Use of virtual casting for optimization the density of complex geometric aluminum parts, casted in to 3D-printed sand foundry molds

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Abstract: *The combined application in a foundry practice of 3D-printing, computer optimization through a virtual casting and modern visualization, by color scales and comparisons allows to be obtained details free of defects from the very first casting. One specific example for a fast optimized casting of a crankcase of aluminum alloy for a turbocharger is shown. The geometry of the detail is of high complexity, developed internal cavities and various wall thicknesses. With the use of three advanced software products, the time to reach the above goal is shortened by about two months and the minimum density in a critical point is increased almost 3 times.*
Keywords*: ALUMINUM ALLOY, DENSITY, SOUNDNESS, 3D PRINTED SAND MOLD, 3D PRINTED SAND CASTING SEGMENTS*

1. Introduction

In order to avoid expensiveadjusting experiments in the development of new foundry technologies, the use of methods for optimizationby virtual casting [1, 2, 3] is innovative. This is even more true in case of casting in 3d-printed forms. In the new processes for 3d-printing of sand segments [4.5], including foundry cores and moulds, foundry slopes are not necessary. Such technologies are used in one-off and small series production of complex-geometric castings, in which 3D-printed elements are expensive, but without any alternative, to quickly create, with the necessary precision and dimensional accuracy the required form of the casted article.

2. Parameters and calculations

The goal of the work is to make an optimization by virtual casting in order to avoid or reduce possible density defects in the casting .

The subject of the survey is a turbocharger housing, the view of which (after machining and assembly of components) is shown in Fig. 1 (a). The complexity of geometry is obvious from the incisions made in two different sections. The aluminum casting of the housing is shown on FIG. 1b. The arrow in the figure indicates the location of the defect for optimisation, and the scale on the right is an automatic scale on which the minimum value corresponds (by color and location) to the lowest calculated density in the casting. The place where there is a risk of the presence of a foundry defect according to the preliminary calculations is indicated by an arrow (intake, porosityleakage etc.). This type of defect is related to density [6].

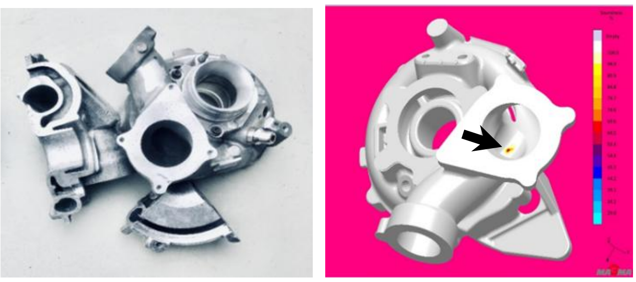


Fig. 1 *Aluminium Turbocharger Housing*
(a)-general appearance and transverse incisions illustrating complexity;
(b)-View of the casting with the place and size of the defect

A more convenient representation of density in percentages for general analysis is selected, but in any case the applied rule is that the 100% density from the scale corresponds to the best density in an aluminum casting = 2.67 g/mm ².

The 29% value of 2.67 g / mm² was not satisfactory. In this place, it is not possible to add a feed with a dead head. This surface has a complex geometry, requires a high smoothness (Ra> 6.5 μm), and no trace of "discontinuity" of the surface.

Improvement will be sought using the most accessible parameters:

- Casting temperature;
- Percentage of silicon.

In this case, a full factor experiment is used as one of the parameters is on 4 levels and the other on 3 levels.

If time is limited and the factors are numerous, "Sobolev" or other experimental planscan be applied, which reduces the number of calculated attempts, but also carries a certain risk of missing the "best result".

Table 1 represents the 12 values of applications full factor experiment in the studied ranges:

- Casting temperature – from 730 ° C to 760 ° c, on 4 levels at 10 ° c;
- For the percentage of silicon-from 6.5% to 7.5%, at 3 levels in 1%.

The casting is carried out in the same parameters for each test, except for the casting temperatures [°c] and the silicon Si content [%] shown in Table 1.

Some of the more important constant parameters are:

- Sand-form temperature: 20 ° c;
- Time to fill the casting: 11.5 sec.;
- The chemical composition: Cu = 0.03 [%], Fe [%] = 0.10 [%], Ti [%] = 0.12 [%], Sr [%] = 0.025 [%], Mn [%] < 0.0 [%], Zn [%] < 0.00 [%].

The 3d-printed sand forms are made according to [7]. Heat-physical parameters are used, specific to 3d-printed sand segments [8].

Optimization calculations were conducted with the "Start-sequence" tool of Magmasoft software 5.4.2

The calculated values specifically for each individual experience are presented in table 2.

Table 1-the temperature of casting and the percentage of silicon and table 2-The minimum density values (Soundness) calculated for each experiment.

