

## Possibilities of Modification of Ploughshares Used for Winter Maintenance of Forest Roads

Miroslava Ťavodová<sup>1</sup>, Monika Vargová<sup>1</sup>, Ladislav Falat<sup>2</sup>

<sup>1</sup>Faculty of Technology, Technical University in Zvolen, Študentská 26, 960 01 Zvolen. Slovak Republic. [tavodova@tuzvo.sk](mailto:tavodova@tuzvo.sk), [xvargova@tuzvo.sk](mailto:xvargova@tuzvo.sk).

<sup>2</sup>Slovak Academy of Sciences Košice, Institute of Materials Research, Watsonova 47, 040 01 Košice. Slovak republic. [lfalat@saske.sk](mailto:lfalat@saske.sk).

The article presents partial results of research to increase the service life of snow ploughshares, which are used for winter maintenance of forest transport roads. The main working tool of vehicles - snow plough is the arrow ploughshare. It is made as a weldment. The contact tool, when in contact with the road, is the rake blade, which is subject to abrasive wear. The experiment consisted of analysing the current state of materials, designing and exploring such options that would ensure a longer service life of the blades. Welding material was designed to be applied to the base material of the blade. Furthermore, the HARDOX 450 was designed for the production of the whole ploughshare. The last design was welding HARDOX 450 with an electrode OK 48.00 with the base material steel 11 484. This proposal is presented in more detail in the article. The hardness of HBW, HV and HRC was measured on the samples and microscopic analysis was performed using light and electron microscopy. The aim was to determine the quality of the connection of materials, mixing in the connection zone and comparison with the condition on the original blade. It is assumed that a suitable choice of welding electrode or a suitable choice of abrasion-resistant steel can achieve an effective increase in the life of the snow ploughshare, whether from a technical or economic point of view.

**Keywords:** snow ploughshare, wear, hardness, forest roads, HARDOX 450

### 1 Introduction

Making forests accessible is very important from the point of view of their farming, management and protection. Forest stands are mostly located in remote, often difficult to access areas. Transporting wood is very strenuous and expensive. Therefore, it is important to make transport appropriate by an adequate and satisfactory network of forest roads [1,2]. This is also associated with taking care of their good condition, not only in summer but also in winter. A snow blades, cutters, but also graders, bulldozers, etc. are used to remove snow from roads. The snow plough works in a heterogeneous environment. When working, it comes into contact with the roadway - with snow, ice, stones, mineral particles, gravel, sand, etc. First, the raking blade comes into contact with the roadway. It is loaded by impact at the first contact. Furthermore, throughout the raked, by corrosion and abrasion. In addition to the raking blade, the rest of the ploughshare is also loading, because the accumulated snow, together with sand and gravel, exerts a force on the ploughshare body from the shirr until it is swept to the side of the road. As a result, wear occurs due to abrasion, impact and corrosion not only the raking

blade, but of the entire working part of the ploughshare, so of weldment. Early decommissioning causes both technical and economic problems for companies operating in forestry. Therefore, it is necessary to focus on the wear of snow ploughshares and find suitable methods to increase their service life.

### 2 Material and methods

A forest road is a purpose-built road that is part of a forest transport network. It is intended for the transport of wood, people, materials, for the passage the special vehicles (fire, medical service), but it can also be used for other purposes. It has a built-in earth body and at least a simple drainage [2]. The transport forest roads of 1st class (1L) are usually single-lane, enabling their spatial arrangement and technical equipment to operate all year round (assuming winter maintenance) with a relevant vehicle, by the considered design intensity of traffic. These roads have a roadway, complete drainage of the crown and the body of the forest road and must be equipped with shunt. The recommended lane width is 3.5 m (at least 3.0 m), the free width of the road is recommended 4.5 m (at least 4.0 m). The maximum permissible longitudinal slope is 10% (max. 12%) (Fig. 1a) [2,3].

Maintenance of forest roads is regular or cyclical

care for the preservation of the forest road in a condition that suits its planned transport use. When performing maintenance, traffic on the forest road is usually not interrupted. The scope of maintenance of forest transport roads is determined by valid standards in the field of maintenance of forest transport roads.



**Fig. 1** The 1st class forest roads - 1L [2], a - forest road in summer; b - forest road without winter maintenance

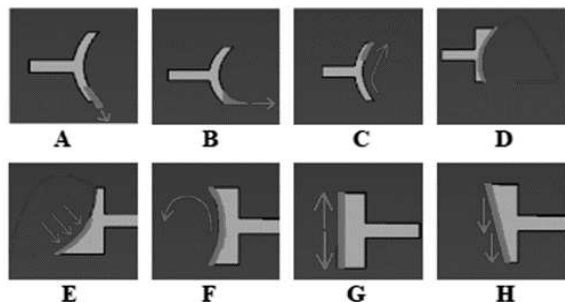
On forest roads, arrow ploughshares, which are mounted in front of trucks or tractors, have proved their worth in removing snow. They are used for winter maintenance of roads and are used to remove snow

from external surfaces. The shape and inclination of the snow ploughshare is adapted so that the snow is deflected onto the relevant part of the road (Fig. 2a and 2b).



**Fig. 2** Examples of the use of snow arrow blades for road maintenance [4]

The ploughshare itself (not only the raked blade) is stressed by abrasive wear due to forces (Fig. 3) from the removed material.



**Fig. 3** The forces impacted to ploughshare [5], A-penetrating, B-cutting, C-digging, D-trapping, E-carrying, F-rolling, G-planning, H-lining

The ploughshares are exposed to abrasive, impact and corrosive wear in the environment in which they work. The current standards state that abrasive wear is characterized by the separation of particles from the worn surface:

a, by grooving and cutting with hard particles - hard foreign particles cut or scratch the surface of the body.

b, by grooving and cutting with a hard and rough surface of the second body - unevenness of the surface of the harder body penetrates into the softer surface of the second body and carves scratches in it. The groove material is usually removed in the form of loose particles [6,7].

