ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 15
Issue 4/2015

75 – 80

15/4

Primary Crystallization Studies and Abrasion Analysis of Cr-Ni-Mo Cast Steel

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Received 30.06.2015; accepted in revised form 15.07.2015

Abstract

The article shows results of studies of primary crystallization and wear resistance of Cr-Ni-Mo cast steel intended for work in corrosive and abrasive conditions. The studies of primary crystallization were conducted with use of TDA method and modified tester allowing measurement casting cooling time influence on the cooling and crystallization curves of studied alloys. After heat treatment of examined cast steel wear tests of the samples were conducted on pin-on-disc type device.

Keywords: Chromium cast steel, Primary crystallization, Wear, Abrasion, Pin-on-disc

1. Introduction

In mining and mineral processing industries the elements of machines are exposed to influence of particles causing wear (such as sand) and corrosive environment (such as highly salted water). Materials for such elements besides having high mechanical properties need to have high wear and corrosion resistance [1-4].

Among cast alloys high wear resistance and high corrosion is presented by ferrous alloys with high Cr content. Wear resistance remarkably increases with the presence of chromium carbides which are harder than most common wearing materials such as quartz sand. Content of chromium higher than 12 % in ferrous alloys grants enhanced corrosion resistance which is strictly connected with the durability of the passive layer made by alloying elements with high affinity for oxygen such as Cr. Nickel as the second basic alloying element in examined cast steel besides having positive influence on corrosion resistance visibly increases plasticity, impact strength and technological properties of cast steel [4]. Molybdenum in corrosion resistant cast steels highly increases resistance for pitting due to modification of passive layer [4].

While choosing corrosion and wear resistant material we have to make a compromise and decide which one is more important for us in examined case. The excess of carbon in corrosion resistant cast steels is unfavourable, but in wear resistant cast steels it is very favourable as it allows formation of carbides. In the Department of Foundry Engineering of Silesian University of Technology while analysing different groups of cast steels the focus was on tool cast steels, especially chromium cast steels. Adding Ni and Mo to those cast steels resulted in creation of new Cr-Ni-Mo cast steel having changeable wear and corrosion resistance due to its working conditions.

In presented article the results of primary crystallization and wear studies of the new Cr-Ni-Mo cast steel obtained in industrial conditions were shown.

2. Materials and methodology of the research

The primary crystallization and wear resistance of two Cr-Ni-Mo cast steels with 12 % and 18 % Cr wt. were examined. Table 1 shows chemical compositions of examined cast steels.

Cr-Ni-Mo cast steel was melted in industrial conditions using electrical arc furnace with the capacity of 0,5 ton from the commonly used materials (steel scrap, ferrochromium, ferromolybdenum, nickel). Prepared alloy was used for mechanical coal miner parts and specimen castings poured according to scheme in Fig. 1.

Table 1.
Chemical composition of examined Cr-Ni-Mo cast steel % wt.

No.	melt	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Mo**	**V**	**Cu**	**Al**	**Ti**
1	Cr18	0,60	0,47	0,64	0,029	0,013	**17,20**	**3,07**	**0,66**	0,043	0,12	0,070	0,033
2	Cr12	0,52	0,68	0,57	0,026	0,014	**12,30**	**1,54**	**0,67**	0,043	0,17	0,072	0,020
3	C8	0,24	1,16	0,71	0,008	0,003	0,65	0,26	0,30	0,009	0,15	0,036	0,044

