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Influence of Titanium on Crystallization and Wear Resistance of High Chromium Cast Iron

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Abstract

Paper presents the results of studies on primary crystallization and wear resistance of high chromium cast iron inoculated with ferrotitanium intended for work in abrasive conditions. Primary crystallization was examined with use of TDA method, wear tests of the samples were conducted using the modified pin-on-disk method.

Keywords: Chromium cast iron, Primary crystallization, Inoculation, Titanium, Wear

1. Introduction

High chromium cast irons are used for production of elements working in intense wear conditions [1]. Their wear resistance is the key factor for mining and mineral processing, energetic, foundry and forging industries. They are used in ball mills, rollers, abrasion shields, transporting elements, etc. mainly because of their exceptional wear resistance to cost of production ratio.

In casting process the structure of the casting highly influences its mechanical properties. Proper control of crystallization processes kinetics in order to optimize casting microstructure and mechanical properties is a vital factor of enhancing the castings quality [3, 4].

Inoculation allows to manipulate the crystallization process, it has heavy impact on the castings structure and properties without the necessity to change its chemical composition [2, 8-10]. From the economical point of view it allows to keep a decent ratio of greatly increased mechanical properties to the production cost. Typically just a fraction of a per cent by weight of inoculant in the melt visibly changes the crystallization process. However in this work higher amounts of inoculants were added in order to not only refine the grain and enhance the shape of participates, but also to increase alloys wear resistance.

Chosen inoculant was ferrotitanium (FeTi67), because of the high similarity of titanium carbide TiC lattice parameters to the Cr_7C_3 carbide lattice parameters (mismatch δ = 4,8 [5]) and because of its high melting point (3160 °C).

The wear resistance of high chromium cast irons is the result of presence of hard (1600 - 1800 HV) chromium carbides,. However titanium carbides TiC serving as underlays for Cr_7C_3 nucleuses might also increase alloys wear resistance (hardness of TiC in Mohs scale is 9 - 9,5).

Presented article shows the results of primary crystallization examination and wear tests of the high chromium cast iron inoculated with ferrotitanium obtained in laboratory conditions.

2. Materials and methodology

The reference melt W0 tended to be eutectic high chromium cast iron was executed with the use of induction furnace with the capacity of 50kg from the materials commonly used for metallic charge (steel scrap, ferrochromium). Melts inoculated with ferrotitanium (FeTi67) Ti2 and Ti2A were made in induction furnace with the capacity of 20kg. The melting loss of inoculant was estimated at 50%. Table 1 shows the content of inoculant and occurrence of additional procedures for each melt. Table 2 shows chemical compositions of examined high chromium cast irons.

Table 1.
Content of inoculant for each melt

	Sample		
	W0	Ti2	Ti2A
Inoculant	-	Ferrotitanium (4% Ti wt.)	Ferrotitanium (4% Ti wt.)
Additional procedure	-	-	inert gas shroud (Ar)

Table 2.
Chemical composition of examined high chromium cast iron melts

	Sample		
Element	W0	Ti2	Ti2A
C	**3,06**	**2,94**	**3,28**
Mn	0,65	0,602	0,529
Si	0,386	0,486	0,449
P	0,019	0,02	0,024
S	0,023	0,051	0,071
Cr	**19,3**	**18,5**	**18,1**
Ni	0,242	0,237	0,268
Mo	0,03	0,052	0,079
V	0,158	0,169	0,206
Cu	0,124	0,125	0,245
Al	0,013	0,059	0,101
Ti	**0,0**	**1,43**	**2,29**

Process of primary crystallization was examined using TDA method. Test stand consisted of two probes granting different solidification times in order to examine crystallization with two different cooling rates [6]:

- ATD-C probe with shorter solidification time,
- ATD-Is probe with longer solidification time.

Solidification time in ATD-Is probe is approximately 2 times longer than in ATD-C probe. Fig. 1 shows the scheme of the test stand.

