OFFICIAL TEMPLATE FOR THE SUBMISSION OF PAPERS
II INTERNATIONAL SCIENTIFIC CONVENTION
"II ICC UCLV 2019"

JUNE 23th – 30th, 2019
CAYOS DE VILLA CLARA. CUBA.

X CONFERENCIA INTERNACIONAL DE INGENIERÍA MECÁNICA COMEC 2019

Determination of the open risers more effective zone for steel wheel casts

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Abstract: The manufacture by casting, remains the most economical way to obtain pieces with complex geometries and diverse alloys. This is a highly complex process given the large number of variables and factors involved in it, thus, when one of these is ignored and/or left out of control, process errors and distortions usually occur. The present paper introduces a design of experiment of the type: Central Composite Design (2^2) + Star, that took into account the variation of important parameters in the pouring, solidification and cooling process, such as pouring temperature and pouring ratio, and that also added the "coefficient factor" relating the geometric parameters of the risers. This design studied the factors 'effects in 16 runs, including 2 central points per block, with the aim of finding the best working area of the risers and the optimal values of the parameters studied under specific conditions. The statistical processing of the data obtained showed the relationships between the parameters studied and the different regression equations. The results obtained allowed to establish new procedures and work volumes for the risers in order to reduce the consumption of material during the process.

Keywords: Reduction of defects, Risers, Steel cast, Simulation

1. Introduction

The introduction of predictive techniques in the production by casting is very important, specially if it is related to the proper and rational use of resources. Considering that this is one of the most raw materials-consuming industries, any decrease in consumption of these has great relevance. On the other hand, it is also necessary to introduce in this industry new production concepts applied nowadays in a more frequent basis [1].

The particular use of designs of experiments in the productive sphere, as can be seen in [2], can be also aimed at decreasing the consumption of raw material. In this regard, responses can be obtained from the statistical behavior of many variables that can later be observed in practice.

There is a significant number of methodologies to obtain the geometrical parameters of the risers. In [3] some of the methodologies are shown and a new one is proposed, introducing a new variable, the average volume. This value is within the same volume calculated by the methodology chosen for it. It is a methodology that uses the modular and volumetric criteria to verify the value of the obtained dimensions, on the other hand, it also uses the minimum value necessary for the work of the risers [3, 4]. However, in the same research it can be seen that even in the simulations carried out there are possibilities of decreasing this coefficient, bringing it closer to the minimum.

2. Methodology

The process of obtaining castings is associated to a large number of variables, which have been indistinctly addressed by several authors to perform optimizations of the process [5-7]. Authors like [8] considered the geometrical shape of the riser and the solidification time of it. On the other hand, [9] took into account the geometry of the feeding system, as well as the pouring time and temperature. Similarly, although a few years later, authors like [10] [11] focused the geometric shape of the riser and the pouring temperature.

Based on the analysis of the literature and the own experience of the authors, this research focused on the study of three variables that are considered very important for obtaining a good quality in castings, i.e.: Pouring Temperature, Pouring Ratio and Coefficient. To better study the influence and interactions of this variables, a design of experiments of the type: Central Composite Design (2^2) + Star has been selected to be used, which will study the effects of the factors in 16 runs, including 2 central points per block. The design should be run in a single block. The order of the experiments has been completely randomized. This will allow avoiding the effect of hidden variables and its possible influence in the study.

The piece analyzed within the study is shown in Fig.1. It is a piece that is manufactured with some regularity in the mechanical industry, and in this case is made from the AISI 1045 steel. This type of steel is also widely used in the mechanical industry for its properties, being a type of steel of medium carbon content and non-alloy. Given that the AISI 1045 steel has a considerable coefficient of contraction, it allows to evaluate certain variables linked to the solidification and cooling processes, and how they affect the occurrence of defects associated with contraction. These are some of the reasons this precise material has been considered for the purposes of this study.

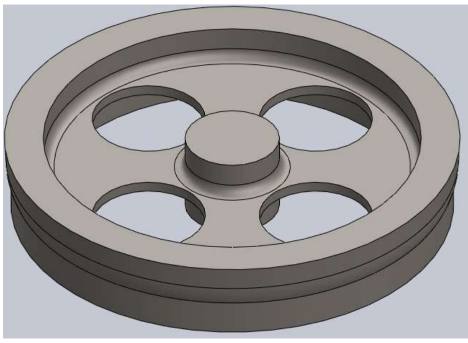

Figure 1. Isometric view of the piece. created by the author

On the other hand, the AISI 1045 steel is a material that is widely used in the automotive industry. It is used in parts of machinery that require hardness and tenacity such as cranks, keys, gears, couplings, shafts, rods, crankshafts, weapons parts, etc. It is also used for the manufacture of agricultural, mechanical and hand tools. Due to its extended use and numerous applications, it is necessary to ensure the quality of the piece produced with this material, both internally and externally, emphasizing the study certain variables´

behavior on the occurrence of defects. Its chemical composition generally oscillates between the values shown in Table 1.

