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COMPUTER SIMULATION BASED COMPARATIVE STUDY ON THE SOLIDIFICATION OF A CAST IRON AND STEEL CASTING

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Abstract: *The authors conducted a comparative study on the solidification of a part cast from three different alloys. The study was achieved by computer simulation and concerned the solidification of a stepped casting. The analysed cases were of castings from 0.1% C steel, 0.5%C steel and eutectic spheroidal graphite cast iron, respectively. The alloys differ by their casting temperature and their solidification temperature interval. Analysis included the influence of the alloy type on macrosolidification parameters like solidification time, hot spot position, temperature distribution in the casting at the end of solidification, map of the solidus front displacement, extent of the two-phase area (solidus + liquidus) in the casting, aspect of the cooling curves, etc.*

Keywords: *alloys, steel, solidification*

1. INTRODUCTION

A comparative study was carried out on the solidification of stepped parts cast from two steels of different chemical compositions, and from eutectic grey cast iron. In the three studied cases both the casting temperature of the liquid alloy and the solidification time interval differ.

2. AIM OF THE PAPER AND WORKING METHOD

The solidification of the casting (test piece) from eutectic cast iron was simulated at equilibrium (constant temperature solidification without reproducing the undercooling and the recalescence occurring during solidification). The aim was to reveal the extent to which the solidification interval influences the solidification parameters of a casting (solidification time, hot spot position, etc.). Figure 1 shows the part studied by simulation. Figure 2 shows the studied casting – mould subassembly. The mould is made from sand hardened with sodium silicate and CO_2. Solidification was simulated for parts cast from the following alloys:

- carbon steel with 0.1%C;
- carbon steel with 0.53%C;
- eutectic spheroidal graphite cast iron with 4.2 % CE (equivalent carbon).

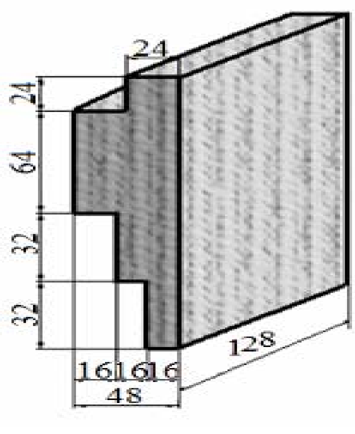


Figure 1 Casting

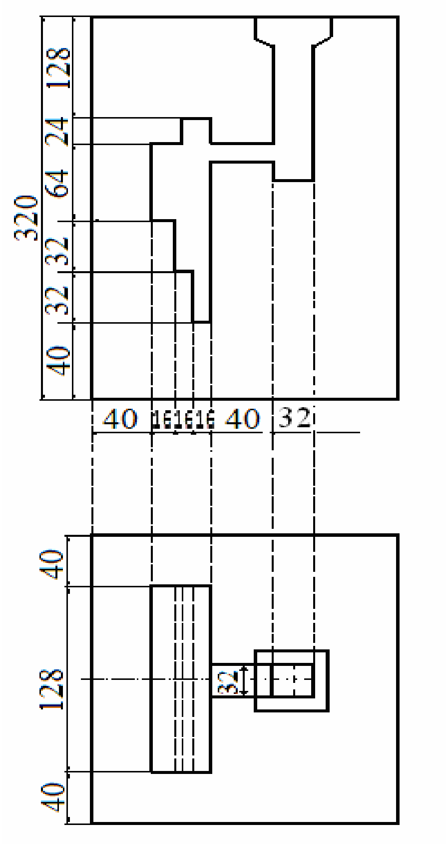


Figure 2 Casting – mould assembly used in simulation.

In all cases simulation maintained the same overheating of the liquid alloy in relation to the liquidus temperature. The overheating related to T_L was $\Delta T = T_{0ME} - T_L - 155^0C$.

Table 1 shows the values for the thermo-physical characteristics of the alloys considered in simulation. The following values were used for the mould sand: density ρ_{FO}=1550Kg/m^3, specific heat c_{FO}=1050J/KgK; λ_{FO}=0.65W/mK.

