A Comparative Study on Gravitational and Centrifugal Casting Solidification

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Abstract
It was studied the solidification of a part cast in both ways, centrifugal and gravitational. The study has been accomplished by computer simulation. Six casting variants were compared, three by centrifugal casting and three by gravity casting. The hot spot position, the solidification time, the solidification front movement, the temperature variation relative to time, the cooling and the solidification kinetics were analysed. The influence of the external cores and the mould coatings with protection layers it was studied too.

Keywords
solidification, casting, centrifugal casting, solidification simulation, cast iron

1. Introduction

Heat transmission during the cooling and solidification of centrifugal castings is different in relation to gravity casting. The causes are:

- The rotation of the mould and the alloy during cooling;
- Very low heat exchange (almost zero) to the inner surface of the casting;
- The geometry and construction of the casting mould with rotational symmetry.

The rotation movement of the mould and the alloy has effect on the heat transfer within the liquid alloy, but also at the interface of the molten metal - mould. From the first moment of the liquid alloy falling in the form, liquid alloy is drawn into an intense rotation [1, 2, 3, 4, 9]. There is a mixing of the liquid alloy and therefore its temperature uniformity throughout its volume. The heat is transmitted by forced convection inside the liquid alloy and at the interface liquid - alloy mould. In addition, the centrifugal forces cause a movement of the heavy particles (high-density particles, for example particles, which have begun to solidify) to the outside. Lighter particles (gas bubbles, inclusions of metal, clay) are pushed toward the inner surface. This movement emphasizes forced convection within the liquid alloy. It can be equated with continue smoothing of the temperature of liquid alloy layers by mixing.

On the other hand, the rotational movement of the mould makes that the transfer of heat mould - environment (the external surface of the mould) to be done by forced convection. The heat transfer coefficient on the surface mould - environment, is larger than at the gravity casting and it depends on the rotation speed of the mould.

The situation is completely different on the inner surface of the casting. Especially for parts that have small internal diameter and large length, the inner surface behaves as a black body. Radiant heat transfer is quite zero. In addition, the air located in the interior is heated quickly to high temperature close to the liquid alloy temperature. Air circulation along its part axis towards the outside is reduced. The heat transfer alloy – air, at the inner surface of the casting, is very small (close to zero) even part rotates. Following the heat is transmitted in one sense in the wall of the casting. This is equivalent to a double wall thickness of the part. The real solidification module and the solidification time of the casting grow considerably and the hotspot position changes. On the other hand, the heat conduction in only one sense could favour the development of columnar crystals (elongated in the radius direction).

At the same time, the rotation of the liquid alloy may have the effect of breaking of the growing crystal at the solid-liquid interface. This can lead to finish the structure. This effect is more pronounced in the case of alloys with high solidification interval or parts that slowly cool and solidify. For example, parts with large wall thickness, low thermal conductivity alloys, castings with very low conductivity (castings with exterior sand cores). These effects are more influenced by cast alloy characteristics.

2. Particularities Regarding Centrifugal Casting Solidification Simulation

The mould rotation makes very difficult (virtually impossible) experimental measurement of the temperature field in centrifugal castings. Solidification simulation software development made it possible that centrifugal castings solidification be thoroughly studied by computer simulation. Simulation has the advantage of allowing gradual change of any parameter of the studied process. Following detail, systematized studies can be carried out by simulation that in any case could not be achieved by experiment.

Centrifugal casting solidification simulation presents several peculiarities. These are determined by the castings geometry and the rotation of the system. Rotational symmetry of parts and mould makes possible and even requires, the use of mathematical models in cylindrical coordinates [5, 8]. Cylindrical coordinate models reproduce more faithful heat transmission by convergent - divergent streams. On the other hand it is possible that the solidification volume of centrifugal castings to be simulated using 2D mathematical models and the respective software. Following the effective duration of the simulation is much lower.

Another feature is linked to how the mathematical model takes into account the influence of the rotational movement on heat transfer within the liquid alloy prior to solidification. It is possible that the heat transfer by forced convection between the layers of the liquid alloy to be taken into account by a corresponding equivalent thermal conductivity of the liquid alloy (i.e. by an equivalent thermal conductivity coefficient that depends on the rotational speed and radius of the form). Another variant is to consider a total mixing (or partial) of liquid alloy layers during rotation. This would lead to a uniform mixing (equalization) temperature of the molten alloy into those layers. Closer to reality is the first hypothesis. Moreover, in this case the mathematical model (and therefore soft structure) is simpler. The software used in the studies in this paper is based on this assumption.

Finally, the third feature of the centrifugal casting solidification simulation is related to the contact casting - mould. Some authors consider that between part and mould a small gap (space) appears that influences (reduces) the heat transfer from the molten alloy to mould. Regarding this case our opinion is different. As long as the alloy is in a liquid state alloy centrifugal force pushes out. Following the liquid alloy is pressed against the wall of the mould and the contact cast alloy - mould is perfect. This contact is maintained immediately after the outer layers of alloy solidify (interface part - mould) when solidified alloy has high temperature close to the liquidus temperature. Solidified layers of alloy are easily plastic deformable and they are also pressed by the centrifugal force on the mould wall. The appearance of a gap between the part and mould could be considered possible only when the part is cooled to lower temperatures (e.g. for iron to 900÷800 °C). At these temperatures, the casting begins to contract. In this case, the part is already solidified. So the gap created, do not affect the alloy solidification. As a result, the gap between the part and mould need not to be taken into account when the casting solidification is studied.

3. The Purpose of the Paper

In the case of cast iron, the cooling regime of the liquid alloy greatly influences the structure and properties of casting. In this sense, the greatest influence has the instantaneous cooling rate (momentary eutectic temperature). Until now the research in the field of centrifugal casting were focused especially on the study of the influence of rotational speed on the structure and properties of casting. Centrifugal castings thermal field has been less studied, primarily because difficulties of temperature measuring inside the rotating mould.

This paper aims to study by computer simulation the qualitative and quantitative impact of technological factors on the thermal regime on centrifugally cast iron parts solidification. These influences are analysed by comparison with gravity casting processes. Knowledge of these influences makes possible the optimization of centrifugal casting process depending on the casting size and structure and the desired properties.

4. Working Mode

Research is conducted by computer solidification simulation. It was used a software for casting solidification simulation of eutectic alloys. The software is based on a mathematical model in cylindrical coordinates. The solidification of a tubular part of cast iron with eutectic composition was simulated. The casting dimensions are shown in Figure 1. Three variants of centrifugal casting and three variants of gravity casting were studied:

- Case 1 - centrifugal casting in metallic mould;
- Case 2 - centrifugal casting in metallic mould with external sand core;
- Case 3 - centrifugal casting in painted metallic mould;
- Case 4 - gravity casting in sand mould with inner core of sand;
- Case 5 - gravity casting in metallic mould with inner core of sand;
- Case 6 - gravity casting in metallic mould with inner metallic core.

