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THE EFFECT OF DIFFERENT DELIVERY CONDITIONS ON THE ACCELERATED DEGRADATION OF STRUCTURAL STEEL IN THE COAL MINE ENVIRONMENT

WPŁYW RÓŻNEGO STANU DOSTAWY NA PRZYSPIESZONĄ DEGRADACJĘ STALI KONSTRUKCYJNEJ W ŚRODOWISKU KOPALNIANYM

The main objective of this work was to determine the effect of different delivery conditions on the accelerated degradation of structural steels used for lifting beams (rails) of the monorail transport systems. Some of these rails, made of the same steel grade as others, undergoes accelerated corrosion in the coal mine environment. Corrosion degradation occurs much faster (more than two times faster), comparing to the same steel grade rails operated under the same conditions but with different microstructures. However, all the provided rails meet the requirements of appropriate standards for steel on the lifting beams of the monorail transport systems.

The investigations were carried out on rails made of the same steel grade but with different microstructures and showed that the main factor influencing the accelerated corrosion degradation of tested steels is the delivery condition, so-called "as rolled" condition. The greatest resistance to the accelerated corrosion showed rails in the normalized or normalizing rolling condition.

Keywords: coal mine environment, corrosion, monorail transport system, structural steel

Głównym celem pracy było określenie wpływu warunków dostawy stali konstrukcyjnych stosowanych na elementy nośne podwieszanej kolejki szynowej na ich przyspieszoną degradację korozyjną. Niektóre z szyn, wykonanych z tego samego gatunku stali co pozostałe, ulegały przyspieszonej korozji w środowisku kopalnianym ponad dwukrotnie szybciej w porównaniu z szynami dostarczonymi przez innych dostawców i pracującymi w tych samych warunkach. Jednocześnie wszystkie szyny spełniały wymagania odpowiednich norm dotyczących stali na elementy nośne szynowych kolejek podwieszanych.

Badania wykonane na szynach dostarczonych z tego samego gatunku stali ale o różnych mikrostrukturach wykazały, że głównym czynnikiem wpływającym na przyspieszoną degradację korozyjną stali konstrukcyjnych jest ich stan dostawy. Największą odporność na korozję wykazały szyny w stanie normalizowanym lub po walcowaniu normalizującym.

Słowa kluczowe: środowisko kopalniane, korozja, podwieszana kolejka szynowa, stal konstrukcyjna

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1. Introduction

For economy reasons and because of good machinability, mild and low alloy steels are the preferred materials for underground coal mine structures. However, the corrosivity of coal mine water, containing usually high concentration of such aggressive components as sulphate and chloride ions vary from mildly to highly corrosive (Ruhi et al., 2009; Singh, 2006). The lifting beams of the monorail transport systems are made of S355 grade structural steel and meet the requirements of relevant standards of chemical composition and mechanical properties. The rails was delivered to coal mine with three different microstructures. Unfortunately, in one case, rails made of the same steel grade, undergoes accelerated corrosion in the coal mine environment (corrosion degradation occurs more than two times faster although rails was operated in the same conditions than other rails. The longest operating lifetime was for rails made of steel 1, than for steel 2 and shortest for steel 3. An example of such accelerated degradation of the lifting beam (rail made of steel 3) is shown in Figure 1.

Fig. 1. Accelerated degradation of the lifting beam in coal mine environment (steel 3)

In this paper, we focus on the relationship between a different microstructure of rails and the accelerated degradation of structural steels in the coal mine environment.

2. Material and experimental procedure

The examinations were carried out on a samples of used rails made of S355J2G3 steel (old designation but still used by purchasers) received with three different microstructures (steel 1, 2 and 3). Hardness measurements, by Brinell method according to EN ISO 6506, were taken on the same specimens as used for metallographic examinations. Characterization of microstructures of investigated steels was performed by an Zeiss Axiovert 200MAT optical microscope. The chemical composition and properties of the coal mine water sample was examined by an Perkin Elmer 6100 ELAN ICP mass spectrometer and by an pH-metr WTW pH 330.

3. Results and discussion

The chemical compositions of the steels are presented in Table 1. As it is shown, chemical compositions of tested steels meet the requirements of EN 10025 standard, although steel delivered by supplier 1 has slighty higher (by 0.04%) carbon content than is allowed by the standard. The maximum carbon content for S355J2G3 is equal 0.20% and for S355JRG3 steel maximum carbon content is 0.24%. For materials grade J2 longitudinal Charpy V-noth minimum imapct energy should be 27J at –20 centigrade temperature and for JR grades minimum imapct energy should be 27J at room temperature. The silicon content (increasing strength properties) is in the case of steels 1 and 2 almost twice higher than for steel 3, while the manganese content in steel from supplier 3 is higher (by about 0.2%) then in steels from other suppliers. It should be noted here, that casted continuously and hot rolled steels with higher manganese content are very susceptible to microstructural banding (Majka et al., 2002; Bhadeshia, 2010).

