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MECHANICAL PROPERTIES OF ABRASION-RESISTANT HARDOX 400 STEEL AND THEIR WELDED JOINTS

ABSTRACT

The mechanical properties of parent material and welded joints of abrasion-resistant HARDOX steel has been discussed in the paper. The results of mechanical properties and technological bending tests have been presented. The possibility of predicting the mechanical properties of HARDOX steel on the base of regression analysis was also considered.

Key words: *abrasion-resistant HARDOX steel, correlation equations, mechanical properties.*

INTRODUCTION

The characteristics of parent material and welded joints of abrasion-resistant HARDOX can be acquired through the laboratory tests or forecasting on the base of correlation equations. The abrasion-resistant HARDOX steel and the welded joints of this steel were the subject of research. The plates of HARDOX steels and technology of their converting were given into admitted procedures of classification societies. The high hardness of HARDOX steel is acquired thanks to heat treatment in continuous process. The hardness of HARDOX steel is a good measure of abrasion-resistance. The very important property of HARDOX 400, which guarantees the long life of products, is a fact, that HARDOX 400 plates are full hardened. HARDOX 400 steel can be welded without initial warming up until the plates' thickness 40 mm. The impact strength and plasticity of HADOX 400 are on the high level. The HARDOX 400 can be used in some cases as a construction plate carrying the load.
The aim of this paper was to compare results of basic mechanical properties obtained in laboratory tests with the results estimated from correlation equations. These correlation equations are applied to the extra high strength steels (420-690) and are described in [5].

MECHANICAL PROPERTIES OF PARENT MATERIAL

Chemical composition, technological bending tests results and Vickers hardness HV10 tests results of HARDOX 400 steel plate 15 mm in thickness are shown in Tables 1÷3. The mechanical properties and technological bending susceptibility tests were conducted according to the requirements of ship classification societies.

Table 1. *Chemical composition of HARDOX 400 steel, [wt %]*

C	Si	Mn	P	S	Cr	Ni	Mo	B	Fe
0,13	0,49	1,42	0,009	0,001	0,04	0,05	0,012	0,002	Bal.

Table 2. *Technological bending susceptibility of HARDOX 400 plate*

Standard tests conditions	Results			
	1	2	3	estimation
α = 120°; D/g = 8, parallel to RD	>120	>120	>120	positive
α = 120°; D/g = 8, perpendicularly to RD	>120	>120	>120	positive
The determination of minimal bend radius	Results $(D/g)_{min}$			
	1	2	3	estimation
Parallel to RD	4,0	3,5	3,5	positive
RD – rolling direction				

Table 3. *Hardness HV10 of HARDOX 400 plate*

HV10	2 mm below upper plate surface	9 mm below upper plate surface	2 mm above lower plate surface
Mean value	392,4	392,5	388,6

MECHANICAL PROPERTIES OF WELDED JOINTS

Investigations of mechanical properties of welded joints were conducted according to the rules of classification societies (GL, PRS) [1, 2]. The conditions of preparing welded joints are given in [3, 4]. To realize the research programme, the welded joints were performed with the use flux-cored wire DWA 55L f. ELGA:

- with additional pad of WEARSHIELD MM40 f. LINCOLN wire,
- with filling of P62MR f. ELGA wire.

The mechanical properties, the technological bending susceptibility of HARDOX 400 butt and tee welded joints are shown in Tables 4÷5.

Designation used in tables 4, 5, 6, 7.

- 1MH - butt joint (thickness 15 mm), downhand welding set of wires: flux-cored wire DWA 55L f. ELGA and additional pad of WEARSHIELD MM40 f. LINCOLN wire,
- 2MH - butt joint (thickness 15 mm), horizontal-vertical welding, set of wires: flux-cored wire DWA 55L f. ELGA and filling of P62MR f. ELGA wire,
- 3MH - tee joint (thickness 15 mm), downhand welding, set of wires:flux-cored wire DWA 55L f. ELGA and additional pad of WEARSHIELD MM40 f. LINCOLN wire,
- 4MH - tee joint (thickness 15 mm), horizontal-vertical welding, set of wires: flux-cored wire DWA 55L f. ELGA and filling of P62MR f. ELGA wire.