Table 1. Chemical composition

Components	Min	Max
% C	0.43	0.50
% Mn	0.60	0.90
% P		0.04
% S		0.05

The next Fig. 2, schematizes a simplified representation of the different manifestations of the shrinkage defects in castings without riser. In the case of steel and gray iron, this scheme shows why it is necessary to study steel parts [12].

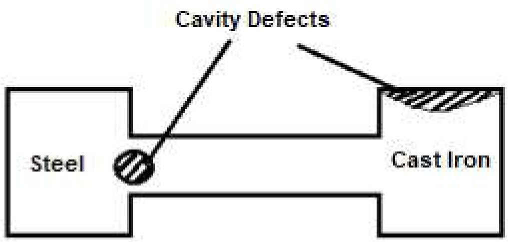

Figure 2. Different manifestations of the shrinkage defects in castings. created by the author

The cavities of shrinkage defects are cavities present inside and outside the piece obtained by casting, caused by a lack of liquid metal feeding that compensates the volumetric shrinkage that occurs during cooling and solidification. According to [13], they usually originate when a mass of molten metal is confined inside the piece that is already superficially solidified. The occurrence of these defects usually depends on the type of material and the conditions of the process, hence the importance of a proper selection of the variables to study.

3. Results and discussion

Several simulations were performed for each of the data of the experimental design shown in Table 2. This was done using the ProCAST software, as it is one of the most used for these purposes and the one with a valid license from the Otto von Guericke University of Magdeburg [14].

Table 2 Results of the experimental design

TempVert	RazVert	Coefficient
ºC	kg/s	
1575	27.5	0.45
1575	23.2	0.45
1575	27.5	0.36
1550	30.0	0.50
1550	25.0	0.50
1600	25.0	0.50
1532	27.5	0.45
1575	27.5	0.53
1575	31.7	0.45
1600	25.0	0.40
1550	25.0	0.40
1617	27.5	0.45
1575	27.5	0.45
1600	30.0	0.50
1550	30.0	0.40
1600	30.0	0.40

The determination of the porosity for certain geometrical parameters of the sprues and the different parameters of the production process were the main elements to be determined in this study. For each combination, a group of images representing the presence of internal defects or not was obtained. These images are shown next in Fig. 2

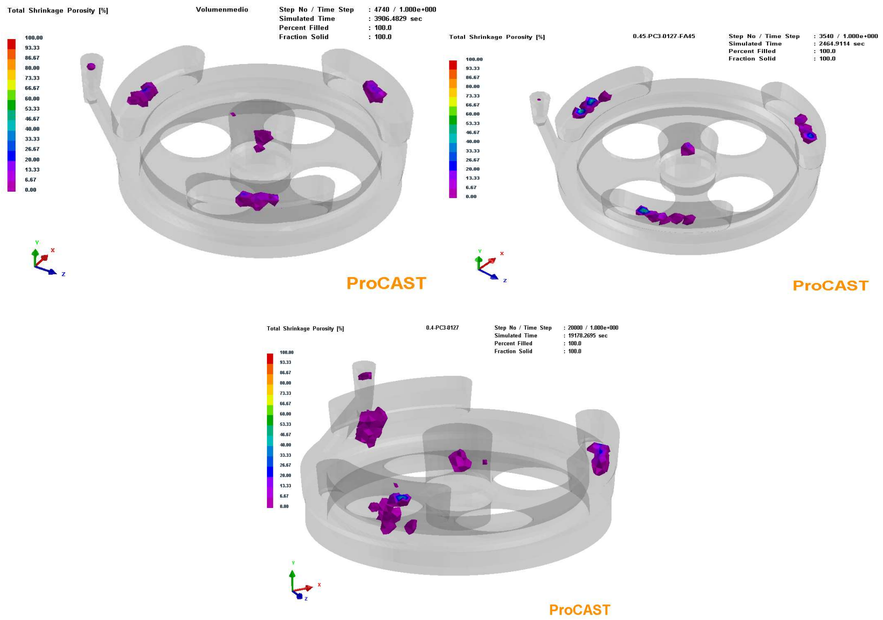

Fig. 2 TempVert 1550 ºC and RazVert 25 kg/s, with a Coefficient of 0.5. TempVert 1533 ºC RazVert 27.5 kg/s, with a Coefficient of 0.45. TempVert 1600 ºC RazVert 25 kg/s, with a Coefficient of 0.4. created by the author

The results obtained by measuring the internal porosity are shown in Table 3. In addition, a column that indicates the percentage relationship between the volume of defect that is really considered a defect and the total volume of defects present in the piece or in the risers has been also added.