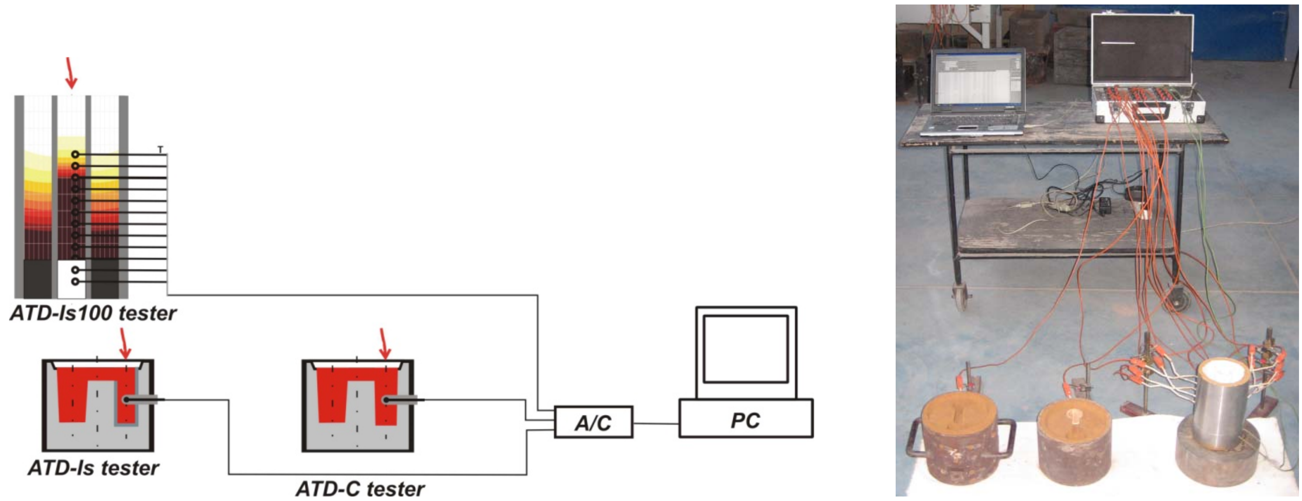


Fig. 1. Test stand

Crystallization process was examined with use of TDA method [5-7, 9]. On the test stand three cooling curves of three castings with different solidification modules were obtained. Specimen casting with the lowest module (M=0,75) was recorded in ATD-C probe, moderate module (M=0,90) in ATD-Is probe and the highest module (M=2,50) in ATD-Is100 probe.

The solidification time of the casting in ATD-Is100 probe is 10 times longer than the solidification time in ATD-C probe. ATD-Is100 probe is commonly used for examination of the thermal gradient in cooling castings. In the studies only the cooling curve registered in the thermal centre of the examined casting was used.

Wear tests were conducted with the modified pin-on-disc method using the Tribotester 3-POD device [9]. In this method the reference sample made of low alloyed wear resistant steel is used (table 1). Figure 2 shows scheme of the device, its photo and the sample. The samples for wear tests were extracted from overflow part of the measuring casting and heat treated using air quenching (950^{o}C/15 min/air). Hardness of examined samples is shown is table 2.

Table 2.
Hardness of examined samples

No.	melt	Heat treatment	Hardness HRC
1	Cr18h	950^{o}C/15 min/air	51
2	Cr12h	950^{o}C/15 min/air	52
3	C8 (reference)	As delivered (Creusabro 8000)	42

In conducted studies the parameters of the work of Tribotester 3-POD device were:

- grinding wheel: abrasive paper C120, silicon carbide,
- rotational speed of the grinding wheel: 100 rpm,
- rotational speed of sample holder: 400 rpm,
- load of single sample: 220 G,
- total time of wear test: 60 min,
- dry grinding.

