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P. POPIELARSKI*#, J. HAJKOWSKI*, R. SIKA*, Z. IGNASZAK*

COMPUTER SIMULATION OF CAST IRON FLOW IN CASTABILITY TRIALS

The paper includes validation studies of the flow module of the NovaFlow&Solid simulation code. Experiments of ductile iron and gray iron casting in a spiral test of castability were carried out. Casting experiments were then carried out in industrial conditions in the Ferrex Foundry in Poznań and the results are the castability spiral length and local cast iron rate during mould cavity pouring. Simulation tests using NovaFlow&Solid Control Volume code were made. The technological castability test was used to determine thermal-physical data through simplified inversion problem. Influence of physical parameters in the database of simulation code on the spiral length obtained as the result of simulation was analyzed. It was found that critical fraction of capillary flow CLFdown has the biggest impact on cast iron castability in the simulation code. The simulations resulted in defining parameters of gray iron GJL 250 and ductile iron GJS-400-15. For the parameters set, the length of castability spiral in simulations was in accordance with casting experiments.

Keywords: Application of information technology to the foundry industry, Castings Defects, Cast iron, Castability trial

1. Introduction

Casting processes are widely used to produce metal components, wherein cast iron castings represent approx. 75% of the world production of castings [1-3]. Designing a new casting technology requires incurring large costs associated with preparation of instrumentation necessary to produce casting moulds. Therefore, before making the mould it is necessary to optimize the procedure of casting technology in order to obtain high quality castings at low production costs. A rational procedure of casting technology design optimization involves the use of computer systems to support this process – simulation codes as they are called in the foundry industry. However, it should be remembered that any casting process simulation is based on models that have a lot of simplifications in relation to the reality of the casting-mould system and the results of these calculations are an approximation of the process physics [4,5].

Many studies on this subject have been made at the CAD/CAE Laboratory of Material Technology at the Poznan University of Technology [4,6]. Effective use of any simulation system requires identification and knowledge of physical (thermal) parameters of the casting – mould system relating to the reality [7,8]. Lack of identification, as complete as possible, of the values used in modelling dependencies is the cause of limitation of the development and scope of models describing casting solidification [7-10].

In this case, it is very important that the code user masters the best possible pre-processing phase corresponding to the actual casting-mould system formulation of the model, which, along with the relevant differential equations also includes certain defined conditions (geometric conditions, physical parameters of the casting-mould, initial and boundary conditions). Credibility of the performed simulations depends on the reliability of these conditions. Introduction of the alloy into the mould cavity is followed by a series of intense physical and chemical processes of interface in a casting-mould system resulting from the heat shock, which the mould material is subjected to. It is believed that the vast majority of problems and casting defects happen at the moment of mould filling (misrun, air entrapment, coldshut, inclusion).

Fluid flow analysis during the mould filling process has been vigorously studied in the recent decades due to the advance of computer hardware and software systems [11-19].

From a macroscopic point of view, casting processes involve coupling of heat transfer and fluid flow. Mould filling simulation helps the designer (foundryman) to: vent design (size, number, position), predict turbulence spot, dead zone, incomplete filling (misrun), check the gating system, locate the gate and fraction effect. Over the years, the biggest problems connected with the reliability of simulation results relate to the formation of incomplete filling. Many simulation codes still have problems with forecasting incomplete filling due to lack of the necessary data [20]. Incomplete fillings in castings are the result of a strong connection between the process of flow and solidification. Castability is the factor ensuring adequate representation of the shapes of the mould cavity by the cast alloy.

* POZNAN UNIVERSITY OF TECHNOLOGY, FACULTY OF MECHANICAL ENGINEERING AND MANAGEMENT, 3 PIOTROWO STR., 61-138 POZNAN, POLAND

\# Corresponding author: pawel.popielarski@put.poznan.pl

Castability depends on fluidity of the metal poured into the cavity of a standard mould made of tested sand. In foundry practice it is the ability of the alloy to flow through the gating system and fill the casting's walls. The castability value as complex property combining both alloy and mould characteristics is quantitatively defined by the maximum length of the obtained casting (often of a spiral shape) [21]. Filling a spiral channel is done without a refresh of stream front which is stopped by the local crystallization process.

Castability is affected by:

- properties of the molten alloy – chemical composition, viscosity, surface tension, content of oxides and gases,
- properties of the mould – specific heat and thermal conductivity of the mould material, surface roughness,
- pouring conditions – temperature of the metal, mould temperature, pressure, rate of filling.

