ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (1897-3310)
Volume 15
Issue 1/2015

25 – 28

6/1

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

Corrosion Behaviour of Low-Alloyed Cast Steel in Diverse State

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Received 14.07.2014; accepted in revised form 22.07.2014

Abstract

In the paper the results and analysis of corrosion tests were presented for low-alloyed cast steel in as-cast state and after heat treatment operations. Such alloys are applied for heavy loaded parts manufacturing, especially for mining industry. The corrosion test were performed in conditions of high salinity, similar to those occurring during the coal mining. The results have shown, that small changes in chemical composition and the heat treatment influence significantly the corrosion behaviour of studied low-alloyed cast steels.

Keywords: Low-alloyed cast steel, Heat treatment, Corrosion, Pitting corrosion, Selective corrosion

1. Introduction

Low-alloyed cast steel belong to the group of alloys applied for fabrication of heavy-duty machinery parts, i.a. the mining industry machinery, due to its high operational properties [1-9]. Work conditions of such machinery include abrasive wear and corrosion, due to high salinity, with tendency to selective and pitting corrosion [3, 4, 10-14]. Steel grades applied for different elements of mining machinery very often did not meet the demands, undergoing the accelerated wear due to not sufficient hardness and tendency to pitting corrosion. The presented studies included the corrosion tests of low-alloyed cast steels with different chemical composition and diverse state.

2. Studies Methodology

The studied low-alloyed cast steels were prepared in laboratory condition using the inductive furnace. Melting, alloying, modification and pouring were performed according to cast steel practice. Four cast steel grades were produced with different content of selected elements (nickel, molybdenum). Alloys were modified with addition of Ti and V. The chemical composition was verified with use of LECO GDS 500A emission spectrometer. Low-alloyed cast steels were tested in as-cast state and after heat treatment operations. The heat treatment included the hardening and tempering. Parameters of hest treatment were presented in Table 1.

Table 1.
Heat treatment parameters applied for studied low-alloyed cast steels

Description	Quenching Temp./medium	Tempering Temp./medium
K1o	920°C/water	550°C/air
K2o		
K3o		
K4o		

Samples from each cast were mechanically and chemically prepared for corrosion tests and metallographic examination. Metallographic analysis was conducted with use of Nikon Optiphot, at different magnification (50 to 1000x). The structure was additionally conducted with use scanning microscope with

EDS. The results of microstructure observations were presented in other publications [6,8]. The corrosion test methodology was based on ASTM G-48 00 and position [15], describing the salinity and chemical composition of mining waters in different mining sites of Silesia. It was similar with methodology used for high chromium cast steels presented in works [3,4]. During the test a cuboid specimen with dimensions 30×30×10 mm was immersed in aqueous solution of natrium chloride (9,77% wt.) and hydrochloric acid (0,81%). For solution preparation pure ingredients and distilled water were used. Each sample was placed in a separate container with 0,41 dm^3 of solution. To retain constant temperature during the studies (35°C) all containers were placed inside a special chamber. The surface changes and weight loss were periodically observed and documented, enabling the qualitative and quantitative description of corrosion processes. The tests duration was different for alloys in as-cast state and after the heat treatment, ranging up to approx. 3000 hours.

3. Results of Studies

In Table 2 the chemical composition of low-alloyed cast steels was presented (alloys K1 – K4). Figs. 1 and 2 shows the surface state of cast steel specimens in as-cast state and after heat treatment operations.

Table 2.
Chemical composition of studied low-alloyed cast steels, in % wt.

No.	melt	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Al	Ti
1	K1	0,27	0,84	0,80	0,019	0,003	0,60	0,29	0,23	0,000	0,43	0,027	0,000
2	K2	0,24	0,79	0,89	0,017	0,002	0,59	0,29	0,23	0,023	0,43	0,007	0,000
3	K3	0,22	0,84	0,95	0,018	0,003	0,60	2,83	0,70	0,000	0,43	0,027	0,028
4	K4	0,22	0,80	0,91	0,018	0,003	0,60	1,13	0,73	0,035	0,48	0,007	0,008