TABLE 1

Chemical composition of the investigated steels (in wt. %)

Steel	C	Si	Mn	P	S	Cr	Mo	Cu	Al	V	B
1	0.24	0.37	1.16	0.023	0.011	0.02	0.005	0.02	0.04	<0,002	<0,001
2	0.17	0.40	1.13	0.006	0.003	0.12	0.040	0.14	0.03	0,005	<0,001
3	0.18	0.25	1.28	0.015	0.006	0.13	0.030	0.21	0.02	<0,002	<0,001
EN10025 standard	max. 0.20 (0.24)	max. 0.55	max. 1.60	max. 0.025	max. 0.025	-	-	-	-	-	-

Mechanical properties (Brinell hardness) of the steels are given in Table 2.

TABLE 2

Brinnell hardness of investigated steels

Steel 1	Steel 2	Steel 3
193±2* HB	180±5* HB	185±4* HB

* – standard deviation

Physico-chemical characteristics of coal mine water are given in Table 3 and 4. According to the classification of mine water made in work (Singh, 1988) tested coal mine water sample could be assigned to soft alkaline waters (ph = 7.5 to 8.5) and by the Cl^- i SO_4^{2-} ions content to the medium-salinity waters (Konieczny & Bodzek, 2003).

However, regardless of the mine water corrosivity, in the same environment "I" beam type rails made of the same steel grade but with different microstructures showed highly diverse susceptibility to corrosion. Because the chemical compositions of the steels and mechanical properties were similar the only possible reason for varying the susceptibility to corrosion is the difference in the microstructures. The microstructures of the steels are shown in Figure 2-4.

As it is seen in Figure 2, the microstructure of the steel 1 is more homogeneous than microstructures shown in Figure 3 and 4 (least homogeneous). The same sequence has a corrosion resistance of the steels (from lowest to highest susceptibility to corrosion).

TABLE 3

General physico-chemical characteristic of coal mine water

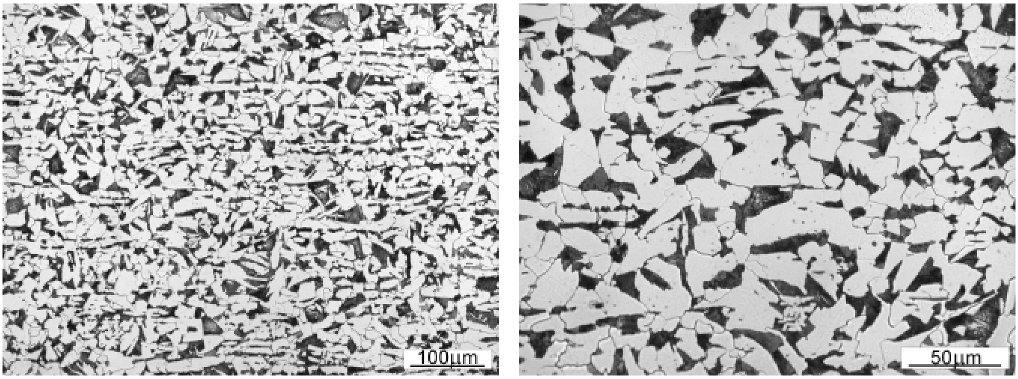
pH	7.72	
Mineralization	6378.8	[mg/dm^3]
General hardness	1030.8	[mg $CaCO_3$/dm^3]
Carbonate hardness	251.6,0	[mg $CaCO_3$/dm^3]
Permanent hardness	15.58	[mval/dm^3]
γ_{25}	11.1	[mS/cm]
SiO_2	2.0	[mg/dm^3]
H_2SiO_3	2.00	[mg/dm^3]

