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The determination of the thickness of the composite layer

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ABSTRACT

Purpose: In this article, the results of thermal simulation of composite layer formation on the steel model casting are shown. The main aim of researches was to work out the technological parameters of composite layer formation process, for which it is possible to get good quality reinforcement layer with desirable thickness.

Design/methodology/approach: 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 the chosen technological parameters. The numerical calculations were conducted with the use of software NovaFlow&Solid 2.9 r81.

Findings: Both the good quality and the desirable thickness of the composite layer depend on the parameters of process and the pouring temperature during the casting process.

Research limitations/implications: Researches made possible to determine technological parameters, which have an direct effect on this process, and the criterions, which should be taken by casting technology of this kind of casting.

Practical implications: Thanks to obtained results, it is possible to work out the guidelines and rules for projecting the construction and the selection of technological parameters of casting with the surface composite layer.

Originality/value: The obtained results and the analysis of them allow to determine the basic guidelines for designing technology and construction of casting with the composite layer.

Keywords: Composites; Casting; Surfacing alloy layer; Computer simulation; Technology design

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MANUFACTURING AND PROCESSING OF ENGINEERING MATERIALS

1. Introduction

The surface composite layers are formed to increase the resistance to the abrasion wear. The production of cast with composite surface layer is not complicated for technological reasons [2, 7, 8, 14]. This method, based on the traditional technologies of forming in sand mass, consists in domiciling the premould in a chosen part of mould or core, where bigger resistance to the wear is desired. Next, it is poured by liquid metal. The premould is melted and the surface composite layer forms thanks to diffusion process. This kind of cast has got main advantages: great plasticity of the core and bigger hardness and resistance to the wear of surface layer. So, the element, which is characterized by two different material features, is obtained. Thanks to it, time and costs are saved in comparison with casts with similar features obtained by other methods. During the research, the basic parameters of this process, such as an optimal temperature and the time of forming the composite, were wanted.

The knowledge of them will make the determination of the thickness of composite layer possible. The special computer program will be worked out to design the surface composite layer with exactly determined thickness [10-12].

2. Researches

The aims of research were the following:

- Working out the constructional assumptions for model cast;
- Working out the optimal technology of pouring (proper construction of pouring system allows to fill the mould cavity as slowly as possible and heat the premoulds evenly);
- Determining the optimal pouring temperature for tested materials of premoulds (optimal – it means - to obtain the composite layer on the cast as thick as possible and to avoid local dissolve of premould or its local erosion by flowing metal).

3. Researches range

The aim was obtained by the following stages:

1. Working out the constructional assumptions for model casting in order to do the model easily and rather quickly.
2. Working out the construction of pouring system and testing it in the process of pouring simulation.
3. Simulation of composite layer forming for:
   - pouring temperature 1510 °C, 15510 °C, 1600 °C,
   - Casting material – cast steel GS240, PN-EN 10213-2,
   - Materials of premoulds ferrochromium FeCr800.
4. Determination of temperature distribution in premoulds at all levels of variation.
5. The analysis of obtained results and indication the optimal pouring temperature for tested materials of premould.
6. Calculation the probability of composite layer formation with exactly determined thickness for assumed technological parameters and premould materials.

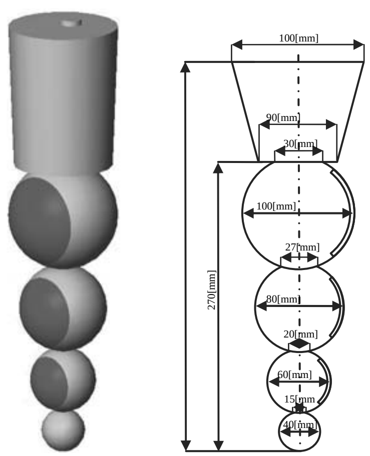

Fig. 1. Scheme of model system – red color means the place of fixing the premould

The constructional assumptions of model casting were enriched by the proper pouring system. It guarantees directional solidification and even heating of premoulds (Fig. 1). The assumptions were checked by the computer simulation.

