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DETERMINATION OF THE GEOMETRIC PARAMETER THAT MORE AFFECTS THE QUALITY IN CASTING USING PREDICTION TOOLS

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Abstract: *The determination of the geometrical parameter, of the wheel type piece, that most influences has in the occurrence of defects in the casting process it is proposed in this paper. Within the parameters used to study thickness of wheel rim, height of wheel rim, thickness of the central plate. Is used as a methodology, the combination of the Taguchi method with the simulation. An orthogonal array, the signal-to-noise (S/N) ratio, and analysis of variance are used to analyze the effect of selected process parameters and their levels on the casting defects. The results indicate that the selected process parameters affect the casting defects and are the height of wheel rim the most important. A simulation technique is used to verify the results, which indicated that this methodology is more efficient in determining the best geometric parameters for a wheel casting part.*

Keywords: *Taguchi's method, Risers, Simulation casting, ProCAST*

INTRODUCTION

The casting process has a large number of parameters that may affect the quality of castings. Some of these are controllable, while others are noise factors [1]. The variations in casting parameters chosen by different researchers [2] have led to significant variations in these empirical guidelines. A large number of experimental investigations linking risers geometric parameters with casting quality have been carried out by researchers and foundry engineers over the past few decades [3]. It has been recognized that risers geometric parameters design plays one of the key elements in casting quality [2].

Up to now, there are following optimization methods applying to the risers geometric parameters: the gradient search method, the finite element method (FEM)-based neural network method and the Taguchi method [4]. Taguchi [5] has introduced several new statistical tools and concepts of quality improvement that depend heavily on the statistical theory of experimental design. Some applications of Taguchi's methods in the foundry industry have shown that the variation in casting quality caused by uncontrollable process variables can be minimized [6].

Taguchi approach is suitable in using experimental design for (a) designing and developing products/processes so as to be robust to component variation; (b) designing products/processes so as to be robust to environmental conditions; and (c) minimizing variation around a target value.

During the 1990s, a lot of developments had been done for the foundry process [7]. Some of these programs were able to simulate the behavior of the molten metal close to reality, as the researchers studied the behavior of the molten grey cast iron during the filling of different gating systems by optical means, and correlated the measurements to obtain the behavior by some simulators. By the end of the 1990s, the trial and error approach practices moved away from the real mould to the virtual one. According to Taguchi [1], the parameters, which exert a great deal of influence on the casting process, can be adjusted, to varying levels of intensity so that some settings can result in robustness of the manufacturing process. Barua et al. [8] used the Taguchi's method to optimize the mechanical properties of the Vacuum V-casting process. In their paper, they considered the effects of the selected process parameters on the mechanical properties of alloy casting and subsequent optimal settings of the parameters, which were accomplished using Taguchi's parameter design approach.

Noise factors are the variables, which influence the response variables. They may or may not be known. Special care should be taken to prevent the noise factors from interfering in the experimental results. Lipinski et al. [9] presented the numerical basis of Magmasoft, a commercial finite difference solver for the simulation of casting. Masters et al. [10] described a robust design method for reducing cost and improving quality in an aluminum re-melting process.

The literature review indicates that the Taguchi method is the best option for design of experiments when number of process parameter are involved in the process. Taguchi approach is suitable in experimental design for designing and developing robust products or processes irrespective of variation in process parameter (within set limits) and or variation in environmental conditions [11].

The present research as associated with the determination of critical geometric parameters of wheel type piece affecting shrinkage porosity, which involves various parameters at different levels and affects the casting quality. Considering these features of Taguchi method, it is used to reduce the % of rejection due to sand and moulding related defects by setting the optimum values of the process parameters of the green sand casting. In [11] Dabade have a picture with a methodology used to achieve optimized process parameters using DoE (Design of experiments), in this picture is show a complete diagram for the sand casting process. In our case is used the way that show the defect produced by the filling and solidification process.

