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THE RESISTANCE OF LEDEBURITIC TOOL STEELS AGAINST THE ABRASIVE WEAR

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Abstract

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The ledeburitic tool steels which used to be used mainly for cutting and shaping tools nowadays are frequently used for a manufacture of injection moulds, moulds for pressure castings of aluminium alloys and for moulds for ceramics processing. The article deals with findings of ledeburitic tool steels resistance against abrasive wear. For the tests there were prepared the test samples of ledeburitic tool steels 19 436 and 19 573 (both according to ČSN). Moreover there were prepared the samples from structural abrasion resistant material Hardox 450 and from unalloyed structural steel 11 373 (according to ČSN). A wear resistance was examined by means of a laboratory test with an abrasive cloth and the Bond's device. Hereafter the article deals with a possibility of utilisation of ledeburitic alloyed steels for a manufacture of tools for a land processing. For the examination of a resistance against wear in land there was made a plough test in which the tested samples were mounted on plough blades. By means of both the laboratory and operational tests there was found multiple higher resistance against wear of ledeburitic tool steels rather than of structural steels. During a land processing there was found unsuitability of steels processed for a maximum hardness, which came out as fractures of several samples.

abrasion, ledeburite, tool steel, test

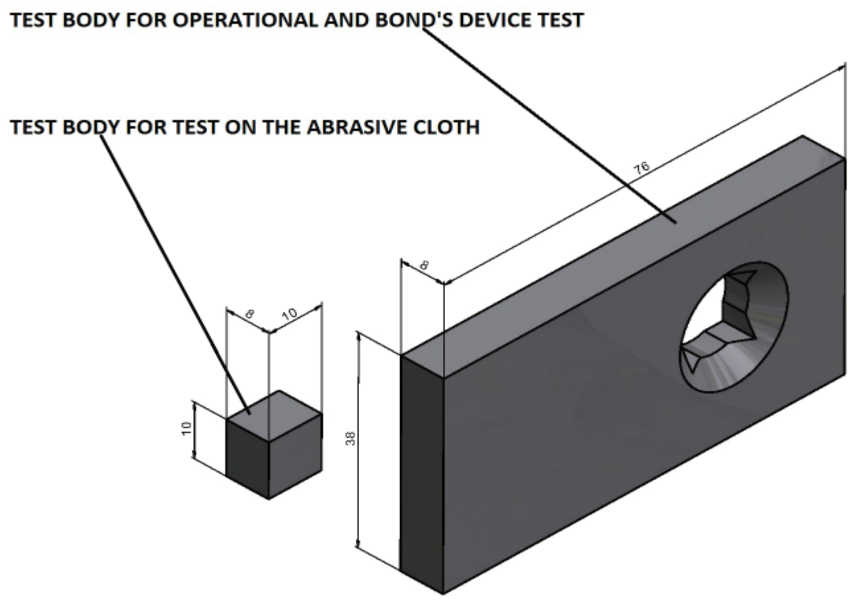
The enormous sum of money is invested into the repairs of abraded and worn parts every year. For example land contains a silica sand with the hardness 900-1280HV with strong abrasive effect (Suchánek *et al.*, 2007). Discovering of right materials and their heat treatment for shelf life of parts in abrasive land environment is more and more important. For example the resistance against wear of low alloyed steel with a carbon content 0.55%, softly annealed and toughened rises 1.5 times and using quench hardening even 2.5 times (Filípek, Černý, 2002). It is no less important to speak about an ecological benefit of parts with higher abrasive resistance, longer lifetime and lower cutting resistance with regard to ecologically thinking times. It is known that blunt parts of a plough increase the energetic difficulty during ploughing about 19% (Sedlák, Bauer, 1998).

High alloyed ledeburitic tool steels are used for making of cutting instruments, moulding tools, compression moulds. These steels are also used for making of high pressure foundry moulds for aluminium castings and hammers and jaws for crushers.

MATERIALS AND METHODS

Test bodies

For abrasive wearing test there were prepared test bodies. These bodies, with defined dimensions consisting (Fig. 1) of two tool materials 19 436 (according to ČSN) or X210Cr12 (according to EN) and 19 573 (according to ČSN) or X153CrMoV12 (according to EN), were prepared for the wear test. The other test bodies were made of the abrasive-resistance material Hardox 400 and for comparing they were made of the unalloyed structural steel 11 373 (according to ČSN) or S235JRG1 (according to EN) with different heat treatment (Tab. I). The samples were manufactured from the flat steel



1: *Test bodies for operational and laboratory tests*

I: *Marking, heat treatment, hardness and chemical composition of test bodies*

Material according to ČSN	Heat treatment	Average hardness [HV]	Chemical composition (%)						
			C	Mn	Si	Cr	Mo	V	Ni
11 373	-	175	0.22						
11 373	quenched	395	0.22						
11 373	quenched + tempered 600 °C	258	0.22						
Hardox 450	-	318	0.21	1.6	0.7	0.5	0.25		0.2 - 0.5
19 436	quenched + tempered	742	1.8 –2.05	0.2 –0.45	0.2 - 0.4	11 –12.5			0 –0.5
19 573	quenched + tempered	670	1.4 - 1.6	0.2 –0.45	0.2 –0.45	11 –12.5	0.6 –0.95	0.8 - 1.2	

profile with a grinding allowance after the heat treatment.

