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The determination of the composite layer thickness with the use of software NovaFlow&Solid and Preforma 1.1

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Abstract

In this article the results of thermal simulation of formation composite layer on steel model casting were presented. The aim of researches was to determine the technological parameters of formation composite layer process for which it is possible to get good quality reinforcement layer with desirable thickness. Methodology. Both the distribution of temperature in model casting and the course of temperature changes in characteristic points of composite premould were determined for assumed changes of chosen technological parameters. The numerical calculations were done with the use of software NovaFlow&Solid 2.9 r81. Finding. Obtaining both the good quality and desirable thickness of composite layer depends on the parameters of process and the level of pouring temperature during the casting process. Research implications. Researches made possible to determine technological parameters directly influencing this process and criterions which should be kept by casting technology of this kind of casting. Practical implication and value. Thanks to obtained results there is a possibility to work out guidelines and rules of projecting the construction and the selection of technological parameters of casting with surface composite layer.

Keywords: Composites, Casting, Surfacing alloy layer, Computer simulation, Technology design.

1. Introduction

Forming composite layer on the casting surface is one of the methods how to increase the abrasion resistance. The most important advantage of this method is the possibility of receipt ready product directly from the mould. Very expensive and time-consuming thermal processing is unnecessary. There is placed a special premould inside the mould on one of its surface. The premould consists of fine-grained, high carbonate ferrochromium and substances active superficially are used as the binder. The premould is over melted because of the influence of hot metal. The composite layer forms on the casting surface thanks to diffusion process. During the research relating this technology, the basic parameters of this process (optimal temperature and time of forming composite) were working out. The knowledge of these parameters will allow to work-out computer program to plan the surface composite layer with exactly determined thickness.

2. Researches

The aim of researches was to work out the constructional assumptions for model casting and to work out optimal pouring technology. The right construction of pouring system guarantees as slow as possible pouring of mould cavity and heating compositing elements at a uniform rate. The most important task was to determine, for worked out constructional and technological assumptions, optimal pouring temperature for tested materials of compositing premoulds. Optimal – it means possibility to obtain as thick as possible composite layer on casting with avoiding local dissolve of premoulds or its local erosion by flowing metal.

3. Researches range

The following stages of researches were done:

1. Working out the constructional assumptions for model casting (The shape of model casting was designed not to be time-consuming and inconvenient).
2. Working out the construction of pouring system and testing it in simulation of pouring process.
3. Simulation of composite layer formation process for:
   - pouring temperature 1510 °C, 1550 °C, 1600 °C,
   - Casting material – cast steel GS240, PN-EN 10213-2,
   - Materials of premoulds ferrochromium FeCr800.
4. Determination of temperature distribution in premould at all levels of variation.
5. The analysis of results and indication the optimum pouring temperature for tested materials of premould.
6. Calculation the probability of formation composite layer with exactly determined thickness for assumed technological parameters and premould materials.

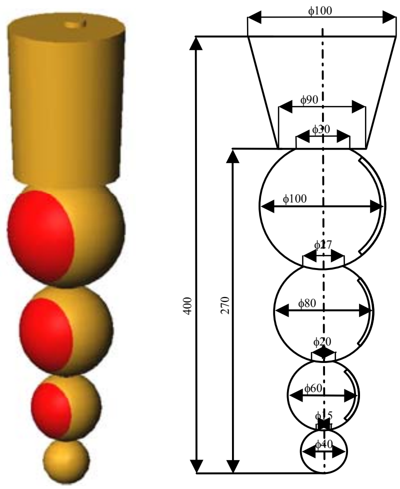


Fig. 1. Scheme of model system – red color means the place of fixing the premould

The worked out constructional assumptions of model casting were the suitable pouring system enriched. It guarantees directional solidification and heating premoulds at a uniform rate. The assumptions were checked by computer simulation.

Next, the simulation cycle of pouring and self-cooling process was done according to accepted plan of the experiment. It allowed to determine optimal pouring temperature for given material of premould. The probabilities of formation the composite layer with exactly determined thickness were calculated. It makes possible to predict the thickness of composite layer based on data obtained during computer simulation of thermal effects in composite forming.

