MODERN LOW-ALLOY WEAR- RESISTANT STEELS –STRUCTURE AND IMPACT STRENGTH

СОВРЕМЕННЫЕ НИЗКОЛЕГИРОВАННЫ СТАЛИ ИЗНОСОСТОЙКИЕ – ИХ СТРУКТУРА И ДИНАМИЧЕСКАЯ ПРОЧНОСТЬ

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Abstract: *In this paper low-alloy steels of new generation, produced in different countries were analyzed. To the group belong steels like Hardox, FORA, RAEX AR 400 or HTK. The steels are characterized with abrasion resistant, high strength and weldability. Structure of the Hardox and HTK steels, their impact strength and character of fracture were investigated. The structures of the steels mainly contain very fine acicular tempered martensite with uniform distributed coherent carbides. Suitable chemical composition and heat treatment of the steels assure those high mechanical properties and sufficient resistant to dynamic load and brittle cracking at operating temperature.*

Keywords: *ABRASION RESISTANT STEEL, IMPACT STREHGTH, FRACTOGRAPHY ANALYSIS*

1. Introduction

Manufacturers requirement materials with higher properties to produce more effective machines. It is very important particularly for big complicating constructions for building industry or mining. High cost of the constructions should influence their longer operating. Heat treatable steels were widely uses as constructional materials for the constructions. Now the steels are replaced by new advanced martensitic steels. The new generation modern steels are produced in several countries. To the group belongs for example Hardox steel made by Swedish metallurgy concern, FORA 400 steel produced by INDUSTEEL-BELGIUM concern, RAEX 400 steel made by Finland RAUTARUUKKI OYJ concern or HTK steel produced by Hut-Trans Katowice in Poland.

The group of steels contents less carbon in comparison to classical heat treatable steels and exactly chosen content of other elements to assure, first of all of weldability and of high strength, high hardenability and high hardness. High strength properties of the steels can cause too low ductility. According to application of the steels it is important to get enough resistant to dynamic loading and to brittle cracking at operating temperature.

Till now we don't have sufficient investigations of the advanced steels and there is lack of scientific publications on their structure and properties. The all information we have about the steels arises mainly from manufacturer. Recently some experiments on the steels were carried out [1-3].

In this paper Hardox and HTK steels in delivered state were examined. Structure of the steels, their impact strength and character of fracture were analyzed.

2. Results and discussion

2.1. Chemical composition of analyzed steels

Chemical composition and mechanical properties of selected steels are presented in table 1.

In the steels, regarding for example Hardox steels, carbon content changes with sheet gauge to guarantee uniform properties in a whole section (table 2).

2.2. Microstructure of the examined steels

Very pure components of alloys and advanced metallurgy processing influence quality of material directly, so in the examine steels we observed low intensity appearance of non-metallic inclusions. The factors result in better resistance to dynamic loading. Analyze of a microstructure of the steels shows post martensitic structure. This is a structure after hardening and tempering. Temperatures of tempering is changed depending on grade and sheet gauge of the steels. The main features of the structure are grain fineness (very fine acicular tempered martensite) and homogeneity (Fig. 1).

Table 1. Chemical composition (for plate thickness - 8mm) and mechanical properties of selected steels

Element Max. value %	Hardox 400	Hardox 500	RAEXAR 400	HTK 700H	HTK 900H	FORA 400
C	0,15	0,27	0,24	0,18	0,18	0,13
Mn	1,60	1,60	1,70	1,4	1,4	1,20
Si	0,70	0,70	0,70	0,45	0,50	-
P	0,025	0,025	0,025	0,25	0,25	0,02
S	0,010	0,010	0,010	0,010	0,010	0,01
Cr	0,30	1,00	1,00	0.50	1,0	0,50
Ni	0,25	0,25	0,70	0,30	0,30	0,25
Mo	0,25	0,25	0,50	0,30	0,40	0,25
B	0,004	0,004	0,004	-	-	0,001
Mechanical properties (typical values)						
R_e[MPa]	1000	1300	-	-	1000	1100
R_m[MPa]	1250	1550	1250	900	1250	1350
A_5[%]	10	8	10	12	12	13
HB	400	500	400	250	400	400
KV_{-40}[J]	45	30	30	-	-	20

Table 2. Chemical composition for different plate thickness of Hardox 400 steel (only elements, which contain are changed)