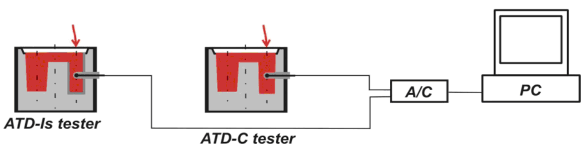

Fig. 1. Scheme of the test stand [6]

Tribotester 3-POD device was used for execution of wear tests based on modified pin-on-disc method. This method uses reference wear test sample made of Creusabro 8000 (C8) wear resistant steel. Measuring castings overflow part was used for preparation of the samples.

Scheme of the sample used in Tribotester 3-POD device and markings of points where hardness was measured are shown in Fig. 3. Table 3 shows the values of hardness of examined samples.

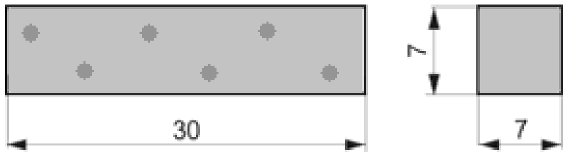

Fig. 2. Scheme of wear test sample with hardness measurement points

Table 3.
Hardness of examined samples

	Sample			
	W0	Ti2	Ti2A	C8
Hardness HRC	53	51,5	51	42

During wear tests following parameters of Tribotester 3-POD were set:

– Abrasive disc: emery paper C120, silicon carbide,
– rotational speed of the abrasive disc: 155 rpm,
– rotational speed of the sample holder: 400 rpm,
– load of a single sample: 220 G,
– total time of the wear test: 60 min,
– dry grinding.

3. Primary crystallization analysis

Analysis of cooling (T=f(t)) and crystallization (T'=dT/dt) curves obtained using TDA method resulted in designation of characteristic points of temperature and time of primary crystallization [7]:

- TL – liquidus temperature for hypoeutectic alloys shows maximum heat effect of γ phase dendrites crystallization, for hypereutectic alloys it shows maximum heat effect of primary carbide M_7C_3 phase crystallization, for eutectic alloys TL = TS,
- TS – solidus temperature shows maximum heat effect of eutectic γ + M_7C_3 phase,
- TH – end of solidification temperature,
- tK - Solidification time tK = TH time – TL time.

Figs. 3, 5 and 7 show both cooling and crystallization curves in function of time for all examined high chromium cast irons. Tables 4-6 present characteristic points temperature and time of examined high chromium cast irons. Micrographs of studied alloys structure are shown in Figs. 4, 6 and 8.