The three-dimensional geometry of experimental casting has been modeled with SolidWorks software based on constructional assumptions. Next the geometry has been imported to simulation software NovaFlow & Solid v2.9 r81, fixed the location of virtual thermoelements (Fig. 2) and loaded suitable data needed for carrying out simulation (Table 1).

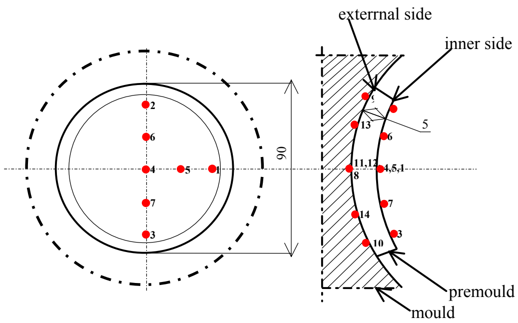


Fig. 2. The location of virtual thermocouple on the premould for ball casting with diameter 100mm

The thermocouples were located in the balls at 80mm (thermocouples from 22 to 28) and 60mm (thermocouples from 36 to 42) diameter in the same way.

The temperatures of materials used in simulation are the following:

- premoulds temperature: 20 [°C]
- mould temperature: 20 [°C]
- surroundings temperature: 20 [°C]
- metal temperature: a) 1510, b) 1550, c) 1600 [°C]

Temperatures solidus and liquidus for premould materials were read out from graphs calculated with Thermo-Calc software:
T_S – solidus temperature for FeCr – 1300^{0}C,
T_L – liquidus temperature for FeCr – 1545^{0}C.

Table 1.
Thermophysical data used in simulation

T [°C]	λ [W/m/°C]	Cp [J/kg/°C]	ρ [kg/m^3]
Ferrochromium FeCr			
0	45	450	-
20	-	-	7500
200	-	475	7447
500	30,6	550	7343
700	26,2	600	7270
1100	24	650	-
1200	-	-	7080
1500	-	750	-
Cast steel AISI-1086			

$T_{liq} = 1505^0C$,	$T_{sol} = 1451^0C$,	$Q_{cr} = 250$ [kJ/kg],	$Q_{eut} = 250$ [kJ/kg]
0	51,8	469	-
500	39,3	661	-
1000	27,2	644	-
1100	28,5	644	7431,1
1200	29,7	661	-
1300	29,7	686	-
1400	-	-	7262,6
1525	-	-	6995
1550	-	740	6978,88
1600	30	740	6946,23
Moulding sand			
20	0,9	550	1550
500	0,6	600	1500
1000	0,5	800	1490
1500	0,5	900	1450

The following abbreviations were used in Table 1:

- T – temperature,
- λ – thermal conductivity,
- Cp – specific heat,
- ρ – density,
- T_{liq} – liquidus temperature,
- T_{sol} – solidus temperature,
- Q_{cr} – heat of crystallization,
- Q_{eu} – eutectic heat.

4. Results of simulation

The result of simulation was set of cooling curves one for each virtual point of temperature measurement. There is shown the diagrams (Fig. 3,4,5) for the premould made of ferrochromium, pouring temperature 1510^0C and the ball diameter 100, 80, 60mm as an example.

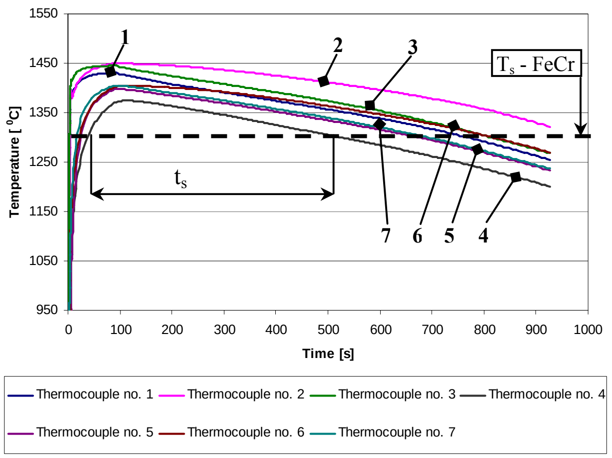


Fig. 3. Cooling curves for the ball ϕ100mm in the points of measurement situated in the inner side of premould; $T_{zal}=1510^0C$; t_s – the time of firing the premould over the temperature solidus