In order to determine optimal pouring temperature for given material of premould, the simulation cycle of pouring and self-cooling process was done according to the taken plan of the experiment [3,1,4,9,13]. The probabilities of the composite layer formation at particular thickness, were calculated. It allows to predict the thickness of composite layer basing on data obtained during computer simulation of thermal effects in composite forming process.

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

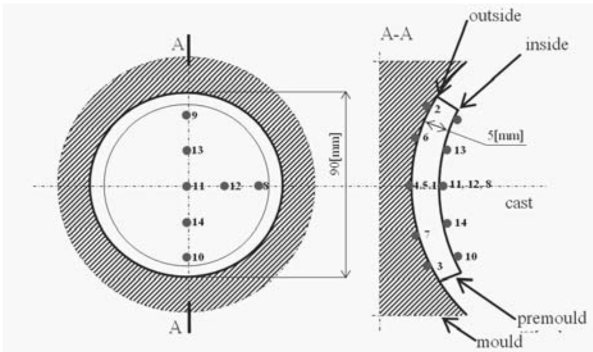

Fig. 2 The location of virtual thermocouple on the premould for ball casting with diameter 100 [mm]

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

The temperatures of materials used in simulation were the following:

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

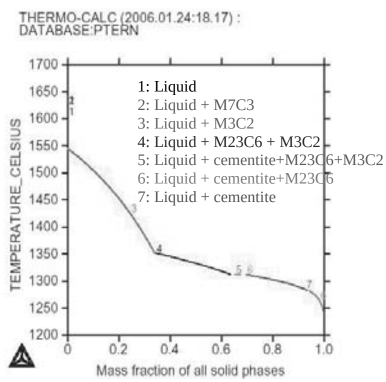

Fig. 3. Course of crystallization of Fe-Cr

Data concerning the solidus and liquidus temperatures for premould materials were read out from graphs done with Thermo-Calc software (Fig. 3).
T_S – solidus temperature for FeCr – 1300^0C
T_L – liquidus temperature for FeCr – 1545^0C

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, T_{sol} = 1451, 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 set of cooling curves for particular virtual points of temperature measurement was a result of simulation [5,6]. The maximal temperatures of heating premould and times of lasting over the solidus temperature were determined thanks to the results from all simulations, which were carried out (Table 2). The temperature distribution in premould for the specified moment of time, when it was the most advantageous, was presented on Figures 4-15.

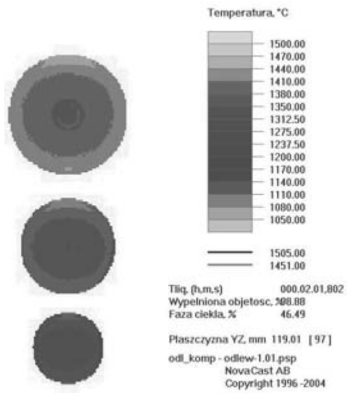

Fig. 4. Maximal temperatures of premould on the inner side for pouring temperature 1510^0C

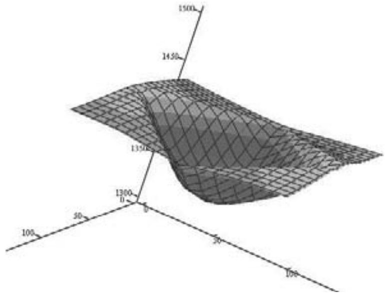

Fig. 5. Premould maximal heating image for the big ball from the inner side for the temperature 1510^0C