TABLE 4

Chemical composition of coal mine water

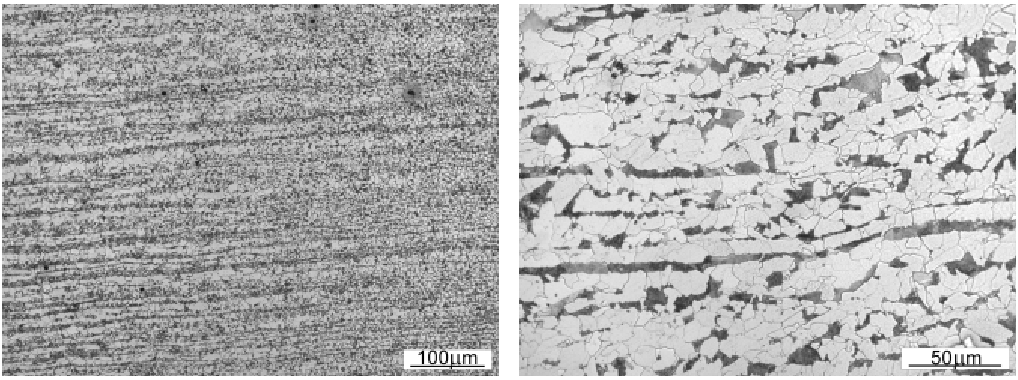
Component	**mg/dm^3**	**mval/dm^3**
Na^+	1904.0	82.783
K^+	75.51	1.931
Li^+	0.413	0.06
Ca^{2+}	73.22	3.654
Mg^{2+}	206.10	16.963
Ba^{2+}	0.038	0.001
Sr^{2+}	1.247	0.028
Fe^{2+}	0.141	0.005
Mn^{2+}	0.008	0.000
Zn^{2+}	0.037	0.001
Cu^{2+}	0.0001	0.000
Al^{3+}	0.028	0.003
Co^{2+}	0.0003	0.000
Se^{2+}	0.030	0.001
V^{5+}	0.169	0.017
Zr^{4+}	0.001	0.00
Cl^-	3626.0	102.026
Br^-	0.5	0.006
SO_4^{2-}	172.1	3.585
HCO_3^-	307	5.033
CO_3^{2-}	<0.5	0.017
BO_3^{2-}	8.89	0.454

The microstructure shown in Figure 2 is almost free of banding and is characterized by a uniform distribution of ferrite and pearlite grains. The trace of banding is present, but this microstructure can be described as not banded. This steel is in normalized or normalizing rolling state. The microstructure of steel 2 (Figure 3) is still homogeneous (probably due to the high rolling reduction ratio) but showing ferrite-pearlite banding. Steel 3 has severe banded microstructure with wide-banded ferrite (Figure 4). Probably, this is the reason of accelerated corrosion in the coal mine environment of "I" beam rails made of this steel, although the mechanical properties and chemical composition complies with the standards and are close to the steels 1 and 2.



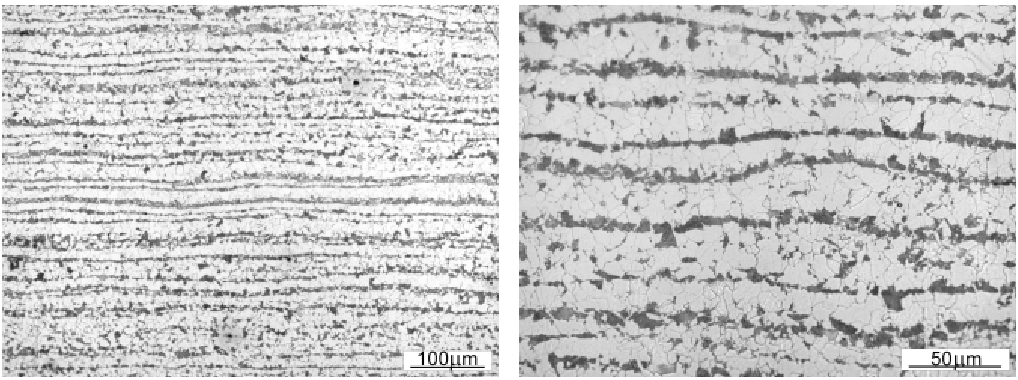
a) b)

Fig. 2. Microstructure of the investigated steel 1. Etched with 2% Nital



a) b)

Fig. 3. Microstructure of the investigated steel 2. Etched with 2% Nital



a) b)

Fig. 4. Microstructure of the investigated steel 3. Etched with 2% Nital

According to the “Comments relating to the new edition of DIN EN 10025 part 1-6 for hot rolled products of structural steel” (http://www.dillinger...), prepared by a technical working group of the Walzstahl-Vereinigung, based on the new edition 2005 of DIN EN 10025, an option to order G3 or G4 delivery conditions is eliminated. Now, for the purchaser exists an option to order the steel product in the normalized (or normalizing rolling) or as rolled state. The symbol +N (delivery condition as normalized or normalizing rolled, old designation G3) or +AR (as rolled, old designation G4) has to be indicated together with the steel grade. However, according to the old standard EN 10025:1993 designation G3 means that only flat products should be supplied normalized or in an equivalent condition obtained by normalizing rolling. Long products (as “I” or “H” beams) of G3 grade should be supplied in a delivery condition at the manufacturers discretion, unless otherwise agreed.

4. Conclusions

The present study has demonstrated that:

- There is a significant difference in the corrosion susceptibility in coal mine environment of rails made of the same steel grade but in different delivery conditions.
- The highest corrosion resistance was observed for steel with homogenous microstructure obtained by the normalizing or normalizing rolling.
- Steel of the most heterogeneous and severe banded microstructure with wide-banded ferrite has the worst corrosion resistance in coal mine environment.
- To avoid accelerated corrosion of „I” beam rails in the coal mine environment in the future, steels should be ordered in the normalized or normalizing rolling state (+N).

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