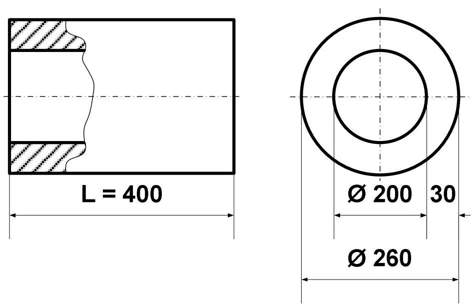


Fig. 1. Casting

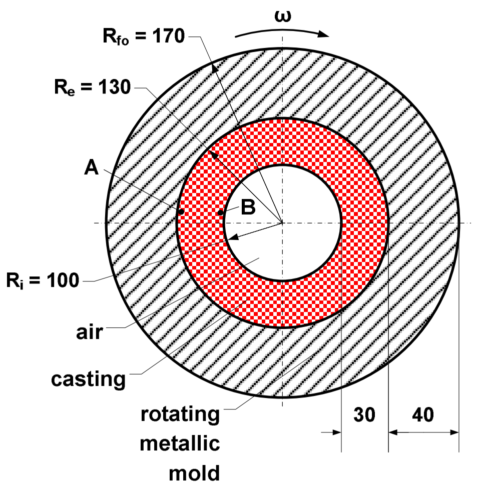
The construction and dimensions of the moulds used in the six cases are shown in Figure 2. There were considered metal moulds and cores made of cast steel. In the case 2 it was used a core of sand (SiO_2) inside the mould. It helps to decrease the cooling speed to obtain a structure of graphite cast iron. In the case 3 it has been considered a surface protective layer, 1 mm thick, of graphite based paint on the mould surface. This casting variant is often applied in practice. The layer of paint is intended to facilitate removal of the casting from the mould. Instances 4-6 correspond to gravity casting with mould and central core of sand (SiO_2) or metal.

In Table 1 are given the initial temperatures of the mould components and of the molten alloy, considered in the simulation. Table 2 presents the characteristics of the materials used for simulation [4, 5, 6, 7]. To obtain more precise information on the cooling conditions inside the castings simulation a network with step division Δ = 1 mm was used. The time step was also very small τ = 0.015 s.

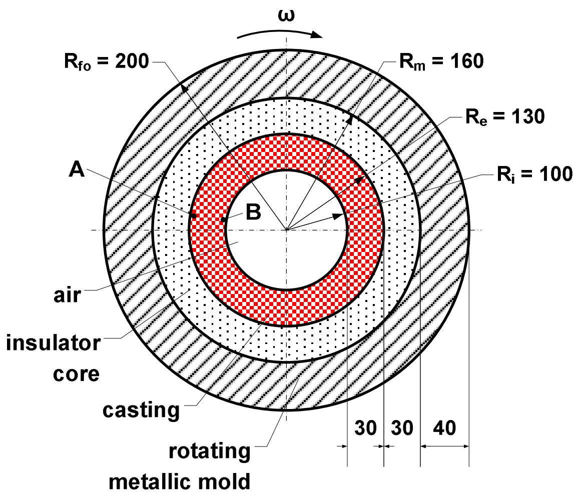
5. Results

There were analysed the following parameters of solidification:

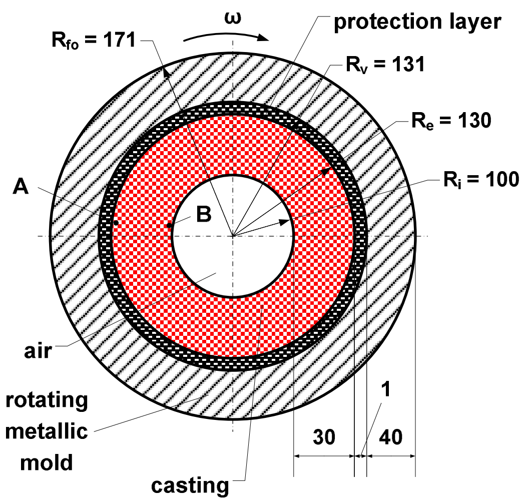
- the hot spot position in the part (the final point of solidification);
- the solidification time of the casting (tsol_p);
- the solidification time of the layer (with a thickness 1 mm) from the outer surface of the casting (tsol_pex);
- the average cooling speed in liquid state (in the range initial temperature - eutectic temperature (T0me - Ts)) of the outer layer (v_ex_med);
- the momentary cooling speed of the outer layer (v_ex_Ts) at the solidus temperature (eutectic temperature -Ts);



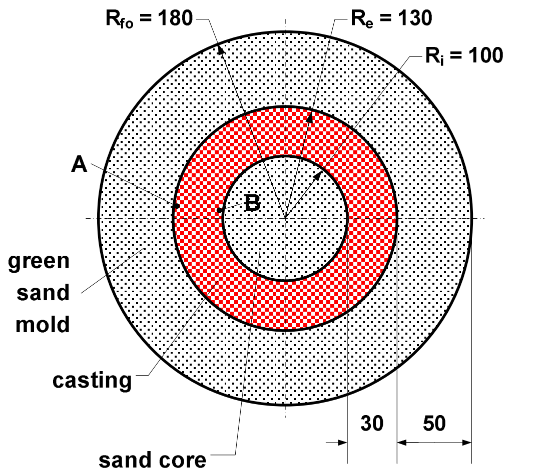
a.) Case 1 - Centrifugal, metallic mould



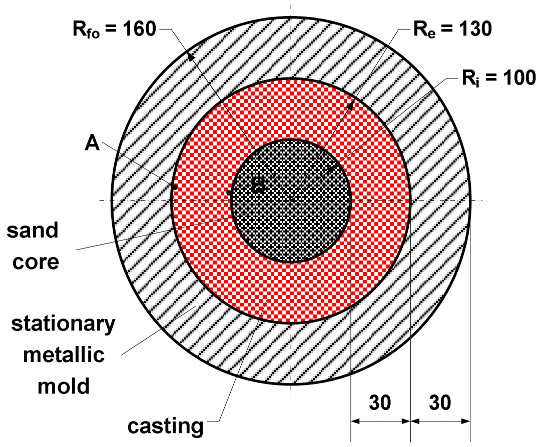
b.) Case 2 - Centrifugal with sand external core



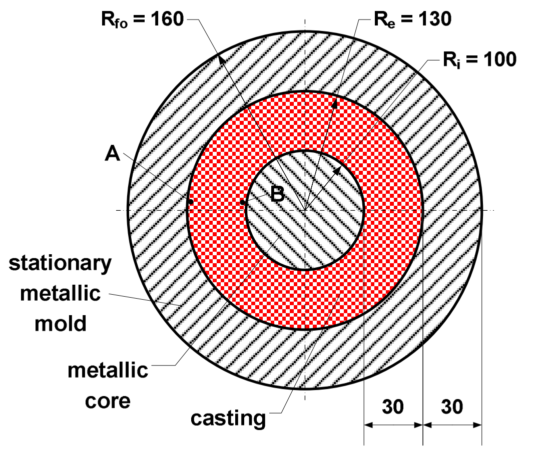
c.) Case 3 - Centrifugal. coating metallic mould with protection layer



d.) Case 4 - Gravitational, sand mould and core



e.) Case 5 - Gravitational, metallic mould and sand core



f.) Case 6 - Gravitational, metallic mould and core

Fig. 2. Design and dimensions of casting moulds

Table 1. Initial temperature components of the system casting - mould as considered in simulation