Plate thickness [mm]	C max [%]	Cr max [%]	Ni max [%]	Mo max [%]
3 - 8	0,15	O,30	0,25	0,25
8 - 20	0,15	0,50	0,25	0,25
20 - 32	0,18	1,00	0,25	0,25
32 - 45	0,22	1,40	0,50	0,60
45 – 51	0,22	1,40	0,50	0,60
51 - 80	0,27	1,40	1,00	0,60
80 - 130	0,32	1,40	1,50	0,60

Investigations on TEM indicate that aciculars of the martensite contain very fine, uniform distributed coherent carbides (Fig.2). Structure like that enhances first of all yield stress, hardness and wear resistance. Operating test of hardox 400 steel exhibited much better abrasion resistance than classical heat treatable steels [4].

HTK 900 steel exhibits similar structure to Hardox steels - fine acicular structure, but HTK 700 grade contains a mixture of structures - martensite, bainite and ferrite. That influences lower yield stress and wear resistance of the steel.

2.3. Impact strength of examined steels

Charpy V-notch (CVN) test of Hardox 400, Hardox 500, HTK 700, HTK 900 and AR 400 steels was carried out. Results of CVN test for the steels in the range of temperatures from -40 to 20^0C, for samples cut longitudinally to the rolling direction, are presented in Figure 3.