3. RESULTS

The influence of the solidification interval (T_L-T_S) on the following solidification parameters was analysed:

- the total solidification time (related to the initial moment, tsol);
- the total actual duration of the solidification of the hot spot (the time elapsed between the beginning and the end of solidification: t_{ES}= tsol – tstart sol);
- the position (coordinates) of the ending point of solidification (x_{NOD}; y_{NOD}, z_{NOD});
- the distribution of the isotherms in the casting at the end of solidification;
- the map of the solidus front displacement;
- the extent of the two-phase area (solidus + liquidus) at a given time, in the case of steels;
- the aspect of the cooling curves (temperature variation) in the hot spot;
- the variation in time of the solidus fraction (kinetics of solidification) in the hot spot;
- the evolution of the instantaneous cooling rate in the hot spot versus time;
- the distribution of temperature along a line/row and a column, respectively in the casting-mould assembly at a given time.

Table 2 and figures 3 to 10 feature the obtained results.

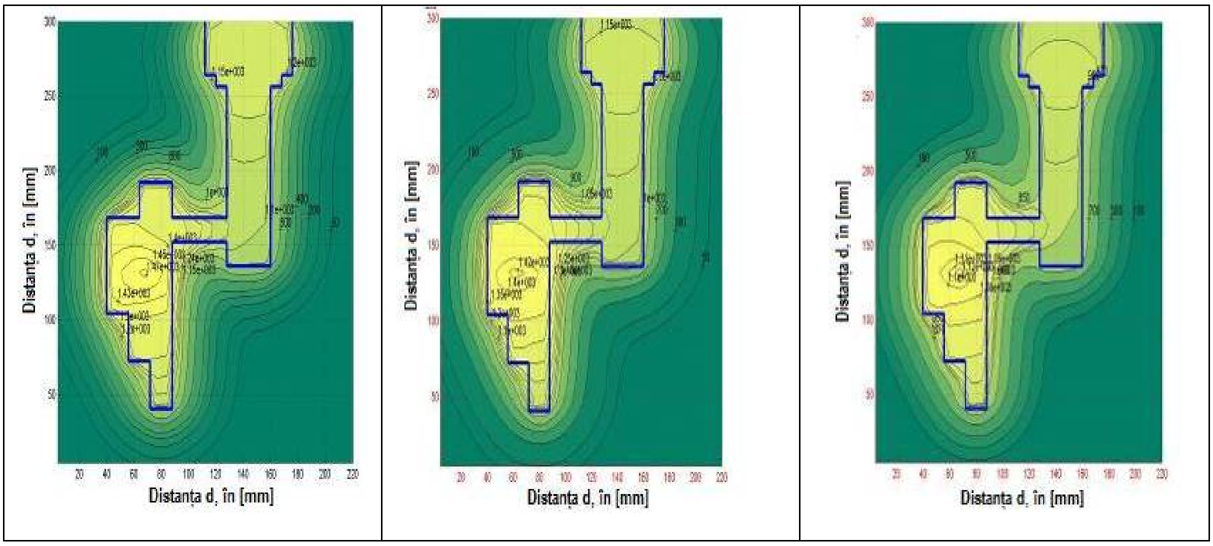
Table 1 Values of the thermo-physical quantities used in simulation

No.	Type of alloy	Solidus temperature	Liquidus temperature	Initial temperature	Overheating of the alloy in relation to T_L	Overheating of the alloy in relation to T_S
Symbol	-	T_S	T_L	T_{0ME}	ΔT	ΔT
u.m.	-	^0C	^0C	^0C	^0C	^0C
1	0.1%C steel	1495	1530	1685	155	190
2	0.53%C steel	1430	1495	1650	155	220
3	Eutectic spheroidal graphite cast iron	1150	1150	1305	155	155

No.	Liquid alloy density	Specific heat in solid state	Specific heat in liquid state	Thermal conductibility in solid state	Thermal conductibility in liquid state	Latent solidification heat
Symbol	ρ	C_S	C_L	λ_S	λ_L	L
u.m.	Kg/m^3	J/kg/K	J/kg/K	W/m/K	W/m/K	J/Kg
1	7200	750	850	30	28	270000
2	7200	750	850	29	27	270000
3	6800	750	850	35	30	250000