Heat treatment of ledeburitic steels

The sample 19 436 – hardening machine Coderre. Heating in the protective atmosphere of a methanol and a nitrogen with carbon potential 0,8. The inclination and soak time are 60 minutes, only soak time 30 minutes at the temperature 940 °C. Cooling down in the oil at 80 °C. Tempering to the hardness 61 HRC, temperature 170 °C, soak time 45 minutes.

The sample 19 573 – vacuum hardening machine Schmetz.

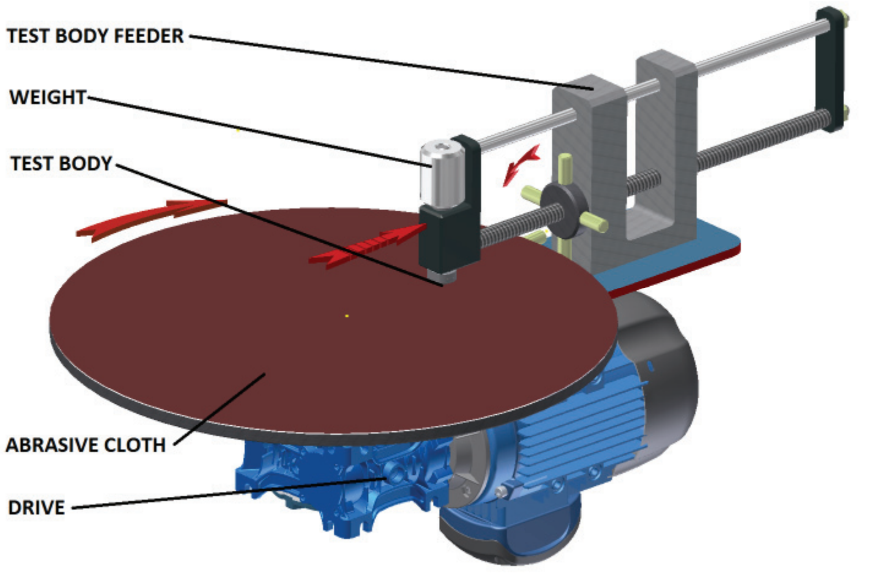
The heating in the vacuum with three-degree inclination 650–850–1 060 °C, inclination and a soak time are 4 hours 30 minutes altogether (samples were quenched or tempered with big parts of moulds, the length of a soak time has to provide the heating of big parts. The sample was treated by nitrogen stream with the pressure 6 bar and the temperature of nitrogen 20 °C. Then the samples were tempered three times at temperatures 510, 530 and 480 °C.

Test device

The samples were tested on an abrasive cloth, in the Bond's device and at an operational ploughing test.

Wear test on the abrasive cloth according to ČSN 01 5084

The instrument consists of a disc with new abrasive cloth for each test, abrasive material – corundum with granularity 120 and a clamping head. The test body is fastened in it and is pressed on



2: *Wear test on the abrasive cloth*

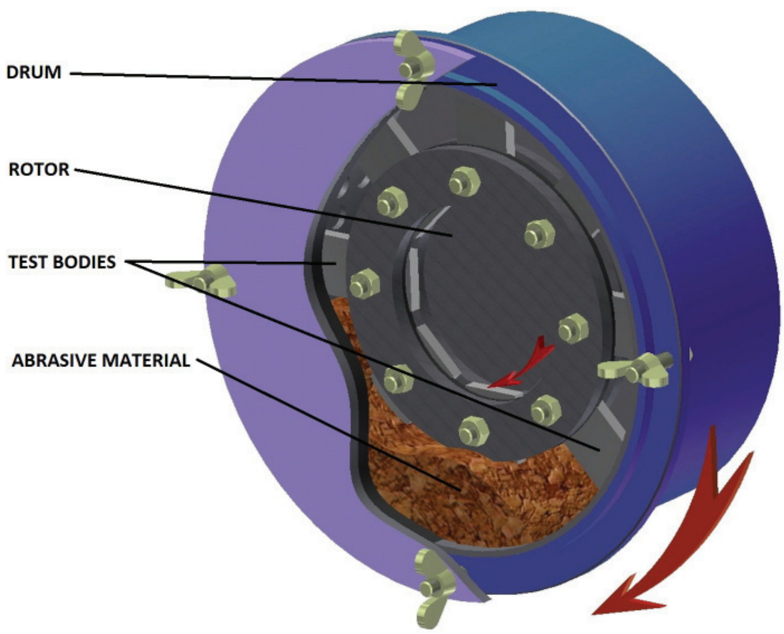
the abrasive cloth by power of 32 N. The weight loss of each sample was measured during the working distance 50 metres (Fig. 2).