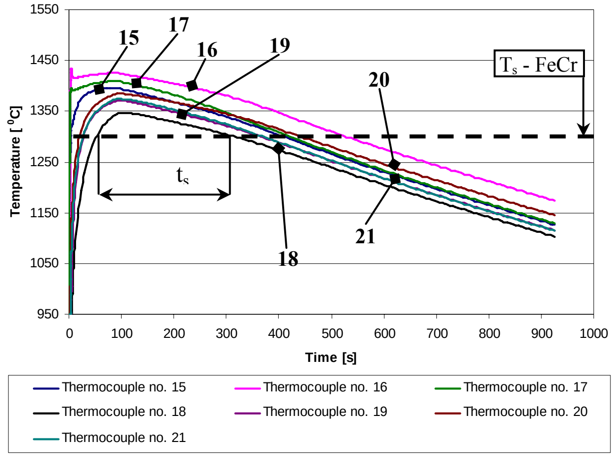


Fig. 4. Cooling curves for the ball ϕ80mm in the points of measurement situated in the inner side of premould; $T_{zal}=1510^0C$; t_s – the time of firing the premould over the temperature solidus

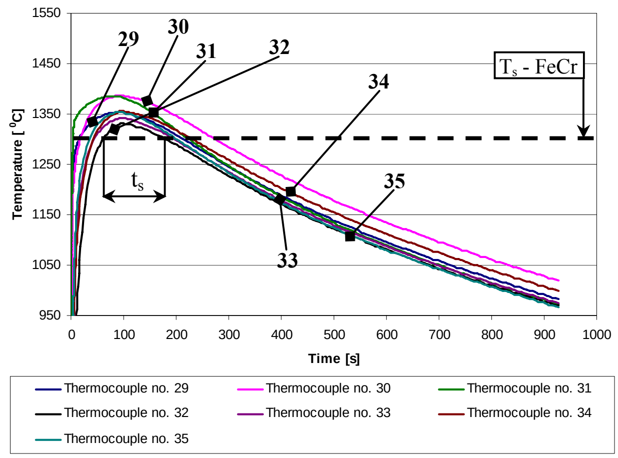


Fig. 5. Cooling curves for the ball ϕ60mm in the points of measurement situated in the inner side of premould; $T_{zal}=1510^0C$; t_s – the time of firing the premould over the temperature solidus

The maximal temperatures of heating premould and times of lasting over the solidus temperature were determined on the base of results for all carried out simulations (Table 2). The temperature distribution in premould for one moment of time when it was the most advantageous is presented on Fig. 6 for pouring temperature 1510^0C, on Fig. 7 for pouring temperature 1550^0C and on Fig. 8 for pouring temperature 1600^0C.

Table 2.
The results of simulation for pouring temperatures 1510^{0}C, 1550^{0}C, 1600^{0}C

Diameter of the ball [mm]	The number of thermocouple	Maximal temperature [^{0}C]	Heating time of premould t_S [s]
Pouring temperature 1510^{0}C			
100	1	1421,31	709,68
	2	1449,68	917,57
	3	1435,48	785,16
	4	1366,84	460,23
	5	1388,34	641,75
	6	1403,60	836,75
	7	1392,02	678,12
80	15	1382,08	354,21
	16	1420,69	516,37
	17	1401,10	390,35
	18	1337,05	237,70
	19	1359,75	318,13
	20	1376,00	425,10
	21	1365,97	336,75
60	29	1336,74	146,78
	30	1385,41	250,75
	31	1378,54	195,26
	32	1321,29	98,44
	33	1321,91	112,73
	34	1353,70	196,03
	35	1347,58	159,29
Pouring temperature 1550^{0}C			
100	1	1430,39	829,21
	2	1436,96	850,52
	3	1472,22	1029,38
	4	1450,95	936,46
	5	1404,93	628,12
	6	1417,21	795,75
	7	1433,58	983,00
80	15	1414,74	564,02
	16	1448,55	722,72
	17	1435,65	587,39
	18	1388,61	488,13
	19	1399,09	540,75
	20	1415,29	653,00
	21	1408,00	551,58
60	29	1372,48	276,91
	30	1418,76	374,21
	31	1407,67	294,94
	32	1364,25	236,69
	33	1360,53	253,13
	34	1392,28	326,75
	35	1380,84	273,12
Pouring temperature 1600^{0}C			
100	1	1451,22	997,57
	2	1486,18	1156,21
	3	1468,65	1088,75
	4	1422,06	726,70
	5	1430,12	908,52
	6	1451,49	1112,58
	7	1437,67	974,34
80	15	1435,74	664,51
	16	1460,47	850,65
	17	1449,62	700,50
	18	1411,10	616,17
	19	1415,78	656,29
	20	1431,95	765,00
	21	1419,82	657,48
60	29	1395,88	353,29
	30	1438,81	459,37
	31	1427,11	347,10
	32	1380,46	319,14
	33	1380,53	329,75
	34	1408,77	400,15
	35	1398,35	334,54

