Simulation of solidification process of cast-iron and aluminum materials

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Abstract. Numerical analyse present a proper solution in order to investigate and quantify what is difficult to appreciate during technical processes. The simulated results are very close to those obtained experimentally fact that creates a big advantage in simulation process usage. Parameters like filling time and filling sequence, solidification time and cooling rate were evaluated for two metallic materials. Different dimensions and geometries of applicative elements influence considerably the casting behavior of a material even if the process is realized in the same conditions.

1. Introduction
Conceiving technical processes request analytical solutions to observe and analyze the real casting processes. The aim of modelling is usually the improvement of production process and the help of obtaining process and production. Applications of computer science in analyze of metallurgical data produced many results to be investigated in all the technological processes and helps the engineering’s work. Many aspects that are difficult to be analyze in real conditions like high temperatures, melt velocity or induction currents can be considered using numerical analyse.

The usage of computer power of mathematical computation is nowadays usually used in analyze of obtaining of complicated parts. In this paper we proposed some details on the solidification of castings in metallurgical engineering castings [1].

The metallurgical phenomena are quite complicated by the means of physical processes during the metals processing like casting, heat treatments or deformation. Both cast iron and aluminum based alloys has many industrial applications even they have different properties. The potential of simulation tools is given by the complexity of analyzed elements [2]. In case of cast element troubles like shrinkage, porosity, cracks and pores can appear based of thick and thin walls of melting forms. Applications of casting modelling requires proper knowledge and understanding of casting processes. In order to apply numerical simulation in casting processes both metallurgical and mathematical information are required [3, 4].

Using the same input parameters like material nature, sand or casting properties a pouring process of a piece was simulated base on a numerical model [5, 6]. The idea the analyze is to observe two materials with other properties (alloys) one based in Fe-C type GGG40 and one on aluminum type
AlSi$_9$Cu$_3$, both commercial alloys [7-9], and to establish which one behave better for a complex geometrical form.

2. Materials and methods

For preparation of the used forming blend was used a quart sand mono granular delivered with medium granulation $M_{50} = 0.120$ mm and uniformity degree $G.U. = 79\%$. Elaboration process takes place in a casting furnace with heating by induction with 1000Hz frequency and carborundum crucible [10]. Pouring and solidification parameters are strictly connected to sand properties, like density, specific heat, thermal conductivity or thermal expansion coefficient, and their variations with temperature modification. The results of these characteristics variation with temperature are presented in figure 1.

![Figure 1. Sand property as density: a) specific heat; b) thermal conductivity; c) and thermal expansion coefficient; d) variation with temperature in a 0 to 1400 °C temperature range.](image)

Analyzing the diagrams is observed a reduce variation of density from a value of 2750 °C at below 0°C to 2700 kg/m$^3$ at 1400 °C, a specific heat increasing constantly during heating from 520 at 0 °C to 1000 J/kgK at 1400 °C, an important characteristic of blending material. Thermal conductivity behaves a decrease from 0.78 at 0 °C to 0.68 at 400 °C and increasing to 0.89 W/mK at 1000 °C and thermal expansion coefficient exceed a logarithmic increase until $5.5 \times 10^{-6}$ (°K). After charge calculation in furnace was put the proper waste materials and brass waste alloys. After heating, but before of liquid phase appearing, was added protection and de-oxidation fondant with content made by NaCl, KCl, NaF, Na$_3$AlF$_6$ in proportion of 1% from loading [11]. After taking a sample and fast chemical analysis effectuation using a spectrometer METALSCAN 2500, was made the adjusting ads of composition...
with clean waste alloy and technical zinc ingot. Simultaneous with this was used the fondants for degassing 0.5% chloride zinc [12]. In casting bath already form was adding the calculated quantities of high purity zinc and ferrous-manganese.

3. Results and discussions
Choosing a complex part like crook or encampment we analyze the material behavior at melting and pouring using a mathematical model evolves in previous study [13]. Elaboration process takes place in a casting furnace with heating by induction with 1000 Hz frequency and carborundum crucible [14]. Pouring and solidification parameters are strictly connected to sand properties, like density, specific heat, thermal conductivity or thermal expansion coefficient, and then variations with temperature [15-19].

As all computational programs, which conduct simulations, a series of parameters must be set at the experiment begging like material properties (density, specific heat, thermal conductivity, liquidus temperature or solidus temperature) fact realize in the previous step. Using a numerical model, already discussed in [13], we analyze some base parameters of pouring process. Paying respect for model functioning was realized a careful study of numerical, physical and technological parameters. Most of the difference will appear from the variable properties of the cast iron supposing a variable behavior at molding as well [20-22].

Having experimental results of molding materials process for different alloys it is now important to analyze two materials with different characteristics like GGG40 cast iron and AlSi9Cu3 in this study. Choosing this configuration is justified by problems complexity connected with modulation and established limit conditions.

Figure 2 represents the emplacement of the temperature sensors along the piece that will take over the experimental data’s so we will be able to compare with the simulation results obtained based on numerical model [13]. Most of them are placed in special positions that have usually problems after pouring and solidification and cover the entire piece surface. In figure 3 is presented, comparatively, for cast iron and aluminum based materials two important factors of molding process, filling time and filling sequence showing details of when and how the material reaches all the body parts.