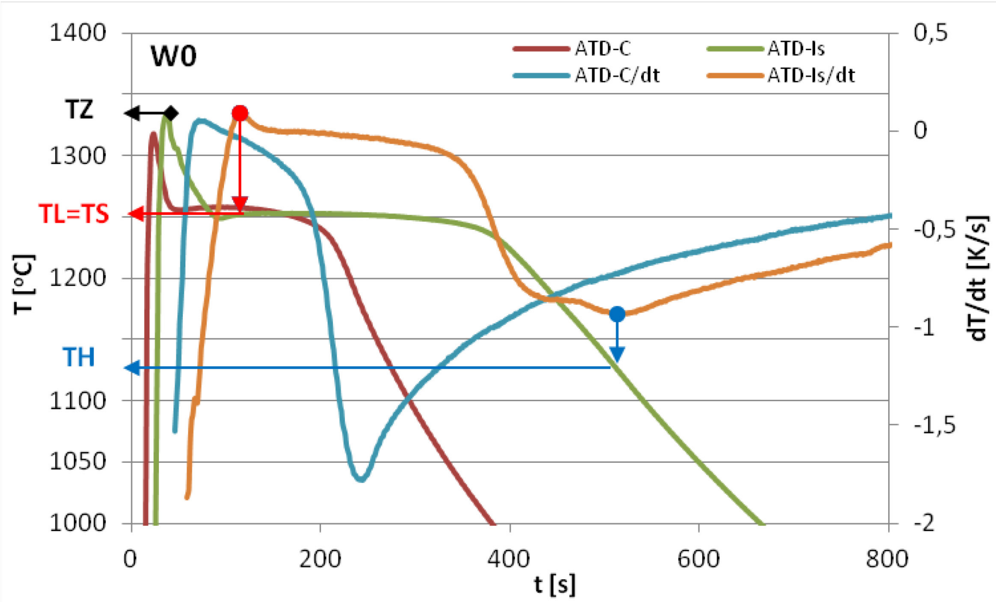

Fig. 3. TDA curves for W0 melt

Table 4.
Temperature in characteristic points of TDA curves for W0 melt

		TZ	TL = TS	TH	tK
Probe	ATD-C	1317°C	1257°C	1177°C	167 s
	ATD-Is	1334°C	1251°C	1124°C	397 s

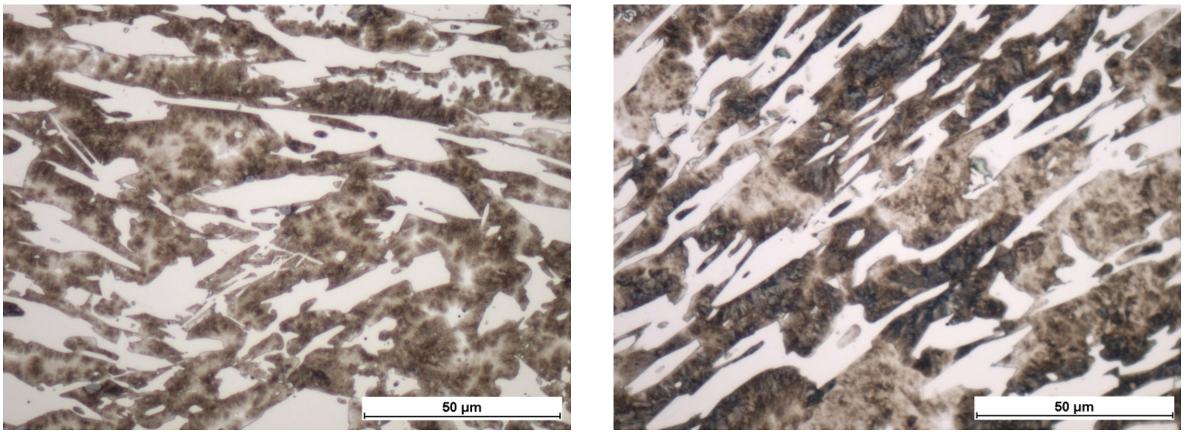

Fig. 4. Microstructure of W0 cast iron from different sample castings; on the left ATD-C, on the right ATD-Is