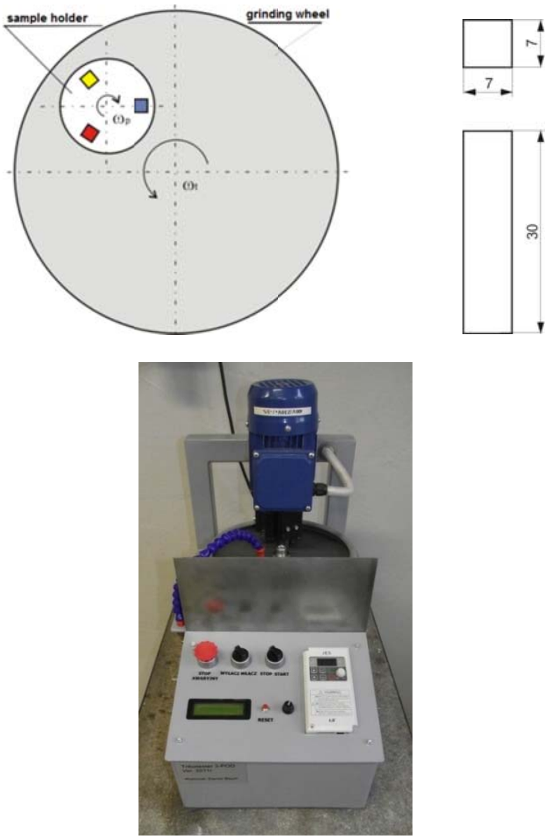


Fig. 2. Scheme and picture of Tribotester 3-POD device

3. Primary crystallization analysis

The analysis of primary crystallization process was initially made using the phase equilibrium diagram of Fe-C-Cr alloy. Figure 3 shows polythermal section of the phase equilibrium diagram of Fe-C-Cr alloy with 17 % Cr wt. on which selected crystallization courses of chromium cast steel were marked. Crystallization analysis was the key study while examining those alloys. Cast steels I and II have the following primary crystallization courses in stable phase diagram:

Cast steel I

$$\mathbf{L \rightarrow L+\alpha \rightarrow L+\alpha+\gamma \rightarrow \alpha+\gamma}$$

Cast steel II

$$\mathbf{L \rightarrow L+\alpha \rightarrow L+\alpha+\gamma \rightarrow L+\gamma \rightarrow L+\gamma+M_7C_3 \rightarrow \gamma+M_7C_3}$$

In the next steps, in secondary crystallization, $M_{23}C_6$ carbides may appear what was shown by structural examination.

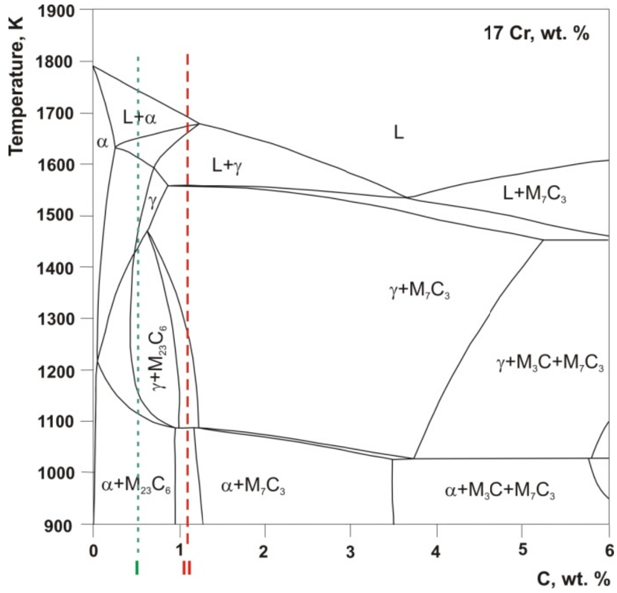


Fig. 3. Polythermal section of the phase equilibrium diagram of Fe-C-Cr alloy with 17 % Cr wt. [8]

In TDA method The first derivative of cooling curve allows deeper analysis of the crystallization process. Figures 4 to 6 show cooling curves (T=f(t)) and crystallization curves (T'=dT/dt) for all examined cast steels and measuring castings with different solidification module. On the crystallization curve (Fig. 4) the start (A) and the end (H) points of primary crystallization are marked. Between those points phase transitions take place. At first from the liquid α phase crystallizes, then γ phase, also as a result of peritectic transition. In the case of Cr18 cast steel on the crystallization curve eutectic transition is visible as a result of which eutectic $\boldsymbol{\gamma+M_7C_3}$ is created**.**

