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Improving the operating properties of coal mining machinery elements

Abstract: It has been presented a possibility of improvement in operating properties of mine skip buckets in drawing engines, made of S355 steel, by welding of lining elements made of Hardox 450 steel to places mostly exposed to abrasive-dynamical degradation.

Keywords: coal mines, mine skip buckets, S355J0, Hardox 450

Introduction

In Polish coal mines shaft hoists have seen many years of operation, requiring the necessity of regenerating worn elements. At the moment, one of the problems which limit maintaining the continuity of a technological process is the necessity of the periodical exchange of mining machinery elements exposed to abrasion and dynamic loads. It is important to replace elements exposed to the greatest loads with materials characterised by a greater resistance to abrasion and dynamic loads than the previously used structural steel S355. Criteria conditioning the selection of a proper steel grade for lining sheets in zones characterised by the highest exposition to dynamic and abrasive degradation not only include very high mechanical properties but also good weldability for various welding techniques while joining such a steel grade with steel S355. High abrasive resistance, significantly higher than that of steel S355 and good weldability is characteristic of low-alloy martensitic steel Hardox 450 [1-4]. However, due to a price approximately three times higher than that of steel S355 it is economically justified to use the steel for replacing only such lining elements which are most exposed to abrasive-dynamic wear. A particularly exposed zone is the one containing upper sheets located centrally in relation to the winning inlet and skip hoist container (see Figure 1).

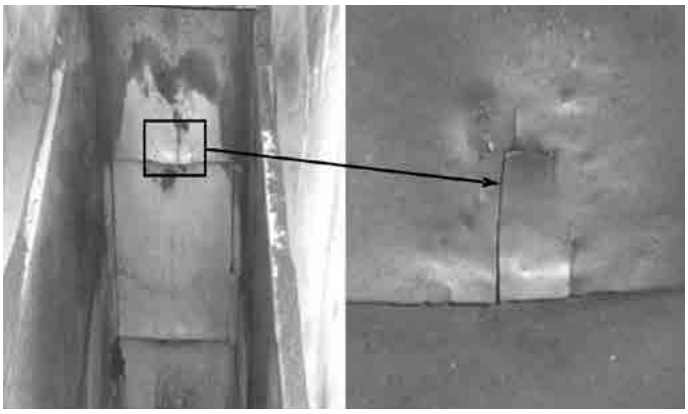

Fig. 1. Damage to lining sheets of skip hoist caused by mining winning falling into skip during loading

In consequence, it has become necessary to develop an efficient technology for repair welding of a shaft skip hoist bucket with reference to joining steel S355 elements with steel Hardox 450 lining sheets and implement this technology for repairing elements of mining machinery.

Tests and results

The technologies applied in the tests were MMA welding and MAG welding of plates

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(200×400×8 mm) made of steel Hardox 450 with plates made of steel S355J0. For each welding method one test plate combining two grades was prepared. Tables 1 and 2 present the chemical compositions and basic mechanical properties of sheets intended for welding on the basis of certificates issued by the manufacturers.

For each welding method one type of a filler metal produced by the ESAB sp. z o. o. company was selected. The MMA welding (process 111) involved the use of low-hydrogen covered electrodes OK 48.00 with a low hydrogen content (below 5 ml per 100 g of weld deposit), whereas the MAG welding (process 135) involved the use of a solid

Table 1. Chemical compositions of base metals of steel Hardox 450 and steel S355J0

Steel grade	Alloying element content, %										Carbon equivalent C_E, %
	C	Si	Mn	P	S	Cr	Ni	Mo	B	N	
Hardox 450	0.20	0.3	1.25	0.01	0.002	0.2	0.04	0.009	0.001		0.45
S355J0	0.19	0.36	1.20	0.03	0.02	-	-	-	-	0.009	0.39

Table 2. Mechanical properties of base metals of steel Hardox 450 and steel S355J0

Steel grade	Hardness, HBW	R_m, MPa	R_e, MPa	A_5, %	KV, J	Testing temperature, °C
Hardox 450	461	1430	1210	10	40	-40
S355J0	-	595	365	22	27	0
R_m – tensile strength, R_e – yield point, A_5 – elongation, KV – impact energy						

Table 3. Chemical composition and mechanical properties of filler metals

Filler metal	Alloying element content, %								Minimum mechanical properties			
									MPa		%	J
	C	Si	Mn	P	S	Ni	Mo	Ti	R_m	R_e	A_5	KV_{-40}
OK. 48.00	0.06	0.5	1.2	0.02	0.015	-	-	-	540	445	29	70
OK Autrod 13.25	0.08	0.6	1.8	-	-	1.0	0.4	0.15	700	620	20	90
R_m – tensile strength, R_e – yield point, A_5 – elongation, KV – impact energy.												