Table 3. Results obtained from internal defects in each simulation and the percentage that represents the total volume of porosity present in the cast.

TempVert	RazVert	Coefficient	Defects	% Vt
	kg/s		mm^3	
1575	27.5	0.45	3600	4.0
1575	23.2	0.45	10390	12.6
1575	27.5	0.36	59968	11.5
1550	30.0	0.50	0	0
1550	25.0	0.50	3298	5.1
1600	25.0	0.50	7180	4.4

1532	27.5	0.45	0	0
1575	27.5	0.53	0	0
1575	31.7	0.45	5523	3.1
1600	25.0	0.40	170000	11.8
1550	25.0	0.40	770	2.8
1617	27.5	0.45	50000	13.4
1575	27.5	0.45	22090	5.5
1600	30.0	0.50	3264	6.0
1550	30.0	0.40	14423	8.0
1600	30.0	0.40	104198	15.0

Statistical analysis of the results

In the Pareto diagram shown in Fig. 3, obtained for the initial design, it can be seen how, the variables Coefficient and TempVert, as well as the interaction between them, have an influence on the results obtained. The variable Coefficient, which relates the geometrical parameters of the risers, presents a negative action, that is, as it increases, the defects decrease. In the case of the variable TempVert, the opposite happens, as it increases, the defects grow. In this result we can see how the variable RazVert does not have an effect on the results.

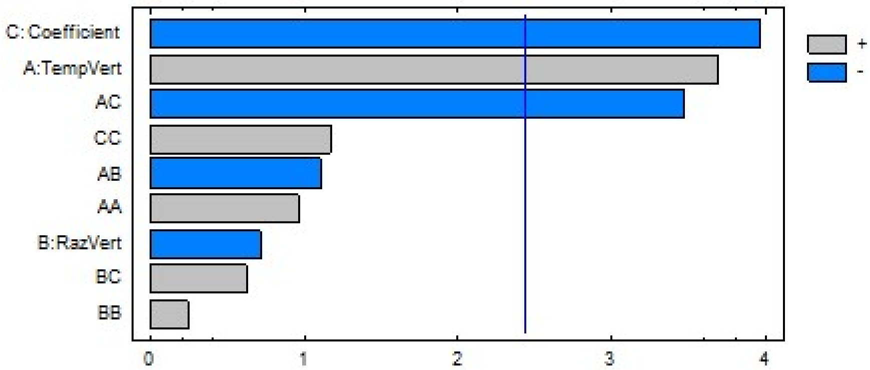

Figure 3. Pareto diagram for the evaluation of the initial design

The following Eq.1, represents the multiple regression equation that is obtained from this study, it includes all the variables and the interactions between them. Similarly, Eq. 2 shows the multiple regression equation which is adjusted to the data/variables that really have an action on the results.

$$Defects = 7.7 * 10^6 - 24184.4 * TempVert + 211585 * RazVert + 3.43 * 10^7 * Coefficient + 12.99 * TempVert^2 - 160.14 * TempVert * RazVert - 25185.9 * TempVert * Coefficient + 335.38 * RazVert^2 + 44935 * RazVert * Coefficient + 3.95 * 10^6 * Coefficient^2$$

$$Defects = -1.92 * 10^7 + 12359.6 * TempVert + 3.91 * 10^7 * Coefficient - 5.58 * 10^{-9} * TempVert^2 - 5.58 * 10^{-9} * TempVert * RazVert - 25185.9 * TempVert * Coefficient - 2.05 * 10^{-8} * RazVert * Coefficient$$

Subsequently Fig. 4 shows, the adjusted Pareto Diagram.