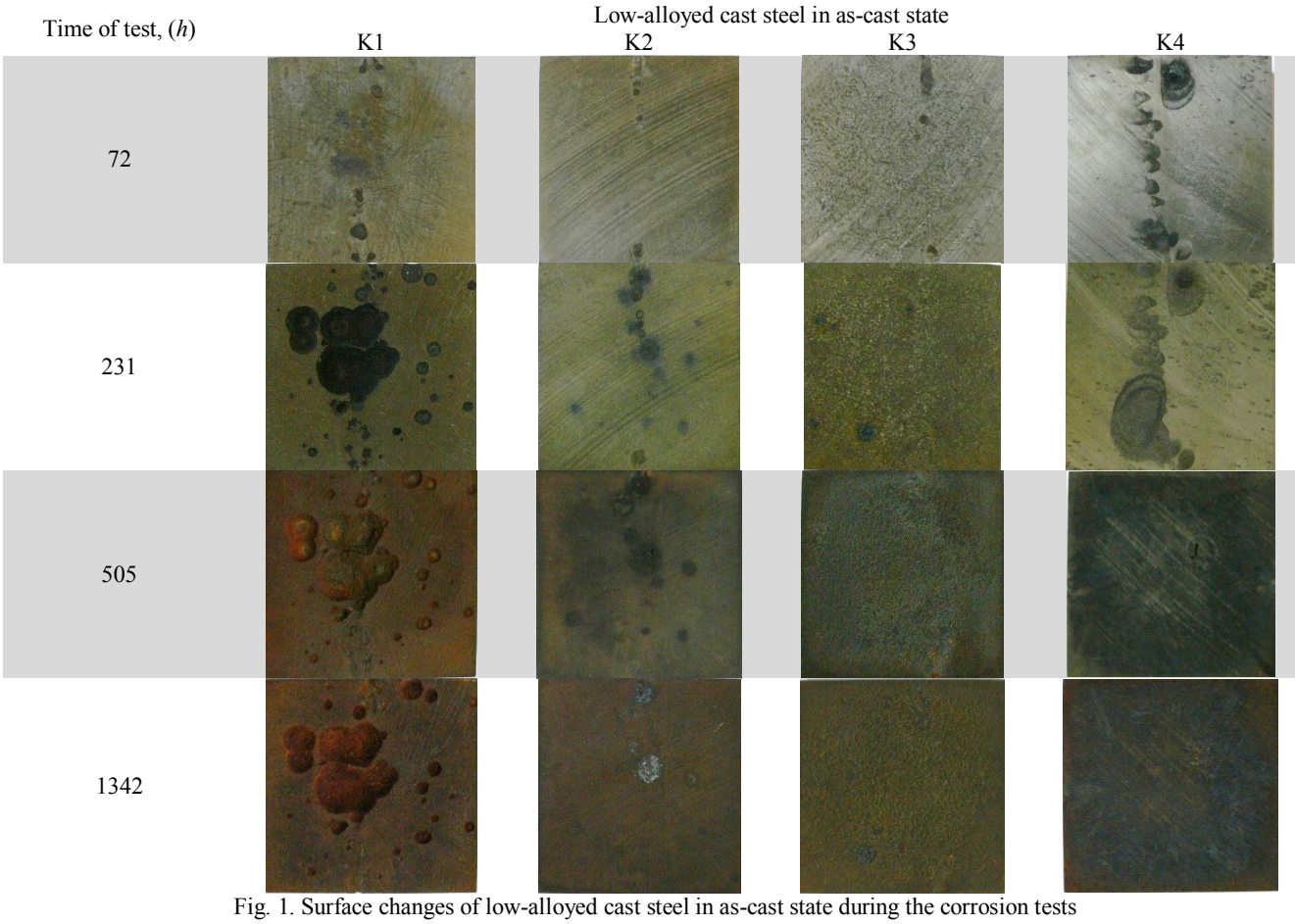

Fig. 1. Surface changes of low-alloyed cast steel in as-cast state during the corrosion tests