Table 4. Process parameters of MMA welding (111) and MAG welding (135)

Run no.	Electrode diameter, mm		Current, A		Arc voltage, V		Welding rate, mm/min		Heat supplied, kJ/mm	
	(111)	(135)	(111)	(135)	(111)	(135)	(111)	(135)	(111)	(135)
1	2.50	1.2	75	132	21	18.7	75	240	1.008	0.555
2	3.25		120	235	22	26.0	150	460	0.845	0.717
3	3.25		130	241	22	26.3	140	440	0.981	0.778
4	4.00		160	238	24	26.1	210	430	0.878	0.780
5	4.00	-	170	-	24	-	210	-	0.933	-
Prior to welding, covered electrodes were dried at ~350°C for 2 hours. Welding was carried out with DC (+) on the electrode. Shielding gas flow rate in MAG welding (mixture 82%Ar and 18%CO_2) ~15 l/min.										

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Table 5. Measurements results obtained in static tensile test of MMA welded joints (111)

Sample no.	Sample cross-section area S_0, mm²	Breaking force F_m, kN	Tensile strength R_m, MPa	Elongation A_5, %
1_1	179.57	106	590.30	19.7
1_2	173.66	101	581.60	20.3

Table 6. Measurements results obtained in static tensile test of MAG welded butt joints (135)

Sample no.	Sample cross-section area S_0, mm²	Breaking force F_m, kN	Tensile strength R_m, MPa	Elongation A_5, %
1_1	179.36	105	585.41	20.8
1_2	183.38	106	578.03	20.1

Table 7. Results of impact tests of MMA butt-welded joint (111)

Sample no.	Notch location	Sample dimensions (at notch location)			Measurement results KV, J
		h, mm	b, mm	S_0, mm²	
3_1	Weld	3	10	0,3	73
3_4					71
3_7					78
3_2	HAZ side S355J0				39
3_5					35
3_8					28
3_3	HAZ side Hardox 450				65
3_6					57
3_9					57

h, b – height and width of the sample at notch location, S_0 – sample cross-section area at notch location, KV – energy used for breaking the sample or drawing between supports

Table 8. Results of impact tests of MAG butt-welded joint (135)

Sample no.	Notch location	Sample dimensions (at notch location)			Measurement results KV, J
		h, mm	b, mm	$S_0{}^a$, mm²	
3_1	Weld	3	10	0,3	51
3_4					62
3_7					68
3_2	HAZ side S355J0				23
3_5					22
3_8					23
3_3	HAZ side Hardox 450				74
3_6					72
3_9					71

h, b – height and width of the sample at notch location, S_0 – sample cross-section area at notch location, KV – energy used for breaking the sample or drawing between supports

low-alloy copper electrode wire OK Autrod 13.25. The chemical composition and the basic mechanical properties of the filler metals are presented in Table 3.

The edges of plates to be welded were bevelled in accordance with standard PN-EN ISO 9692-1:2008 obtaining a V-shaped weld groove with an angle of 55°. The plates were welded without preheating, in vertical up position (PF), not exceeding an interpass temperature of 150°C. Joints were made in a multi-run manner. Process parameters were selected on the basis of results obtained in the initial welding tests (Table 4).

The test joints underwent visual testing and radiographic testing 72 hours following the welding process completion. No welding imperfections eliminating the joints from further tests were detected. The radiographic tests were carried out in accordance with the requirements of standard PN-EN 1435:2001. The radiograms revealed the presence of single pores in the welds; the dimensions of the pores were contained within the joint quality of level B according to PN-EN ISO 5817:2009.

The static tensile tests were carried out in accordance with the requirements of standard PN-EN ISO 4136:2013-05E. In each test the samples underwent rupture outside the welded joint area in the base metal

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of steel S355J0. The results of measurements concerning MMA and MAG welded butt joints are presented in Tables 5 and 6.