During impact wear, the material is exposed to im-

pact and high pressure, deformation or local disturbance may occur, possibly even breakage [8].

Corrosive wear is a permanent undesirable change in the surface of the material caused by electrochemical and chemical influences of the environment. According to the mechanism of corrosion phenomenon, we know chemical and electrochemical corrosion, and according to the environment where it takes place, it is atmospheric, soil corrosion or corrosion in water, gases and etc. The most common corrosion is atmospheric corrosion. It is formed and takes place when moisture, ions of mineral salts and atmospheric oxygen and other gases ( $\text{SO}_2$ ,  $\text{H}_2\text{S}$ ,  $\text{Cl}$ , ...) are present. The product of corrosion is the so-called rust. Rust is a mixture of said compounds, starting materials and compounds of simultaneous reactions. Water and  $\text{H}_2\text{SO}_4$  are always in the rust, so corrosion can continue independently of the access of other corrosive agents even under coatings and preservatives [9].

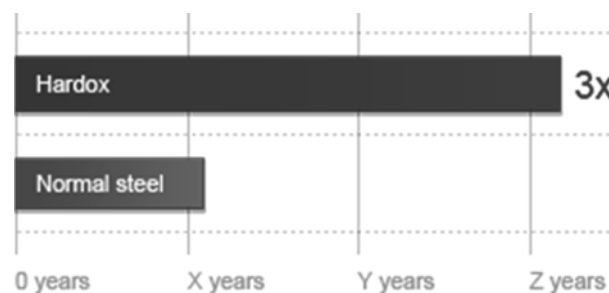
There are several possibilities to increase the resistance of tools to mainly abrasive wear:

- technological processes of heat treatment in order to create a structure more resistant to wear,
- application of sintered carbide elements or material-like materials,
- used the hardface materials on exposed, most heavily loaded parts,
- complete change of material - e.g. steels of the HARDOX, ABRACORR type, etc. [10].

HARDOX low-alloy steel achieves high strength properties due to appropriate composition of the alloying additives (low content of harmful elements such as S and P) at a relatively lower price in comparison with other structural steel [11]. HARDOX steel differ depending on the species and plate thickness, carbon content and alloying elements (Ni, Mn, Cr, Mo, B). Nickel with a content from 0.25 to approximately 2.50% does not form a carbide in these steels but causes lowering of the austenitizing temperature (with the formation of a fairly wide area like austenite + ferrite) and lowers the transition temperature of the material in the brittle fracture. Manganese is added at a level of 1.0 to 1.6%, improving the durability of this steel and increasing its hardenability by solution hardening. Manganese as an austenite stabilizer reduces the carbon content in pearlite and reduces the ferrite grains during the hot rolling process. Carbide forming elements, such as Cr, Mo, Ti, V, W, increase the time which is taken to start transformation diffusion, thereby the hardenability of the steel is increasing. Furthermore, the content of molybdenum in an amount from 0.25 to 0.60% (excluding HARDOX 600 steel) influences the positive effect of secondary hard-ness and reduces the occurrence of the temper brittleness for temperature in the range between 250–400 °C (HARDOX steels are tempering mainly in temperature from range 200 and 700 °C). The presence of

molybdenum in steel (minimum content of Mo is approximately 0.2%) is even more important because of chromium (as well as nickel in his presence) which causes an increased brittleness of the steel after tempering. This effect is also observed for phosphorus and other elements in trace amount [12].

HARDOX sheets are a unique combination of hardness and toughness, considered the standard in the field of abrasion protection. It is a trademark for abrasion-resistant sheets manufactured by the Swedish company SSAB. The properties of this steel allow its use also for load-bearing parts of structures and application in abrasive and aggressive environments. HARDOX has better wear resistance, higher load capacity, longer service life compared to normal, common steel with the same hardness and good weldability (Fig. 4). The hardness of this steel ranges from 400 HBW to 600 HBW [13]. It is available in the form of sheet metal in thicknesses from 0.7 mm to 160 mm, but also in the form of tubes and rods [14].



**Fig. 4** Comparison of resistance of HARDOX and normal steel [14]

HARDOX 450 steels are widely used in constructions where it is necessary to combine abrasion wear resistance with good mechanical properties. HARDOX 450 is an abrasion-resistant steel with excellent construction properties. The hardness of this steel is 450 HBW,  $R_e = 1.100\text{MPa}$  to  $1.300\text{MPa}$ . HARDOX 450 is well flexible and has guaranteed weldability. Provides good abrasion resistance and longer life.

The extreme performance of HARDOX is combined with exceptional weldability. Any conventional welding method can be used for welding these steels to any type of weldable steel. This information is aimed at simplifying, improving and boosting the efficiency of the welding process. It offers good advice on preheat and interpass temperatures, heat input, welding consumables, shielding gas and a great deal more [15].

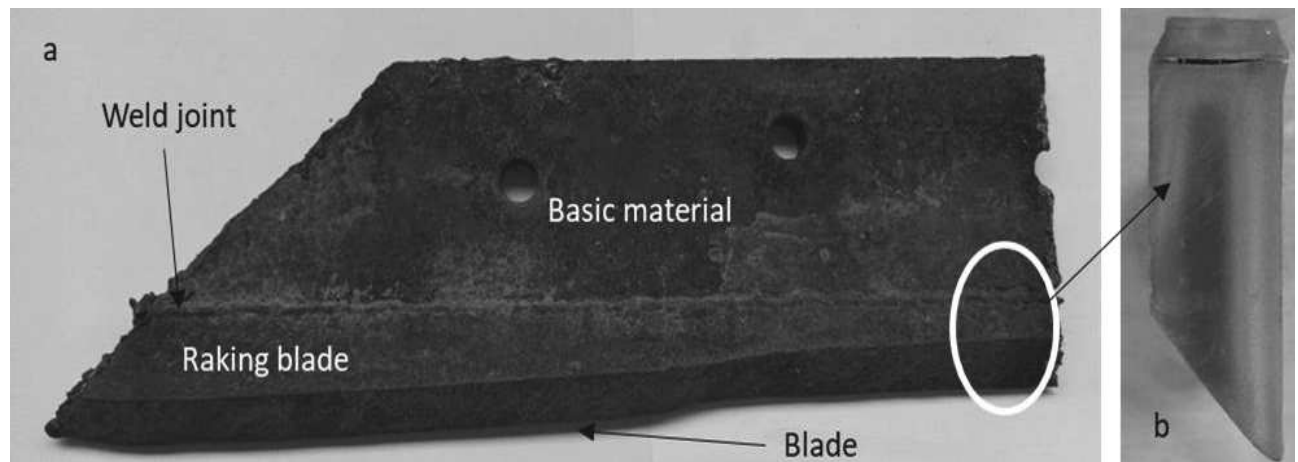
The weldability of high-strength steels is comparable to the weldability of microalloyed steels. These materials are considered to be well weldable due to their low carbon content and low alloying values. The weldability of these steels can be very good, but even though the weld does not have the same chemical composition as the base material, as the strength pro-

