation rate and thus the final oxide content in the casting depends on the flow velocity and the turbulent rate. The oxide occurrence can be well observed on casting design for the analysis of the mechanical properties. In the area of the biggest turbulence caused by the suddenly braked at its end of runner is oxide occurrence the worst (Figure 7). In the case of modified ending certain decrease in the formed oxides can be observed by approximately 20% (Figure 8). [6]

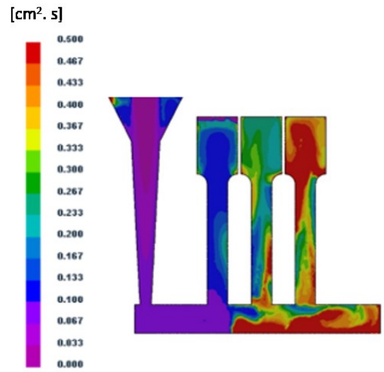

Fig. 7. Oxide occurrence - non-pressurized gating systems

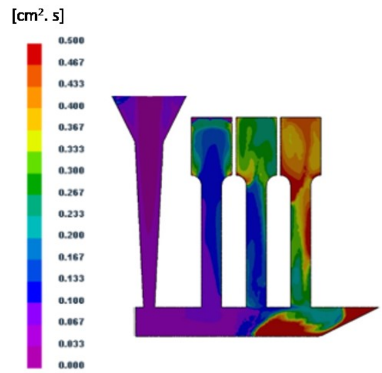

Fig. 8. Oxide occurrence - non-pressurized gating systems with chamfer

By application of naturally pressurized gating system a significant decrease in the oxide occurrence can be observed in Figure 9, compared to a pressurized gating system. The melt braked at the end of the runner minimizes turbulence (due to full system), but the lack of reservoir at the end of the runner, all oxides created during pouring are directed to the castings, mainly to the last tensile strength test bar as shown on the Figure 9.

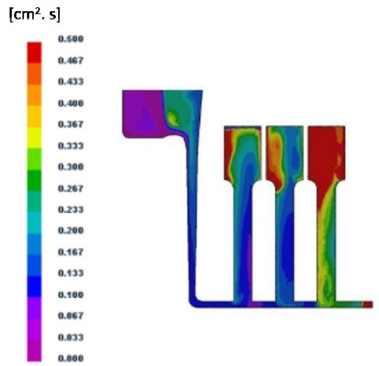

Fig. 9. Oxide occurrence – naturally pressurized gating system

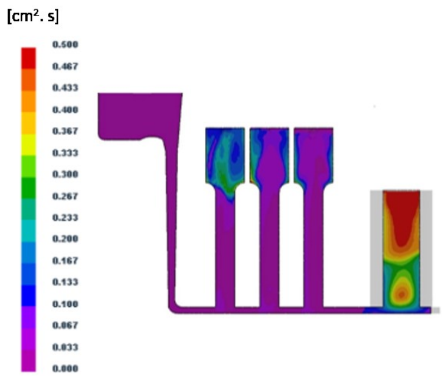

Fig. 10. Oxide occurrence – non-pressurized gating systems with vortex extension

The best results of oxide occurrence were observed in the case of the naturally pressurized gating system with vortex extension of the runner. (Figure 10). The melt is headed to the cylindrical end, where is the flow directed to a tangential gradient eddying motion. A lot of oxides is trapped in this area. By directing the melt flow into the vortex extension of runner we achieved a significant reduction in the melt velocity, which then enters through the gates at lower speed avoiding spattering. [1,5]

4. Experiment

As the experimental material was used aluminum alloy AlSi7Mg0.3, the chemical composition is shown in Table 1. The casting represents three test bars for evaluating tensile strength and elongation. The melt temperature was 720 ±5 °C and the mold was prepared from green sand mixture. As mentioned before, for every concept, three test bars were prepared and submitted for evaluations and the arithmetic average represents values shown in table 2 and table 3 which are furthermore graphically presented in Figure 11 and Figure 12.

Table 1.
Chemical composition of used alloy

element	Si	Fe	Cu	Mn
wt.%	7.3	0.15	0.03	0.10
element	Mg	Zn	Ti	Al
wt. %	0.3	0.07	0.15	bal.

As we can see from Table 2, the highest arithmetical value of tensile strength 210 MPa, was obtained by naturally pressurized gating system with vortex extension of runner. The lowest value of tensile strength was obtained by application of naturally pressurized gating system without modification. Due to the critical velocity of flow and absence of mechanism for deceleration of flow, there is spattering of melt in entrance area. In places of spattering there is high oxide occurrence which acts as bifilm source (Figure 13).

Table 2.
Arithmetic average of R_m [MPa]

Gating system	a	b	c	d
R_m [MPa]	165	175	160	210

Elongation for gating system (a) and (b) is almost identical, without significant changes. Again, after application naturally pressurized system, elongation achieved higher values, furthermore improved by vortex element. Numerical values are shown in table 3.