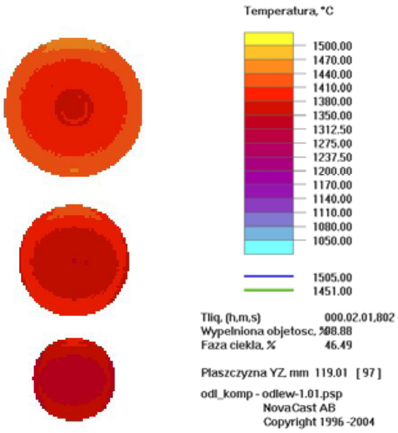


Fig. 6. Maximal temperatures of premould on the inner side for pouring temperature 1510^{0}C

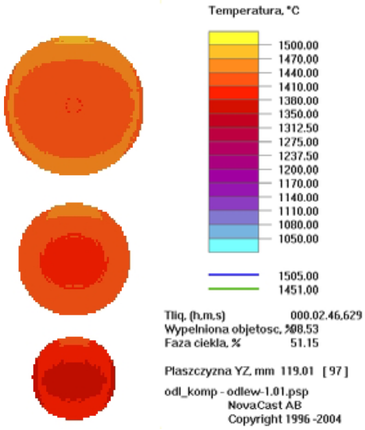


Fig. 7. Maximal temperatures of premould on the inner side for pouring temperature 1550^{0}C

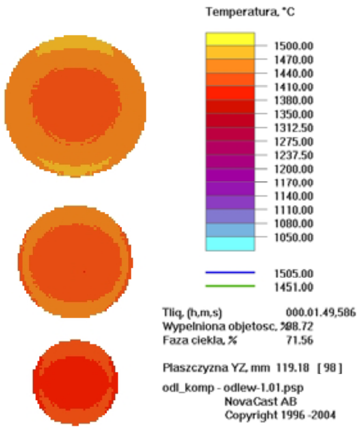


Fig. 8. Maximal temperatures of premould on the inner side for pouring temperature 1600^{0}C

5. Planning the thickness of composite layer with the use of computer simulation

In mathematical model, there is an assumption that composite layer forms as the sum of n partial layers. At such determined problem the probability $P_n(t)$ means the probability that n - partial layer will form in time ***t*** and is calculated in the following way:

$$P_n(t) = \frac{\alpha^n t^n}{n!} e^{-\lambda t} \qquad (1)$$

where:

- α - intensity coefficient,
- ***n*** – number of partial layer,
- ***t*** – time of composite forming.

In this way the discrete variable (n, $P_n(t)$) is determined.

To determine the thickness of composite layer the computer program Preforma 1.1 was used. The input data were pouring temperatures and times t_s of lasting over the solidus temperature T_s obtained thanks to carried out simulations in program NovaFlow&Solid. The algorithm of program Prefomra 1.1 is based on the equation (1). The final result of this program is finding the dependence between the time of firing premould and the thickness of composite layer. It is done as the linear regression between these variables (for example Fig.9)

$$g_k = at_s + b \qquad (2)$$

where:

- g_k – the thickness of composite layer,
- t_s – the time of firing the premould over the temperature solidus.

The probabilities of forming and the thickness of composite layer for pouring temperature 1510^0C, 1550^0C, 1600^0C and the thickness of premould 5mm were calculated thanks to date carried out from simulation (Table 3).