perties and toughness could deteriorate. For this reason, it is necessary to use an additive material with a higher content of alloying elements, especially molybdenum. When welding high-strength low-alloy steels, it is necessary to minimize the formation of hydrogen and delayed the cold cracks. Cracks arise especially when a coarse brittle decay structure is formed in the heat-affected zone and high stresses are generated during cooling. The risk of cold cracks during welding can be minimized by a suitable welding method, design solution, technological process designed to minimize residual stresses and precise cleaning of welded

surfaces [15,16,17].

### 3 Results of experiment

The ploughshare that was the subject of the experiment is a commonly used tool for road modification in winter. It is attached to the working machine with a front clamping plate or, in the case of more difficult terrain, with a three-point hitch. In Fig. 5 is a part of an arrow ploughshare from which samples were taken for the experiment.



**Fig. 5** Part of the decommissioned ploughshare used in the experiment (a); detail of part of ploughshare (b)

Since we did not know what material was used in the manufacture of the ploughshare, an input analysis of the base material and the raking blade was performed. It consisted of:

- Chemical analysis;
- Hardness measurements;
- Microscopic analysis of material and rake knife - light

and electron microscopy.

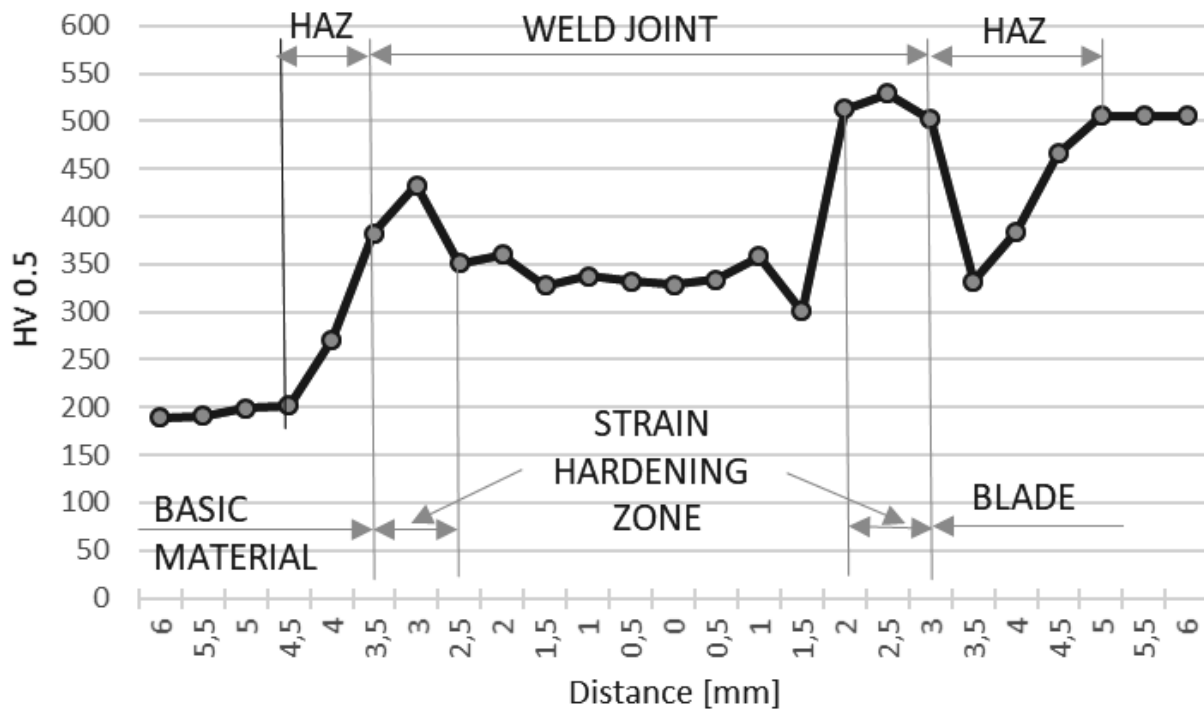
Chemical elemental analysis of the samples was determined by the atomic emission method with spark discharge on ARL 4460 spectrometers. THERMO ARL and IR absorption. In tab. 1 shows the values of the investigated material.

**Tab. 1** Chemical composition of ploughshare parts (wt%)

Elements	C	Mn	Si	Cr	Ni	Cu	Al	Mo	P	S	Fe
Basic material	0.2	1.4	0.3	0.041	0.055	0.16	0.02	<0.01	<0.005	<0.15	rest
Raking blade	0.33	1.24	1.36	0.27	0.47	0.04	0.015	0.178	0.017	<0.15	rest

Based on the performed chemical analysis, we found that the basic material of the weldment used in the experiment was made of 11 484 steel. It is a fine-grained steel of the usual quality for low temperatures with guaranteed weldability. It is used in parts of equipment operating at temperatures up to  $T = -50^\circ\text{C}$  made of sheet metal with a guaranteed value of notched toughness up to  $T = -50^\circ\text{C}$ . The is  $R_e = 355\text{MPa}$  and the  $R_m = 470\text{--}610\text{MPa}$ .