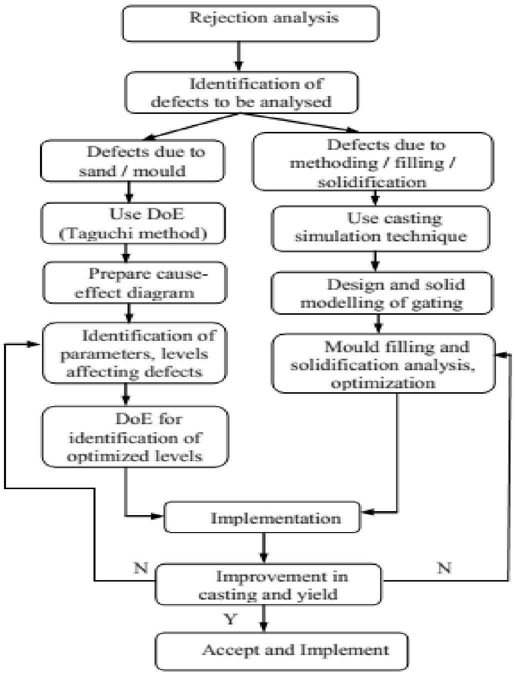

***Figure 1**. Complete analysis of the sand casting process design by Dabade*

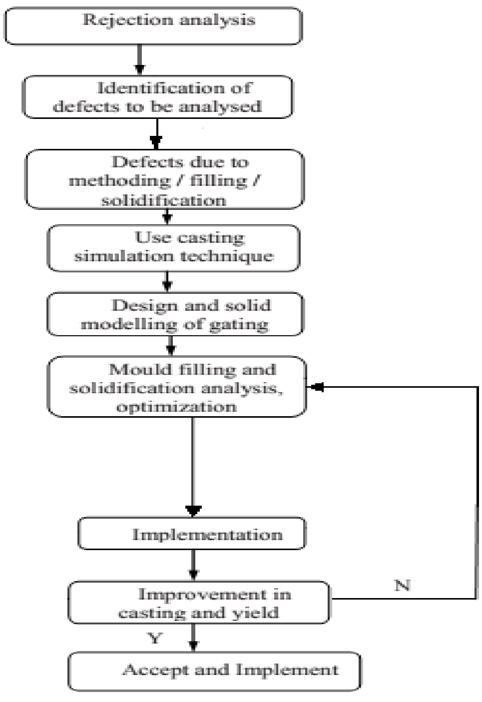

***Figure 2**. Related stage with the filling and solidification process*

PROCESS PARAMETERS OF RISERS CALCULATION

The focus of this paper is on the robustness of the parameters of risers calculation and the case company is a foundry located in Villa Clara, Cuba. The basic steps for achieving the above target are summarized below [12]:

1. *To select the most significant parameters that causes variations in the quality characteristics.*
2. *Casting defects have been selected as the most representative quality characteristics in the green sand casting process, as it is related to many internal defects (shifts, warpage, blow holes, sand drop, etc.). The target of the green sand casting process is to achieve "lower casting defects"while minimizing the effect of uncontrollable parameters.*
3. *Make the green sand casting process under the experimental conditions dictated by the chosen orthogonal array and parameter levels. Based on the experimental conditions, collect the data.*
4. *An analysis of variance (ANOVA) table is generated to determine the statistical significance of the parameters. Response graphs are plotted to determine the preferred levels for each parameter.*
5. *Beside the optimum settings of the control parameters and predict the results of each of the parameters at their new optimum levels.*
6. *Verify the optimum settings result in the predicted reduction in the casting defects.*

An Ishikawa diagram (cause and effect diagram) is drawn to identify the parameters of risers calculation that may influence green sand casting defects as shown in Figure 3.

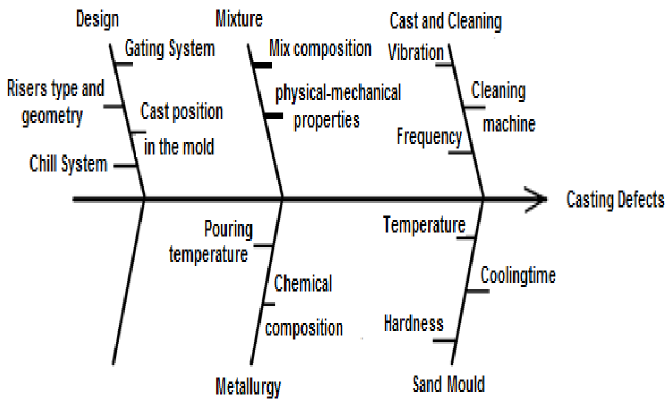

***Figure 3.** Cause and effect diagram*

***Table 1.** Process parameters with their ranges and values at three levels*

Parameter designation	*Process parameters*	*Range*	*Level 1*	*Level 2*	*Level 3*
A	*Thickness of wheel rim (mm)*	*50-185*	*50*	*117.5*	*185*
B	*Height of wheel rim (mm)*	*150-600*	*150*	*375*	*600*
C	*Thickness of the central plate (mm)*	*50-140*	*50*	*95*	*140*

To visualize the effect of process parameters on the casting defects, following parameters are selected:

- Thickness of wheel rim (Factor A)
- Height of wheel rim (Factor B)
- Thickness of the central plate (Factor C)

The range of the parameters is show in the table 1.