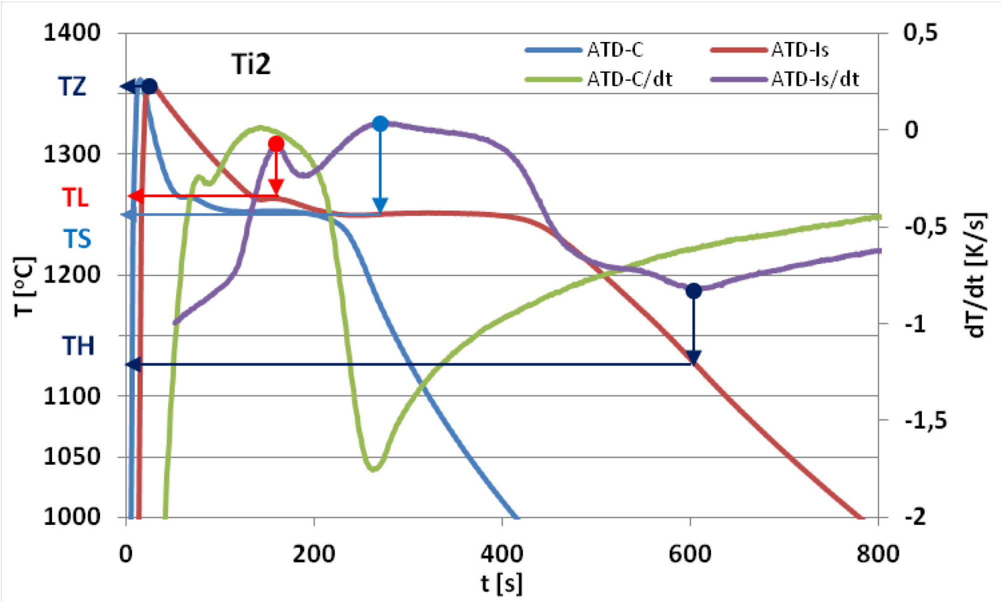

Fig. 5. TDA curves of Ti2 melt

Table 5.
Temperature in characteristic points of TDA curves for Ti2 melt

		TZ	TL	TS	TH	tK
Probe	ATD-C	1361°C	1261°C	1252°C	1190°C	185 s
	ATD-Is	1358°C	1263°C	1251°C	1130°C	440 s

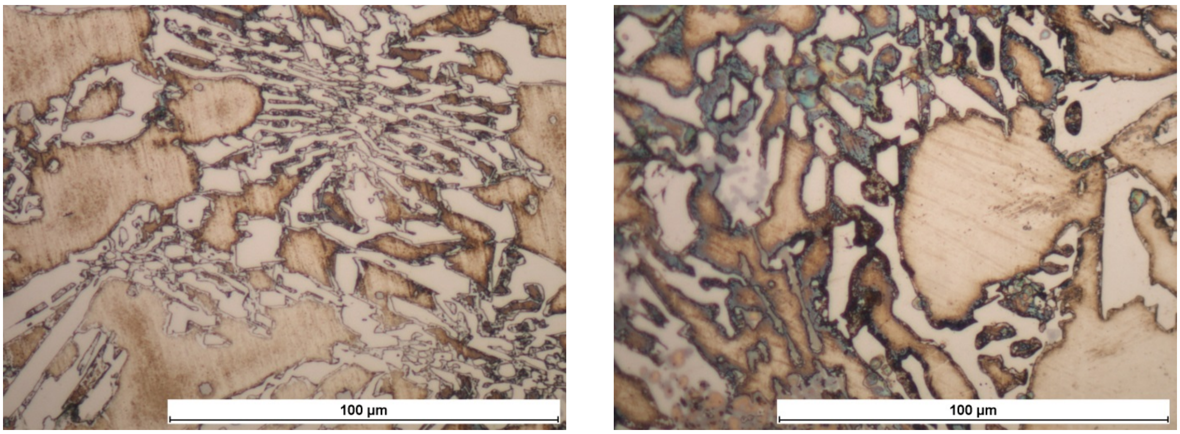

Fig. 6. Microstructure of Ti2 cast iron from different sample castings; on the left ATD-C, on the right ATD-Is