Table 3.
The calculated thickness of composite layer for temperatures 1510, 1550, 1600^0C

The composite thickness calculated by program Preforma 1.1		
Pouring temperature 1510^0C		
The number of thermocouple	Heating time of premould [t_s]	The thickness of composite [mm]
8	709,68	5,61
9	917,57	6,87
10	785,16	6,71
11	460,23	5,39
12	641,75	5,82
13	836,75	6,17
14	678,12	6,27
22	354,21	4,74
23	516,37	5,06
24	390,35	5,13
25	237,70	4,19
26	318,13	4,15
27	425,10	4,64
28	336,75	4,35
36	146,78	4,14
37	250,75	4,44
38	195,26	3,95
39	98,44	3,99
40	112,73	4,11
41	196,03	3,96
42	159,29	4,03
Pouring temperature 1550^0C		
8	850,52	8,26
9	1029,38	8,11
10	936,46	7,63
11	628,12	6,26
12	795,75	7,69
13	983	8,68
14	833	7,51
22	564,02	6,56
23	722,72	6,67
24	587,39	6,79
25	488,13	6,08
26	540,75	5,71
27	653	6,96
28	551,58	6,44
36	276,91	5,08
37	374,21	5,32
38	294,94	4,50
39	236,69	4,77
40	253,13	4,72
41	326,75	4,90
42	273,12	5,02
Pouring temperature 1600^0C		
8	997,57	8,36
9	1156,21	8,87
10	1088,75	9,28
11	726,7	6,70
12	908,52	7,95
13	1112,58	8,96
14	974,34	8,68
22	664,51	7,06
23	850,65	7,98
24	700,5	6,49
25	616,17	6,74
26	656,29	6,99
27	765	7,64
28	657,48	7,00
36	353,29	5,36
37	459,37	5,37
38	347,1	5,07
39	319,14	5,53
40	329,75	5,32
41	400,15	5,07
42	334,54	4,91

The results are presented in the Fig 9, 13, 17. Data were subordinated to proper points of temperature measurement and the graphs of composite thickness were done for examined balls. The graphs are presented on figures (Fig. 10-12, 14-16, 18-20). The point zero on the z axis means the transition zone of composite joint with cast steel. The light color (a) means composite formed as a result of premould joint penetration. The dark color (b) means the additional thickness of composite formed as a result of chromium ion diffusion into cast steel and ferro ion diffusion into premould.

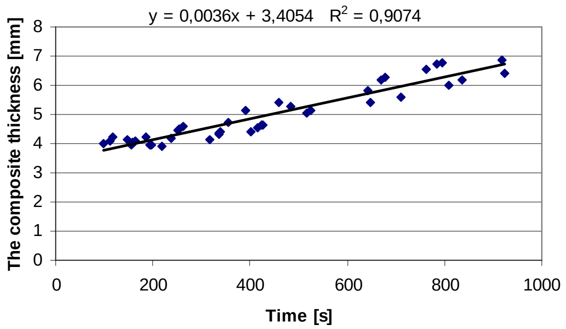
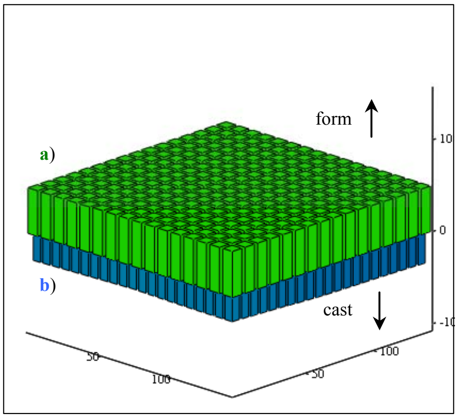
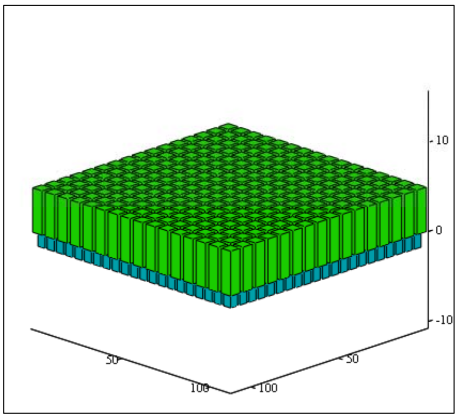


Fig. 9. The thickness of composite layer depending on heating time of premould in the temperature over T_{Sol} for pouring temperature 1510^0C