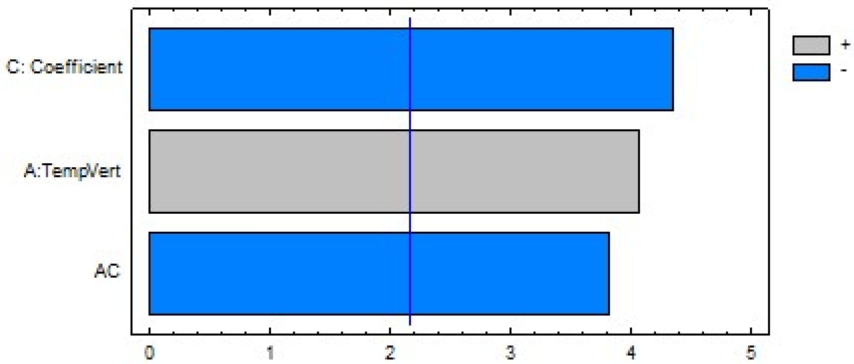

Figure 4 Adjusted Pareto Diagram

The Fig. 5 and 6 show the effects of the variables under study and the response surface obtained for a Coefficient 0.5, respectively.

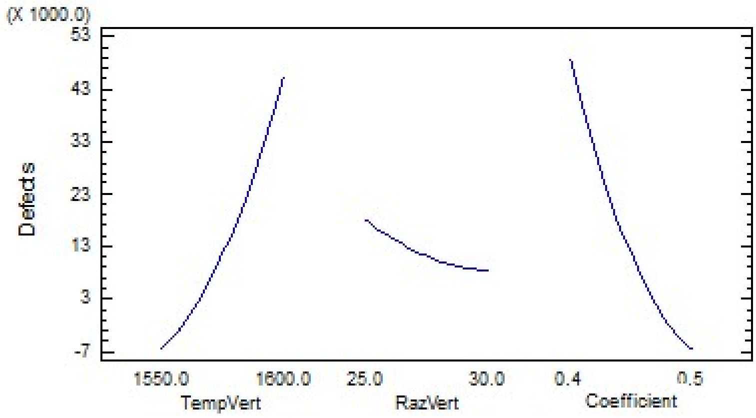

Figure 5. Main effects for Defects

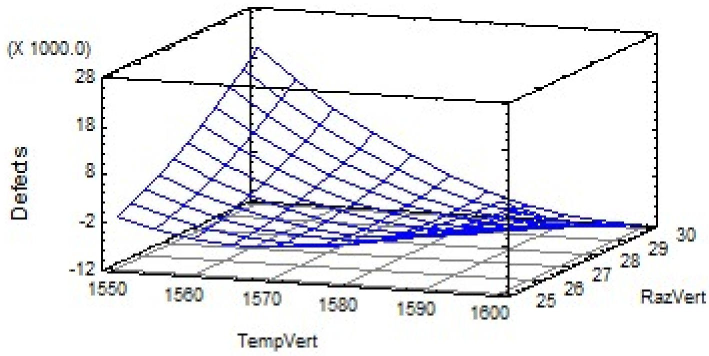

Fig. 6 Response surface estimated for a Coefficient 0.5

On the other hand, Fig. 7, 8 and 9 represent the response surfaces, the result of the interaction between the variables that are studied.

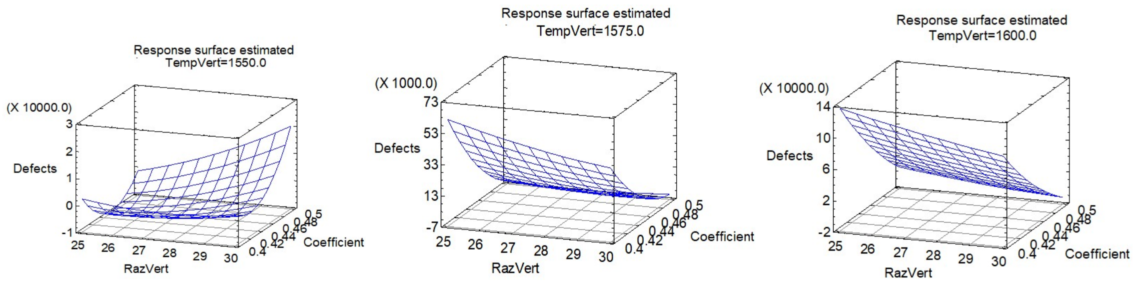

Figure 7. Response surface that relates, RazVert and Coefficient, depending on the defects. For a pouring temperature of 1550 °C, 1575 °C and 1600 °C