The above properties are included in simulation codes at the stage of pre-processing when uniqueness conditions are defined and relate to simplifications used in the code. Since each of the simulation code simplifications introduced into the model may be different, transfer of the determined parameters from one code to another might result in different simulation outcomes.

2. Castability trails

A series of experimental studies was performed in the Ferrex Foundry in Poznan. Experimental studies were carried out on the basis of a modified spiral test of castability BN 80/4051 17 [22] (Figure 1a), which included a system of local filling times registry. Gray iron GJL 250 and ductile iron GJS-400-15 castability were tested. Chemical composition of cast irons are summarized in Table 1.

TABLE 1

Chemical composition of cast iron

	GJL 250 Participation [%]	GJS-400-15 Participation [%]
C	3,23	3,47
Si	2,16	2,75
Mn	0,68	0,24
P	0,03	0,028
S	0,021	0,012
Cr	0,06	0,039
Cu	0,06	0,039
Al	0,02	0,014
Mg	0,0	0,045

Experimental tests were carried out according to the following scheme:

- instrumentation and model set preparation (Fig. 1b, 1c),
- mould cavity instrumentation in fiber optic contacts so that to identify (with an approximation) the time of filling of the various zones of the mould cavity (Fig. 2),
- use of spiral reverse pattern plate with holes made at a distance of 100 mm in order to introduce iron presence sensors; measurement was made according to Patent no P.415693 [22],
- testing of chemical composition of two alloys,
- test castings of castability spiral,
- casting knock out.

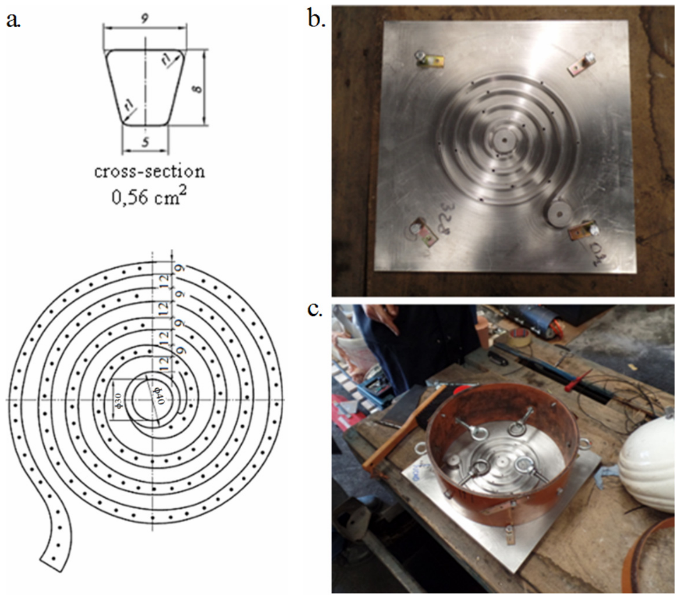

Fig. 1. Mould preparation instrumentation view: a. castability trial BN 80/4051 17 (spiral shape), b. spiral reverse pattern plate, c. spiral pattern plate with bottom moulding box

Castability tests involved examining the effect of moisture of the moulding sand and the degree of the metal superheating on the cast iron castability. The moulding sands were made from a green sand of moisture content of 3.3% and 6.6%. Pouring was performed using the following superheating temperatures: 1316°C, 1348°C, 1367°C (pouring temperature was measured in the ladle prior to metal casting). In each of these cases a spiral cast was made and its length was experimentally determined. Exemplary measurement results of the range of spiral filling are shown in Fig. 3.

3. Computer simulation of castabality trials

Simulation tests were performed in the NF&S CV code. The aim of the research was to validate the tested simulation code and to examine the sensitivity of the simulation code to errors in defining material parameters and initial conditions.