For Cr12 cast steel characteristic temperatures of primary crystallizations are:

- start of primary crystallization ~1460 °C
- end of primary crystallization ~1310 °C

For Cr18 cast steel characteristic temperatures of primary crystallizations are:

- start of primary crystallization ~1430 °C
- crystallization of eutectic ~1260 °C
- end of primary crystallization ~1230 °C

Those temperatures are dependent on solidification module, the higher the module, the higher the temperature. With increasing solidification module of the casting characteristic temperature values of crystallization process are moved in the direction of equilibrium temperature of examined alloy.

Figs. 4 and 6 show metallographic structure of examined cast steels. In Cr12 cast steel with lower content of Cr and C there is no remarkable carbide phase, only its small precipitates. In Cr18 cast steel explicit carbide phase is visible on grain boundaries. Heat effect of carbide eutectic crystallization was shown on crystallization curve as a clear peak just before the end of primary crystallization presented by point H. Fig. 7 shows the areas of the structure of examined cast steels containing the carbide phase.

Cooling speed of the casting highly influences the grain size. Analyzing the metallographic photos of the casting with 0,75 module (Fig. 4) and 2,50 module (Fig. 6) high influence of castings wall thickness on grain size of examined cast steel can be stated. In thick-walled castings inoculation should be taken into consideration.