According to the data obtained from the chemical analysis, the raking blade of the welded part of the examined blade was made of steel 13 240 (37MnSi5). It is a manganese-silicon steel suitable for tempering. It is used on medium-stressed parts of machines and parts of road vehicles particularly resistant to wear, e.g. shafts, axles, connecting rods, levers, bolts. Value of  $R_m = 760\text{MPa}$  and HBW 217.



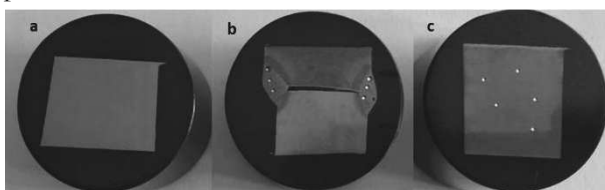
**Fig. 6** Hardness curve of the decommissioned ploughshare – weldment

Vickers HV 0.5, Rockwell and Brinell hardness measurements were performed on samples taken from the decommissioned blade. Vickers hardness was measured according to the ISO 6507-1:2018 methodology [18] with a Vickers 432SVD hardness tester. Load duration  $t = 15\text{ s}$ , load force  $F = 98.07\text{ N}$ . In Fig. 6 is a graph of HV0.5 measurements. The curve indicates how the hardness changes from the base material through the weld to the ranking blade material. We can observe zones at the boundary between the weld and the welded materials, where the hardness increased. We can state that during long-term use of the blade, a lot of pressure is created, which caused local strengthening in these zones.

**Tab. 2** Hardness values of materials 11 484 and 37MnSi5

Method	HBW	HRC	HV
Basic material - 11 484	156±25	-	200±20
Raking blade - 37MnSi5	217±30	50±2	438±80

Using light microscopy, microscopic analysis was performed on samples (Fig. 7) prepared in a standard process.



**Fig. 7** Samples for input microscopic analysis, a – basic material; b – weld joint; c – raking blade

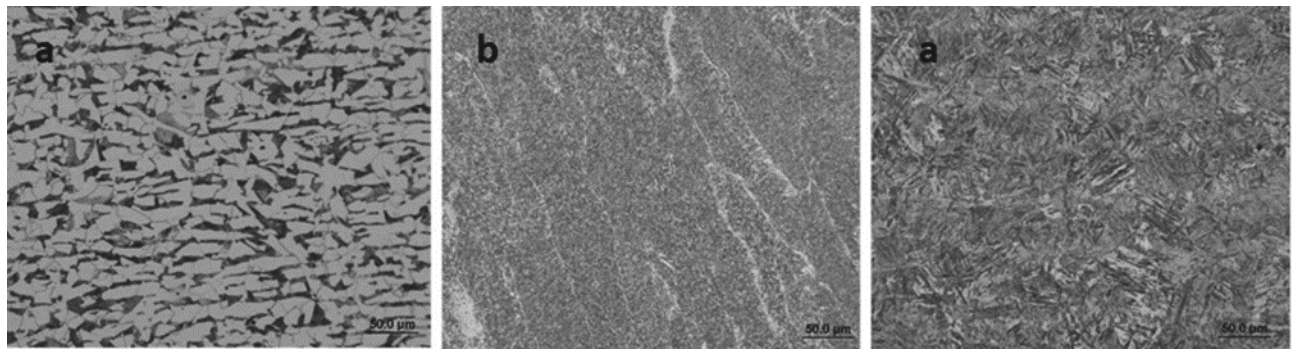
When measuring the hardness by the Rockwell method, the methodology according to ISO 6508-1:2016 was used [19]. The measurement was performed on a universal hardness tester UH250. The loading force was  $F = 1\,471\text{ N}$ .

Brinell hardness was measured according to the methodology of ISO 6506-1:2005 [20] with a universal hardness tester UH250. Load duration  $t = 15\text{ s}$ , ball diameter  $D = 2.5\text{ mm}$ , load force  $F = 187.5\text{ kp}$  ( $1\,839\text{ N}$ ). In Table 2 are the values measured by all three methods for the base material 11 484 and the rake knife 37MnSi5. Average values are calculated from five measuring.

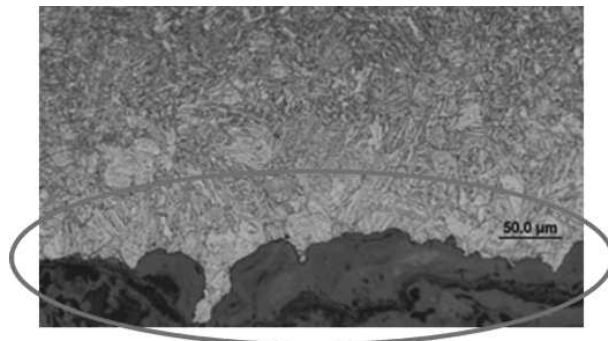
After etching the samples (2% Nital) of the base material, the weld joint and the material of the raking blade, we can in Fig. 9a shows the microstructure of basic material, which is characterized by a slight linearity. It is a ferritic-pearlitic steel with a higher proportion of ferrite. An indicate of linearity indicates that it is rolled steel. We can admit that the steel was also normalized annealed. In Fig. 9b we can see the microstructure of the weld with a characteristic growth of structural elements, which were welded

parts of the ploughshare – basic material and the raking blade. In Fig. 9c is the microstructure of the rake

blade material. It is a sorbitic structure that was formed after tempering.



