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Optimization of geometry of ceramic gating systems for large-size ferrous castings

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The purpose of the study was analysis of existing solutions and development of the new ones in the scope of designing ceramic gating systems for large-size castings. The current study covers the numerical simulations and experimental investigation of liquid - air flows. The authors focused on phenomena occurring during liquid metal motion in characteristic parts of ceramic gating systems. Analyses were aimed at determination of the optimal geometry of fireclay shapes allowing to obtain laminar flow and to decrease the amount of entrained air.

The results confirmed that the geometry of the currently used gating system components can promote turbulence formation. Thus, the authors proposed its modification, which allowed to limit the air entrainment phenomenon. Technological recommendations, allowing to reduce turbulences accompanying the liquid metal flow in the gating system, were also presented.

Keywords: *gating system, fireclay shapes, air entrainment, numerical simulations.*

1. Introduction

Foundry engineering is a branch of science and industry encompassing a wide range of technologies and production methods significantly differing from each other. An interesting example is production of specific large-size ferrous castings. Such castings are usually required to be of high quality, hence their production is costly and time consuming. Their characteristic feature is using ceramic gating systems at the mould preparation and filling stage. These systems are built of ready prefabricated ceramic products, the so-called fireclay shapes [1,2].

In the case of large-size castings special issues constitute turbulences accompanying the liquid metal flow in the gating system. These are caused by high stream velocity as well as by dimensions of the system [3]. These turbulences, in turn, contribute to air entrained in liquid, which leads to forming casting defects that are difficult to remove [4]. Utilization of ready ceramic systems simplifies development of technology and mould preparation, however, it can be increase these unfavourable effects. Thus, it seems justified to search for a more optimal geometry of ceramic gating systems.

2. Numerical simulations

The first part of the current study covers the numerical simulation of liquid metal (steel) - air flows in characteristic parts of ceramic gating system performed in the Flow-3D software (Fig. 1).

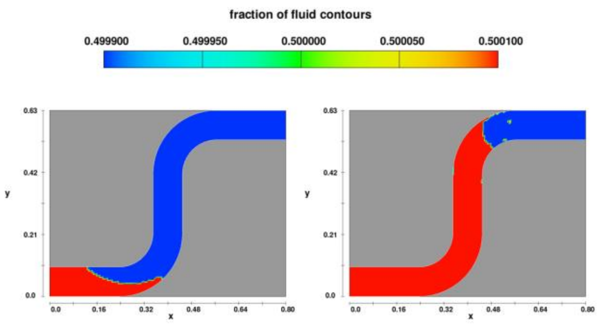

Fig. 1. Examples of simulation results

The results have shown that the highest amount of air is entrapped in liquid when stream is split or suddenly changes direction of the motion. These processes accompanied by flow turbulences occur in fireclay shapes such as tees and elbows. Hence the geometry and position of these gating system components have significant meaning for nature and kinetics of flows.

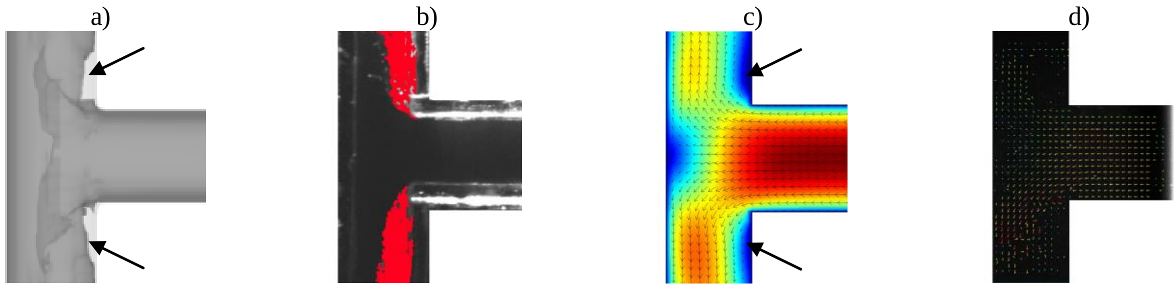

Fig. 2. Gas bubbles: a) - simulation, b) - experiment and dead zones: c) - simulation (2D), d) - PIV analysis

3. Experimental investigation

In the second part of this study the simulation results were compiled with the data obtained during experimental tests. Two-phase (model liquid - air) and single-phase (model liquid) flows in model systems composed of pipes, elbows and tees were analyzed. At this stage of the research authors used a test stand equipped with a ultra-fast digital camera [5].

3.1 Two-phase flows

Experimental evaluation has confirmed the simulation results (Fig. 2). Studies of two-phase (water - air) flows have also shown that tee type fireclay shapes have particularly negative impact on the flow behavior. It has been found that during pouring in these gating system components large gas areas are formed (Fig. 2b). The air entrapped in such regions is gradually released in the form of small bubbles, which is especially dangerous, as bubbles may not have enough time to leave the mould cavity (before solidification begins).

3.2 Single-phase flows

In order to clarify this phenomenon we also performed an analysis of single-phase flows in model systems by the use of PIV method (Particle Image Velocimetry). It showed that during the liquid flow in certain areas of gating system such as elbows or tees “dead zones” (where velocity is close to zero) are formed (Fig 2d). Hence such regions remain unfilled (filled with air) for a longer period (during pouring). This process depends strongly on the orientation (typically horizontal or vertical) of fireclay shapes in relation to the gravity vector.

4. Geometry optimization

Based on the numerical and experimental studies the authors suggested modification of gating system geometry. Among others, the tees ("T" shape) were replaced by a "Y" shapes. This allowed for a significant reduction in the volume of entrained air (Fig. 3).

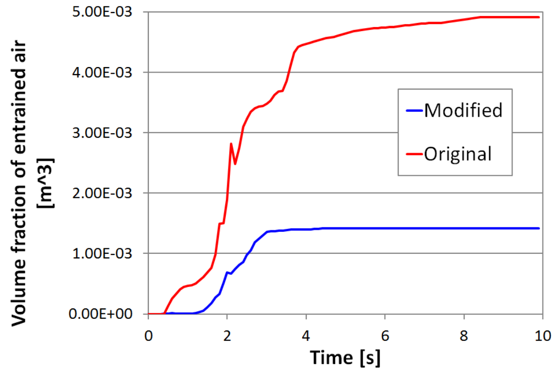

Fig. 3. Comparison of volume of entrained air for the gating system with the use of original (“T”) and modified shapes (“Y”)

5. Conclusion

Currently used ceramic gating system can promote the air entrainment effect. In components such as elbows and tees the turbulence and “dead zones” are created which, in consequence, lead to formation of gas defects in castings. Significant reduction of the entrained air volume is possible by changing the orientation and geometry of the fireclay shapes.

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