The number of levels for each control parameter defines the experimental region. For each control factor, three levels are selected, out of which, one level is the starting level.

SELECTION OF ORTOGONAL ARRAY

Before selecting a particular orthogonal array to be used for conducting the experiments, two points must be considered

1. The number of parameters and interaction of interest.
2. The number of levels for the parameters of interest.

Therefore, the L9 orthogonal array is selected with 9 experimental runs and 3 columns. Taguchi has provided two tools to aid in the assignment of factors and interaction to arrays. The tools are: (1) the linear graph and (2) triangular tables. Linear graphs indicate various columns to which factors may be assigned and the columns subsequently evaluate the interactions of those factors [1]. The various factors and their interactions are assigned in each column of the L9 orthogonal array. The assigned L9 orthogonal array is shown in Table 2.

Table 2. L9 orthogonal array

Trials	Factor A	Factor B	Factor C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

CASE STUDY

Once the parameters and parameter interactions are assigned to a particular column of the selected orthogonal array, the factors at different levels are assigned for each trial. The assigned experimental array is shown in Table 3.

Table 3. Experimental L9 array

Trials	Factor A	Factor B	Factor C
1	50	150	50
2	50	375	95
3	50	600	140
4	117.5	150	95
5	117.5	375	140
6	117.5	600	50
7	185	150	140
8	185	375	50
9	185	600	95

The experiments were conducted thrice for the same set of parameters using a single-repetition randomization technique [13]. The casting defects that occur in each trial conditions were measured. The average of the casting defects was determined for each trial condition as shown in Table 4. The casting defects are the "lower the better" type of quality characteristics. Lower the better S/N ratios were computed for each of the 9 trials and the values are given in Table 4.

Table 4. Shrinkage defects values and signal-to-noise (S/N) ratio against trial numbers

Trials No.	Shrinkage volumen 1	Shrinkage volumen 2	Shrinkage volumen 3	Total	Average	S/N ratio
1	274.5	590.4	257.0	1121.8	373.9383	-52.1298
2	350.7	1758.9	1112.6	3222.2	1074.0820	-61.7170
3	1821.0	2027.0	2264.7	6112.7	2037.5540	-66.2164
4	500.9	684.2	570.1	1755.3	585.0983	-55.4164
5	1918.6	1586.0	1119.6	4624.2	1541.3877	-63.9502
6	2343.9	1924.1	1908.2	6176.1	2058.7155	-66.3134
7	206.6	808.4	273.7	1288.7	429.5713	-54.1003
8	1474.2	1234.5	1067.5	3776.1	1258.7159	-62.0742
9	2420.3	2576.2	1961.5	6958.0	2319.3383	-67.3619

SIMULATION OF THE PROCESS

Version 2011 of the finite method based commercial software package ProCAST® was used for simulations of fluid flow during mold filling and the subsequent solidification. The software showed the defects product to the application of different geometrics parameters and different risers too.

Typical material properties were used. Assumptions made in the simulations with regard to heat transfer coefficients and initial temperatures are given in Table 5.

Table 5. Assumptions relating to software simulations

Interface	Heat transfer coefficients ($Wm^{-2}K^{-1}$)	Material	Initial temperatures (°C)
		Sand mold	30
Steel alloy /sand mold	500	Steel alloy (Ck45)	1540

Some pictures of the simulation process are shown below:

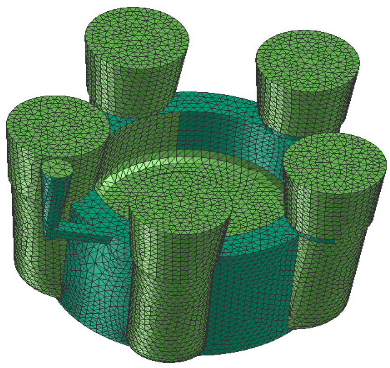

Figure 4. Meshing of the piece

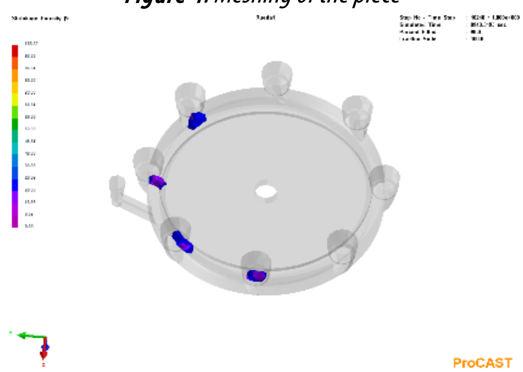

Figure 5. Shrinkage porosity

ANALYSIS OF EXPERIMENTAL RESULTS

Analysis of experimental results was performed using Minitab 16 software and ANOVA plots obtained are given in table 6 and figure6 respectively. ANOVA in table 6 indicates that the Height of wheel rim significantly influence the % of defects at 95% confidence level.