The wear test in the Bond's device

Free parts of abrasive materials are poured into the rotational cylinder with angular speed 7.3 s^{-1}. The rotor, in which 8 bodies are fixed on, rotates on the coaxial shaft by the angular speed 64.4 s^{-1} in the same direction (Fig. 3). Three kinds of abrasives were used for this test (Tab. II). Volume of abrasive was 0.001 m^3.

Operational wear test

The ploughing unit of the plough Lemken Varidiamand 10 and the tractor CASE Magnum 250 (Fig. 4), consisting of seven ploughs, was used for this operational test. The test took place in Czech-Moravian highland in autumn 2011 (Oberreiter, 2012). The test samples were fixed between a blade and a clearing part on each ploughing body (Fig. 5). The length of a groove was measured by a radar. The operational wear test was situated near Kralovka (centre of the field 49°18'29.109"N, 16°13'45.420"E) and land samples were taken for a definition of a granulometry (Tab. III).



3: *The wear test in the Bond's device*

II: *Granulometry of abrasive materials for test in the Bond's device*

	Fraction size (mm)	10.00–2.00	2.00–0.25	0.25–0.05	0.05–0.01	< 0.01
concreting sand from locality Bratčice	**Fractions content (%)**	22.3	67.06	7.45	1.21	1.98
shale	**Fractions content (%)**	-	38.28	61.72		
ceramic mixture	**Fractions content (%)**	-	15.96	84.04		

4: *Operational wear test*

5: *Test samples fixed on ploughing body*

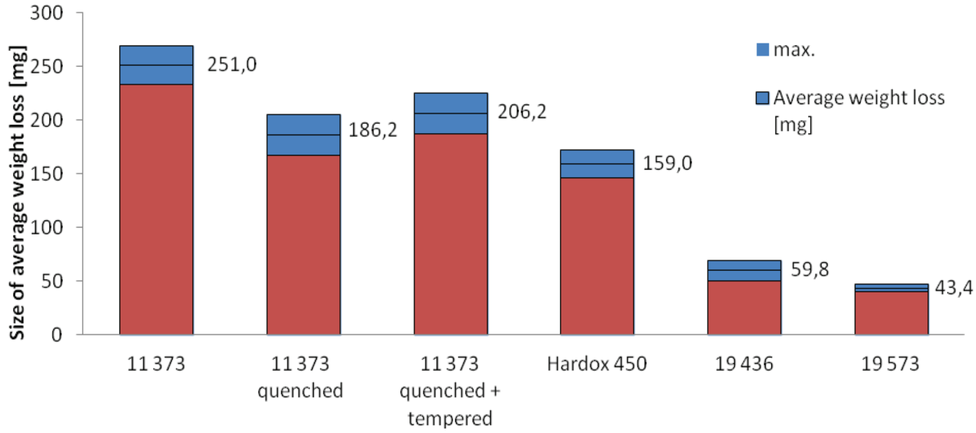
III: *Granulometry of land sample*

Fraction size (mm)	2.00–0.25	0.25–0.05	0.05–0.01	0.01–0.001	< 0.001
Fractions content (%)	7.18	29.14	30.52	19.14	13.76

RESULTS AND DISCUSSION

Wear test on the abrasive cloth

The size of an average weight loss and wear resistance on the abrasive cloth was measured by the laboratory test, which was always done on five samples of each type of material. The length of a sample trajectory on the abrasive cloth was 50 metres (Fig. 6, Fig. 7). The ledeburitic tool steels have a multiple higher wear resistance than structural



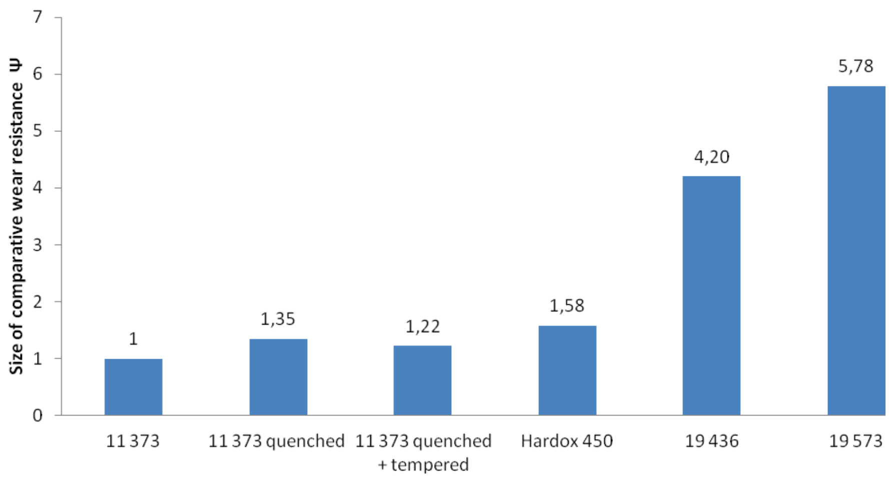
6: *Size of average weight loss on the abrasive cloth (α = 0.05)*