Table 1

Optimization factors		
Exp. N°	Casting temperature T[°C]	Content of Si [%]
1	730	6.5
2	740	6.5
3	750	6.5
4	760	6.5
5	730	7.0
6	740	7.0
7	750	7.0
8	760	7.0
9	730	7.5
10	740	7.5
11	750	7.5
12	760	7.5

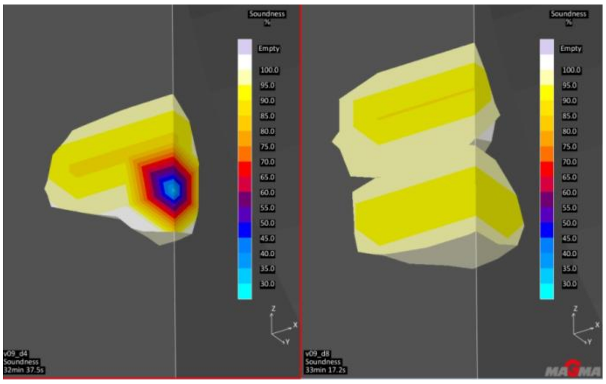
Table 2

Optimization parameter	
Exp. N°	Soundness [%]
1	49.15
2	35.00
3	70.16
4	31.99
5	78.64
6	69.24
7	59.64
8	89.71
9	70.41
10	88.74
11	88.40
12	80.04

2. Visual presentation of the results after optimization.

In optimization, density values from minimum-31.99% to maximum-89.71% were obtained. This means that only with the variation of these 2 factors within the studied limits, the density can be changed almost 3 times.

The two extreme values (lowest and highest minimum density) are shown schematically in Fig. 2a) and fig. 2 (b), on the same scale in both cases.



а) *б)*

б Two of the results of the study area, mapped in the maximum transparency, the same incisions, the same three-dimensional scale and the same colour scale (30%-100%) In two cases:

a)-the lowest value of the minimum density = soundness 31.99%,
(b)-the highest value of the minimum density = soundness 89.71%.

From Fig.2 It is obvious that in both cases the critical zone is in the center, but while the abrupt density decrease of 100% to 31% is observed in Fig. 2a, the decrease in density is quite smooth between 100% and 89.71%.

3. Analysis of results and discussion

From the parallel coordinates diagram, it is obvious that very good results can be obtained in a sufficiently wide range of the two factors tested, T [°C] and Si [%].

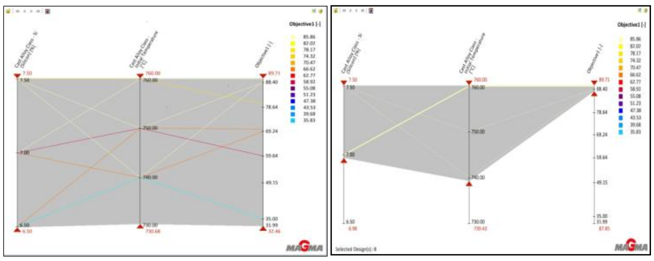


Fig.3 *Presentation of optimisation results through parallel coordinates diagram*

From the diagram of the private effects, it is obvious that the pouring temperature T [°C] in the research interval has no effect on the density of the critical zone. At the same time, the private effect of increasing the percentage of silicon is visibly large with a strong increase.

Accurate statistical confirmation of the described visual effects is given with the correlation matrix of Fig. 5 – Coefficient 0.75 for the silicon content against the minimum value 0.07 of the casting temperature coefficient.

4. Conclusions

1. Optimization through virtual casting gives an important and decisive contribution to the increasing application of modern 3D printedcasting segments in the development of new technologies.
2. The application of virtual casting may be used in comparative research for scientific and applied development, where accurate quantitative measurements are required in the area without access for the installation of sensors.
3. Setting up new foundry technologies using 3D printer technologies by using virtual casting in parallel, displaying the results of the calculations in the most appropriate geometry and in the right colors, significantly reduces the time and the cost to achieve the correct result.
4. The results of measurements or calculations, shown at the exact pointof the desired geometric shape, are the best way to be quickly and accurately understood by all those who wish to learn about them, in order to continue the prompt approach to the solve problem.

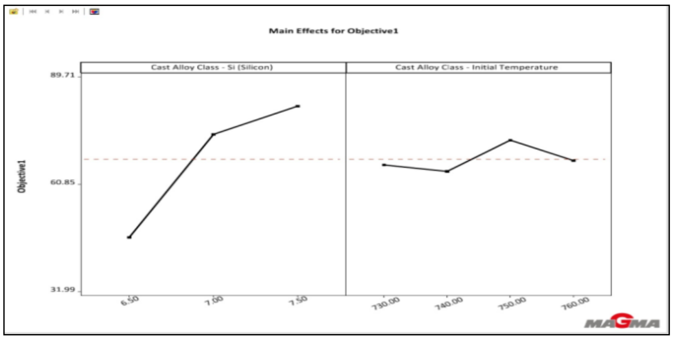


Fig. 4 *Presentation of optimisation results through the private effects diagram*

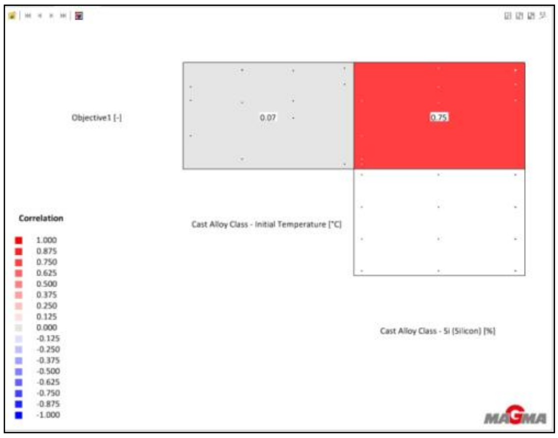


Fig. 5 *Presentation of optimization results through the correlation matrix for quantification of the contribution of each of the independent factors*

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