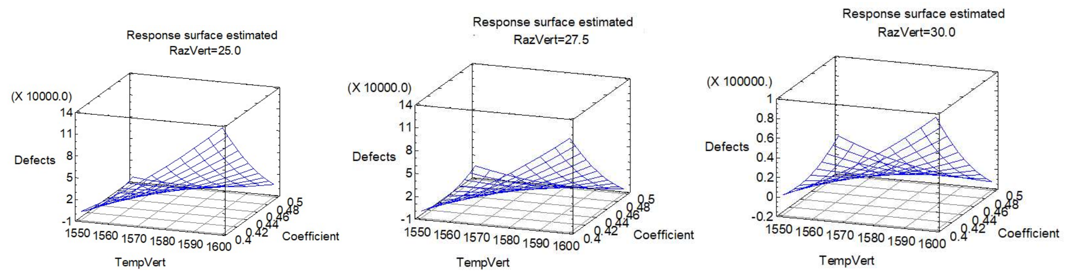

Figure 8. Response surface that relates, TempVert and Coefficient, depending on the defects. For a RazVert of 25 kg/s, 27.5 kg/s y 30 kg/s

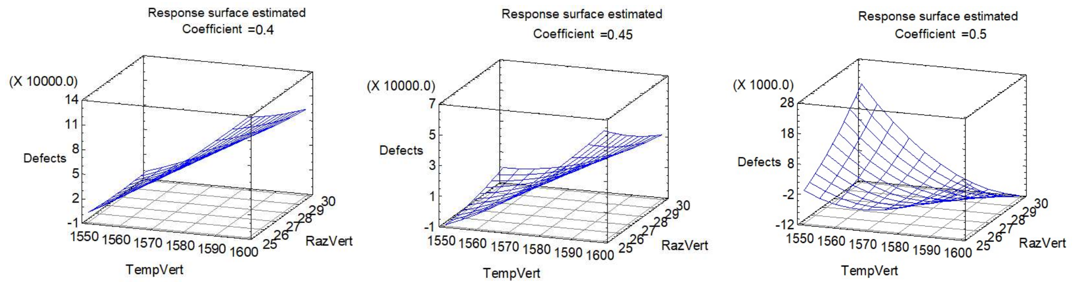

Figure 9. Response surface that relates, TempVert and RazVert, depending on the defects. For a Coefficient of 0.4, 0.45 y 0.5

A study carried out using the software Statgraphics, shows a combination of data for optimizing the results with regard to the reduction of the defects, these are shown in table 4.

Table 4. Optimal values obtained through the experimental design

Factor	**Low**	**High**	**Optimal**
TempVert	1532.96	1617.04	1603.15
RazVert	23.29	31.70	28.42
Coefficient	0.36	0.53	0.53

The next Fig. 10 shows the response surface based on contours, it reflects how the least number of defects in volume moves between the values 0.45 and 0.48.

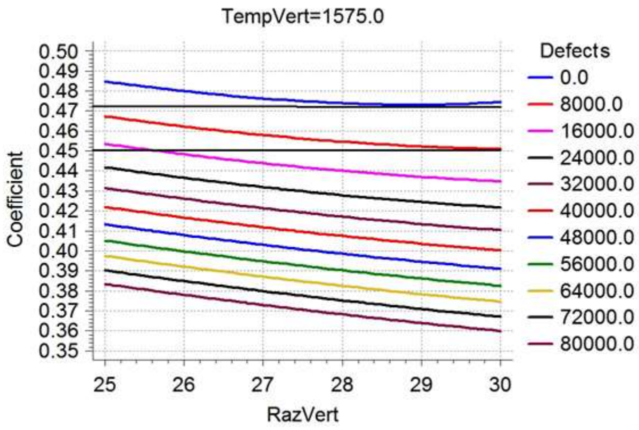

Figure 10. Contours of the estimated response surface

4. Conclusions

The study carried out demonstrates the importance of the variables TempVert and Coefficient in the analysis of the occurrence defects. This last variable, relates the geometrical parameters of the risers. In the case of the variable Coefficient, its action is negative, that is, if its value increases, the defects decrease. In the case of the TempVert, the opposite happens, if it increases, the defects grow. This result shows how the variable RazVert has no effect on the results. From the Response Surface obtained, it is possible to define the best work zone of the risers studied, the least number of defects produced are between 0.5 and 0.45 of the variable Coefficient**.** The study carried out reflects how the best points for the work of the risers are found in the TemVert of 1603, the RazVert of 28.4 kg / s and a Coefficient of 0.53.

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