Charpy V-notch tests on the samples were carried out at ~20°C in accordance with standard PN-EN ISO 9016:2011. Due to the thickness of the tests plates amounting to 8 mm and the necessity of mechanical working of the samples, their thickness was reduced to 5 mm. A notch was made in the weld and HAZ. The results of the tests involving the butt joints made by means of methods 111 and 135 are presented in Tables 7 and 8.

The butt joints underwent bend tests in accordance with standard PN-EN ISO 5173:2010/A1:2012 with bending from the weld face side (FBB) and bending from the weld root side (RBB). A bending mandrel was selected on the basis of data contained in standard PN-EN ISO 15614-1. The bend test results were acceptable for each welding method. Bending angles obtained were from 130° to 155° (greater for RBB). No cracks in the joint were revealed.

Vickers hardness tests were conducted in accordance with standard PN-EN ISO 6507-1:2007. The tested cross-section of the MMA-welded (111) and MAG-welded (135) joint sample with measurement points located along measurement lines A and B are presented in Figure 2. Figures 3 and 4 present the hardness distribution curves in the joints made using methods 111 and 135.

In the case of both welding technologies, macroscopic tests revealed the proper shape

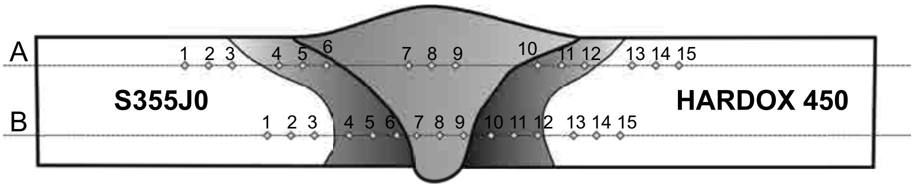

Fig. 2. Location of hardness measurement points in welded joins

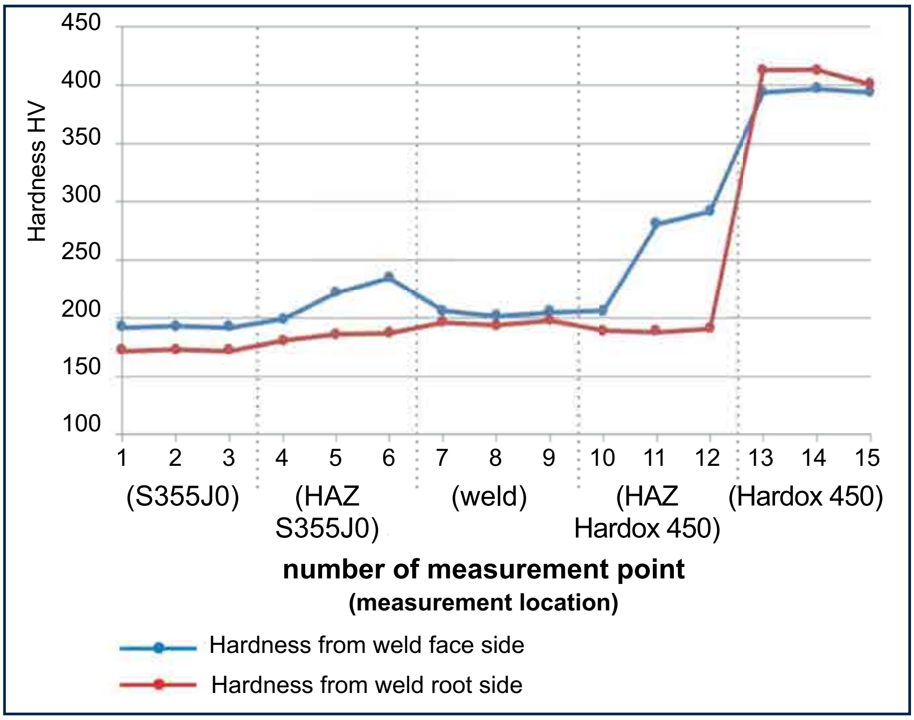

Fig. 3. Curves of hardness distribution in MMA-welded joins (111)