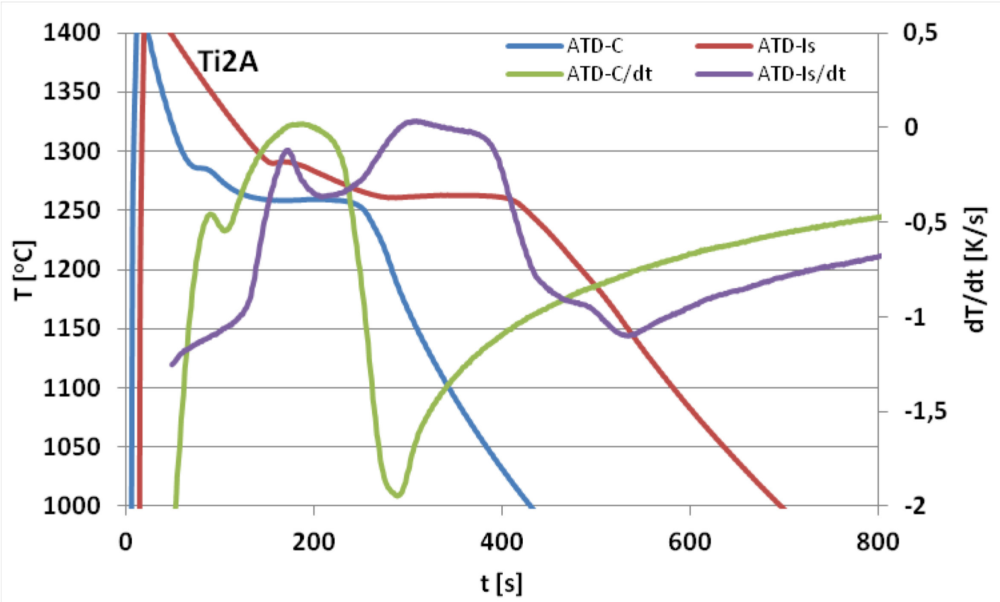

Fig. 7. TDA curves of Ti2A melt

Table 6.
Temperature in characteristic points of TDA curves of Ti2A melt

		TZ	TL	TS	TH	tK
Probe	ATD-C	1419°C	1283°C	1259°C	1186°C	199 s
	ATD-Is	1426°C	1291°C	1263°C	1148°C	364 s

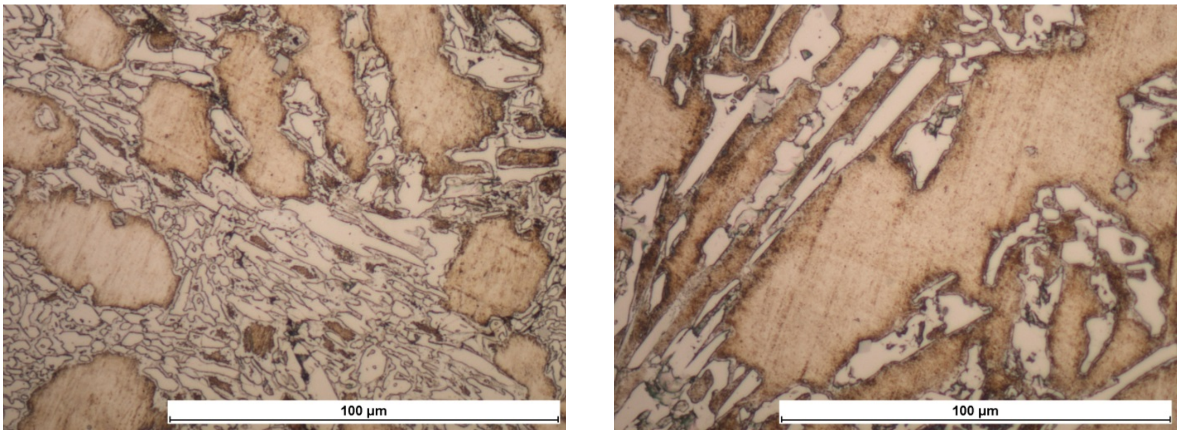

Fig. 8. Microstructure of Ti2A cast iron from different sample castingsł on the left ATD-C, on the right ATD-Is

4. Wear tests analysis

The diagram of weight losses of examined high chromium cast iron samples in wear tests measurement cycles is shown in Fig.9. Relative weight loss of examined samples in comparison to the wear test reference sample is presented in Fig. 10 (Ref, C8).

W0 sample is 44% more wear resistant than C8 sample. Both inoculated samples demonstrated higher wear resistance than sample W0 and C8.