Filling time and sequence simulation of both investigated materials present small differences, starting from the bottom part with 0.0054 seconds and reaching 2.7527 and 2.616 second at the complex part in the top for cast iron respective aluminum alloy.

In Figure 4 is represented the cooling rate variation by body part. The cooling factor is one of the most important facts that influence directly the molding process and the material and sample quality.
Figure 3. Filling time and filling sequence of the same geometrical form sample but for different molding materials are represented by simulation program a) and c) for steel material and b) and d) for cast iron material.

Figure 4. Cooling rate factor simulated for both materials: a) cast iron in and b) aluminum based in.

From Figure 4 is observed that in cast iron material the cooling process is starting with 0.8497 °C per second a bigger value comparative with aluminum material that express a 0.1204 °C per second rate, based on them thermal conductivity properties and finishing as well at with a high cooling rate for iron based material 9.19 °C, 45-th times bigger than aluminum based alloy behavior of 0.2752 °C/seconds. In table 1 are presented the most important molding simulation parameters; get from the graphical results; that characterize and represent the behavior during process for both analyzed materials.
Table 1. Theoretical results of melting and pouring simulation of a cast iron and a steel commercial alloy, the main process parameters.

| Property/sample | Filling time | Solidification time | Filling sequence | Solidification sequence | Reciprocal interface moving velocity | Cooling rate |
|-----------------|--------------|---------------------|------------------|-------------------------|---------------------------------------|--------------|
| Cast iron GGG40 | 0.0054-2.7527 | 8.16-55.96          | 0.005-2.75       | 8.16-55.97              | 0-67.74                               | 0.8497-9.1926 |
| Aluminum alloy  | 0.0054-2.616 | 111.982-302.4       | 0.0054-2.616     | 1.76-302.4              | 0-56.3                                | 0.1204-0.27527 |

In figure 5 are represented the results concerning the solidification process of the analyzed alloys of time and sequence. The solidification process represents one of the most important parameter concerning the quality of the molded sample paying respect for material characteristics and helping the operator to choose a specific alloy for fast or slow solidification time.

![Figure 5](image_url)

**Figure 5.** Comparative simulation of cast iron and a aluminum based materials molding by solidification time, in a) for steel and b) for cast iron and solidification sequence for c) and d) also for different materials steel respectively cast iron.

Comparing the solidification times of these two materials is observed a difference given by the materials thermal properties so in cast iron case the material starts with 8.16 seconds time and finishing in 55.96 seconds, 5 to 10 times faster than in the aluminum alloy case that has a solidification time between 111.982 and 302.4 seconds. In all these discussions we have to pay respect to the geometrical body shape and to take in account the materials nature.

From solidification sequence results the aluminum based alloy start faster with a 1.76 seconds time but finish later at 302.4 seconds comparing to the cast iron solidification sequence range starting with 8.16 to 55.97 seconds. The complexity and dimensions of the sample influence the material
solidification as geometrical point but the big difference in materials behavior is given in this case by the metallic material properties.

After analyzing the most important molding parameters the virtual simulation software appreciates some other parameters, presented in table 2, like temperature gradient, local solidification time, retained melt modulus or volume, fracture curvature or melt surface area, parameters that help understanding a better combination of material properties with a special form, which was the idea of this article.

Table 2. Theoretical results of melting and pouring simulation of a cast iron and a steel commercial alloy, other simulation parameters with interest in molding process realization.

| Property/sample        | Temperature gradient | Local solidification time | Retained Melt Modulus | Retained Melt Volume | Fraction Curvature | Melt Surface Area |
|------------------------|----------------------|---------------------------|-----------------------|---------------------|-------------------|-----------------|
| Cast iron              | 5.81-217.84          | 0-80.1098                 | 0.066-0.55            | 0.106-335.503       | 0-26.43           | 1.62-602.82     |
| Aluminum, AlSi9Cu3 alloy | 0.256-124.072-312,499 | 0.27367-0.261-335.503    | 0.56642-0.106-335.503 | 0-26.7393-0.55     | 3.84-33.84-602.82 |

The local solidification point gives precious details about all the body parts completing the filling and solidification sequences information, having as well a better behavior in steel material case comparing to cast iron.

All parameters interpretation role is to find a material, from a class of materials all with proper properties for that geometrical piece, that will behave at molding fine avoiding the casting, poring or solidification problems. Also, if a material needs to chill in a longer time, for different properties, the results can be investigated through different points of view.

The results are very close to the experimental values obtained by sensors measurements more than 98% match fact that qualify the numerical model and the simulation program as a specifically accurate one with very good results for practical applications.

4. Conclusions

Different shapes and different geometries influence considerably the casting behavior of a material even the processes are realized in the same conditions. Using the advantages of a powerful calculation capacity like new computers haves is able to control many pouring facts like filling time and sequence or solidification time. Between normal casting and solidification of a metallic material and virtual simulation, are not big differences using the right numerical model. It is economical the virtual one, realized on computer obtaining an optimal variant of casting and solidification and faster as well. Connecting all the information obtained from the theoretical model the casting process of any material became easier to be done finding without material losses the weak points like reduce filling or solidification sequence or time areas. Choosing proper geometrical dimensions, sand properties or materials many defects after melting, pouring and solidification processes can be avoiding by doing a simulation of these processes first. Good result of comparative tests between experimental registered results and numerical calculus result promote the numerical method to be used in any initial case to reduce charges and gain experience on a special alloy casting.

5. References

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