Table 3.
Arithmetic average of A_5 [%]

Gating system	a	b	c	d
A_5 [%]	2.7	2.8	3.2	3.6

Figure 11 and Figure 12 are shown for better clarification of gating system changes on improvement of mechanical properties.

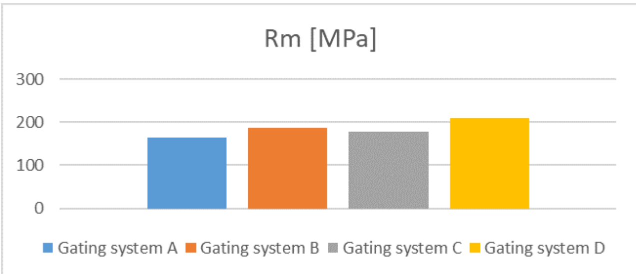

Fig. 11. Tensile strength evaluation

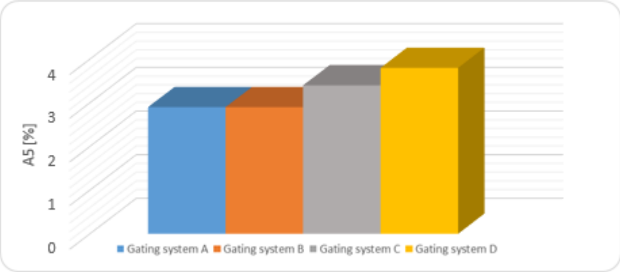

Fig. 12. Elongation evaluation

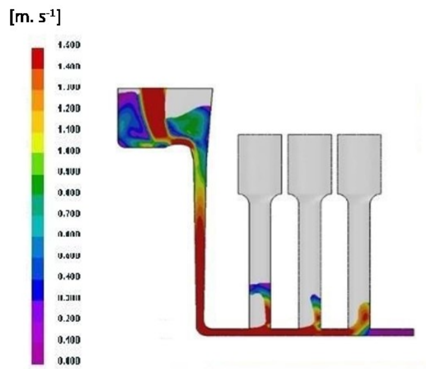

Fig. 13. Metal spatter – naturally pressurized gating system

Bifilms are forming to a compact shape and this folded and furled shape acts as a crack initiator. When is the mold cavity filled, the turbulent character of flow subsides and the bifilms are in a relatively calm environment. At this point, they begin to acquire their initial shape, which leads to the decreasing of mechanical properties. In the concept of naturally pressurized gating system with vortex extension of runner is the melt flow rectified to the rising rotation direction in the extended part, which acts like a oxides "trap". This action eliminates the turbulence and ensure calm entrance to the mold cavity (Figure 14). [1,2]

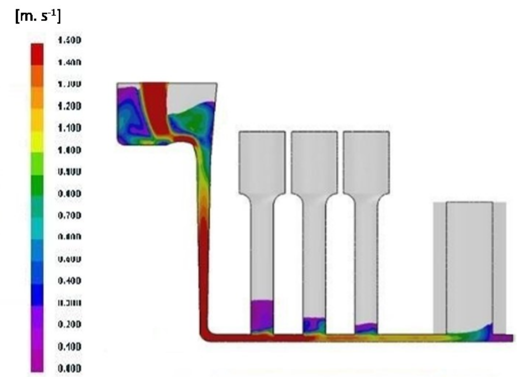

Fig. 14. Metal spatter – naturally pressurized gating system with vortex extension

5. Conclusions

Aim of the paper was to point out the importance of the gating system in an attempt to achieve high-quality castings. Gating system has an influence on the character of melt flow and also on turbulence occurrence. Turbulence character of melt flow has an important influence on the presence of reoxidation processes which leads to the entrainment the surface oxide layer and creating bifilms - "double oxide layer". This term was mentioned for the first time by Prof. Campbell and he considers it as the initiator of many castings defects.

By simply changing the system design and individual parts of the gating system we can improve mechanical properties and suppress an extensive amount of bifilms introduced to the mold cavity. From the results presented above, it is clear that the gating system used for filling the mold and its characteristics have effects on the occurrence oxide affecting on the final tensile strength the turbulent character of flow causes that bifilms are forming to a compact shape. Results confirm the fact, that naturally pressurized system with modification and ratio 1:1.2:1.2 used for aluminum castings is more appropriate than non-pressurized system with ratio 1:4:4. By application of extension of the end of the runner, there can be the question, if it's economically profitable (because more of the batch material is needed). However, in many cases is more profitable having more batch material resulting in high quality castings then economize the amount of batch material. Size of extended vortex element will be subject of further investigation, to achieve better quality casting without using too much batch material.

The future work of this research will be focused on X-ray and SEM-EDS to confirm the presented results and also by the study of other unconventional elements of the gating system.

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