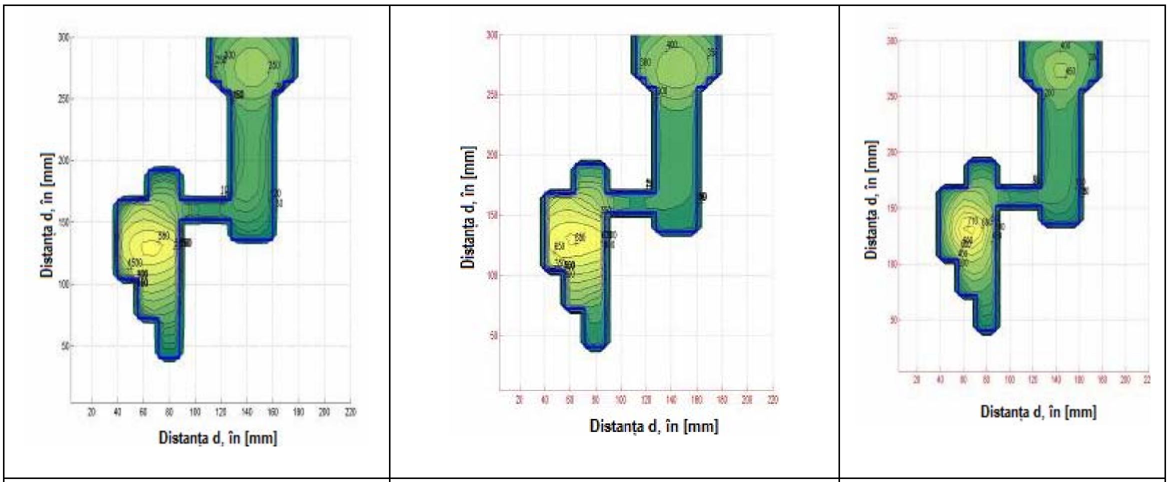
Table 2 Results on the influence of the solidification interval on the parameters of solidification

No.	Type of alloy	Start time of solidification	End time of solidification	Actual solidification time of hot spot	Coordinates of the hot spot
Symbol	-	$T_{START\ SOL}$	T_{SOL}	$t_{EF\ SOL}$	x_{NOD}; y_{NOD}; z_{NOD}
u.m.	-	s	s	s	mm
1	0.1%C steel	166.5	589.5	423.0	68,132,104
2	0.53%C steel	166.5	684.0	517.5	60;132,104
4	Eutectic spheroidal graphite cast iron	573.0	718.75	145.75	68,132,104



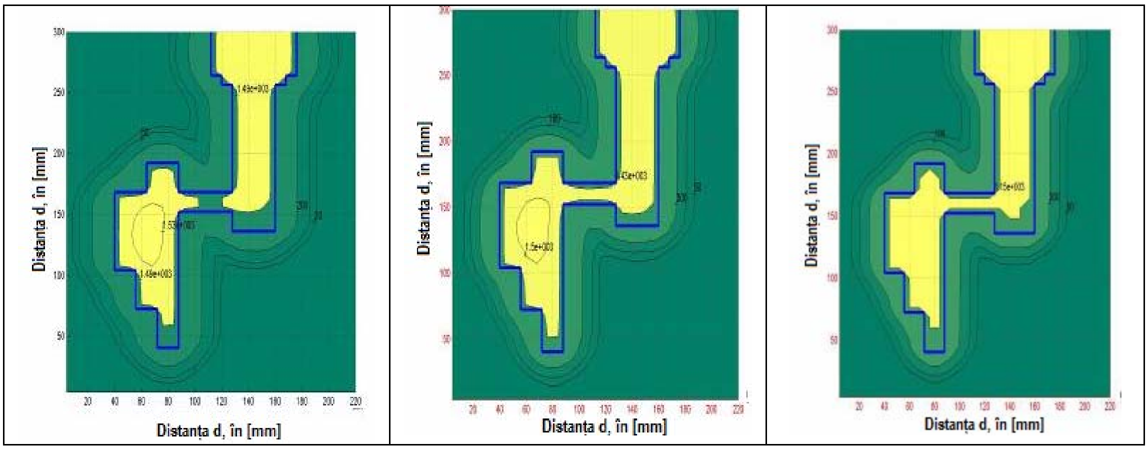
a.) 0.1%C steel b.) 0.53%C steel c.) Eutectic spheroidal graphite cast iron