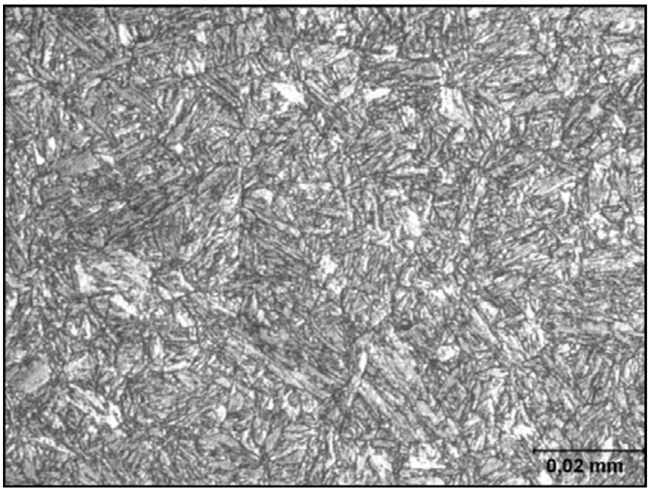

Fig. 1. Hardox 500 in delivered state. Light microscopy

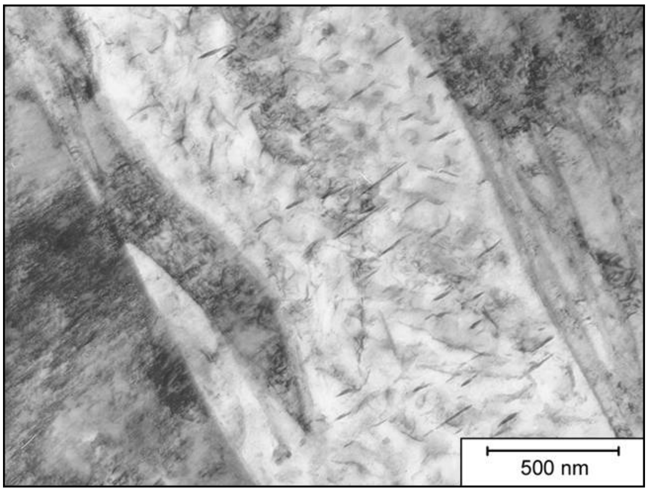

Fig. 2. Hardox 500 in delivered state. TEM

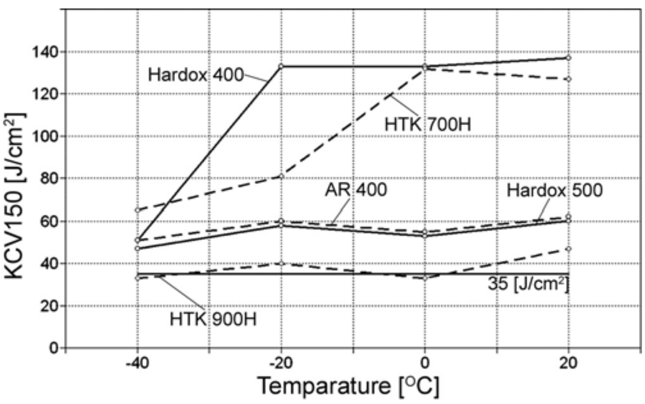

Fig. 3. Variation in impact strength with temperature for the analyzed steels

.When we assume minimum impact strength of 35 J/cm^2 (what is used for same parts of machines as a criterion for materials) values measured for all materials tested are higher except for HTK 900 steel, which shows lower values but close to the criterion. CVN test not always predicts properly ductile - to - brittle transition. Therefore studies of character of fracture have been performed. Hardox samples after CVN test, both 400 and 500 grade, show an entirely ductile fracture at 20^{0}C and exhibits a mixture of ductile and cleavage fracture at -40^{0}C (Fig. 4).

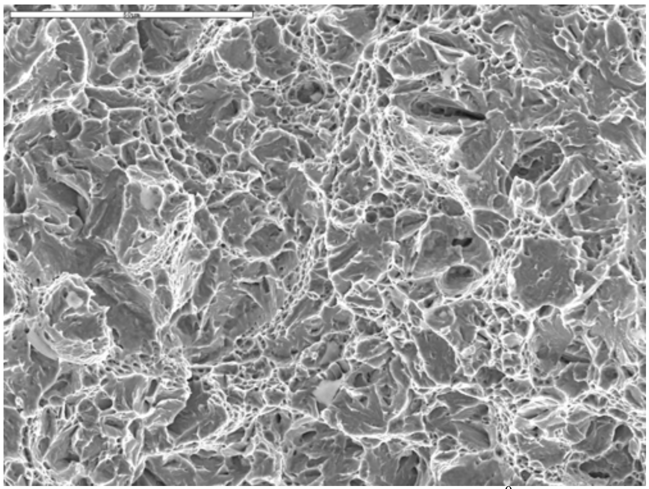

Fig. 4 Fractography of Hardox 500 steel tested at -40^{0}C

Even in transversal samples at -40^{o}C temperature a significant participation of plastic fracture is seen. Besides in Hardox steels, in whole temperature range, all samples exhibits shear lips. There is also a fibrous region ahead of the notch root.

Although values of Charpy V energy absorbed are relatively low for Hardox 500 steel and samples of the steel exhibit cleavage fracture in a central zone, the cleavage fracture is not exactly brittle one and curved cleavage facets associated with slip have been seen.

Samples of HTK steels exhibit cleavage fracture in the central zone as small isolated areas in 700 grade and more than 50% in 900 grade at room temperatures. At temperatures of -40^{0}C more than 50% areas of cleavage fracture in central zone in 700 grade and more than 70% of cleavage fracture in 900 grade have been observed. In the areas, like in Hardox steels, the cleavage fracture consist of partially deformed plastically facets with slip bands.

3. Conclusion

The analyzed steels exhibit mainly fine acicular tempered martensite with uniform distributed carbides. That kind of structure and suitable chemical composition certify high strength and hardness of the steels. The combination of high purity and low content of alloying elements also assures of weldability of the steels. The investigation results indicate generally sufficient resistance to impact loading of examined steels in delivered state up to temperatures of -40^{o}C. The structure of the steels are characterized with sufficient resistance to fracture initiation and its propagation in dynamic load conditions at the temperature range 20 - -40^{0}C. The use of the new generation steels extends operating period of constructions. The goal of the studies is look deeper at the structure of the steels to make their further development.

4. References

[1] Frydman S., Konat Ł., Pękalski G., Structure and hardness changes in welded joints of Hardox steels, Arch. of Civil and Mech. Eng., No 4, 2008.

[2] Frydman S., Konat Ł., Łętkowska B., Pękalski G., Impact resistance and fractography of low-alloy martensitic steels, Arch. of Foundry Eng., spec. iss. 1, vol.8, 2008, 89-94.

[3] S. Frydman, Ł. Konat, G. Pękalski, Properties of Hardox 400 and Hardox 500 steels in dynamic loading condition, Proceedings of the 24th Danubia-Adria Symposium on Developments in Experimental Mechanics, Sibiu, Romania (2007) 219-220.

[4] Dudziński W., Haimann K., Pękalski G., Structural, strength and corrosive characterisics of low-alloy martensitic steels, it will be published in Arch. of Civil and Mech. Eng., 2010.

This research was supported by the grant under project No. NR03 0039 06/2009.