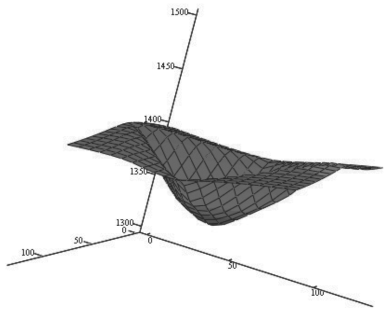

Fig. 6. Premould maximal heating image for the medium ball from the inner side for the temperature 1510^0C

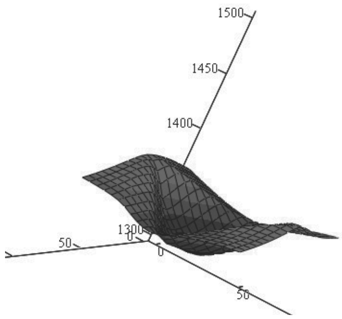

Fig. 7. Premould maximal heating image for the small ball from the inner side for the temperature 1510^0C

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

Diameter of the ball [mm]	The number of thermocouple	Maximal temperature [^{0}C]	Heating time of premould t_S [s]
Pouring temperature 1510^0C			
100	8	1421.31	709.68
	9	1449.68	917.57
	10	1435.48	785.16
	11	1366.84	460.23
	12	1388.34	641.75
	13	1403.60	836.75
	14	1392.02	678.12
80	22	1382.08	354.21
	23	1420.69	516.37
	24	1401.10	390.35
	25	1337.05	237.70
	26	1359.75	318.13
	27	1376.00	425.10
	28	1365.97	336.75
60	36	1336.74	146.78
	37	1385.41	250.75
	38	1378.54	195.26
	39	1321.29	98.44
	40	1321.91	112.73
	41	1353.70	196.03
	42	1347.58	159.29
Pouring temperature 1550^0C			
100	8	1430.39	829.21
	9	1436.96	850.52
	10	1472.22	1029.38
	11	1450.95	936.46
	12	1404.93	628.12
	13	1417.21	795.75
	14	1433.58	983.00
80	22	1414.74	564.02
	23	1448.55	722.72
	24	1435.65	587.39
	25	1388.61	488.13
	26	1399.09	540.75
	27	1415.29	653.00
	28	1408.00	551.58
60	36	1372.48	276.91
	37	1418.76	374.21
	38	1407.67	294.94
	39	1364.25	236.69
	40	1360.53	253.13
	41	1392.28	326.75
	42	1380.84	273.12
Pouring temperature 1600^0C			
100	8	1451.22	997.57
	9	1486.18	1156.21
	10	1468.65	1088.75
	11	1422.06	726.70
	12	1430.12	908.52
	13	1451.49	1112.58
	14	1437.67	974.34
80	22	1435.74	664.51
	23	1460.47	850.65
	24	1449.62	700.50
	25	1411.10	616.17
	26	1415.78	656.29
	27	1431.95	765.00
	28	1419.82	657.48
60	36	1395.88	353.29
	37	1438.81	459.37
	38	1427.11	347.10
	39	1380.46	319.14
	40	1380.53	329.75
	41	1408.77	400.15
	42	1398.35	334.54

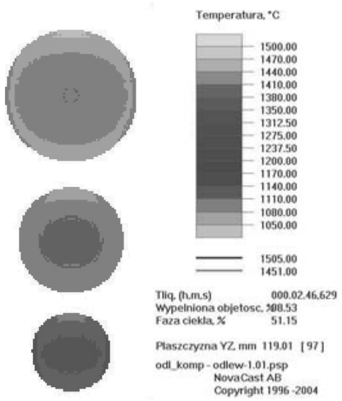

Fig. 8. Maximal temperatures of premould on the inner side for pouring temperature 1550^{0}C

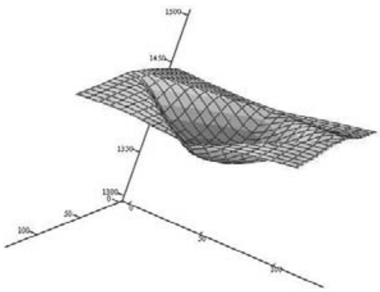

Fig. 9. Premould maximal heating image for the big ball from the inner side for the temperature 1550^{0}C