No.	Parameter name	Symbol	Unit.	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
1	Initial cast alloy temperature	T0_me	^{0}C	1320	1320	1320	1320	1320	1320
2	Initial core temperature	T0_mi	^{0}C	-	20	-	20	20	200
3	Initial mould temperature	T0_fo	^{0}C	200	200	200	20	200	200
4	Exterior environment temperature (air)	T_ex	^{0}C	20	20	20	20	20	20
5	Interior environment temperature (air)	T_in	^{0}C	100	50	100	-	-	-
6	Painting initial temperature	T0_vo	^{0}C	-	-	200	-	-	-
7	Cast iron solidification temperature	TS_me	^{0}C	1150	1150	1150	1150	1150	1150

- the solidification time of the layer (with a thickness 1 mm) from the inner surface of the casting (tsol_p_in);
- the average cooling speed of the liquid (in the range initial temperature - eutectic temperature (T0me-Ts)) of the inner layer (v_ex_med);
- the momentary cooling speed of the inner layer (v_in_Ts) at the solidus temperature (eutectic temperature -Ts);
- the temperature in the casting wall at the end of cast alloy solidification;
- the solidification time of the casting wall;
- the temperature evolution versus time in the hot spot, on the outer surface and on the inner surface of the part.

Table 3 shows data on the position of the hotspot, the hotspot solidification time, and the solidification time of the inner and outer surface of the part in the six cases. In Figures 3-4 are shown the casting wall temperature distribution at the end of its solidification (the hotspot solidification). It is noted that in the case of centrifugal casting with outer sand core, at the end of part solidification, the outer surface layer has high temperatures (above 1100 ^{0}C). In the case of centrifugal casting without sand core, at the end of solidification, the outer surface layer of the part has a high temperature too (over 870 ^{0}C). This confirms the hypothesis of a direct contact between the part and mould during solidification. Also in these two figures is observed that the temperature field inside the centrifugal casting wall is much different compared to gravity casting. This is explained by the very low heat exchange on the inner surface of the casting.

Figures 5-6 show the time solidification in the part wall in the six cases. These figures highlight the movement of the solidification front and the hot spot position in each individual case. It was also observed that the position of the hot spot in the part is much different at centrifugal casting.

Figures 7-12 show the evolution of the temperature in points A and B (Figure 2) on the outside and inside of the casting, in the six cases. In Tables 4 and 5 are given data values that characterize the kinetics of solidification in the points A and B located on the outer and the inner surface of the part (time of beginning of solidification, time for complete solidification, the medium cooling speed in the liquid state in the range of T0 - Ts (initial temperature - eutectic temperature), the momentary cooling speed at the solidification temperature (the eutectic temperature denoted by Ts). In Table 6 are given values on the kinetics of solidification of the hot spot in each case.

Figure 4 highlights the best the solidification front movement inside the casting wall and the hot spot position. It is noted that in the case of centrifugal casting solidification front moves from the outside to the inside surface of the casting. This is due to the very low heat exchange molten alloy - air on the inner surface of the part. In the case of centrifugal casting in metal moulds (coated or not) hotspot is placed on the inner surface of the part. In the case of centrifugal casting with outer sand core simulation show that the hot spot is located near the inner surface (3 mm from the inner surface). In reality grace of centrifugal force, the alloy still liquid (colder and denser) located on the inner surface of the part is pushed some millimetres (2-3 mm) to virtual hotspot (to a greater radius). In this way the liquid alloy (with higher temperature and lower density) of the virtual hot spot (located at 3 mm from the inner surface) is pushed towards the inner surface of the casting. As a result, the hot spot is formed in this case too on the inner surface of the part.

Table 2. Thermo-physical characteristics used in the simulations

No.	Parameter name	Symbol	Unit.	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
1	Specific heat of the liquid cast iron	C_l_me	J/KgK	850	850	850	850	850	850
2	Specific heat of the solid cast iron	C_s_me	J/KgK	750	750	750	750	750	750
3	Specific heat of the mould	C_s_fo	J/KgK	750	750	750	1170	750	750
4	Specific heat of the inner core	C_mi	J/KgK	-	-	-	1170	1170	750
5	Specific heat of the external core or painting	C_iz C_vo	J/KgK	-	1170	1000	-	-	-
6	Latent heat of solidification of cast iron	L_me	J/Kg	220000	220000	220000	220000	220000	220000
7	Thermal conductivity of the liquid cast iron	λ_l_me	W/mK	150	150	150	30	30	30
8	Thermal conductivity of the solid cast iron	λ_s_me	W/mK	40	40	40	40	40	40
9	Thermal conductivity of the mould	λ_fo	W/mK	30	30	30	0.8	30	30
10	Thermal conductivity of the inner core	λ_mi	W/mK	-	-	-	0.8	0.8	30
11	Thermal conductivity of the exterior core or painting	λ_iz λ_vo	W/mK	-	0.8	32	-	-	-
12	Cast iron density	ρ_me	Kg/m^3	7000	7000	7000	7000	7000	7000
13	Mould density	ρ_fo	Kg/m^3	7600	7600	7600	1550	7600	7600
14	Inner core density	ρ_mi	Kg/m^3	-	-	-	1550	1550	7600
15	Exterior core or painting density	ρ_izρ_vo	Kg/m^3	-	1550	1800	-	-	-
16	Heat exchange coefficient with the air, outside	α _ex	W/m^2K	50	50	50	10	20	20
17	Heat exchange coefficient with the air, inside	α_in	W/m^2K	2	2	2	-	-	-

Table 3. Results on the solidification time and the hot spot position

No.	Casting mode	Solidification time of part	Solidification time exterior	Solidification time interior	Casting hot spot radius	Hot spot distance from inner surface of casting
Symbol	-	tsol_p	tsol_pex	tsol_pin	Rnod	Δr_nod = Rnod-Ri
Unit	-	**s**	**s**	**s**	mm	mm
1	Centrifugal, metallic mould	96.295	0.13	96.295	100	0
2	Centrifugal, external sand core	1940.34	394.440	1077.72	103	3
3	Centrifugal, metallic mould, painted	98.25	0.255	98.25	100	0
4	Gravitational, sand mould and core	647.7	109	120.6	113	13
5	Gravitational metallic mould and sand core	69.50	0.10	49.300	103	3
6	Gravitational metallic mould and core	25.92	0.12	0.12	114	14