Simulation tests were carried out according to the following scheme:

- preparing casting geometry in the Siemens NX system,
- casting geometry import and volume mesh generating in the NF&S CV system (Fig. 4),
- implementing boundary, initial and material conditions (green sand parameters were based on [23]),

Fig. 2. View of instrumentation for mould preparation

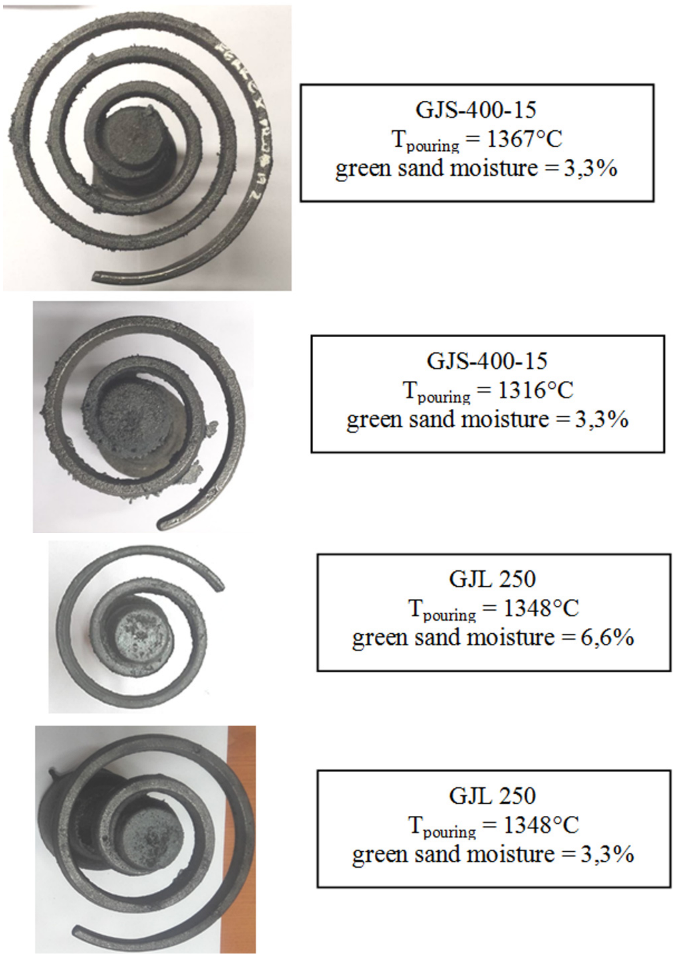

Fig. 3. Spiral castings obtained in castability trials (selected tests)

- introduction of sensors into the simulation in locations corresponding to the placement of fiber optics in the experiment (Fig. 5),
- simulation of the process of filling the mould cavity and casting solidification of castability spiral in the NF&S CV system (Fig. 6),
- validation tests.

In result of validation tests, spiral casting length obtained by simulation was compliant with the experiment for the determined parameters (Fig. 7-9).

As is known, permeability of the two-phase medium, i.e. a mushy zone, which is treated as a kind of porous media, determines feeding flows from the riser to hot spots. This has an impact on the quantitative flow conditions depending on the shrinkage of the solidifying casting. In the NF&S code in order to control these flows critical fractions of liquid CLFup (criterion of limited fraction of the liquid phase – mass flow) and CLFdown (criterion of limited fraction of the liquid phase – capillary flow), were introduced. Their differentiation for the process of filling of the mould cavity and performed sensitivity tests of the NF&S simulation code showed their unexpected impact on the calculated (simulated) length of the castability spiral casting. The tests included also:

– impact of the initial temperature of cast iron,
– impact of critical fractions CLFup and CLFdown of cast iron (Fig. 10),
– impact of moulding sand moisture.

The tests confirmed the influence of the parameters tested on the simulated length of the spiral casting. Preliminary studies