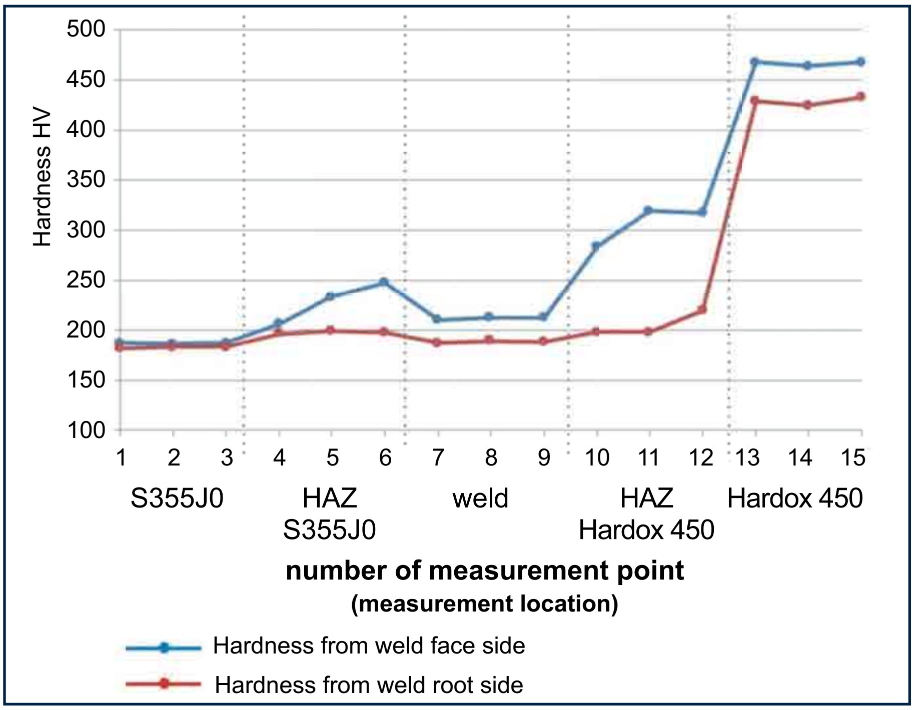

Fig. 4. Curves of hardness distribution in MAG-welded joins (135)

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of a weld face and a weld root as well as the proper shape of fusion into the base metal. No blowholes or slag inclusions in the weld were detected. The results of microscopic tests are presented in Figures 5-7.

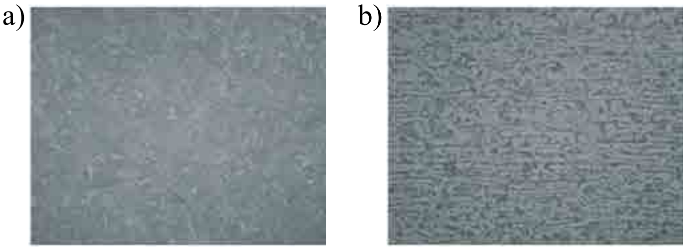

Fig. 5. Base metal macrostructure of:
a) steel Hardox 450 – high-tempered martensite structure;
b) steel S355J0 – ferritic-pearlitic structure;
mag. x200, etchant Mi1Fe

Fig. 6. Microstructure of MMA-welded joint (111); mag. x200, etchant Mi1Fe

Fig. 7. Microstructure of MAG-welded joint (135); mag. x200, etchant Mi1Fe

The tests aimed to determine resistance to abrasive wear were carried out in accordance with the recommendations of standard ASTM G 65-00, Procedure A. In order to conduct the tests it was necessary to cut two samples out of the welded joints; the dimensions of the samples were 75×25×8 mm. The faces of the welds were ground to the plate surface. The tests also involved the preparation of two samples (having the same dimensions) cut out of steel Hardox 450 plate and two samples cut out of steel S355J0 plate. Before and after the abrasive resistance tests, all the samples, following the instructions of standard ASTM G 65-00, were weighed with an accuracy of 0.0001 g. The mass loss of the welded joints and the mass loss of the samples made of steel S355J0 were compared directly with the mass loss of the samples made of steel Hardox 450. During the test a frictional wheel made six thousand revolutions. The abrasive material flow rate was 335 g/min. The force exerted on the samples during the test amounted to 130 N. The results obtained in