The figure 6 indicates that the numbers of defects is minimum at first level of Thickness of wheel rim (A1), first level of Height of wheel rim (A1), and first level of Thickness of the central plate (C1).

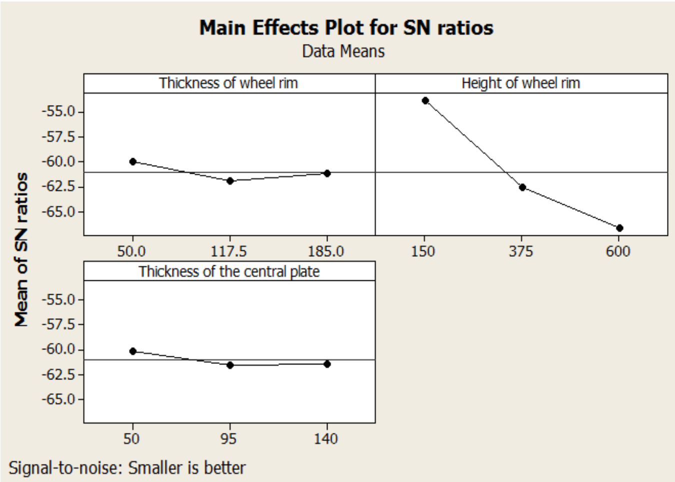

***Figure 6**. Main effects plot for S/N ratios*

***Table 6**. Coefficients of estimated model for S/N ratios*

Terms		*Coef*	*SE Coef*	*T*	*P*
Const.		*-61.0311*	*0.1625*	*-375.588*	*0.000*
Thicknes of wheel rim	*50.0*	*1.0098*	*0.2298*	*4.394*	*0.048*
	117.5	*-0.8622*	*0.2298*	*-3.752*	*0.064*
Height of wheel rim	*150*	*7.1490*	*0.2298*	*31.109*	*0.001*
	375	*-1.5494*	*0.2298*	*-6.742*	*0.021*
Thicknes of The central plate	*50*	*0.8583*	*0.2298*	*3.735*	*0.065*
	95	*-0.4672*	*0.2298*	*-2.033*	*0.179*

S = 0.4875

R-Sq = 99.8%

R-Sq(adj) = 99.3%

Fuente P

Thickness of wheel rim 0.082

Height of wheel rim 0.002

Thickness of the central plate 0.125

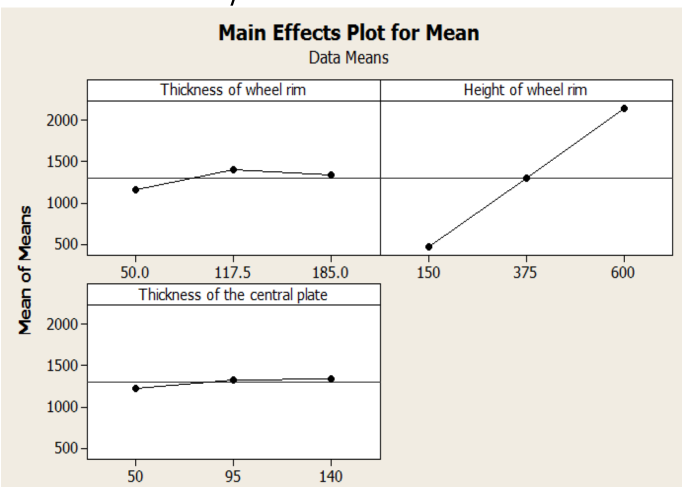

***Figure 7**. Main effects plot for mean*

The tables 7 and 8 confirm that the parameter B or Height of wheel rim has the most significantly influence.