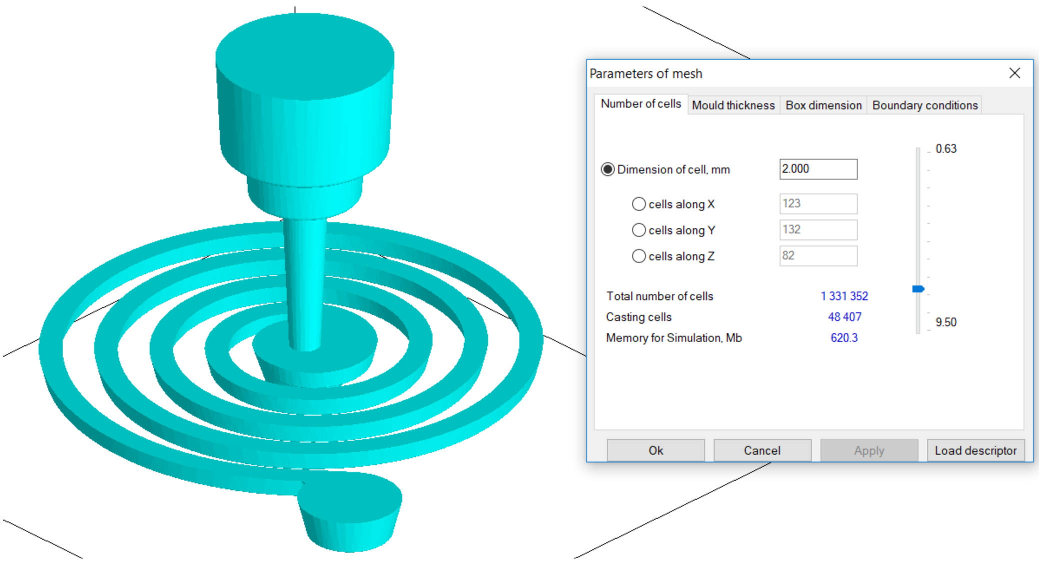

Fig. 4. Castability trial – Control Volume (CV) mesh parameters

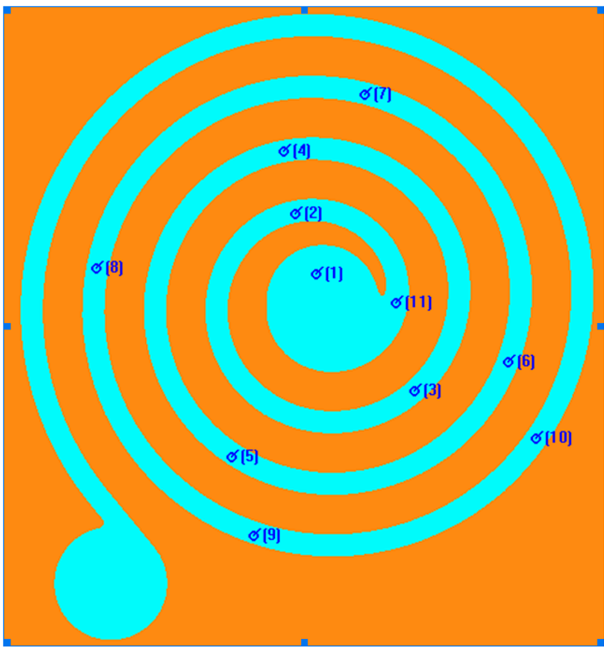

Fig. 5. Castability trial – points where sensors were placed in the experiment

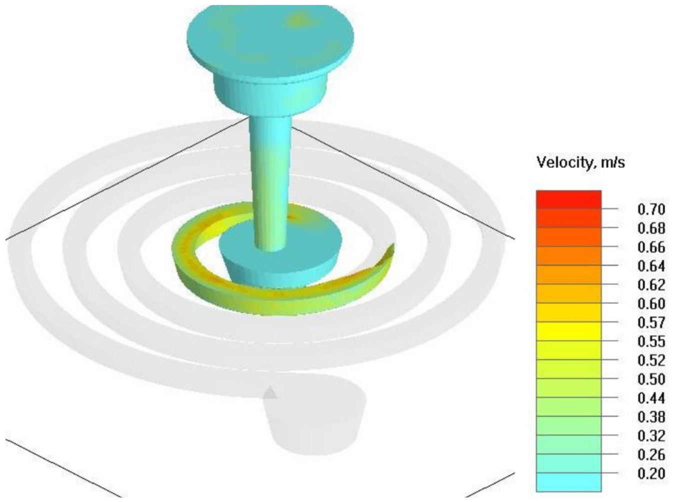

Fig. 6. Castability trial (spiral shape) – simulation results

have shown that this size of the casting requires the maximum grid size of 2 mm. All subsequent tests used the grid size of 2 mm (using grid elements of a smaller size does not affect the accuracy of the calculations, but significantly increases the time). The results of sensitivity tests are shown in Fig. 10. These tests showed that critical fractions CLFdown have the greatest impact on the simulated length of the castability spiral (Fig. 11). Lowering the value CLFdown causes a significant increase in the simulated length of the spiral. In case of pouring temperature effect tests, its expected effects on castability were confirmed (Fig. 12). It has been established that the influence of the analyzed temperature variation of pouring has a much smaller effect on the results than the possible changes of the critical fraction CLFdown. This may result from the assumptions which were adopted by the authors of the NF&S code and can only apply to this simulation tool.