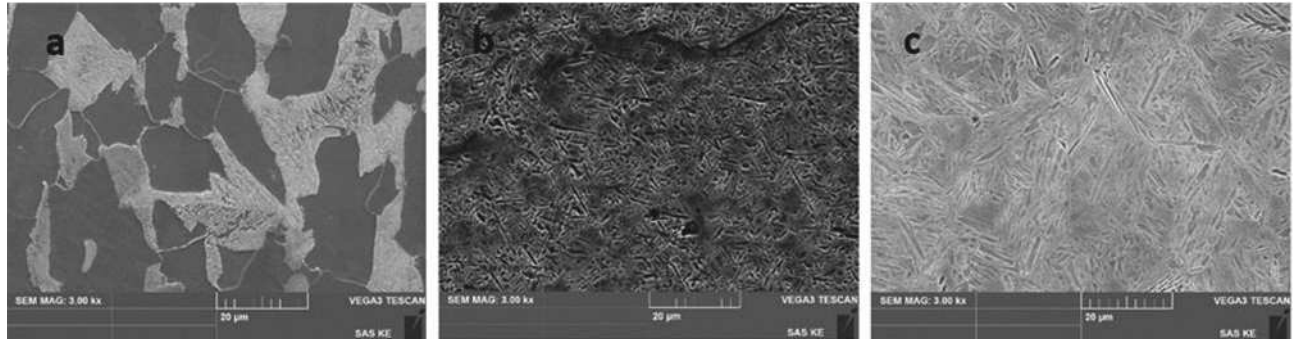
**Fig. 9** Microstructure – light microscopy - input analysis of weldment, a – basic material; b – weld joint; c - raking blade



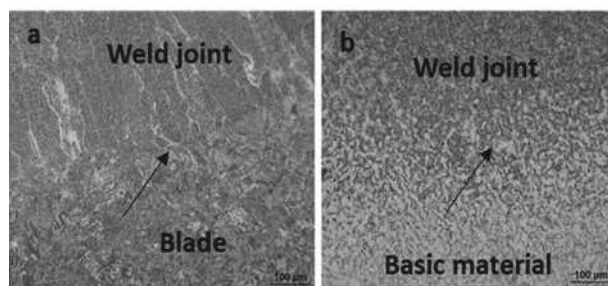
**Fig. 10** Microstructure - wear condition of the raking blade

In Fig. 10 is a state of wear of the raking blade. In the lower part we can see uneven wear on the blade.

In Fig. 11a is the microstructure of basic material. Fig. 11b shows the microstructure of the weld joint to which the blade parts – basic material and the rake blade were connected, and in Fig. 11c we can see the microstructure of the rake blade material, which was performed by electron microscopy. As declared by the authors using SEM, it is possible to analyse in detail the disturbances, errors or deformations on the worn surface with greater magnification as possible by light microscopy. It was confirmed the type of structures obtained from light microscopy.



**Fig. 11** Microstructure - SEM - input analysis of weldment, a – basic material; b – weld joint; c - raking blade



**Fig. 12** Joining and mixing materials in zones: a - weld joint – blade; b – weld joint - basic material

In Fig. 12a we can see the mixed zone of the weld – the blade. The weld has a typical dendritic structure.

in Fig. 12b is weld joint - basic material. We can state that in both cases there was sufficient mixing of both materials with the weld, without the occurrence of defects.

Based on the performed analyses, a change in the material of the part of the snow ploughshare - raking blade was proposed. The abrasion resistant material HARDOX 450 was selected for the experiment, which will be welded with an electrode OK 48.00 with the base material 11 484.

HARDOX abrasion-resistant sheets can be welded without preheating, all types of welding processes can be used for welding. The mechanical properties are achieved by hardening and, if necessary, subsequent

tempering. The properties of HARDOX are not maintained at temperatures above 250 °C [14]. Its chemical composition is in Tab. 13. Used in various components and constructions that are subject to wear.

When choosing the electrode for welding the base material with abrasion-resistant sheet metal, we used the data for welding HARDOX. We chose the electrode OK 48.00 ISO 2560 - A: E 42 4 B 4 2 H 5. It is the most widespread OK basic electrode for welding unalloyed and low-alloyed steels, especially P235/S235 (unalloyed structural steel of common quality, class 11) to P420/S420 (fine-grained structural steel) and others. A reliable, general purpose electrode for manual metal arc welding of carbon steels, carbon

manganese steels and fine-grained carbon manganese steels with elevated yield strength. OK 48.00 deposits a tough, crack-resistant weld metal. The coating is of the low moisture absorption type. High welding speed in the vertical-up position. OK 48.00 is insensitive to the composition of the base material within fairly wide limits. The electrode can be used for welding structures where difficult stress conditions cannot be avoided. It can be used for all welding positions except the vertical top-down position (PG). The reduced wetability casing gives a tough weld metal resistant to cracking and with a low hydrogen content [22]. The chemical composition is in Tab. 3.

**Tab. 3** Chemical composition of HARDOX 450 steel and electrodes OK 48.00 (bm. %)

Element	C	Si	Mn	P	S	Mo	Ni	Cr	B	Fe
<b>HARDOX 450</b>	max. 0.23	max. 0.50	max. 1.60	max. 0.025	max. 0.010	max. 0.25	max. 0.25	max. 1.20	max. 0.005	rest
<b>Electrode OK 48.00</b>	0.06	0.50	1.2	-	-	-	-	-	-	rest

The hardness measurement of HARDOX 450 material by HBW, HRC and HV methods was performed