IV: *Average weight loss of test bodies*

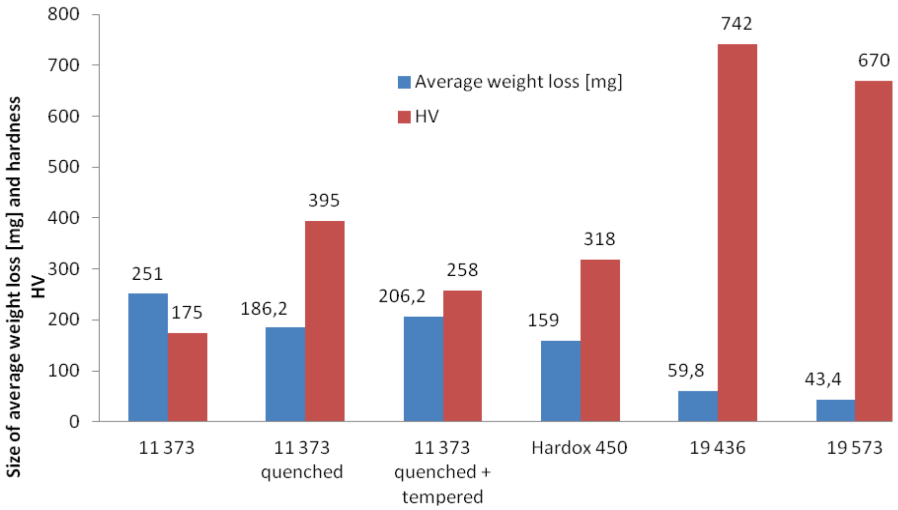
Kind of test		Material according to ČSN	Heat treatment	Number of samples	Statistical characteristic (mg)				
					x_{min}	x_{max}	$\bar{x}$	Confidence interval for parameter μ (α = 0.05)	s
Abrasive cloth		11 373	–	5	235	270	251.00	233.05–268.95	14.46
		11 373	quenched	5	171	207	186.20	167.24–205.16	15.27
		11 373	quenched + Tempered 600 °C	5	193	226	206.20	187.65–224.75	14.94
		Hardox 450	–	5	148	173	159.00	145.89–172.11	10.56
		19 436	quenched + tempered	5	53	72	59.80	50.05–69.55	7.85
		19 573	quenched + tempered	5	40	47	43.40	40.05–46.75	2.70
Bond's device	concreting sand from locality Bratčice	11 373	–	8	29	64	47.50	37.05–57.95	12.50
		11 373	quenched	8	25	51	38.38	30.47–46.29	9.46
		11 373	quenched + Tempered 600 °C	8	31	59	43.75	35.44–52.06	9.94
		Hardox 450	–	8	28	51	42.25	33.93–50.57	9.95
		19 436	quenched + tempered	8	12	17	14.13	12.55–15.71	1.89
		19 573	quenched + tempered	8	11	14	12.63	11.64–13.62	1.19
	shale	11 373	–	8	19	27	24.50	22.27–26.73	2.67
		11 373	quenched	8	13	19	15.63	13.85–17.41	2.13
		11 373	quenched + Tempered 600 °C	8	15	27	20.00	16.26–23.74	4.47
		Hardox 450	–	8	16	27	21.38	16.63–26.13	5.68
		19 436	quenched + tempered	8	3	8	5.63	4.22–7.04	1.69
		19 573	quenched + tempered	8	5	10	7.50	6.16–8.84	1.60
	ceramic mixture	11 373	–	8	8	17	11.13	8.55–13.71	3.09
		11 373	quenched	8	5	9	7.25	5.93–8.57	1.58
		11 373	quenched + Tempered 600 °C	8	7	12	9.25	7.48–11.02	2.12
		Hardox 450	–	8	5	11	7.63	5.74–9.52	2.26
		19 436	quenched + tempered	8	1	3	1.88	1.05–2.71	0.99
		19 573	quenched + tempered	8	1	3	2.00	1.37–2.63	0.76

V: *average weight loss of test bodies*

Kind of test	Material according to ČSN	Heat treatment	Number of samples	x_{min}	x_{max}	$\bar{x}$	Confidence interval for parameter μ (α = 0.05)	s
				Statistical characteristic (g)				
Operational wear test	11 373	–	6	9.58	14.65	12.32	9.52–15.12	2.67
	11 373	quenched	2	9.00	9.26	9.13	7.48–10.78	0.18
	11 373	quenched + tempered 600 °C	6	5.64	12.74	9.58	6.97–12.19	2.49
	Hardox 450	–	6	7.57	13.46	10.55	8.04–13.06	2.39
	19 436	quenched + tempered	2	2.28	2.74	2.51	0.41–5.43	0.33
	19 573	quenched +tempered	6	1.31	4.54	2.85	1.51–4.19	1.28