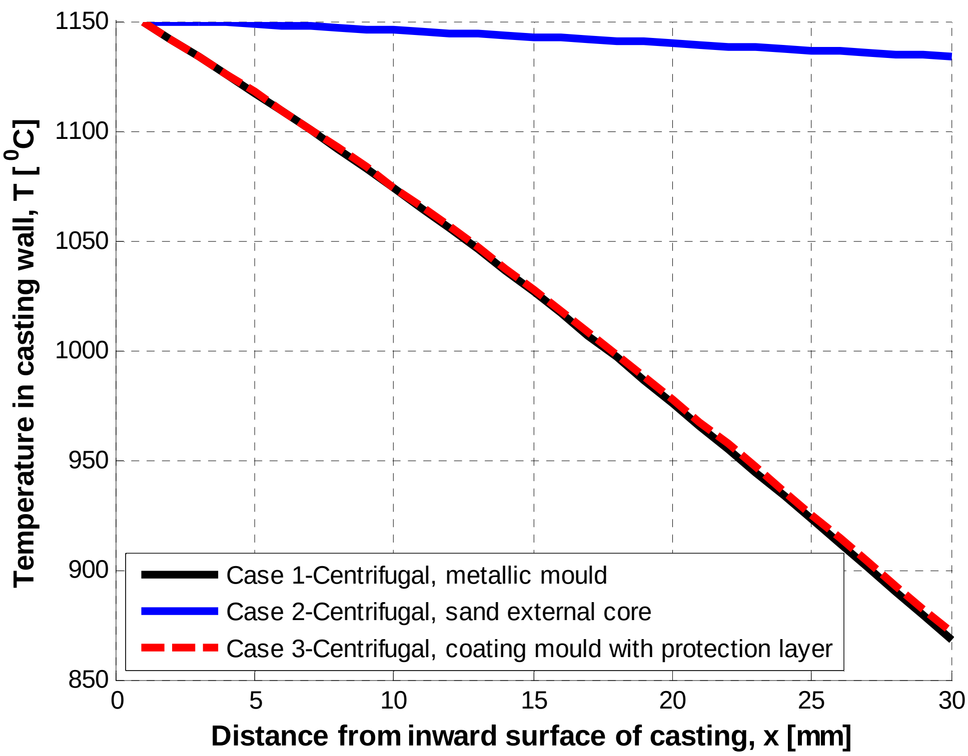


Fig. 3. Temperature in centrifugal casting wall at solidification end time
1 - Centrifugal, metallic mould, time t = 96.295 s; 2 - Centrifugal with external sand core, time t =1940.340 s; 3 - Centrifugal, metallic mould with coating protection layer, time t = 97.590 s

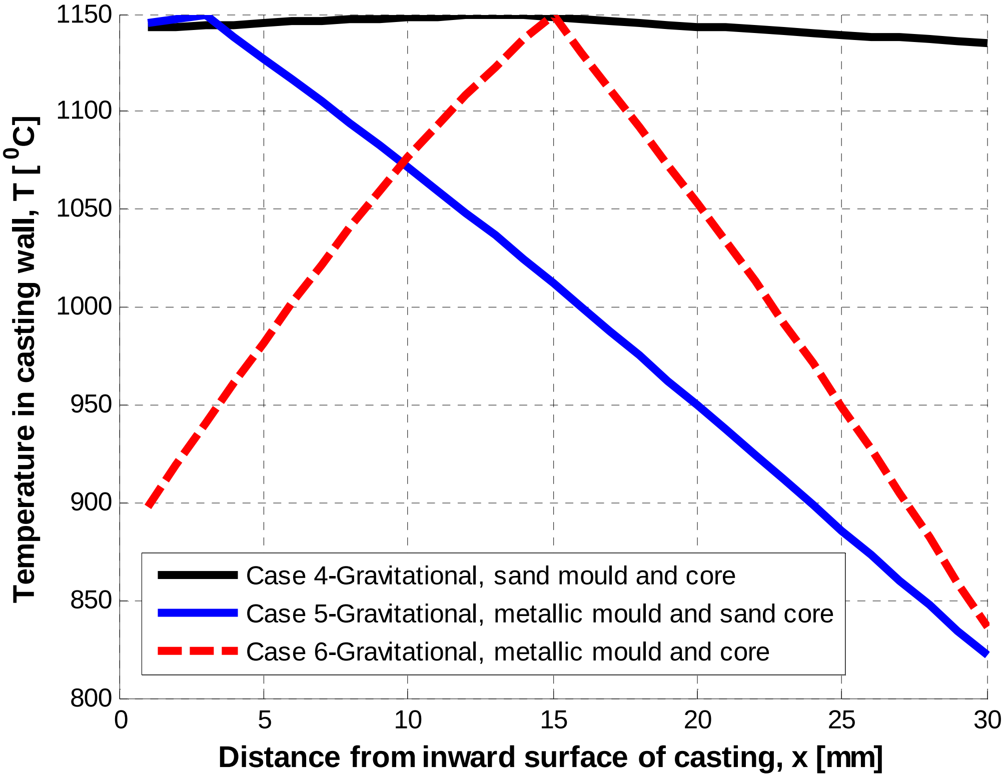


Fig. 4. Temperature inside gravitational casting wall to solidification end time
4 - Gravitational sand mould and core at time t = 647.700 s; 5 - Gravitational, metallic mould and sand core to time t = 69.500 s; 6 - Gravitational metallic mould and core at time t = 25.920 s

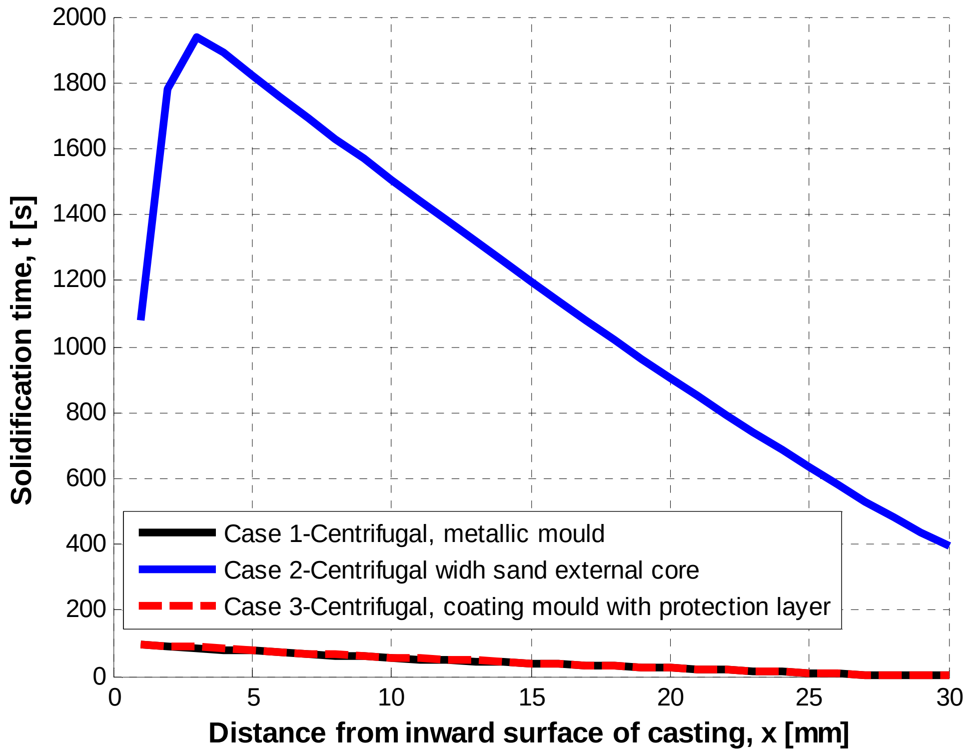


Fig. 5. Solidification time inside centrifugal casting wall
Case 1 - Centrifugal, metallic mould; Case 2 - Centrifugal, with sand external core;
Case 3 - Centrifugal, metallic mould coated with protection layer