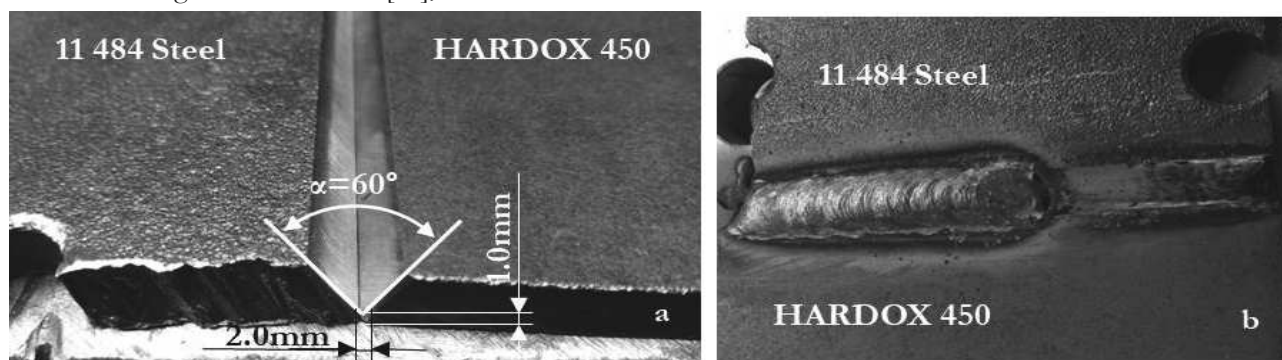
**Tab. 4** HARDOX 450 hardness values

Hardness measurement method	HBW	HRC	HV
<b>HARDOX 450</b>	440±15	45±1	420±20

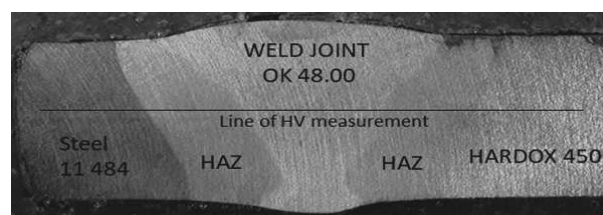
Welding was performed by certified welders. The electrodes were dried in a ZEPACOMP oven (KEMPPI MINARC 150) for 2 hours at 350 °C. The preheating of both welded parts (steel 11 484 and HARDOX 450) with a thickness of 10 mm was at a temperature of 150 °C. The welded length was 125.0 mm. According to ISO 9692 – 1 [23], at the thickness

according to valid standards [18,19,20]. The measured values are in Tab. 4.

of the welded parts  $s = 10.0$  mm, the bevel angle of the welded edges  $\alpha = 60^\circ$ , the width of the root weld  $b = 2.0$  mm and the height of the root weld  $c = 1.0$  mm. selected. In Fig. 13a are dimensional parameters of the welded joint before welding, Fig. 13b shows the appearance of the weld during welding.



**Fig. 13** Dimensional parameters of the welded joint (a); welding process (b)

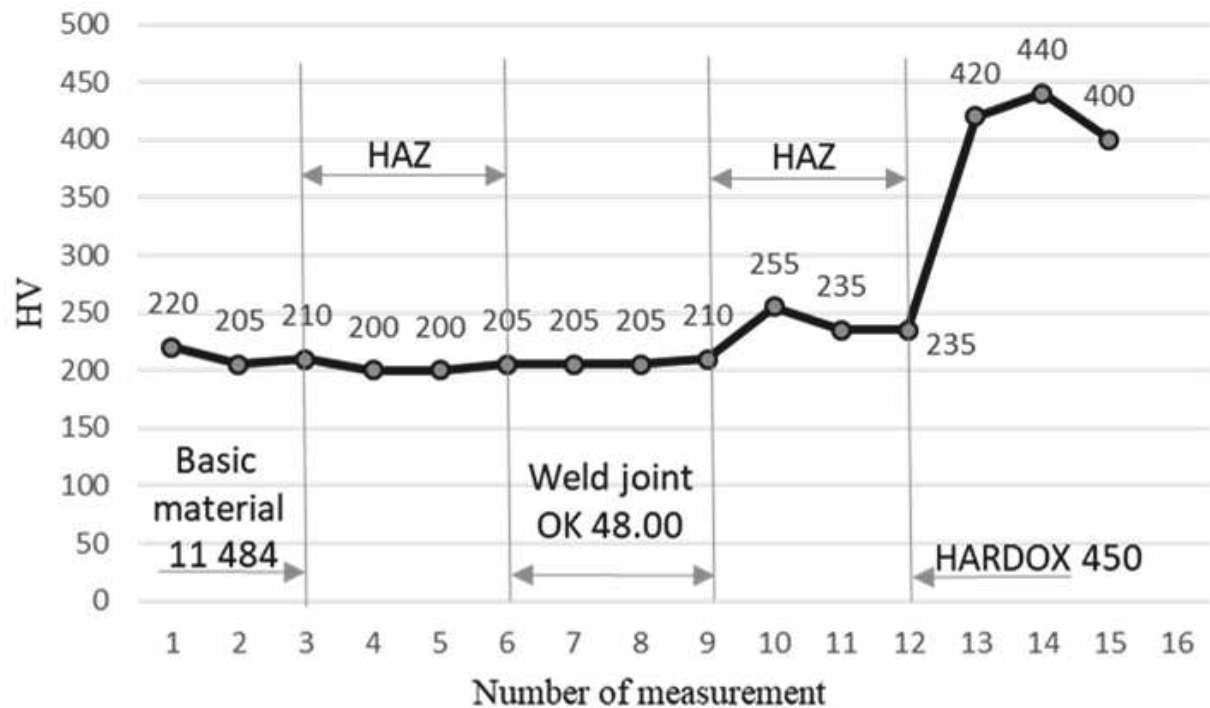


**Fig. 14** Macroscopic image of the welded joint

A macroscopic image of the welded joint was taken with a STEMI 2000 stereomicroscope at 63x magnification (Fig. 14).

In Fig. 15 is a graph of course of measurements according Vickers. The curve indicates how the hardness changes from the base material through the weld to the HARDOX.