Analysing Ti2A the increase was 58% in comparison to the wear resistance of W0 sample and 71% compared to C8 sample.

Analysing Ti2 the increase was 52% in comparison to the wear resistance of W0 sample and 69% compared to C8 sample.

Ti2A melt has 5% better wear resistance than Ti2 melt. Strong influence of inoculation with ferrotitanium and the content of titanium in the melt on weight loss can be noticed.

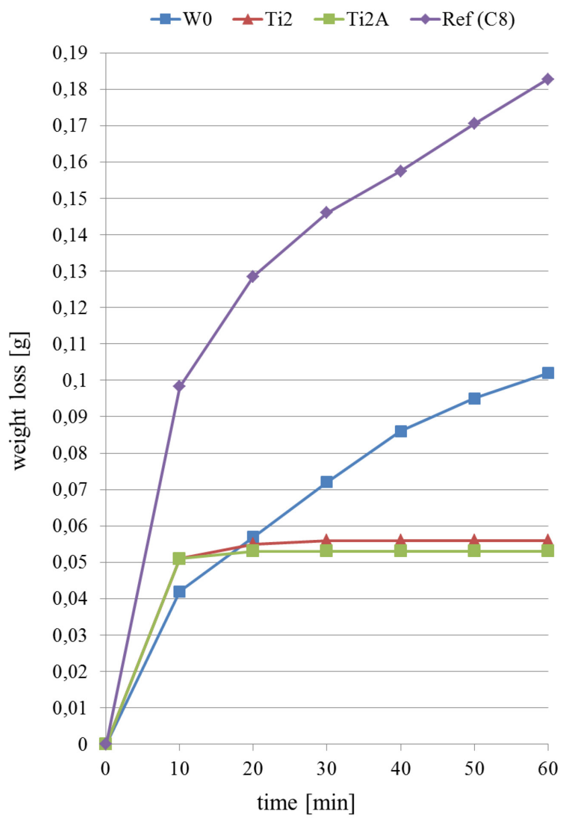

Fig. 9. Weight loss of samples in wear measurement cycles

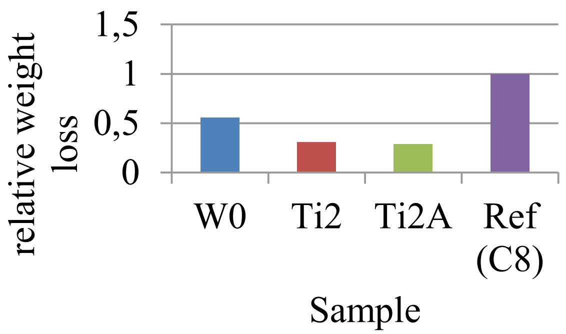

Fig. 10. Relative weight loss of examined samples in comparison to the wear test reference sample (C8)

5. Summary

The course of primary crystallization process for examined high chromium cast iron samples shows the influence of ferrotitanium on carbides crystallization and thus on the structure and mechanical properties of the alloy.

Refinement of the structure was achieved in all inoculated melts. It proves that titanium carbide TiC can be used as an crystallization underlay for austenite and Cr_7C_3 carbide.

All inoculated melts have shown carbides of more regular morphology than the reference melt (W0), with eutectics closer to lamellar. The plate-like carbides observed in W0 cast iron became more rounded, what will probably result in increase of the impact strength.

Hardness of inoculated samples was lower than the hardness of the reference sample (W0), successful inoculation causes refinement of the carbide phase which results in decrease of hardness, in examines samples the decrease was 1,5 to 2 HRC.

Samples from inoculated melts exhibited better wear resistance than the not inoculated sample. It was noticed that wear resistance of examined samples depended on the content of titanium in the melt. Sample Ti2A after the second measurement and sample Ti2 after the third measurement cycle did not show further wear, which was the effect of erosion of the grinding wheel. It may be caused by the presence of titanium carbide TiC, which hardness (9-9,5 in Mohs scale) is equal to the hardness of the silicon carbide SiC, used in the grinding wheel.