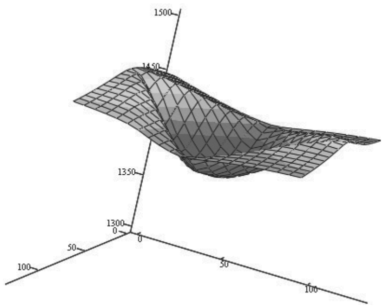

Fig. 10. Premould maximal heating image for the medium ball from the inner side for the temperature 1550^{0}C

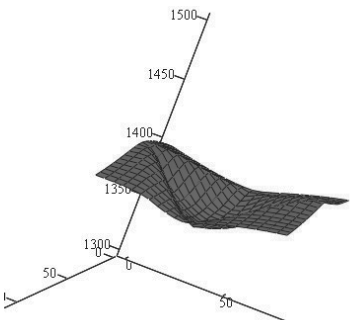

Fig. 11. Premould maximal heating image for the small ball from the inner side for the temperature 1550^{0}C

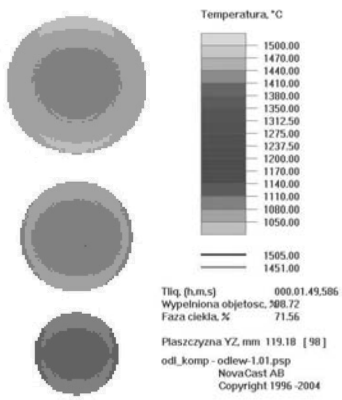

Fig. 12. Maximal temperatures of premould on the inner side for pouring temperature 1600^{0}C

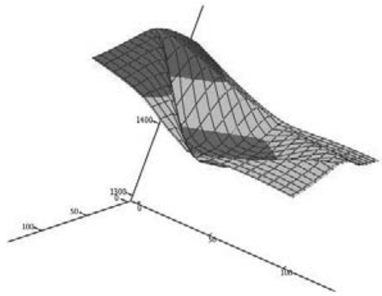

Fig. 13. Premould maximal heating image for the big ball from the inner side for the temperature 1600^{0}C

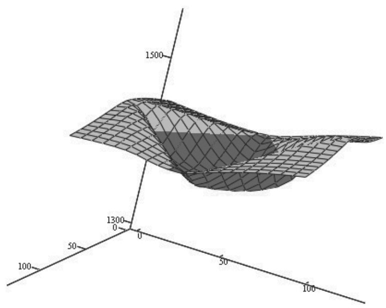

Fig. 14. Premould maximal heating image for the medium ball from the inner side for the temperature 1600^{0}C

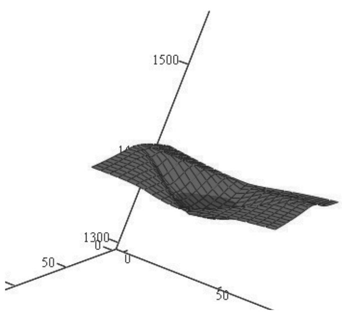

Fig. 15. Premould maximal heating image for the small ball from the inner side for the temperature 1600^{0}C

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

In mathematical model, the assumption, that composite layer forms as the sum of n partial layers, was taken. So, the probability $P_n(t)$ of the n - partial layer forming in time $\boldsymbol{t}$ is calculated in the following way:

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

where:
$\boldsymbol{\alpha}$ - intensity coefficient,
$\boldsymbol{n}$ – number of partial layer,
$\boldsymbol{t}$ – time of composite forming.

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

The probabilities of forming and, as a result, the thickness of composite layers for pouring temperature 1510^{0}C, 1550^{0}C, 1600^{0}C and the thickness of premould 5 [mm], were calculated thanks to data carried out from simulation (Table 3).