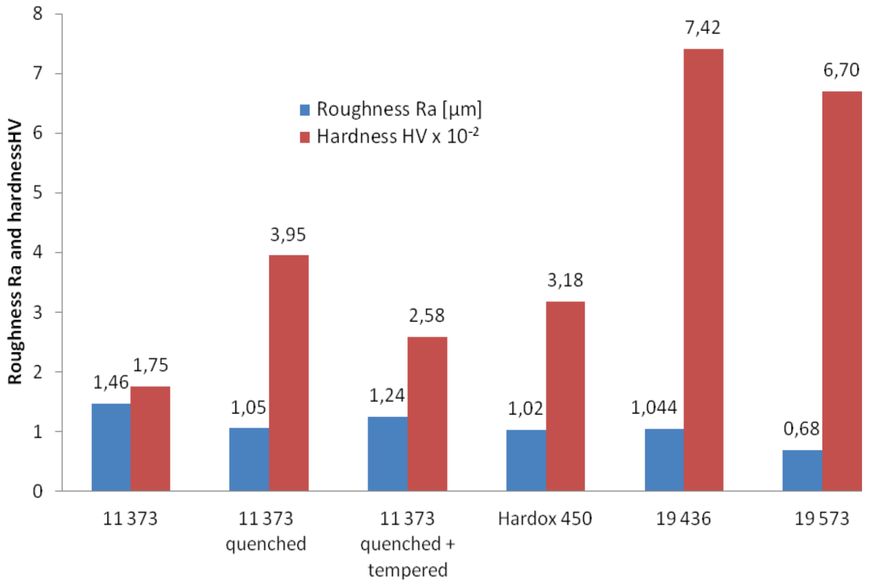


7: *Size of comparative wear resistance on the abrasive cloth*

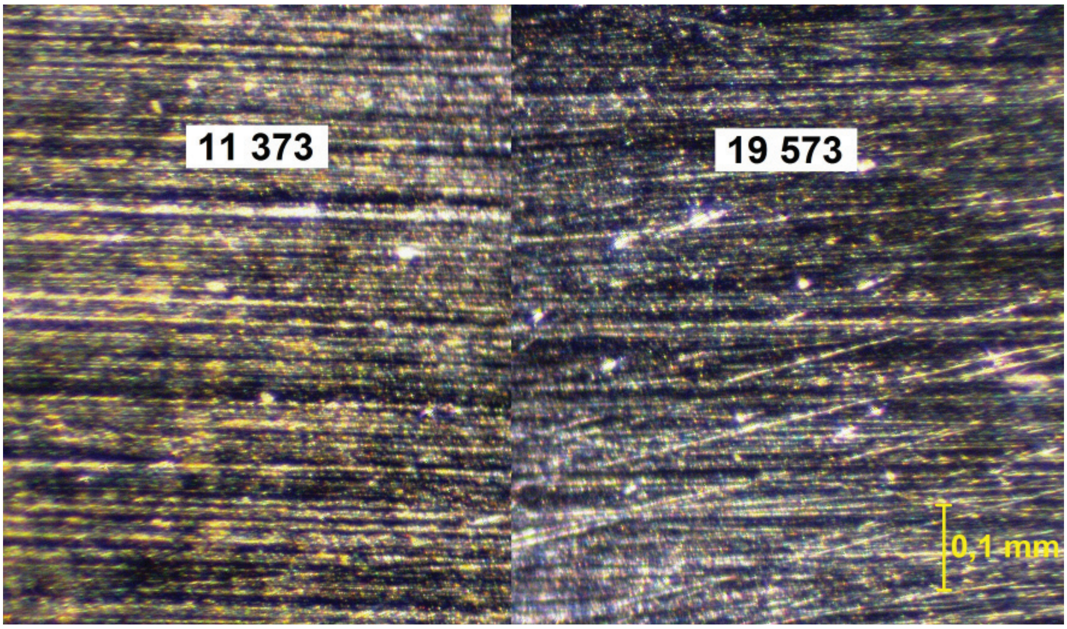


8: *Size of average weight loss and test bodies hardness on the abrasive cloth*

materials (steel 19 573 nearly six times more). The wear resistance of most samples depends on the hardness (Fig. 8). The sample of steel 19 573 (according to ČSN) has higher resistance than the sample 19 436 (according to ČSN). It depends on higher toughness and some presented elements (e.g. molybdenum, vanadium). The roughness of all samples was measured after the test (Fig. 9, Fig. 10). Looking at the picture it is clear that the decreasing hardness depends on a rising roughness of the wear surface.