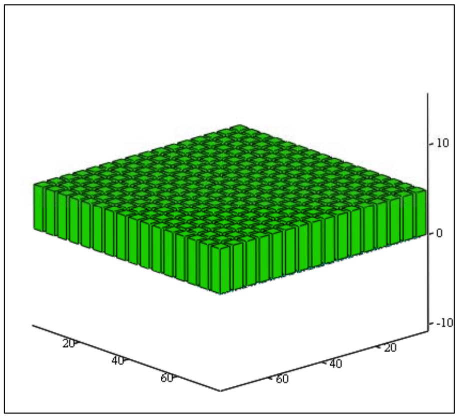
(x,y,dz),(x,y,dw)

Fig. 10. The thickness of composite for the ball 100mm



(x,y,dz),(x,y,dw)

Fig. 11. The thickness of composite for the ball 80mm



(x,y,dz),(x,y,dw)

Fig. 12. The thickness of composite for the ball 60mm

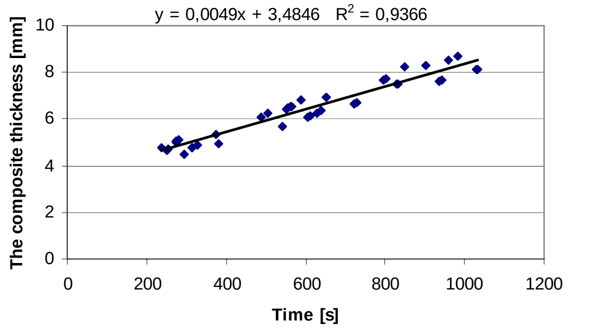
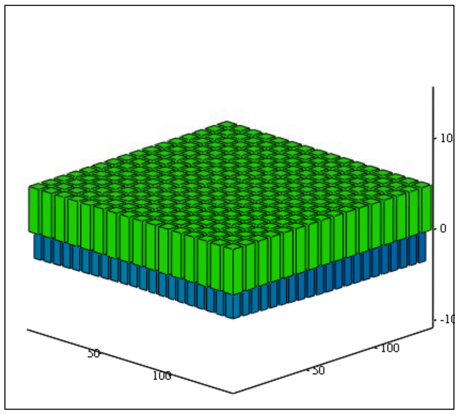
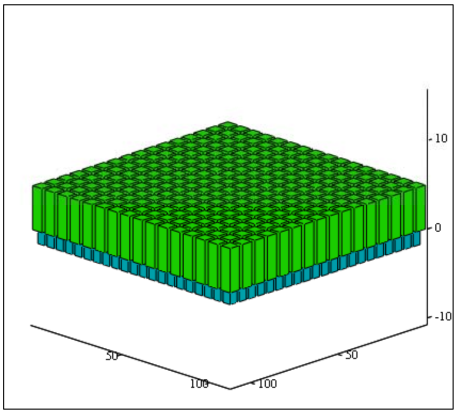


Fig. 13. The thickness of composite layer depending on heating time of premould in the temperature over T_{Sol} for pouring temperature 1550^0C



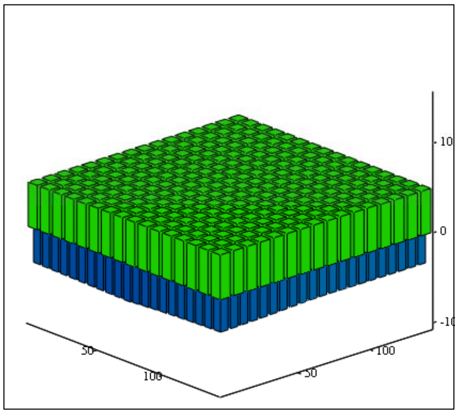
(x,y,dz),(x,y,dw)

Fig. 14. The thickness of composite for the ball 100mm



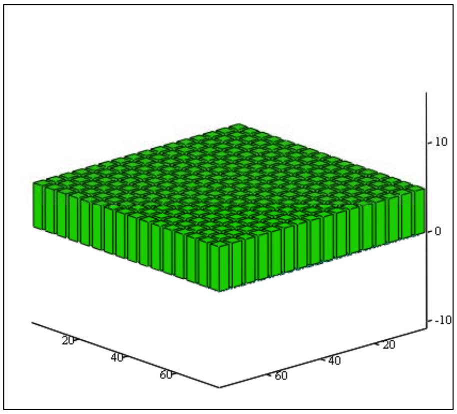
(x,y,dz),(x,y,dw)