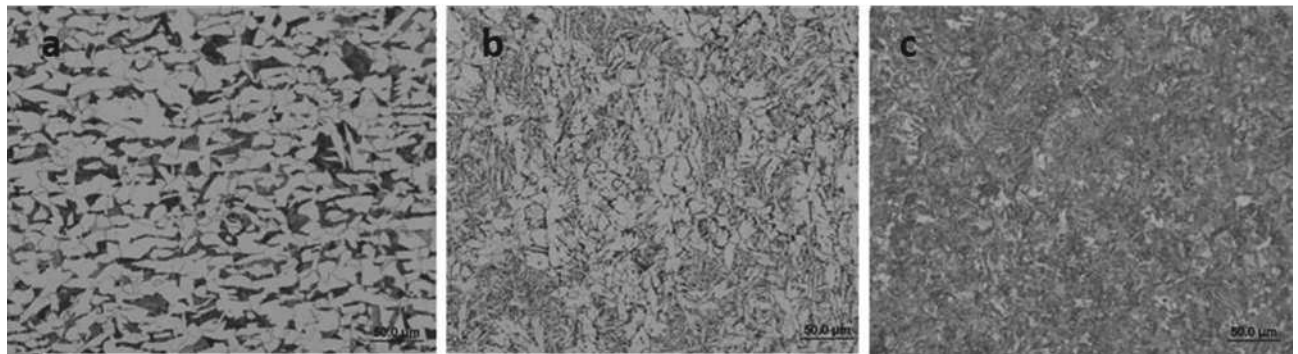




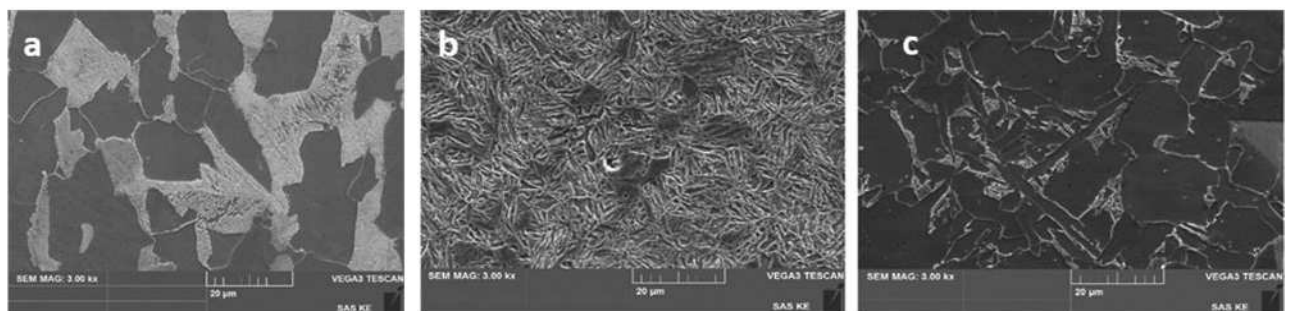
*Fig. 15 Hardness curve on experimental weld joint*

In Fig. 16b we can observe the microstructure of the weld OK 48.00, which was welded steel 11 484 (16a) with HARDOX 450. Compared to the microstructure of the weld from the input analysis of the decommissioned raking blade, this is a different weld structure. The structure in FIG. 16b is finer-grained than the structure on the original weldment (Fig. 9b). We assume that a different electrode was used on

the original weldment. In Fig. 16c we can observe the microstructure of HARDOX 450. It is a sorbitic structure. This is confirmed by information from the Technical Data Sheet [14], which states that in this type of steel, the mechanical properties are achieved by heat treatment - hardening and subsequent tempering.



*Fig. 16 Microstructure of individual parts of a welded joint - light microscopy, a - steel 11 484; b - weld joint OK 48.00; c - HARDOX 450*

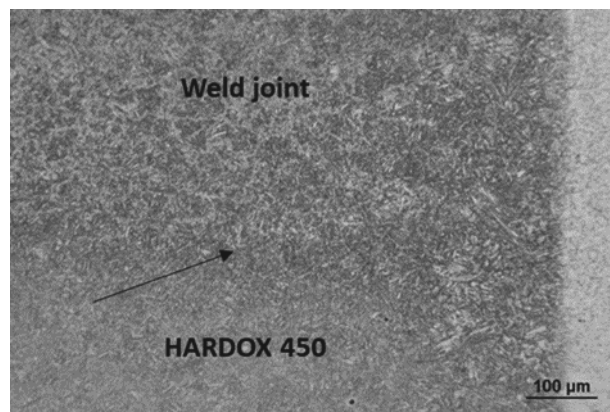


*Fig. 16 Microstructure of individual parts of a welded joint - electron microscopy, a - steel 11 484; b - weld joint OK 48.00; c - HARDOX 450*



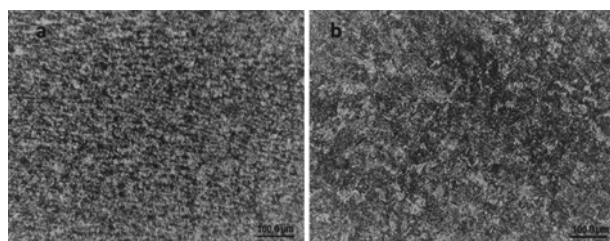
In Fig. 17 we see the structures of materials from electron microscopy, which confirms the results obtained from light microscopy.

In Fig. 18 shows the microstructure of the connection of the HARDOX 450 to the OK 48.00 electrode. We can state that there is a sufficiently satisfactory connection of materials. No defects are visible. The welding parameters were therefore set correctly.



**Fig. 18** Connection of HARDOX and electrode OK 48.00

In Fig. 19a we can observe the heat-affected zone (HAZ) of the steel 11 484, which has a fine-grained structure characteristic of the state achieved during welding when the material is heat-affected. In Fig. 19b we can observe the HAZ of HARDOX 450. Not so significant change from the structure of HARDOX 450 (see Fig. 17c.).



**Fig. 19** Microstructure of heat-affected zone, a - steel 11 484; b - HARDOX 450

The authors [9,11,13] in their works present the structure and change of hardness of selected welded HARDOX steels. It has been shown that structures with lower wear resistance are formed due to the welding of these materials in the "delivered" state (i.e. with a tempered martensite structure) in the heat affected zones. They are 80 to 90 mm wide, which causes their uneven and rapid wear in the intended applications [24]. When comparing the material structures of the original blade and experimental samples, we can state that they have a similar composition. The sorbitic structure of the knife is the result of martensite tempering. This is characteristic for the researched steels (37MnSi5 and HARDOX 450). The evaluation of the hardness of the researched materials and welded

joints was performed by the HBW, HRC and HV methods. HRC values are similar for both 37MnSi5 and HARDOX 450 materials. The average value of 37MnSi5 was 50HRC and HARDOX 45HRC. There was also no significant difference in HV values.