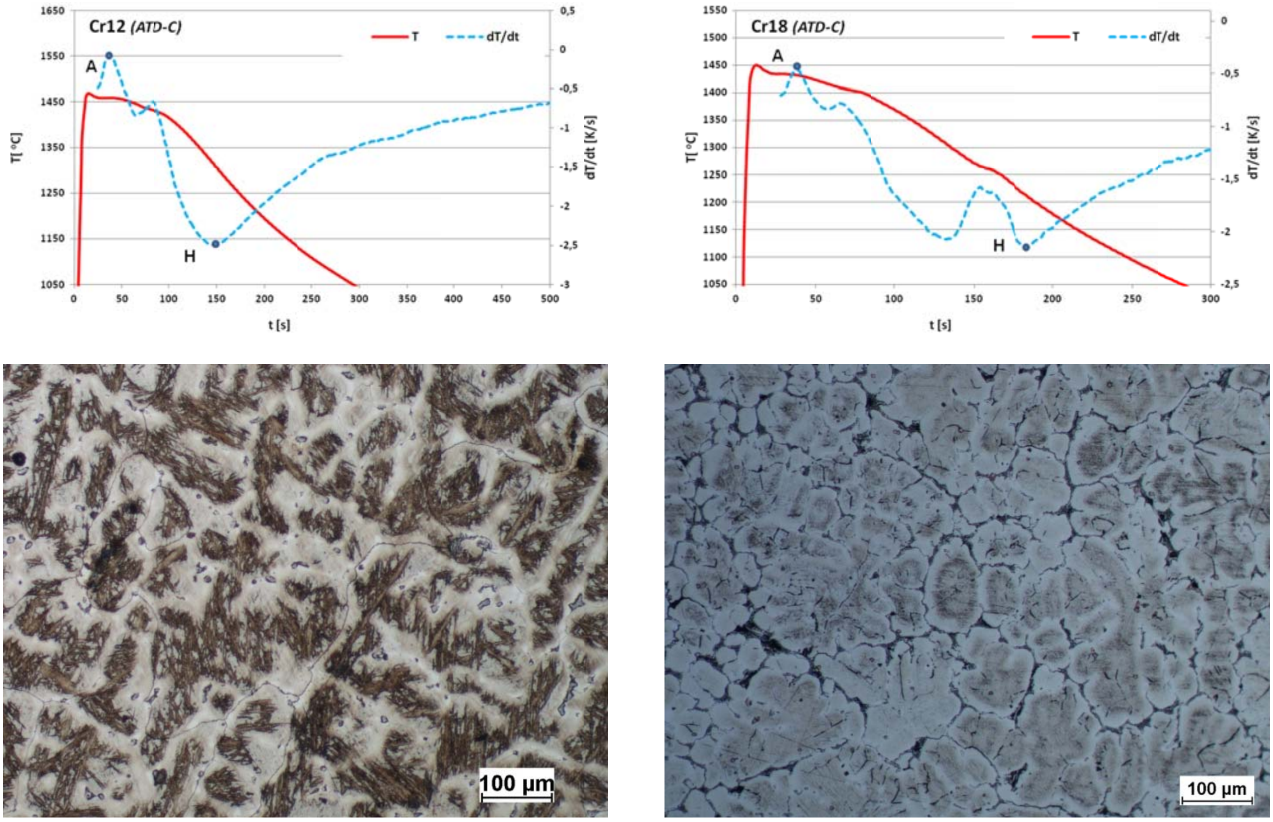


Fig. 4. TDA curves and structures of examined cast steels – specimen casting with the lowest solidification module (M=0,75)

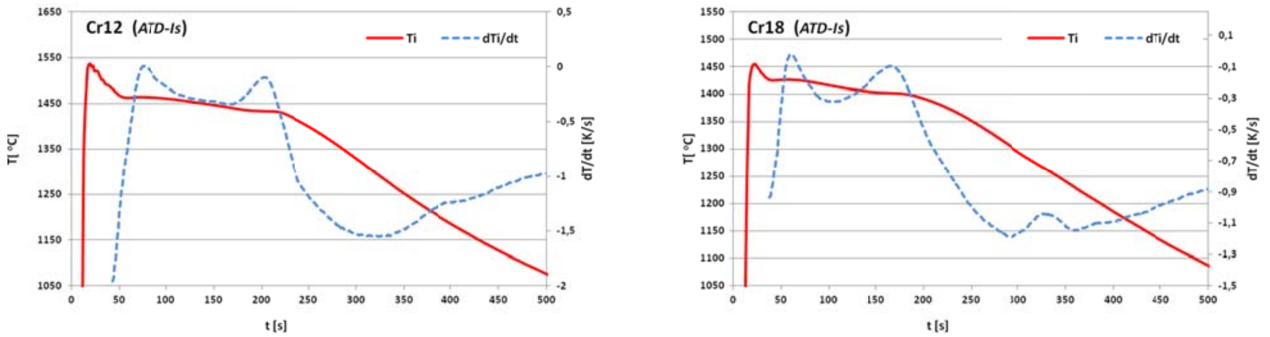


Fig. 5. TDA curves of examined cast steels – specimen casting with moderate solidification module (M=0,90)