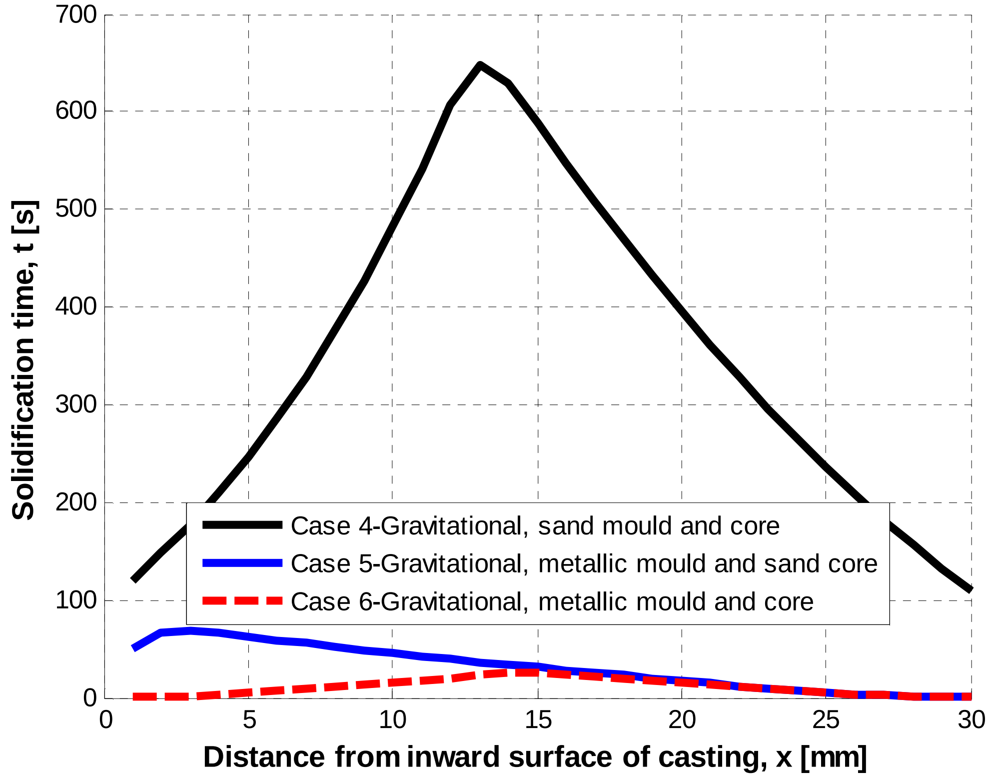


Fig. 6. Solidification time inside gravitational casting wall
4 - Gravitational sand mould and core; 5 - Gravitational, metallic mould and sand core;
6 - Gravitational, metallic mould and core

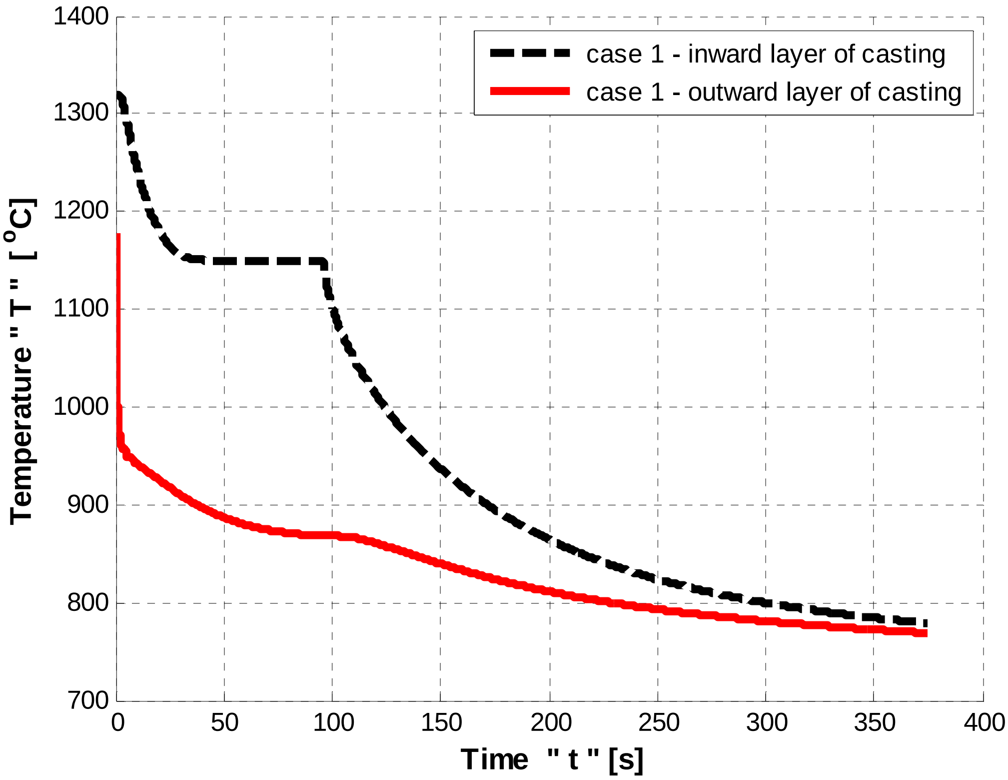


Fig. 7. The temperature evolution inside outward and inward layer of the casting
Case 1, centrifugal casting, metallic mould