The Figs. 16, 20, 24 show the results. Data were conform to the proper points of the temperature measurement and the graphs of composite thickness were done for the examined balls. These graphs are presented on Figs. 17-19, 21-23, 25-27. The point zero on the z axis means the area of transition between the composite and the cast steel. The green color (a) means the composite formed as a result of premould joint penetration. The blue color (b) means the additional thickness of composite formed as a result of chromium ion diffusion into the cast steel and ferro ion diffusion into the premould.

The constructional assumptions appeared to be correct. It was proved experimentally. As a result of measurement on the real castings, the average thickness of composite layers for the premould 5[mm] and pouring temperature 1550^{0}C 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.

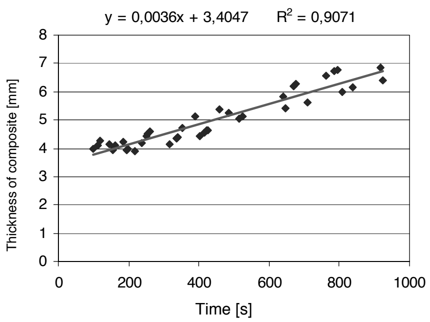

Fig. 16. The thickness of composite layer depending on heating time of premould in the temperature over T_{Sol} for pouring temperature 1510^{0}C

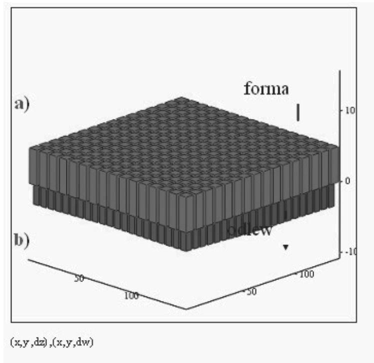

Fig. 17. The thickness of composite for the ball 100[mm]

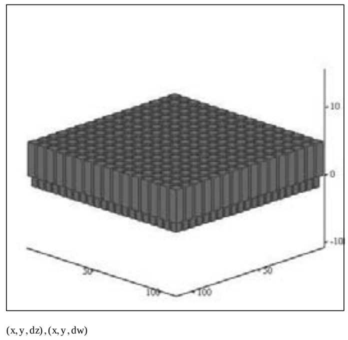

Fig. 18. The thickness of composite for the ball 80[mm]

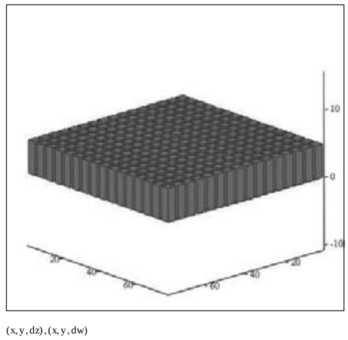

Fig. 19. The thickness of composite for the ball 60[mm]

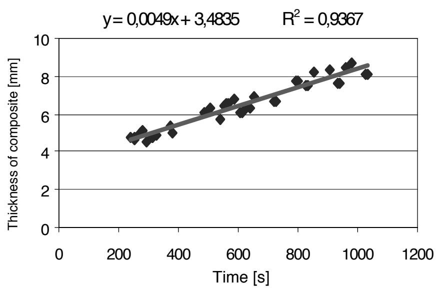

Fig. 20. The thickness of composite layer depending on heating time of premould in the temperature over T_{Sol} for pouring temperature 1550^{0}C

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 [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

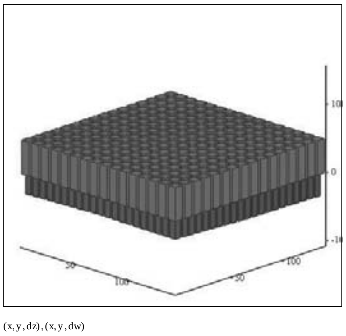

Fig. 21. The thickness of composite for the ball 100 [mm]