For two of the experiments, cast iron rate in the mould cavity was set and compared with results coming from a simulation. Cast iron rate was analysed for two sections of 100 mm length between sensors indicated on Fig. 5 – section 1 (from sensor 2 to sensor 3, section 2 (from sensor 3 to sensor 4). Results were put together in Table 2.

TABLE 2

Cast iron flow rate during real life mould filling and in simulation

	Experiment average velocity [m/s]	**Simulation average velocity [m/s]**
GJL 250 filling of two sections of 100 mm length	0,51	0,59
GJS-400-15 filling of two sections of 100 mm length	0,43	0,41

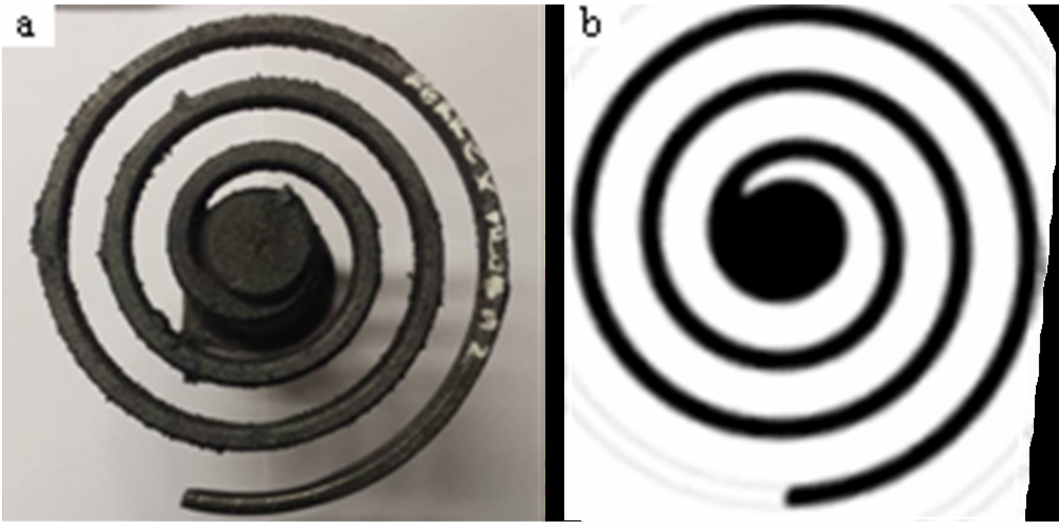

Fig. 7. Castability trial (spiral shape) – validation result (GJS-400-15, Tpouring = 1367°C, green sand moisture = 3,3%), a. experiment, b. simulation result (CLFup = 70%, CLFdown = 10%)