Table 9. Results of metal-mineral abrasive resistance tests of welds made with methods (111), (135) and of steel S355J0 plate, related to abrasive resistance of steel Hardox 450; reference standard ASTM G 65-00

Sampling spot	Sample designation	Mass before test, g	Mass after tests, g	Mass loss, g	Average mass loss, g	Relative abrasive resistance, %
Joint (111)	$1S_1$	117.1719	115.1279	2.0440	2.0423	72.53
	$1S_2$	116.8654	114.8248	2.0406		
Joint (135)	$3S_1$	115.5903	113.5186	2.0717	2.0704	71.54
	$3S_2$	115.8544	113.7852	2.0692		
S355J0	P_1	115.3390	113.5577	1.7813	1.7960	82.47
	P_2	116.4360	114.6254	1.8106		
Hardox 450	H_1	116.2391	114.7533	1.4858	1.4812	100
	H_2	117.1134	115.6368	1.4766		

Results were referred to the samples made of Hardox 450 plate. The force exerted on the samples during the test was 130N.

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the tests and the calculated relative metal-mineral abrasive resistance of individual welds referring to steel Hardox 450 are presented in Table 9 and in Figure 8.

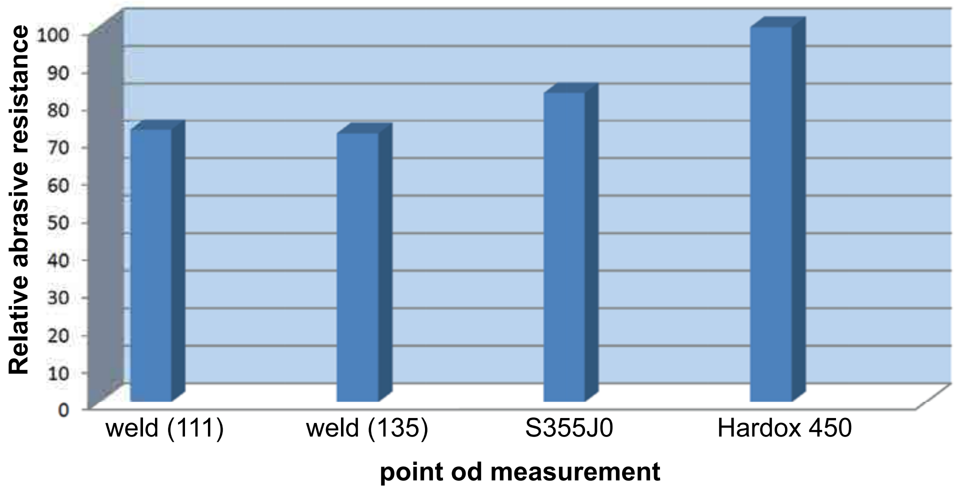

Fig. 8. Relative metal-mineral abrasive resistance of welds made with methods (111) and (135) and of S355J0 plate in relation to abrasive resistance of steel Hardox 450

Concluding remarks

The analysis of the results of the tests dedicated to the development of a technology for repair welding of a shaft skip hoist bucket using MMA welding (111) with a low-hydrogen electrode OK 48.00 and MAG welding (135) with a welding wire OK Autrod 13.25 makes it possible to formulate the following conclusions:

1. NDT and DT of butt joints of steel S355J0 welded with steel Hardox 450 by means of methods 111 and 135 revealed that the technology developed for welding by means of the aforesaid methods ensures the acceptable quality of such joints.

2. The metal-mineral abrasive resistance of the MMA-welded butt joints with a low-hydrogen electrode OK 48.00 and of the MAG-welded joints made with a welding wire OK Autrod 13.25 constitutes approximately 70% of the relative abrasive wear resistance of Hardox 450 steel.

3. The amount of supplied heat ensuring the production of high-quality joints is higher in method 111 and very similar to the boundary value of welding linear energy being 1.0 kJ/mm, which according to recommendations of the producer of steel Hardox 450 for 8 mm thick plates should not be exceeded.

4. The tests results obtained indicate the possibility of improving the operational properties of a shaft skip hoist bucket made of steel S355 by providing the areas most exposed to abrasive-dynamic degradation with lining elements made of Hardox 450 steel.

References

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