9: *Roughness and test bodies hardness on the abrasive cloth*



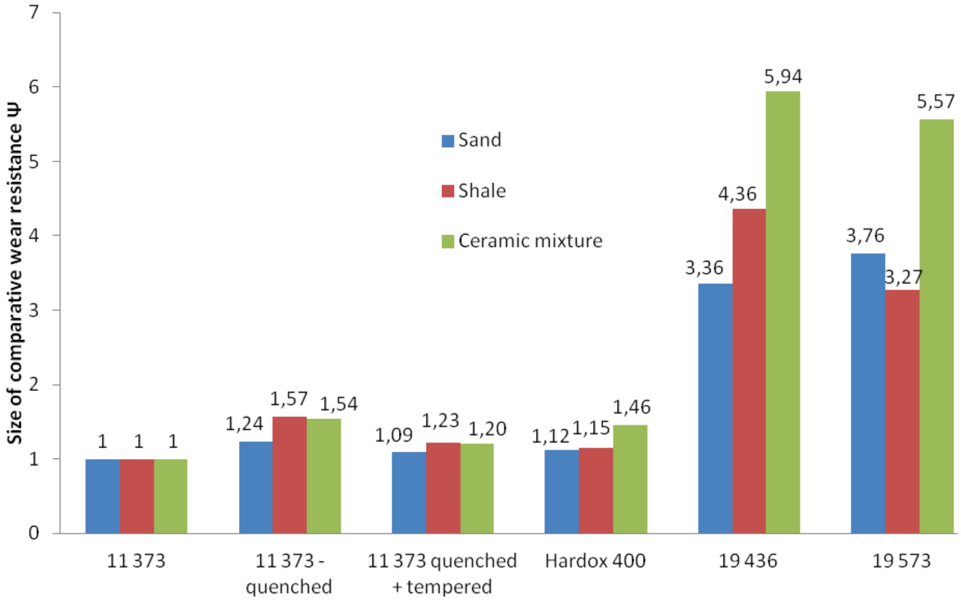
10: *Micro-photograph of the wear surfaces after the test on the abrasive cloth*

Laboratory test in the Bond's device

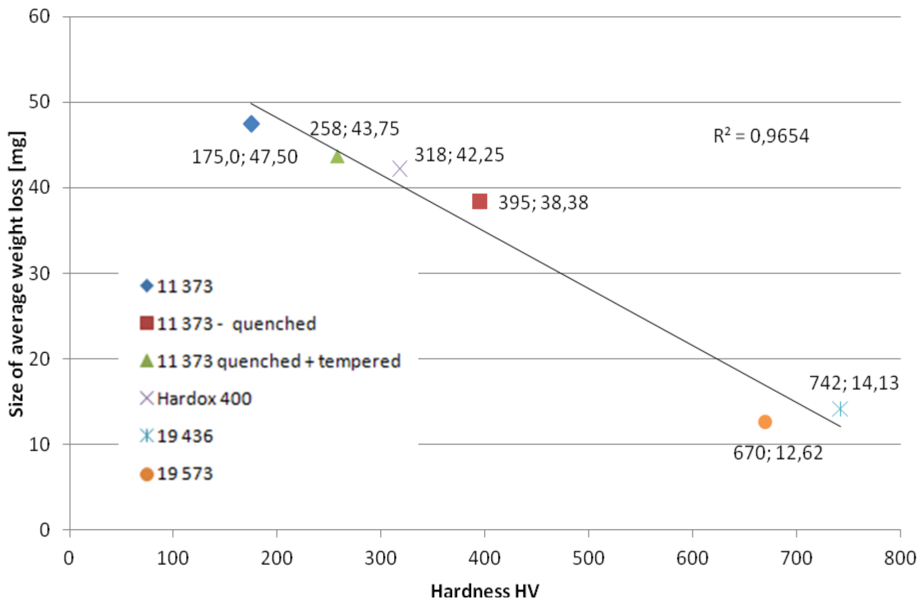
Tests were performed always with eight tested samples which were in a motion for sixty minutes in each used abrading agent (0,001 m^3). After weight measuring of each sample the value of an average weight loss (Tab. IV) and the wear resistance was found out (Fig. 11). Looking at some pictures and charts II the highest wear was reached using the abrading agent including the roughest parts. The grinding, crushing of an abrasive material for rounding edges of abrasive grains were realised, the intensity of wear process is the biggest at the beginning of test. It is necessary to change the abrasive material (Březina *et. al.*, 2005). Ledeburitic tool steels showed higher wear resistance in the test, the average weight loss falls down depending on rising wear resistance (Fig. 12). There is the biggest wear on the leading edges (Fig. 13). The resistance against wear of steel samples tested in the Bond's device depends on an abrasive medium. E.g. in case of land samples from 14 localities of the South Moravian Region there were up to 15 multiple differences in the wear (Filípek, Jandák, 1999).

