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Failure analysis of a railway brake disc with the use of casting process simulation

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ABSTRACT

Software for modelling of industry processes is an integral part of production involving many segments of industry. The use of simulation software in foundry industry is perceived as a tool for visualization of ongoing processes in casting production. These tools eliminate defects and imperfections within the process before the production even begins which has a subsequent positive effect on quality increase and reduction of financial costs in product manufacturing. The paper deals with a solution of formation and occurrence of foundry defects such as shrinkage in the casting produced from ductile iron with the use of simulation software. The casting of railway brake disc and its 3D model were used in the experiments. The goal of the study was evaluation of simulation results with regard to casting quality increase and decrease of shrinkage formation, as well as decrease in manufacturing costs during casting production. The paper focuses on a possibility of improving the utilization of liquid metal in the solidification of castings with the help of simulation that compares basic as well as adjusted parameters of casting. Computer simulation of casting uncovered the gating system elements' adjustments and technological modifications effect on the entire casting and on reduction or elimination of shrinkages incidence along with the increase of liquid metal utilization during casting. These imply the reduction of financial costs and increased efficiency in production of castings. The paper presents the results of the simulation casting of the railway brake disc. Based on the results of these simulations, the shape of gating system and position of casting in mould was modified and the number of feeders has been reduced from 6 to 1. This technology modification saves the liquid metal and the casting has been without shrinkages.

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1. Introduction

Railway transport plays an important role in various types of logistic systems in a wide range of industrial fields. Its operation is very closely linked with high demands on safety and reliability. To meet the demands, it is necessary to pay closer attention not only

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to the operation of individual components and equipment, but also to the process of their actual production. The most important elements that are exposed to extreme stress while being operated are brake discs of a railway wagon. They are a key factor for ensuring safe operation, and are manufactured using technology of casting and subsequent machining of individual castings. One of the main factors of brake disc proper functioning is casting quality of the initial semi-product.

Final quality of a railway disc brake casting is affected by many factors and foundry principles such as unidirectional freezing, technology of feeding and chills/chilling. Other important accompanying phenomenon is the shrinkage of cast iron during casting solidification process. This takes place from the point when casted iron is in liquid state until the ambient temperature is reached. Shrinking or volume change occurring while in liquid state is called shrinkage, specific foundry property of the given material [1,2]. The issues are being dealt with by several authors, e.g. volume changes during ductile iron solidification were studied by Chen et al. [3], Yeung et al. [4] and Falat et al. [5]. The actual shrinkage occurs in the interval of liquid - solid. Shrinkages, however, can be prevented by replacing reduced volume of the melt with increased volume from another source – feeder. The issues of shrinkage and feeding are further presented in [6–8]. When the process is deployed, the size of feeders is chosen based on the volume capacity of casting and type of alloy. Subsequently, the shape and dimensions of the cast are crucial for selecting a suitable type of feeder and its correct positioning on the cast so that the metal is refilled into the entire volume of the cast during volume shrinkage. An important role in this process is played by a gating system and its connection to the casting.

The issue of gating and feeder system in ductile iron castings is described in [9]. A basic condition for prevention of volume defects such as cast shrinkages and micro shrinkages is an appropriate shaping of the casts already in the process of their construction. Solidification of ductile iron castings along with their construction were dealt with by Bjerre et al. [10].

Volume changes in casting during solidification interval, resulting in creation of shrinkages, are a physical phenomenon that cannot be avoided. Shrinkage is a phenomenon concerning the reduction in size of casting during its transition from a liquid to a solid state. This phenomenon also causes the formation of shrinkage cavities and porosity in the casting [11]. However, an appropriate technological intervention can help the resulting shrinkage occur in an additional portion, in the feeder, which will help the cast solidify properly. Formation and elimination of shrinkages and micro shrinkages in ductile iron casting were dealt with by Siclari et al. [12].

In order for shrinkage to be formed in the feeder, not in the casting, a positively unidirectional freezing needs to be ensured [13]. Solidification occurs in two stages. In its first stage, solidification front progresses from the surface towards the inside of the casting along with smooth metal refilling from the feeder. The second phase has limited options of refilling the casting with molten metal from a feeder in a two-phase zone. Positively unidirectional freezing takes place in the case when solidification fronts meet at an angle ω, which is open towards a feeder [14]. Volume decrease in the solidification of metal can thus be almost completely compensated, ensuring healthy solidification of the casting. If the angle ω is open away from the feeder, negatively unidirectional freezing occurs. The solidification process was dealt with more specifically by Davis [15] and its further description is given in [16].

In the castings with various wall thickness, it is therefore important that the thicker and more massive casting parts were directional upwards, so that thicker parts could be equipped with feeders more easily ensuring positively unidirectional freezing. The issue of solidification of ductile iron castings with different wall thickness was dealt with by several authors [4,17,18].

In the production of quality castings, the simulation of filling and solidification of castings is an integral part of production quality [19]. Computer simulation of casting processes is a highly effective tool for optimizing processes and events that take place during the filling of the mould cavity and casting cooling [20]. In the pre-production stage, flaws in castings such as shrinkages and micro porosity can be prevented by simulation of filling and solidification. Adjustments of gating and feeder system along with technological adjustment of casting and casting parameters by means of a computer simulation can help to prevent such flaws. Computer simulations had been employed in the research of several authors. Olofsson [21] dealt with the issue of the influence of chemical composition on the mechanical properties of the casting during solidification. The effect of wall thickness on the microstructure and mechanical properties was solved by Salanet [22]. Sarath [23] in article focuses on the use of castings for the casting of ductile iron. The authors Jolly [24] and Strohmandl [25] deal with computer simulation of casting and its advantages in dealing with the removal of defects in castings.Semi-product of a brake disc of railway wagon can also be classified as a quality casting.

The main problem in the manufacturing of railway wagon brake disc is the low utilization of liquid metal in the casting process along with considerable incidence of shrinkages resulting in increased economic cost of production. The aim of the paper is to present the possibilities of increasing the utilization of liquid metal in the casting process with the use of simulation which compares basic as well as adjusted parameters of casting. The purpose of casting computer simulation is to identify how gating system elements' adjustments and technological modifications impact the entire casting and reduce or eliminate the incidence of shrinkages while increasing the utilization of liquid metal during casting. This also implies reduction in financial costs and increased efficiency of castings production.

2. Material and methods

In the production of castings which are the initial semi-product of brake discs of railway wagons various processes occur that are considered undesirable and can result in damaged castings. The issue is wide in scope and is subject to many completed studies and presented works. Nevertheless, the research into this topic is always needed as it is often closely related to a specific product. The method of computer simulation can be applied from a number of methods and procedures available for further research needs.

The paper presents an analysis followed then by solution of the issue of brake disc production process for a railway wagon, Fig. 1.

The disc brake being dealt with is a classic one used in many railway wagons. Its geometric 3D model with basic dimensions shown in Fig. 2 was created with the use of CATIA V5R20 [26].