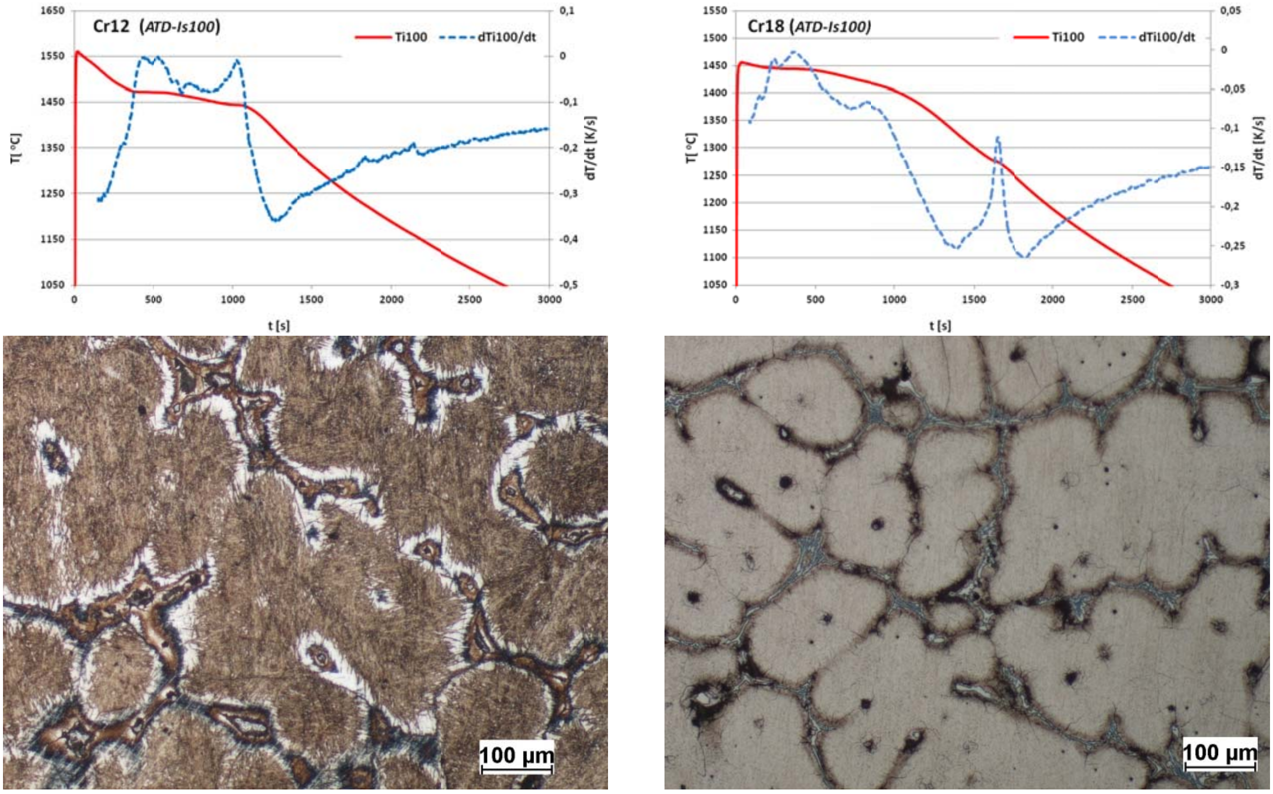
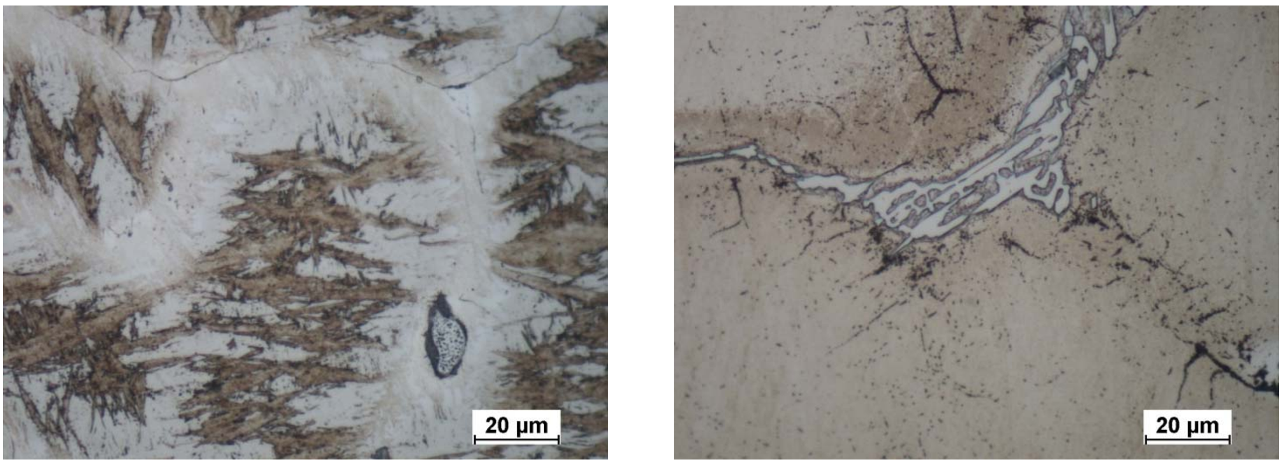