Operational wear test

The operational test was done in the land distance of 10 000 metres always on six samples. Again there was proven a high abrasive resistance of ledeburitic

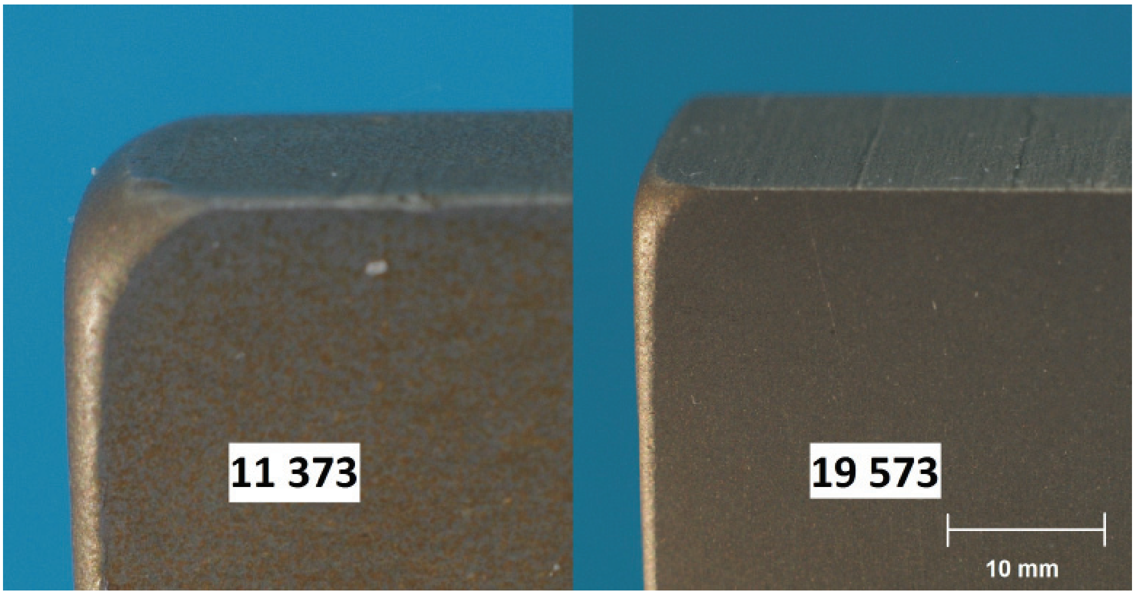


11: *Size of comparative wear resistance during the test with different abrasives in the Bond's device*

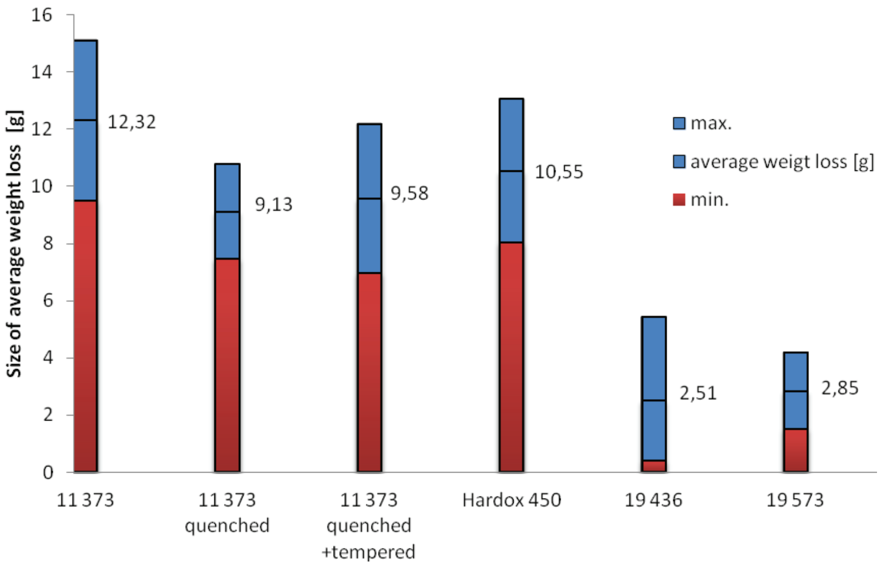


12: *Size of average weight and test bodies hardness in the Bond's device*

tool steels used under real operational conditions (Fig. 14). Both tool steels are five times more resistant than structural materials. The best treatment of unalloyed construction steel 11 373 (according to ČSN) does not increase the abrasive resistance (Fig. 15). With relation to the low toughness of steel 19 436 there were some broken samples during the operational test but this steel was the most resistant thanks to the high hardness (Fig. 16). The operational test has the biggest material wastage (Fig. 17). From the tests with abrasive cloth not always decide about wear during ploughing. E.g. mass decrease of a steel 11 373 (according to ČSN) achieved with an abrasive cloth were up to 25 times higher than at welded-on-piece materials (Filípek, Březina, 2007). During a ploughing test the wear mechanism is different, the mass decrease of a steel 11 373 (according to ČSN) was 7 times higher than at compared welded-on-pieces.