***Table 7**. Means of S/N ratios: Smaller is better*

Level	*A*	*B*	*C*
1	*-60.02*	*-53.88*	*-60.17*
2	*-61.89*	*-62.58*	*-61.50*
3	*-61.18*	*-66.63*	*-61.42*
Delta	*1.87*	*12.75*	*1.33*
Rank	*2*	*1*	*3*

***Table 8**. Mean of means*

Level	*A*	*B*	*C*
1	*1161.9*	*462.9*	*1230.5*
2	*1395.1*	*1291.4*	*1326.2*
3	*1335.9*	*2138.5*	*1336.2*
Delta	*233.2*	*1675.7*	*105.7*
Rank	*2*	*1*	*3*

A regression analysis contributes the following values:

Regression Analysis: Defects 1 vs. Factor A-B-C

The regression equation is:

$$Defects\ 1 = -728 + 4.09\,(A) + 4.15\,(B) - 0.54\,(C)$$

S = 470.458

R-Sq= 83.7%

R-Sq(adj) = 74.0%

Regression Analysis: Defects 2 vs. Factor A-B-C

The regression equation is:

$$Defects\ 2 = -76 + 0.60\,(A) + 3.29\,(B) + 2.49\,(C)$$

S = 262.328

R-Sq. = 90.8%

R-Sq(adj) = 85.2%

Regression Analysis: Defects 3 vs. Factor A-B-C

The regression equation is:

$$Defects\ 3 = -281 - 0.819\,(A) + 3.73\,(B) + 1.58\,(C)$$

S = 149.394

R-Sq. = 97.5%

R-Sq(adj) = 95.9%

In the picture 9 is shown the result of application of the regression equation for each combination of geometric parameters.

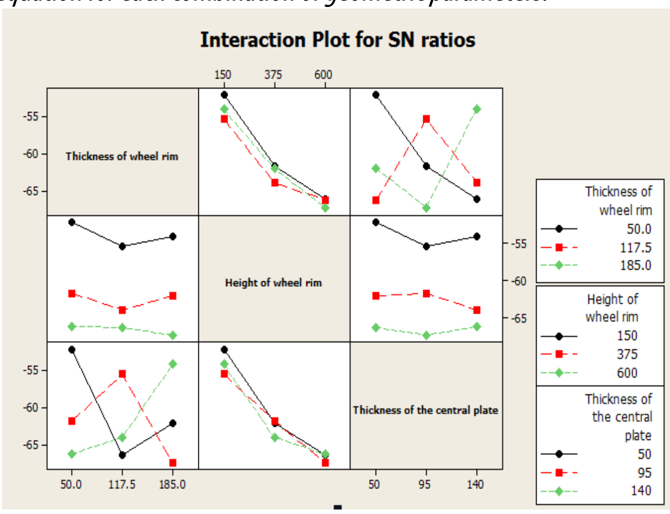

***Figure 8**. Interaction S/N ratio for smaller is better*

Figure 2 shows the interaction between the thickness of wheel rim and the height of wheel rim (AxB), the thickness of wheel rim and the *thickness of the central plate (AxC) and the height of wheel rim and the thickness of the central plate (BxC). The S/N ratio value at (AxB) level 1 (50 mm) is a best interaction because of it gives the biggest delta value, and then followed by interaction (AxC) level 1 (50 mm). The thickness of wheel rim at level 1 (A1) and the height of wheel rim at level 1 (B1) have a maximum value.*

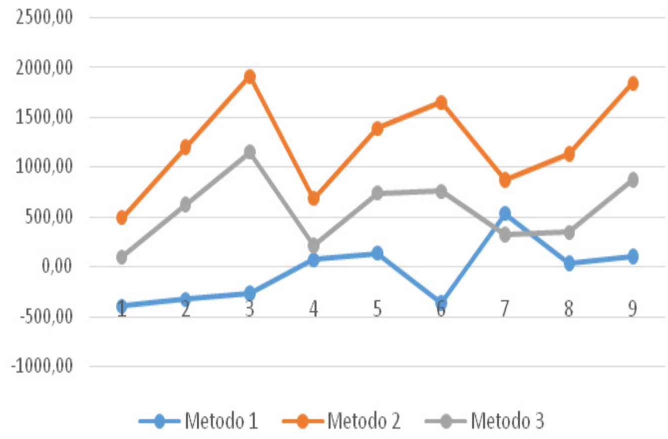

***Figure 9**. Final graph of the application of the regression equations for each method*

CONCLUSION

- *The geometrical parameter, according to the results obtained in the experiment, most influential in the occurrence of defects produced by the shrinkage, is the Height of wheel rim.*
- *The geometry values that shows fewer defects, for this experiment are:*
  - *Thickness of wheel rim: 50 mm*
  - *Height of wheel rim: 50 mm*
  - *Thickness of the central plate: 150 mm*
- *Application of Taguchi method to determine the geometrical parameter that has the greatest influence on the presence of defects in castings is very important technique for the design of optimal casting.*

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