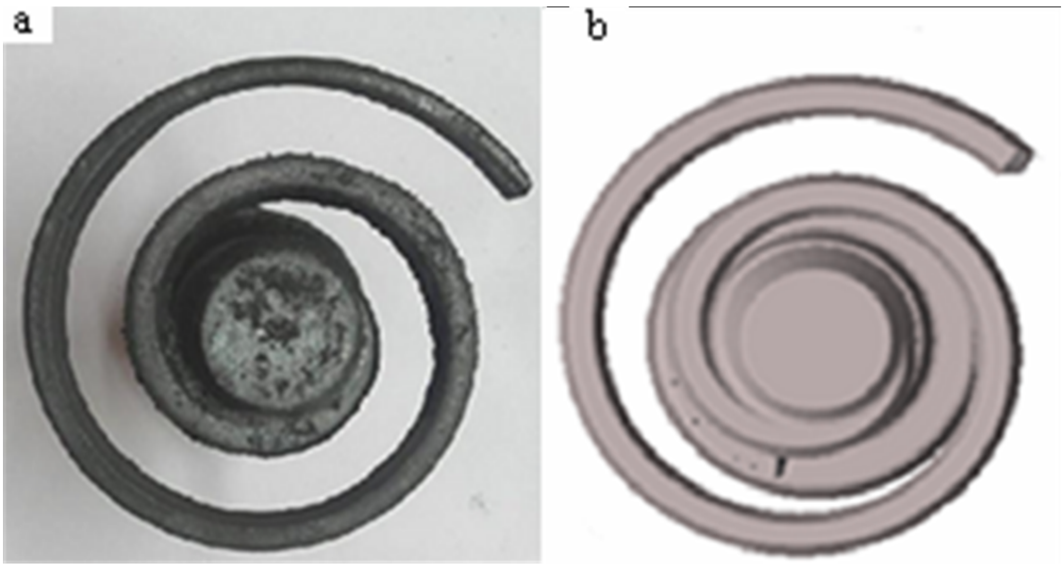

Fig. 8. Castability trial (spiral shape) – validation result (GJL 250, Tpouring = 1348°C, green sand moisture = 6,6%), a. experiment, b. simulation result (CLFup = 90%, CLFdown = 60%)

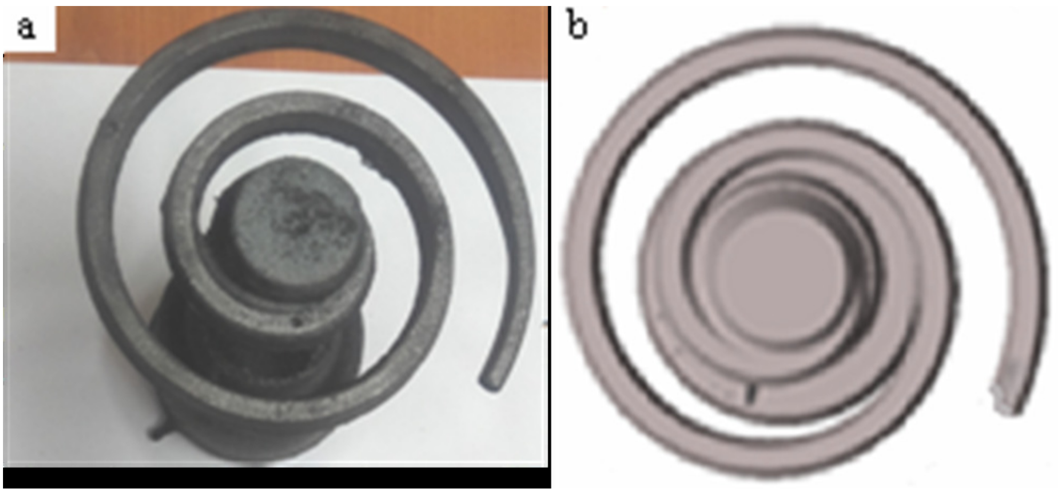

Fig. 9. Castability trial (spiral shape) – validation result (GJL 250, Tpouring = 1348°C, green sand moisture = 3,3%), a. experiment, b. simulation result (CLFup = 90%, CLFdown = 60%)