Tables 7 and 8 show the differences between characteristic points temperature and time of primary crystallization of examined high chromium cast iron in comparison to the reference melt (W0) without any inoculants.

Table 7.
Differences between characteristic points temperature and time in comparison to W0 in ATD-C probe

	W0	Ti2	Ti2A
TL	1257 °C	> 4 °C	> 26 °C
TS	1257 °C	< 5 °C	> 2 °C
TH	1177 °C	> 13 °C	> 9 °C
tK	167 s	> 18 s	> 32 s
TL-TS	0 °C	> 9 °C	>24 °C
TL-TH	80 °C	< 9 °C	> 17 °C

Table 8.
Difference between characteristic points temperature and time in comparison to W0 in ATD-IS probe

	W0	Ti2	Ti2A
TL	1251 °C	> 12 °C	>40 °C
TS	1250 °C	> 1 °C	> 13 °C
TH	1124 °C	> 6 °C	> 24 °C
tK	397 s	> 43 s	< 33 s
TL-TS	1 °C	> 11 °C	> 27 °C
TL-TH	127 °C	> 6 °C	> 16 °C

Inoculation of high chromium cast iron with use of ferrotitanium moves the eutectic point to higher carbon values.

Use of inert gas atmosphere (Ar) greatly increases the stability of inoculation, reduces the melting loss. While using high amount of ferrotitanium as inoculant it is necessary.

More specific examination of the inoculating influence for high chromium cast iron with Ti requires further experiments which will be continued.

References

[1] Sakwa, W., Jura, S., Sakwa, J. (1980). *Wear resistance iron alloys*. *Part II Cast steel*. Kraków: ZG STOP. (in Polish).

[2] Fraś, E. (2003). *Crystallization of metals*. Warszawa: WNT. (in Polish).

[3] Gromczyk, M., Kondracki, M., Studnicki, A. & Szajnar, J. (2015). Stereological Analysis of Carbides in Hypoeutectic Chromium Cast Iron. *Archives of Foundry Engineering*, *Vol. 15, Issue 2*. 17-22. Katowice-Gliwice: PAN.

[4] Stawarz, M., Gromczyk, M., Kondracki, M. & Szajnar, J. (2014). Analysis of the Effect of Heat Removal from the Mould on the Crystallization of Cast Iron with High Si Content*.* *Archives of Foundry Engineering, Vol. 14, Special Issue 4*. 119 – 122 (in Polish).

[5] Ma, Y., Li, X., Liu, Y., Zhou, S. & Dang, X. (2012). Effect of Ti-V-Nb-Mo addition on microstructure of high chromium cast iron. *China Foundry*, *Vol.9, No 2*.

[6] Studnicki, A. (2013). *Role of selected inoculants in crystallization of wear resistant high chromium cast iron.* Monography. Katowice-Gliwice: Archives of Foundry Engineering. (in Polish).

[7] Studnicki, A. & Jura, S. (1999). Identification of characteristic temperatures of solidification of high chromium cast iron. *Solidification of metals and alloys*, *Vol. 1, No 40*, 189-195. Katowice, Opole PAN.

[8] Kopyciński, D., Guzik, E., Siekaniec, D. & Szczęsny, A. (2015). The effect of addition of titanium on the structure and properties of high chromium cast iron. *Archives of Foundry Engineering, Vol. 16, issue 3*. 43-46.

[9] Kopyciński, D. & Piasny, S. (2012). Influence of tungsten and titanium on the structure of chromium cast iron. *Archives of Foundry Engineering, Vol. 12, issue 1*. 57–60.

[10] Kopyciński, D. (2015). *Development of structure and mechanical properties in cast iron for operation under harsh conditions*. Archives of Foundry Engineering. Monograph. 1-182 (in Polish).