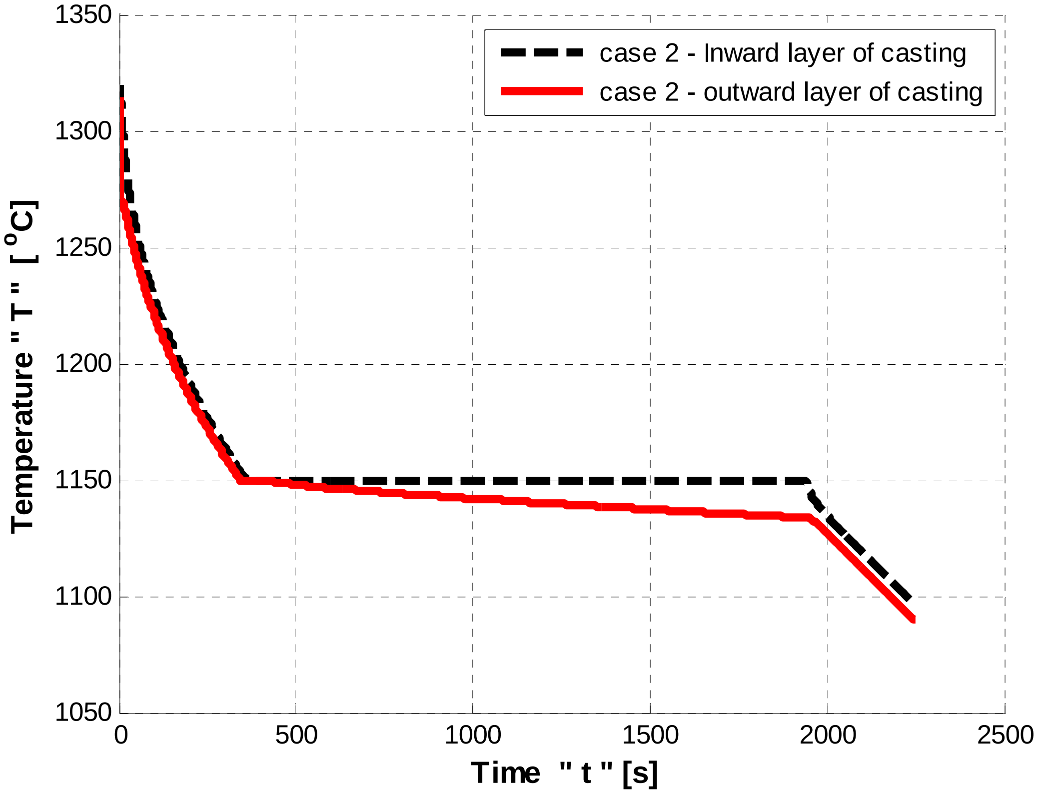


Fig. 8. The temperature evolution inside outward and inward layer of the casting
Case 2, centrifugal casting, metallic mould with external sand core

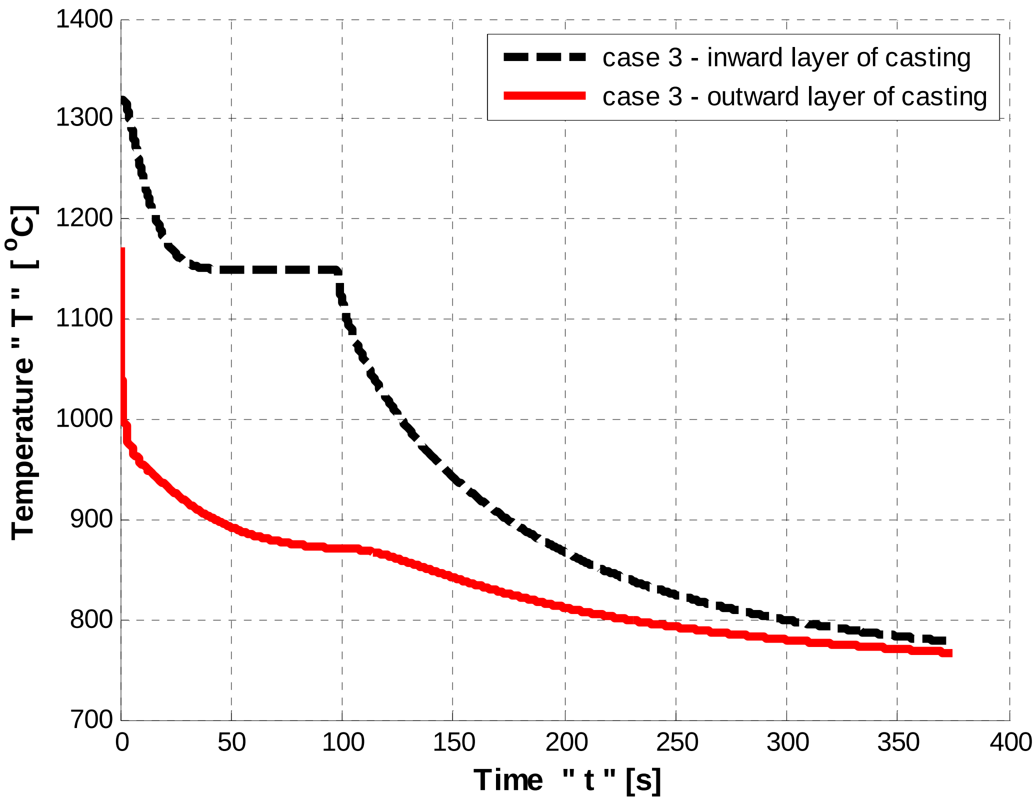


Fig. 9. The temperature evolution inside outward and inward layer of the casting
Case 3, centrifugal casting, metallic mould coated with protection layer

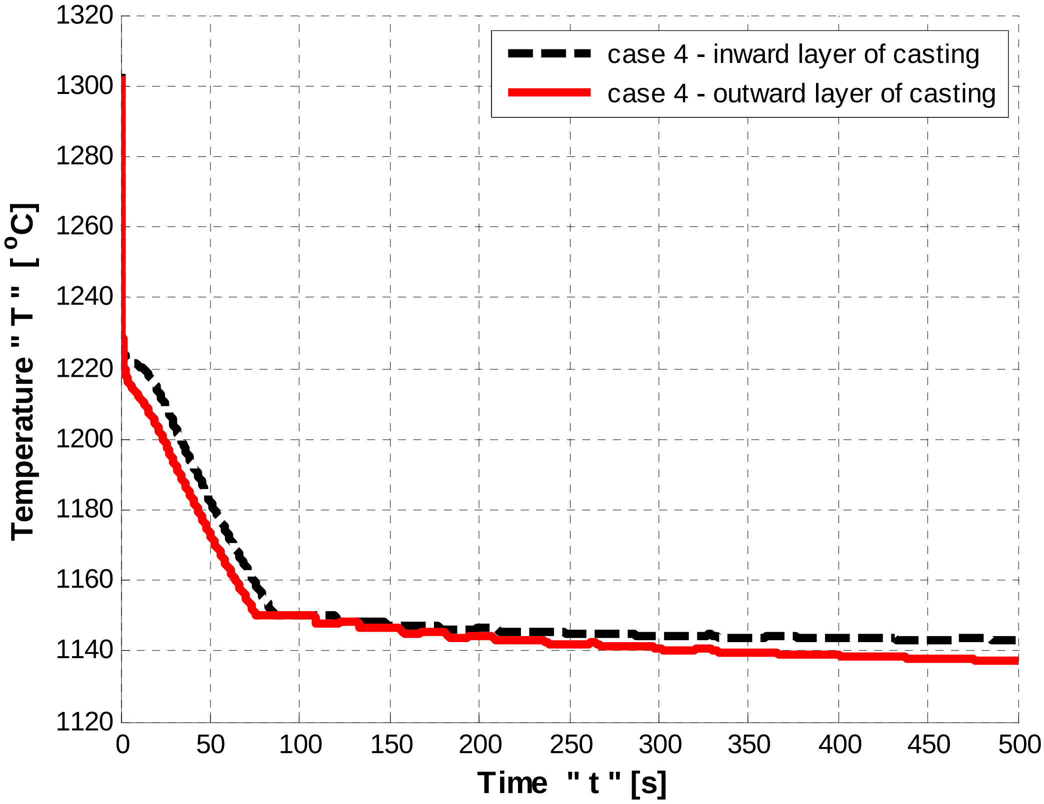


Fig. 10. The temperature evolution inside outward and inward layer of the casting
Case 4, gravitational casting, sand mould and core