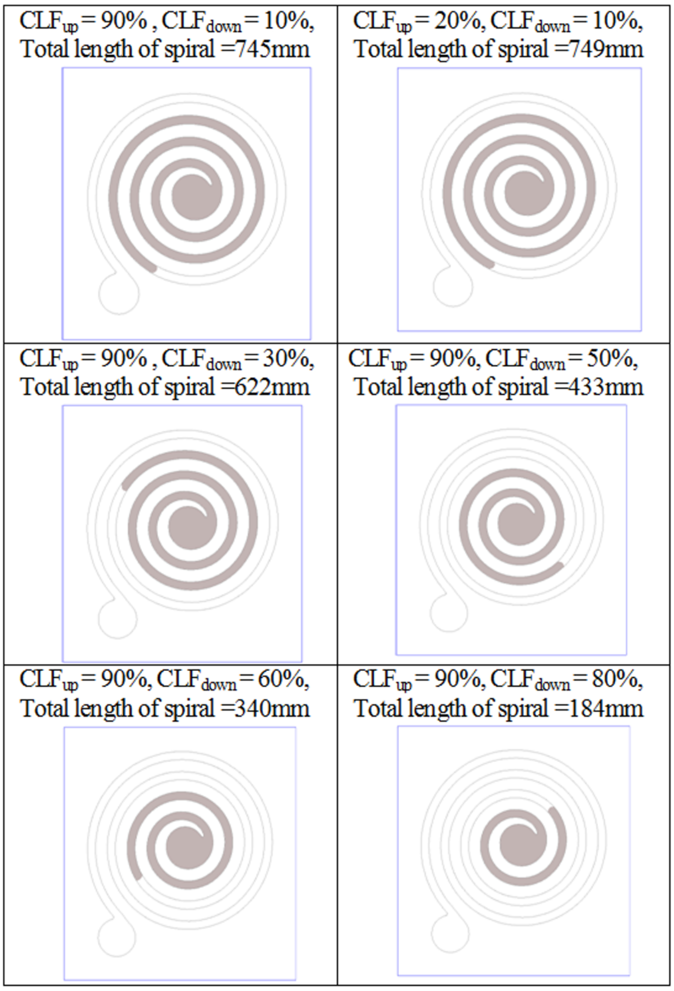

Fig. 10. Castability trial, simulation results (Cast Iron GJL 250, Tpouring = 1348°C, green sand moisture = 3,3%) – sensitivity test of simulation results (obtained length of the spiral) on the variation of CLFup CLFdown

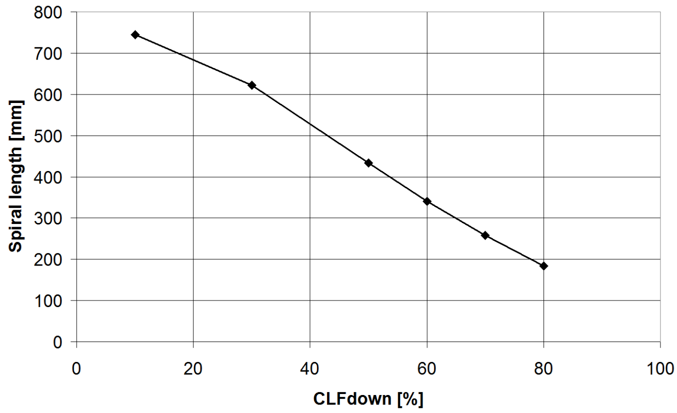

Fig. 11. Sensitivity test of simulation results (obtained length of the spiral) on the changes of CLFdown (Cast Iron GJL 250, Tpouring = 1348°C, green sand moisture = 3,3%)

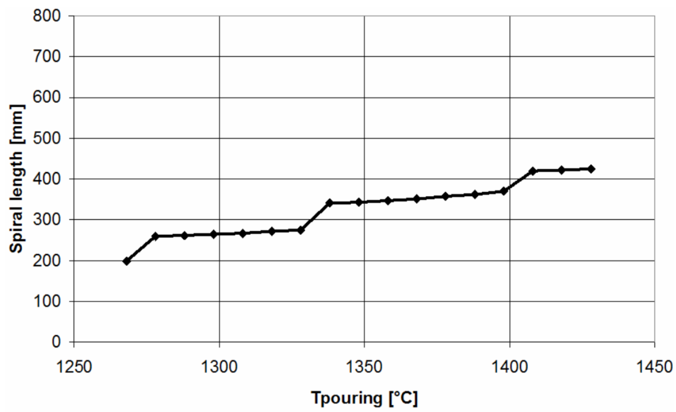

Fig. 12. Sensitivity test of simulation results (obtained length of the spiral) on the changes of pouring temperature (Cast Iron GJL 250, CLFup = 90%, CLFdown, = 60%, green sand moisture = 3,3%)

4. Conclusions

- Based on validation tests, the critical fractions CLFup and CLFdown of gray cast iron GJL 250 and ductile iron GJS-400-15 were determined. The determined coefficients (CLFup = 90%, CLFdown = 60% for gray cast iron GJL 250 and CLFup = 70%, CLFdown = 10% for ductile iron GJS-400-15) were compatible in the simulation and the experiments results.
- It was established that critical fraction of capillary flow CLFdown has the biggest impact on cast iron castability in the NF&S CV simulation code (obtained length of spiral casting). This fact should be associated with the specificity of this simulation code (the degree of simplification in physical-mathematical model), and it should not be generalized without having carried out appropriate testing of other simulation codes.
- The influence of mould moisture on cast iron castability was confirmed. The tests clearly indicated that the length of the spiral was made in the mould of 6.6% moisture is more than 30 mm smaller than in the mould with the moisture content of 3.3%.
- There was an accordance between the experiment and the simulation of the first two sections of mould cavity flow velocity during filling.
- Sensitivity tests showed a significant impact of the tested parameters on the results of the mould cavity filling simulation process. It is of great significance especially during the simulation of filling of the channels of the gating system and/or thin walls of the casting.

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