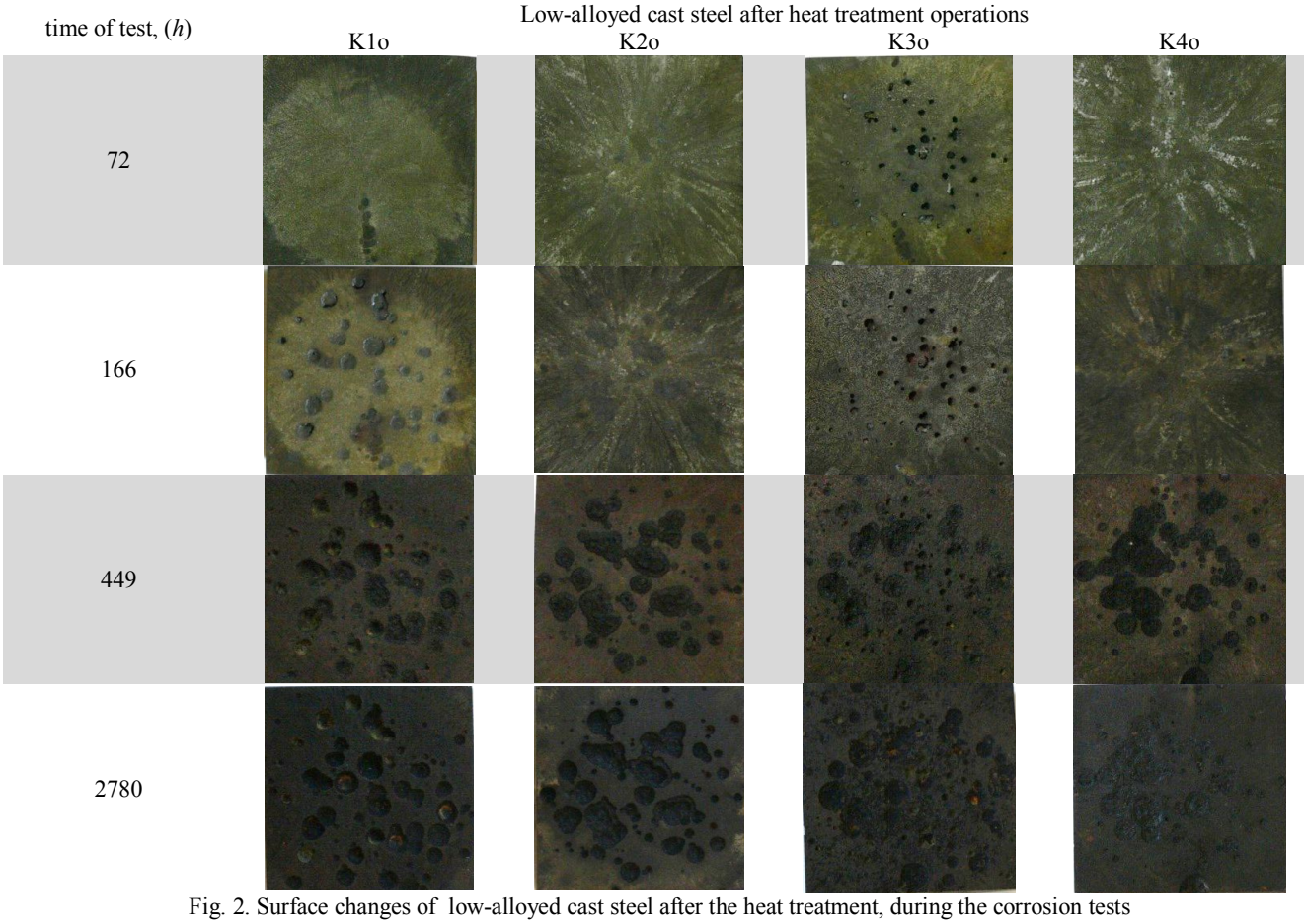

Fig. 2. Surface changes of low-alloyed cast steel after the heat treatment, during the corrosion tests

In case of low-alloyed cast steel in as-cast state only K1 alloy showed significant susceptibility to pitting corrosion. Other alloys was characterised by good resistance to applied environment with high concentration of chlorides. The best results were obtained for K4 alloy, which showed none susceptibility to pitting or selective corrosion. In case of K2 alloy some tendency to pitting corrosion was observed, however in less extent than K1 alloy.

The heat treatment operations caused deterioration of corrosion resistance for all studied alloys. As in case of as-cast state the lowest resistance was observed for K1o alloy. K2 and K4 behaviour was similar; in the first stage the surface was attacked in a uniform manner. The second stage, after approx. 400 hours, included pitting corrosion and selective deterioration. K3 alloy surface was from the start of the test attacked by pitting corrosion, but in an extent lower than in case of K1 alloy.