Figure 3 Isotherms at the end of hot spot solidification



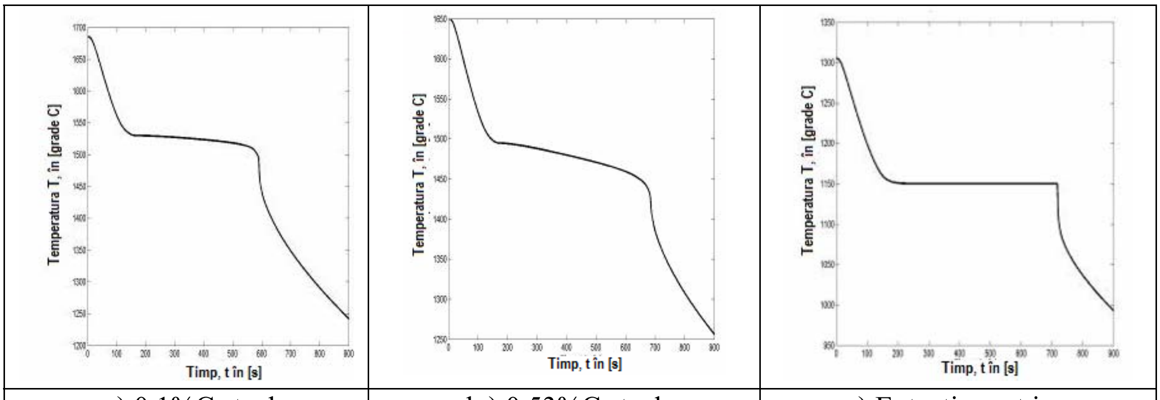
a.) 0.1 %C steel	b.) 0.53 %C steel	c.) Eutectic spheroidal graphite cast iron

Figure 4 Map of the displacement of the solidification front



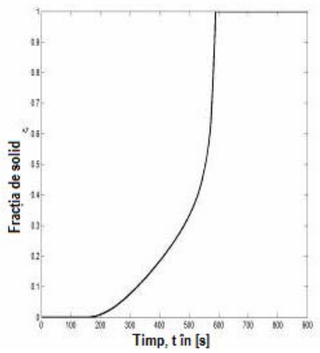
a.) 0.1%C steel b.) 0.53%C steel c.) Eutectic spheroidal graphite cast iron

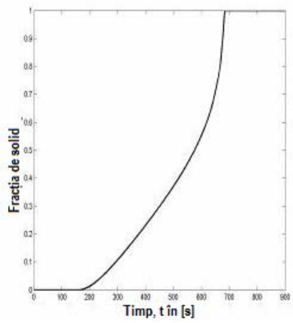
Figure 5 Distribution of the two-phase area (solidus + liquidus) at time t = 150s