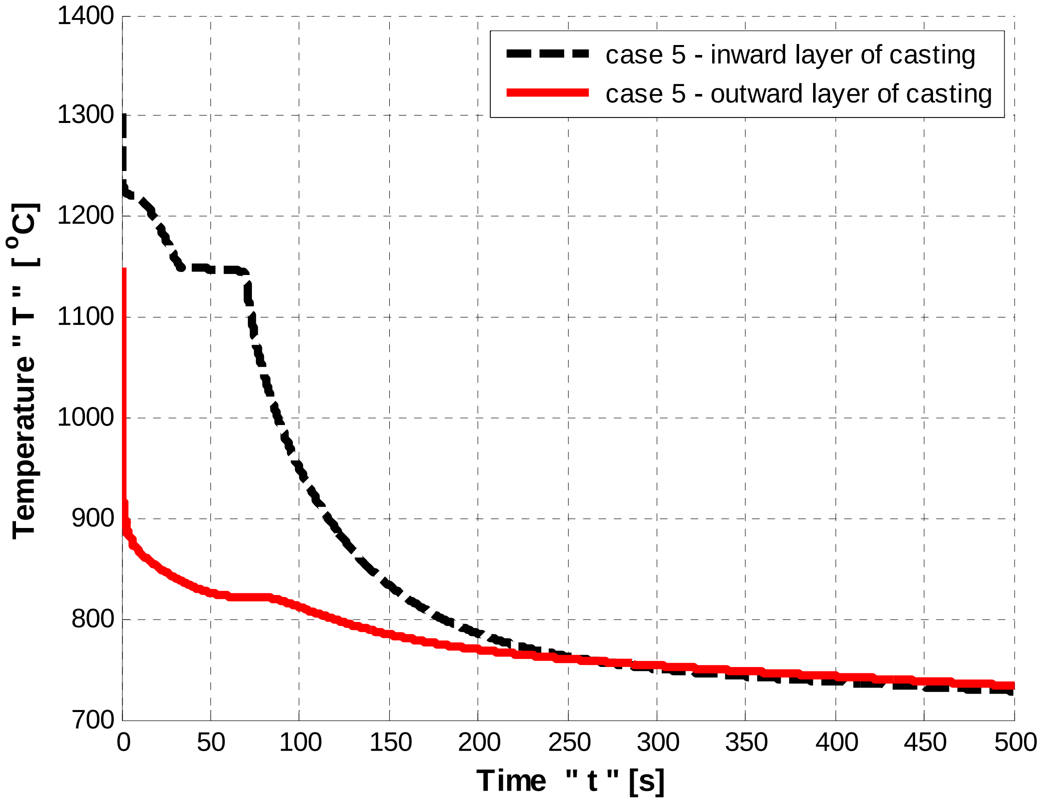


Fig. 11. The temperature evolution inside outward and inward layer of the casting
Case 5, gravitational casting, metallic mould and sand core

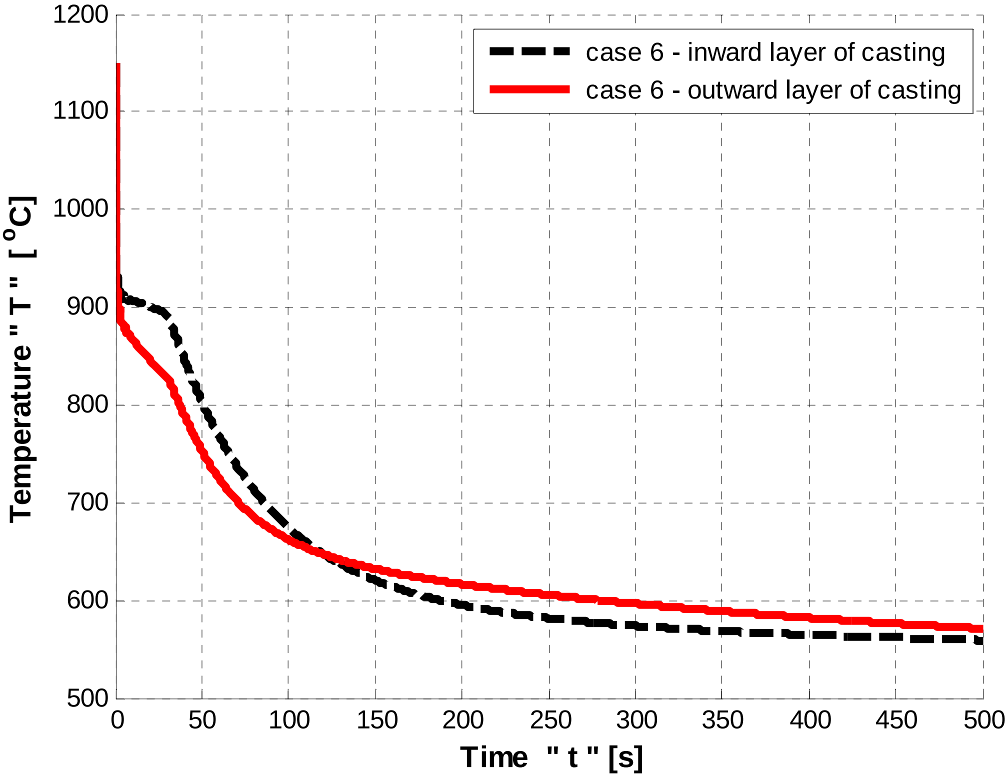


Fig. 12. The temperature evolution inside outward and inward layer of the casting
Case 6, gravitational casting, metallic mould and core

Table 4. Results on the solidification kinetics of the outer surface of the casting (point A, Figure 2)

No.	Casting mode	Cooling time to Ts of the exterior surface	Mean cooling rate in liquid state at the exterior surface in the range Tt-Ts	Instantaneous cooling speed to solidification temperature Ts of the outer surface	The end of solidification at the outer surface of casting	The actual solidification duration at the outer surface of casting
Symbol	-	t inc_solp_ex	v med raclic	v rac la mom solid	tsol_pex	tsol_pex - tinc_solpex
Unit	-	s	°C/s	°C/s	s	
1	Centrifugal, metallic mould	0.025	- 6800	-4014.13	0.135	0.110
2	Centrifugal, external sand core	343.770	- 0.494	- 0.21699	394.440	50.67
3	Centrifugal, metallic mould, painted	0.03	- 5667	-1217.0419	0.255	0.225
4	Gravitational, sand mould and core	76.350	- 2.226	- 0.80429	109.000	32.65
5	Gravitational metallic mould and sand core	0.020	- 85000	-5668.862	0.120	0.10
6	Gravitational metallic mould and core	0.02	- 8500	-5668.862	0.120	0.10

Table 5. Results on the solidification kinetics on the inner surface of the casting (B, Figure 2)

No.	Casting mode	Cooling time to Ts of the exterior surface	Mean cooling rate in liquid state at the exterior surface in the range Tt-Ts	Instantaneous cooling speed to solidification temperature Ts of the outer surface	The end of solidification at the outer surface of casting	The actual solidification duration at the outer surface of casting
Symbol	-	τ in_sol_pex	v_medraclic	v rac la mom solid	τ_sol_pex	τ_sol_pex - t_sol_p_in
Unit	-	s	^{0}C/s	^{0}C/s	s	s
1	Centrifugal, metallic mould	43.515	- 3.9067	- 0.06521	96.295	52.780
2	Centrifugal, external sand core	375.300	- 0.453	- 0.02981	1077.72	702.42
3	Centrifugal, metallic mould, painted	44.385	- 3.8301	- 0.06454	98.250	53.865
4	Gravitational, sand mould and core	86.250	- 1.971	-0.79143	120.600	34.35
5	Gravitational metallic mould and sand core	33.080	- 5.1390	- 2.9336	49.280	16.200
6	Gravitational metallic mould and core	0.02	- 8500	-5618.964	0.12	0.1