13: *Wear on the leading edges*



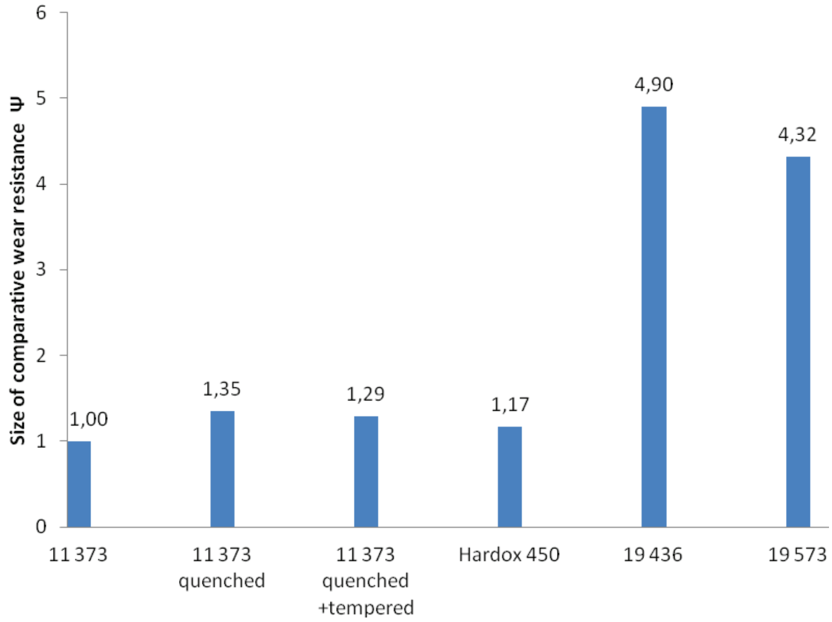
14: *Size of average weight loss of the test bodies in the distance 10 000 m (α = 0.05)*

CONCLUSION

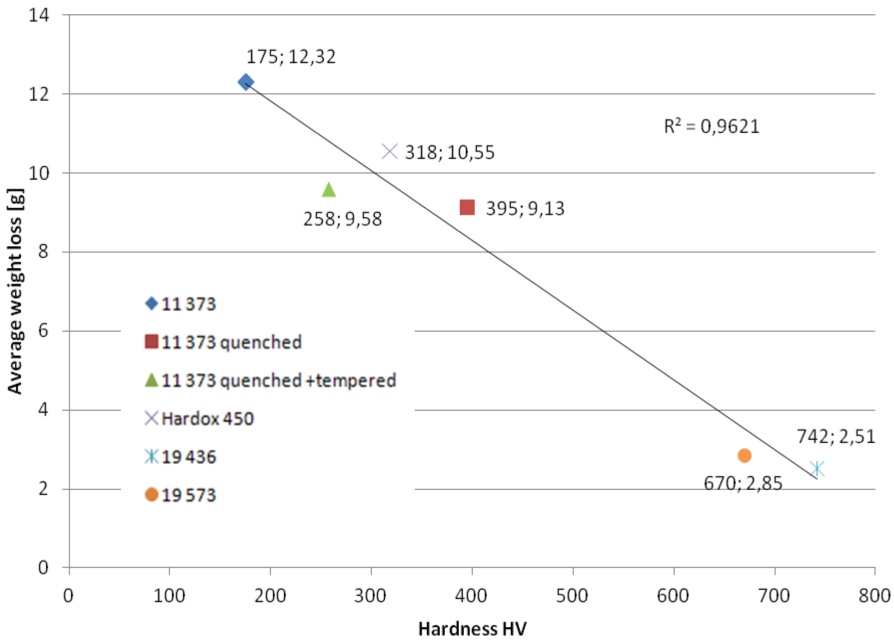
The ledeburitic tool steels, which were mainly used for a manufacture of cutting and moulding tools, are now used for a manufacture of compression moulds, high pressure foundry moulds for aluminium alloys and the injection moulds for ceramic processes. The article deals with the wear hardness of tool steels evaluated in laboratory and operational tests. Some samples of ledeburitic tools steels are compared with structural materials with a different heat treatment. The operational test checks up the using of ledeburitic tool steels for making land processing instruments.

According to the test on abrasive cloth these types of steels showed a higher wear resistance than martenzitic weldings (Müller *et al.*, 2011). The steel 19 573 (according to ČSN) had a bigger wear resistance than the steel 19 573 (according to ČSN) in spite of being tempered to the hardness less for 72HV. The content of extremely hard vanadium carbide caused higher wear resistance.

The rising abrasive resistance with rising hardness of steel samples were showed in the Bond's device tests, especially the ledeburitic steel samples had five times higher resistance than the structural steels with the low hardness (Fig. 12). The steels 19 436 (according to ČSN) and 19 573 (according to ČSN) are suitable for making of complex mould parts for semi-arid mixtures.



15: *Size of comparative wear resistance during the operational wear test*



16: *Size of average weight and test bodies hardness during the operational wear test*

The operational test corresponds with the test in the Bond's device but the tool steel 19436, quenched to the hardness 742HV, is thanks to its brittleness not suitable for land operation. This was proven by breaking and losing of some test samples during the operational tests. According to that the authors have found out that the steel 19 573 (according to ČSN) is suitable for that purpose. This steel tempered three times showed sufficient toughness at the same hardness and required abrasive resistance. Although the price of tool steels is higher, there would be possible to use steel 19 573 (according to ČSN) for the parts whose complicated and long-lasting adjustment compensate the price of a more expensive and more durable materials.

17: *Wear test bodies after the operational test in the distance 43 500 m*

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