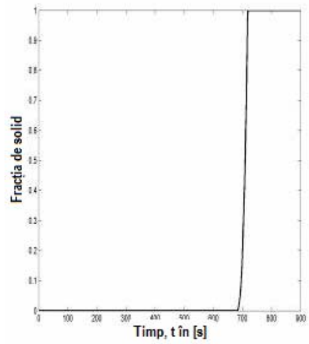


a.) 0.1%C steel	b.) 0.53%C steel	c.) Eutectic cast iron

Figure 6 Variation of temperature in the hot spot

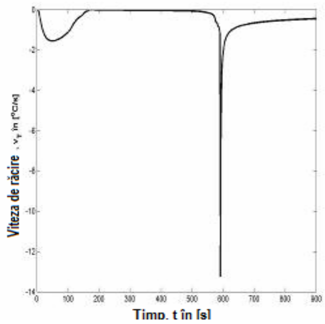


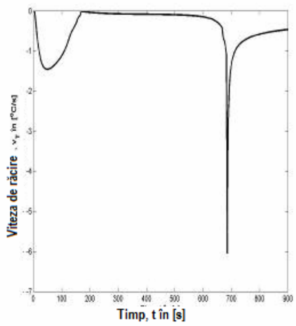


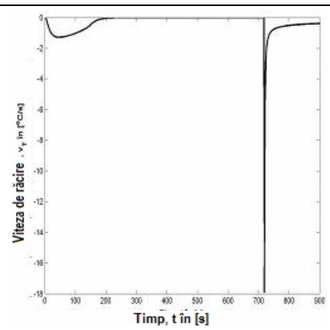


a.) 0.1%C steel	b.) 0.53%C steel	c.) Eutectic cast iron

Figure 7 Variation of the solidus fraction in the hot spot

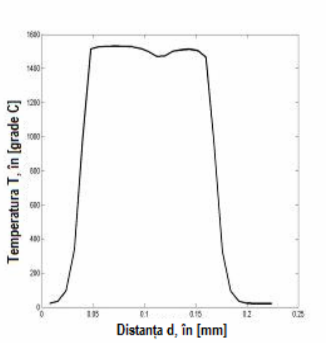


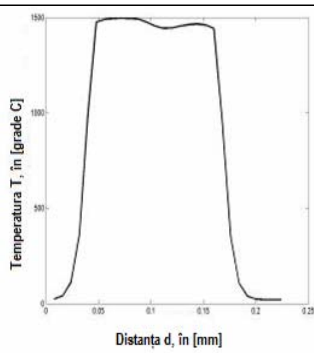


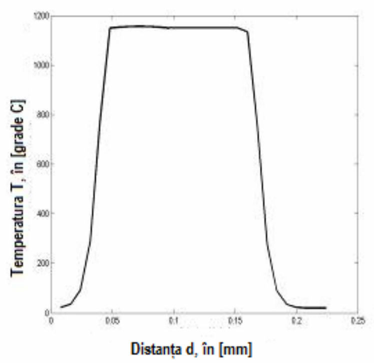


a.) 0.1%C steel	b.) 0.53%C steel	c.) Eutectic cast iron

Figure 8 Cooling rate in the hot spot

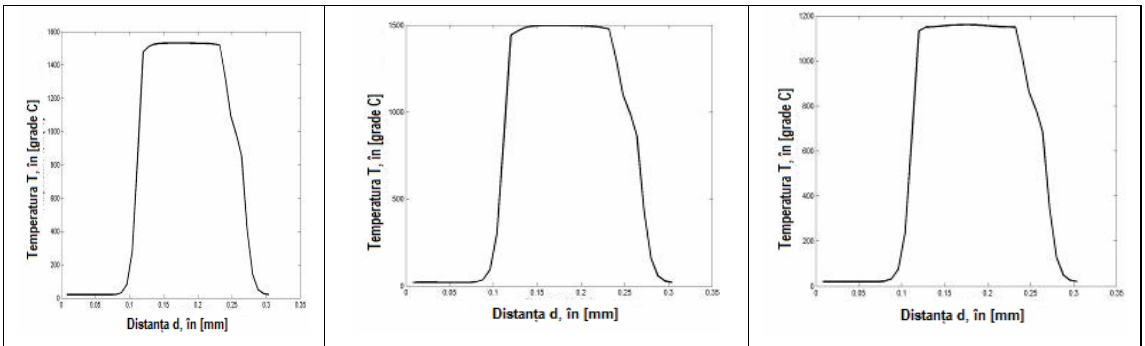






a.) 0.1%C steel	b.) 0.53%C steel	c.) Eutectic cast iron

Figure 9 Distribution of temperature along line L= 19 at time t = 150s



a.) 0.1%C steel	b.) 0.53%C steel	c.) Eutectic cast iron

Figure 10 Distribution of temperature along column C=9 at time t=1500s

4. CONCLUSIONS

The results presented in table 2 and in figures 6 to 10 yield the following conclusions:

- the position of the hot spot is identical in all three studied cases, what shows that the solidification interval does not influence this solidification parameter at all; this can be explained by the fact that the dynamics of heat transmission from the casting to the mould is not influenced by the solidification interval, but only by the geometry of the casting and of the mould.