Figs. 3 – 7 show the quantitative description of the corrosion process, based on weight loss measurements. As can be seen form Figs. 3 and 4, the process consisted of two stages. In the first stage the corrosion rate is higher and during that period mainly uniform corrosion took place. During the second stage the corrosion rate decreased significantly. This is mainly caused by corrosion product deposit covering the specimen surface. It partially decreases the corrosion rate. During this stage the pitting corrosion prevails over the uniform process of material deterioration. The rate of the process for both stages can be described by weighted average value. Fig. 7 shows these parameters for all studied alloys in as-cast state and after the heat treatment. For K1 alloy the average rate of corrosion is the same for both cases. For other alloys average rate is higher for material after the heat treatment.

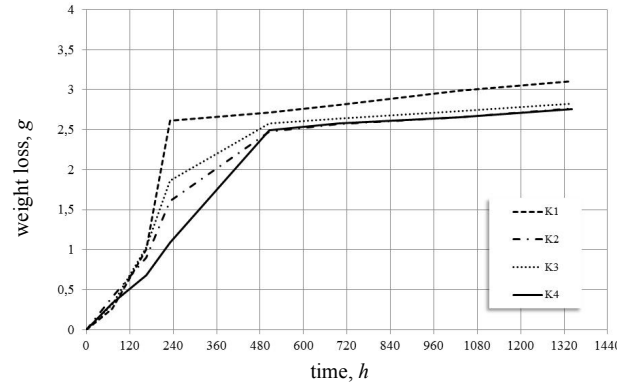

Fig. 3. Weight loss for low-alloyed cast steel in as cast-state

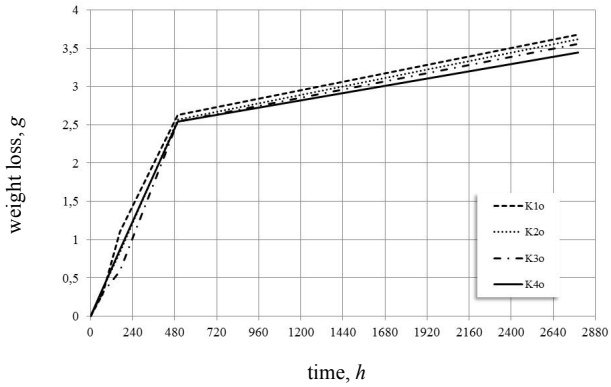

Fig. 4. Weight loss for low-alloyed cast steel after heat treatment operations

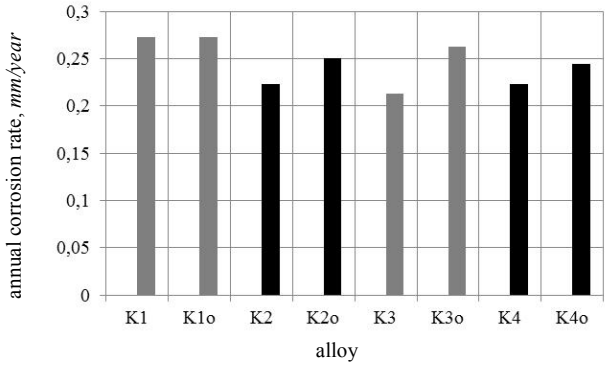

Fig. 5. Average annual corrosion rate calculated for both stages of corrosion

4. Conclusions

Conducted studies enabled formulation of following conclusions:

- Low-alloyed cast steel show proper resistance to pitting corrosion in as-cast state in case of alloys with higher content of Ni and Mo.
- Modification of the alloy with vanadium decreases the susceptibility of the alloy to pitting corrosion.
- The heat treatment operations applied to enhance the mechanical properties cause deterioration of material corrosion resistance.
- For all studied alloys after the heat treatment pitting and selective corrosion was observed.
- The best results were observed for alloys modified with vanadium. The pitting corrosion occurred in case of these alloys at the latest.
- The corrosion rate for studied alloys was accelerated by the heat treatment operations of 10 to 20% (excluding K1 alloy).

Acknowledgement

This work was prepared under the Research and Development Project N R507 0054 10, financed by Polish Ministry of Science and Higher Learning.

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