Fig.6. TDA curves and structures of examined cast steels – specimen casting with the highest solidification module (M=2,50)



Cr12 Cr18

Fig.7. Carbides in the structure of examined cast steels

4. Wear analysis

Fig. 8 shows the diagrams of weight loss of examined cast steel samples in measurement cycles of wear test. High influence of Cr content on weight loss can be noticed. Fig. 9 shows relative wear of each sample in comparison to reference sample. Both examined cast steels present higher wear resistance than the reference material, which is Creusabro 8000 wear resistant steel. In the case of Cr18 cast steel almost 50% increase in wear resistance in comparison to the reference value can be noticed. In the case of Cr12 cast steel the increase is about 30%. When considering the influence of Cr content in examined cast steel on its wear resistance almost 30 % increase with the high Cr content can be seen (Cr18 cast steel in comparison to Cr12 cast steel).

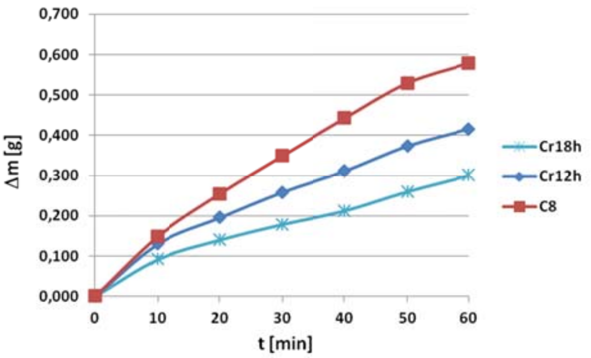


Fig. 8. Weight loss of the samples in wear measurement cycles of Cr-Ni-Mo cast steel

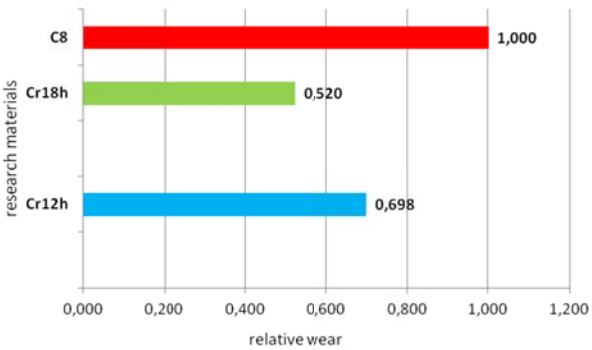


Fig. 9. Relative wear of Cr-Ni-Mo cast steel

5. Summary

The primary crystallization processes courses of examined Cr-Ni-Mo cast steels based on cooling and crystallization curves (TDA curves) show high influence of Cr content on carbide eutectic crystallization. With higher Cr content (18%) on crystallization curve (dT/dt) a peak showing carbide eutectic crystallization appears. Maximum heat effect of this process takes place at about 1260 ^{o}C.

Conducted studies have shown high influence of castings cooling speed on its metallographic structure. In thick-walled castings coarse-grained structure may appear. Possible solution of this problem is inoculation of the melt.

Wear of examined cast steels highly depends on appearance of the carbide phase in its structure, even small amount of carbide eutectic distinctly increases wear resistance. Measurements have shown that in examined cast steels the volumetric content of carbide phase does not exceed 1%. In the case of Cr18 cast steel where the carbide eutectic crystallizes on grain boundaries (Fig. 7) significant increase of wear resistance in comparison to Cr12 cast steel without remarkable carbide phase was shown. However the negative effect of carbide phase on grain boundaries on cast steels mechanical propertied must also be taken into consideration. In examined Cr-Ni-Mo cast steels content of carbide eutectic responsible for wear resistance can be easily adjusted by changing Cr and C content.

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