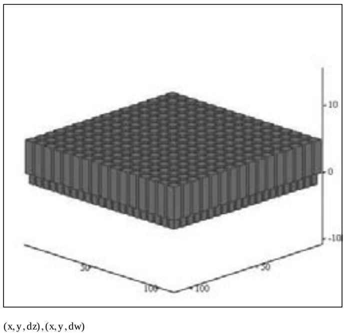

Fig. 22. The thickness of composite for the ball 80 [mm]

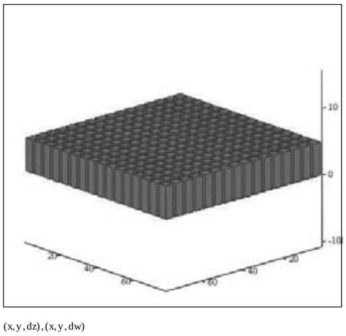

Fig. 23. The thickness of composite for the ball 60 [mm]

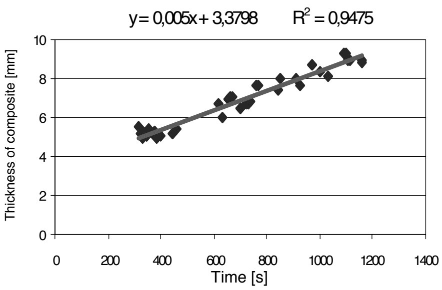

Fig. 24. The thickness of composite layer depending on heating time of premould in the temperature over T_{Sol} for pouring temperature 1600^0C

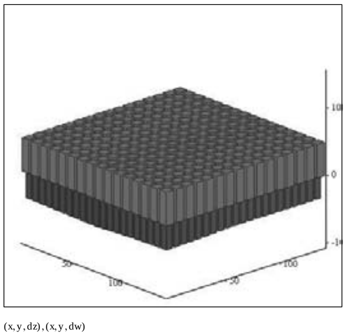

Fig. 25. The thickness of composite for the ball 100 [mm]

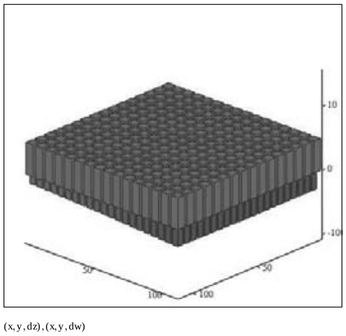

Fig. 26. The thickness of composite for the ball 80 [mm]

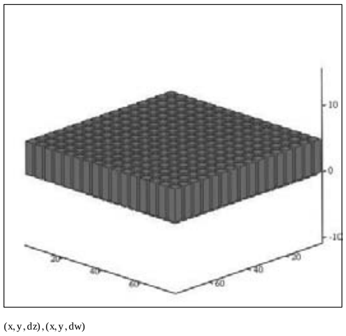

Fig. 27. The thickness of composite for the ball 60 [mm]

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]
100	8.1	7.8
80	6.0	6.4
60	4.6	4.8

The results obtained from the calculation based on the simulation and the stochastic method are compatible to the results obtained from the real experiment

6. Conclusions

1. The most advantageous pouring temperature is temperature of 1550^{0}C because, at this temperature, the thorough joint penetration of premould was done and the composite layer formed on the whole reinforced surface.
2. The most advantageous temperature distribution was observed in premould for the biggest ball, as a result of thermal capacity of casting.
3. The way of pouring and leading the liquid metal into the mould (directional solidification) caused the shift of thermal center. It had an effect on the minimal increase of the composite thickness in lower and upper part of the ball.
4. The analysis of the results and calculations of probability of composite layer formation at particular thickness confirm that, the most advantageous conditions for composite layer formation are for the biggest ball.
5. The obtained results and the analysis of them allow to determine the basic guidelines for designing technology and construction of casting with the composite layer.

Acknowledgements

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