Table 6. Results on the solidification kinetics of casting hot spot

No.	Casting mode	Cooling time to Ts of the exterior surface	Mean cooling rate in liquid state at the exterior surface in the range Tt-Ts	Instantaneous cooling speed to solidification temperature Ts of the outer surface	The end of solidification at the outer surface of casting	The actual solidification duration at the outer surface of casting
Symbol	-	t in_sol_pex	v med raclic	v rac la mom solid	τ_sol_pex	τ_sol_pex - tin_sol_pex
Unit	-	s	^{0}C/s	^{0}C/s	s	s
1	Centrifugal, metallic mould	43.515	- 3.9067	- 0.06521	96.295	52.780
2	Centrifugal, external sand core	442.110	- 0.384	$< -10^{-5}$	1940.340	1498.230
3	Centrifugal, metallic mould, painted	44.385	- 3.8301	- 0.06454	98.250	53.865
4	Gravitational, sand mould and core	316.800	- 0.5367	$< -10^{-5}$	647.700	330.900
5	Gravitational metallic mould and sand core	58.400	- 2.9109	$< -10^{-5}$	69.500	11.100
6	Gravitational metallic mould and core	23.880	- 7.1189	$< -10^{-5}$	25.920	2.040

Tables 3, 4, 5 and figures 5, 7, 9 show that the mould coating with a layer of paint based on graphite (having a thickness of 1 mm) did not greatly impact the temperature field and the kinetics of cooling and solidification of centrifugally casting (in relation to unpainted metal mould). Solidification times, the cooling rates, the curves of temperature versus time and distance are almost identical. This explains. On the one hand graphite has thermo-physical parameters (thermal conductivity, specific heat) close to metal mould. On the other hand the paint layer thickness (1 mm) is very small.

From the point of view of the hot spot position, centrifugal casting with outer core (Case 2) is similar to gravity casting in metal moulds of sand core (Case 5) (see Table 3 and Figures 5 and 6). These two cases varies widely though, with values for solidification temperatures in the part wall and cooling rates.

In terms of solidification time and kinetics of solidification on the surfaces of the casting, between the cases 1, 2, 4, 5, 6 are very large differences. Centrifugal casting with outer sand core solidifies slowest. It follows in terms of solidification time the part cast in sand mould with sand core. The solidification time of the centrifugal casting with external sand core (Case 2) is (t_{sol_p} = 1940 s) three times higher than the gravity sand casting (Case 4, t_{sol_p} = 647 s). This high solidification time is explained by the fact that in centrifugal casting the melt alloy releases the heat in only one sense, towards the outside. In the Case 4 the molten alloy, releases the heat in two directions, to the outer mould and to the inner core. Therefore, in the case of centrifugal casting the solidification thickness of the casting (and the real solidification module) is almost twice as high. Following the solidification time (which is proportional to the square of the real solidification module), the increase is approx. three times. In other cases (cases 1, 3, 5, 6) the solidification time is of order of tens of seconds (between 25 s and 98 s). The shortest solidification time is in the case of gravity casting with metallic mould and core (Case 6).

Analysis of the results on the cooling rate at the time of solidification (Ts) shows great differences. For eutectic cast iron castings, momentary cooling rate (instantaneous) at the solidus temperature (T = 1150 °C) is very important. If this speed is high, iron solidifies as white iron. The cooling rate at which the transition occurs gray - white iron during solidification, much depends on the chemical composition of the iron. Usually, in the case of alloyed gray irons, that speed is of the order of 30 - 40 °C/s. Tables 4 and 5 show that in the case of the layers located on the outer surface and that the inner surface of the casting momentary cooling rate (instantaneous) at the solidus temperature depends very much on the material which is in contact with the liquid alloy:

- If the molten alloy is direct contact with the metal mould this speed values are in the range 4000 - 5700 °C/s.
- If the molten alloy is in contact with a graphite coating instantaneous cooling speed at Ts is about 1200 °C/s.
- If the molten alloy is in contact with sand mould or core, instantaneous cooling speed at Ts is of the order 0.2 - 2.8 °C/s.
- If the liquid alloy is in contact with the warm air inside casing (the case of centrifugal casting) instantaneous cooling rate at Ts is of the order 0.02 - 0.07 °C/s.

These results underline very well the trend of whitening structure of iron parts cast in metal moulds. Also it can be seen the effect of the coating the mould with layers of paint. It is possible that by studying the cooling rate of the alloy at Ts temperature in the wall part, to determine with sufficient precision the thickness of white iron layer.

The above results show that in the case of centrifugal casting, the cooling rate at Ts on the inner surface of the casting is very small. Therefore, the solidified inner layers of the part usually have gray cast iron structure.

The results in Table 6 about the solidification kinetics of the hot spots, lead to interesting observations:

- In all cases of centrifugal casting studied by simulation, the cooling rate at the temperature Ts (at the time of starting the solidification) has very small values. These lead to stable equilibrium structures (type iron - graphite) on the inner surface of the casting;
- The gravity casting with inner sand core the cooling rate at the inside is low and so gray iron is obtained.

The results are obviously valid for particular studied cases. If the diameter and wall thickness of the casting, outer core thickness, mould temperature, type and thickness of paint etc., are modified numerical results will be different. However considering the big differences on order of magnitude of solidification time and cooling rates at solidification moment, we do suppose that the general conclusions regarding the hot spots position of the solidification tendency (following iron - graphite diagram) in the case of centrifugal casting does not change.

6. Conclusions

The study provides some general conclusions on centrifugal casting of cast iron parts:

- solidification is directed along the radius in one sense, from the outside towards the axis of rotation;
- the real hot spot is placed on the inner surface of the part;
- on the inner surface the cooling rate at the solidus temperature is very low, which makes the iron to solidify conforming the stable diagram (iron - graphite);
- for the metal moulds a white iron layer is always obtained at the outer surface;
- coating paint on metal moulds does not influence considerably the solidification time and the temperature field inside casting;
- protective coating with graphite layer influences the cooling rate of the outer surface of the part, but it remains at levels that lead to white iron;
- to get over the entire part wall thickness gray cast iron (solidification iron - graphite) an outer core of sand is necessary to be used.

The study is necessary to be expanded gradually changing the values of the parameters of influence (the diameter and the wall thickness, the thickness of the outer core, the thickness and material of the layer of paint, the material and temperature of the mould, etc.). The results are of interest to industrial practice. On this basis general rules can be established for the rapid design of centrifugal casting technology of cast iron parts (for example for the rapid determination of the solidification time of the part, the time of extracting the part from the mould, the thickness of the exterior core, type and the thickness of the paint layer, the mould temperature, etc.).

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