- for the same overheating in relation to the liquidus temperature (which in this case was $\Delta T = T_{0M} - T_L = 155^0C$) the solidification time of the hot spot (in steels of different chemical compositions and different solidus and liquidus temperatures and in eutectic cast iron) is influenced to a relatively great extent. This influence can be. explained by the different amounts of thermal energy (heat) discharged by the alloy during solidification;

- in the case of steels solidification starts at a significantly higher rate than in the part cast from eutectic cast iron. (Table 2, $t_{START\ SOL\ OTEL} = 166.5s$ while $t_{START\ SOL\ FONTA} = 573.0s$); this can be explained by the temperature difference at the initial moment between the liquid alloy and the casting mould ($T_{0ME} - T_{FO}$), which is significantly greater for steels that are cast at a higher temperature; for this reason the heat transfer from the liquid steel to the mould immediately after filling of the mould is much more intensive for steels, what determines a higher cooling rate of the alloy at the beginning of cooling in liquid state;

- for steel parts the actual solidification takes longer ($t_{SOL} - t_{START\ SOL}$) than for the eutectic cast iron part; this can be explained by the larger overheating of steels in relation to the solidus temperature, as the overheating in relation to the solidus temperature is equal to the overheating in liquid state plus the solidification interval. Thus during solidification the steel parts have to discharge a larger quantity of heat – the latent heat plus the heat corresponding to the solidification interval;

- the start time of solidification ($t_{START\ SOL}$) and the end time of solidification (t_{SOL}) for the eutectic cast iron part are higher than those for the steel parts; this is explained by the smaller casting temperature of cast iron; thus the intensity of heat transfer to the mould is smaller for cast iron parts and the solidification time is greater;

- in the case of the two studied steels, at the same overheating in relation to the liquidus temperature, the magnitude of the solidification interval $\Delta T = T_L - T_{S,}$ (*i.e.* the liquidus and solidus temperatures) has little influence on the extent of the liquidus area. For the same filling time of the mould (for example at t = 1250s) the position of the liquidus front is approximately the same (figure 5).

- in the case of the two studied steels, at the same overheating in relation to the liquidus temperature, the magnitude of the solidification interval $\Delta T = T_L - T_{S,}$ (*i.e.* the liquidus and solidus temperatures) influences the magnitude of the two-phase area (solidus + liquidus) and its evolution in time in the section of the casting. This is caused by the modification of the position of the solidus front. For the same filling time of the mould (for example at t = 1250s) the two-phase area is smaller in the steel with a smaller solidification interval (0.1%C steel) and a higher casting temperature, the solidified area being more extended (figure 5).

- a two-phase area does not occur in the eutectic cast iron, only a liquidus area, and at the same time (a-150s since the filling of the mould) its extent is comparable to the extent of the two-phase + liquidus areas in steels with a solidification interval (for the same initial overheating) (figure 5);

- in the case of the two studied steels no differences occur as to the start time of solidification ($t_{START\ SOL}$); differences occur, however, related to the end of solidification (t_{SOL}) and the actual duration of hot spot solidification (t_{SOL} - $t_{START\ SOL}$); the 0.53%C steel has a greater end of solidification time than the 0.1%C steel, due to the larger solidification interval;

- in the studied steels (alloys with a solidification interval) the obtained evolution curves of temperature in the hot spot are influenced by the casting temperature (by the magnitude of the solidification interval and the liquidus temperature), as well as by the fact that during solidification temperature is no longer constant; the slope of the variation curve of temperature within the solidification interval is greater when the casting temperature (liquidus temperature) is smaller;

- in the studied alloys with a solidification interval (steels) the evolution curves of the solidus fraction in the hot spot (kinetics of solidification) differ significantly from the solidification curve of the eutectic cast iron; in the latter the evolution curve of the solid fraction is significantly more abrupt, what reveal s a slower solidification kinetics in steels (alloys with a solidification interval); the greater the solidification interval is, the kinetic curves (the variation of the solidus fraction) have a smaller slope, what shows that the actual solidification of the hot spot occurs within a greater time interval; alloys solidifying at constant temperature (eutectic cast iron) have significantly swifter solidification kinetics.

- the general aspect of the variation curves of the cooling rates for the three studied alloys is similar, given the presence of peaks of the cooling rates in the first stage of cooling and immediately after completed solidification of each volume element;

- in the studied steels and cast iron the aspect of the evolution curves of the cooling rate in the hot spot differs as regards the cooling rate peaks, occurring prior to the beginning of solidification and at the end of solidification;

- the temperature distribution curves along a line/row or column of the casting-mould system, at a given time, are of similar shape, but differ by the values of the temperatures; the different values are explained by the different casting temperatures of the studied alloys.

5. REFERENCES

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