Table 4. *Mechanical properties of HARDOX 400 welded joints*

Joint number	Tensile strength R_m [MPa]	Mean value R_m [MPa]
1MH	720; 710	715
2MH	730; 715	722,5
3MH	710; 730	720
4MH	720; 710	715

Table 5. *Technological bending susceptibility of HARDOX 400 welded joints*

Joint number	Test conditions	Test results – bend angle [°]	Assessment
1MH, 2MH, 3MH, 4MH	α_{min} = 120° D/g = 8	For 1÷4 180	Positive

FORECASTING OF MECHANICAL PROPERTIES

To estimate the mechanical properties of parent material and welded joints, the correlation equations were used [5]. The correlation equations which assess the tensile strength R_m, yield point R_e, elongation A_5, reduction of area at fracture, and impact strength KV depends on (among other things) the following factors :

- cementite hardening,
- solution hardening,
- grain dimension hardening,
- precipitate hardening.

The chemical compositions of parent material, weld metal, and welded joints are shown in Table 7, the mechanical properties of butt welded joints calculated on the base of correlation equations are given in Table 6.

Table 6. *Mechanical properties of welded joints calculated on the base of correlation equations*

Joimt number	R_m [MPa]	R_e [MPa]	A_5 [%]	α_{min} [%]
1MH	731	666	27	154
2MH	739	675	27	148
3MH	688	624	28	185
4MH	688	622	28	178

Table 7. *Chemical composition of parent material, weld metal and welded joints [wt%]*

	Parent material	Weld metal			Welded joints			
	HARDOX 400	DWA55L	WEAR-SHIELD MM40	P62MR	1MH	2MH	3MH	4MH
C	0,14	0,04	0,20	0,055	0,086	0,084	0,052	0,051
Si	0,49	0,35	0,20	0,31	0,33	0,33	0,36	0,35
Mn	1,42	1,40	0,40	1,29	1,18	1,17	1,38	1,38
P	0,009	0,01	0,01	0,011	0,01	0,01	0,01	0,01
S	0,001	0,01	3,00	0,007	0,009	0,009	0,008	0,009
Cr	0,04	0,03	–	0,02	0,68	0,72	0,03	0,03
Ni	0,05	1,50	–	0,83	1,00	1,05	1,20	1,23
Mo	0,012	0,01	–	0,003	0,008	0,008	0,009	0,009
B	0,002	0,004	–	0,0002	0,003	0,003	0,003	0,003
Cu	–	0,01	–	0,01	0,007	0,007	0,009	0,007
V	–	0,015	–	0,02	0,01	0,001	0,015	0,015
Nb	–	0,01	–	0,006	0,007	0,007	0,008	0,008
Ti	–	0,04	–	0,011	0,003	0,003	0,029	0,030

ANALYSIS

The control tests of basic mechanical properties of HARDOX 400 confirmed the producer's data. Estimation of parent material mechanical properties shows some differences in values, which come from the lack of adequate data base and connected with it difficulty of correlation factors calculation. The correlation equations and factors connected with them concern of extra high strength steels (category 420÷690). The HARDOX 400 steels are supplied in hardened condition. The chemical composition and R_m and HV (HB) are subjected given into control. In spite of above, it should be stressed, that the preliminary estimation results are promising and encourages to future tests in this direction. The precise estimation of those properties will be able to perform after the loading data of these group of steel research results. The control testing of welded joints mechanical properties were performed with procedure of admitting the HARDOX 400 processing technology. Sufficient compatibility of estimation and testing results was acquired for welded joints R_{ms}. Both – the correlation equations not supported on physical model and supported on physical model – the enough compatibility was acquired in compare to laboratory tests results.

CONCLUSIONS

Investigations of HARDOX 400 steel plates and their welded joints brought the following final conclusions:

- The plates of abrasion-resistant HARDOX 400 steel meet requirements of classification societies and can be used for ship construction parts,
- The butt welded joints made of HARDOX 400 meet requirements of classification societies (GL).
- The good agreement of laboratory tests results and assessment results obtained from correlation equations for mechanical properties of parent material and butt welded joints was indicated.
- The better assessment of mechanical properties of HARDOX 400 steel needs further laboratory tests and theoretical analysis.

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