Fig. 15. The thickness of composite for the ball 80mm



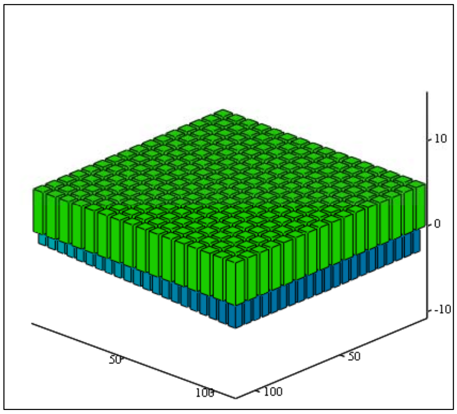
(x,y,dz),(x,y,dw)

Fig. 18. The thickness of composite for the ball 100mm



(x,y,dz),(x,y,dw)

Fig. 16. The thickness of composite for the ball 60mm



(x,y,dz),(x,y,dw)

Fig. 19. The thickness of composite for the ball 80mm

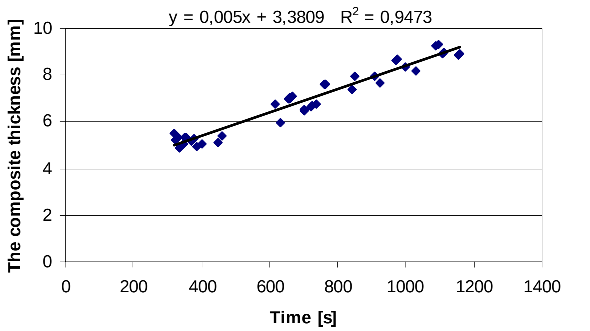
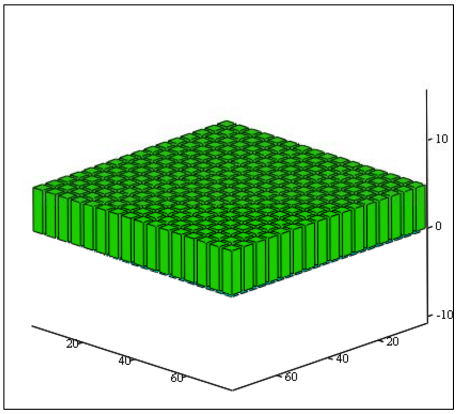


Fig. 17. The thickness of composite layer depending on heating time of premould in the temperature over T_{Sol} for pouring temperature 1600^0C



(x,y,dz),(x,y,dw)

Fig. 20. The thickness of composite for the ball 60mm

The constructional assumptions turned out to be good. It was confirmed experimentally. As a result of measurement on the real castings, the average thickness of composite layers for the premould 5mm and pouring temperature 1550^0C were found. The average thickness of composite layers for real casting and the average thickness of composite layers for simulation data are presented in Table 4.

Table 4.
The average thickness of composite layer for ball casting

Diameter of the ball [mm]	Pouring temperature 1550^0		
	The average thickness of composite layer for real casting [mm]	The average thickness of composite layer for simulation data [mm]	The relative error [%]
100	8,1	7,8	3,7
80	6,0	6,4	6,6
60	4,6	4,8	4,3

The results obtained from the simulation calculation based on the stochastic method are corresponding to the results obtained from the real experiment.

6. Conclusions

1. For undertook casting construction the most advantageous pouring temperature is 1550^0C. At this temperature the joint penetration of premould was completely done and the composite layer formed on the whole reinforced surface.
2. The most advantageous temperature distribution was in premould for the biggest ball. It was the result of thermal capacity of casting.
3. The method of pouring and leading the liquid metal into the mould (directional solidification) caused the shift of thermal center. It influenced the minimal increase of the composite thickness in lower and upper part of the ball.
4. The carried out analysis of results and calculations of probability formation composite layer at particular thickness confirm the most advantageous conditions of composite layer formation for the biggest ball.
5. The obtained results and its analysis make possible to determine basic guidelines for designing technology and construction of casting with composite layer.

Acknowledgements

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