However, when comparing the hardness measured by the HBW method, the 37MnSi5 material had only half the average value of 217HBW out of the measured HARDOX450 average value of 445HBW. This suggests that the lifetime of the HARDOX raking blade could be higher than that of the original material 37MnSi5. Comparing the course of the HV hardness curves in Fig. 6 and 15 we can state, a more uniform hardness was recorded in the welded joint of the base material 11 484 and HARDOX. On the original raking blade, the hardness of the welded joint was on average higher. As stated [6,10], however, hardness is not always a guarantee of higher wear resistance, rep. impact load. The type of structure, resistant to the effects of wear, is also important too. Based on the above, we can conclude that the resistance in connection with the microstructure is comparable for both welded joints. The connecting of materials (Fig. 18) as well as HAZ of steel 11 484 and HARDOX 450 (Fig. 19) document that the weld quality is sufficient. There are no visible defects.

Further tests will be performed to obtain further information on the suitability of the material replacement for the raking blade. They will focus on the evaluation of resistance to abrasive wear in the working environment of a snow ploughshare.

## 4 Conclusion

Forest roads are important in terms of making the forest accessible for heavy machinery for wood transport. Therefore, it is necessary to keep these roads passable both in summer and in winter. In winter, it is necessary to remove a layer of fallen snow or ice from the road surface, which can be mixed with hard mineral particles (rocks, gravel, sand etc.). Snow is removed from the road with snow ploughshares. The arrow blades are connected to the vehicle at the front. As the raking blades are exposed to high wear during their operation, especially abrasive wear, and their replacement is relatively economically demanding, it is necessary to look for ways to increase their service life. Replacing the original 37MnSi5 material with HARDOX 450 would be a suitable alternative to maintain or increase the service life of snow ploughshare used in forestry.

## Acknowledgment

*The article was supported by the APVV-16-0194 "Research on Impact of Innovation in Production Processes on the Life of Tooling and Components of Forest Mechanisms."*

## References

- [1] HNILICA, R., MESSINGEROVÁ, V., STANOVSKÝ, M., SLUGEN, J., HNILICOVÁ, M., FERENČÍK, M. (2015). *Možnosti mechanizácie prác pri zariadení a výchove lesa*. Monography. (2015). pp. 99, ISBN 978-80-228-2722-5.
- [2] STN 73 6108:2000 Forest Transportation Network (Lesná dopravná sieť), SÚTN Bratislava.
- [3] KRIŠTOF, M. Kvalita životného prostredia. Naše lesy a hospodárstvo. [online]. [cit. 16-07-2020]. Available from: [http://www.enviromagazin.sk/enviro6\\_2/lesy10.html](http://www.enviromagazin.sk/enviro6_2/lesy10.html).
- [4] AGROTYP [online]. 28.07.2020. Available from <http://www.agrotyp.sk/komunalnatechnika/>.
- [5] MAZURKIEVIČ, I., GULAN, L., IZRAEL, G. (2012). *Mobilné pracovné stroje Cestné stroje*. Vydavateľstvo STU, 2012, Bratislava, ISBN 9788022736534.
- [6] MÜLLER, M., NOVÁK, P., CHOTĚBORSKÝ, R., HRABĚ, P. (2018). Reduction of Ploughshare Wear by Means of Carbide Overlay In: *Manufacturing technology*. Vol. 18, No. 1 pp. 72-78. FME JEPU. Czech Republic.
- [7] JAVAHERI, V. et al.: Slurry erosion of steel – Review of tests, mechanisms and materials [online]. [cit. 27-07-2020]. Available: [https://www.researchgate.net/figure/Schematic-representation-of-erosion-caused-by-deformation-mechanism-at-normal-impact-and\\_fig1\\_325855349](https://www.researchgate.net/figure/Schematic-representation-of-erosion-caused-by-deformation-mechanism-at-normal-impact-and_fig1_325855349).
- [8] FALAT, L., DŽUPON, M., ŤAVODOVÁ, M., HNILICA, R., EUPTÁČIKOVÁ, V., ČIRIPOVÁ, L., HOMOLOVÁ, V., ĎURIŠINOVÁ, K. (2019) Microstructure and abrasive wear resistance of various alloy hard-facings for application on heavy-duty chipper tools in forestry shredding and mulching operations. In *Materials*. 2019. s. 2019. ISSN 1996-1944.
- [9] TEKER, T., KARATAS S., YILMAZ, O. S. (2014). Microstructure and Wear Properties of AISI 1020 Steel Surface Modified by HARDOX 450 and FeB Powder Mixture. In: *Protection of Metals and Physical Chemistry of Surfaces*, 2014, Vol. 50, No. 1, pp. 94–103. ISSN 20702051.
- [10] KALINCOVÁ, D., ŤAVODOVÁ, M., EUPTÁČIKOVÁ, V. (2018). Application of the Weld Deposits on Function Surfaces of the Forest Machines Components In: *Manufacturing Technology* 2018, Vol. 18 No. 3. pp 400-405 FME JEPU. Czech Republic.
- [11] FRYDMAN, S., KONAT, Ł., PEKALSKI, G. (2008). Structure and hardness changes in welded joints of Hardox steels, In: *Archives of Civil and Mechanical Engineering*. Volume 8, Issue 4, 2008, Pages 15-27.
- [12] PAWLAK, K. (2015). A review of high-strength wear-resistant steel – hardox [online]. 28.07.2020. Available from [https://www.researchgate.net/publication/283568934\\_A\\_REVIEW\\_OF\\_HIGH-STRENGTH\\_WEAR-RESISTANT\\_STEEL\\_-\\_HARDOX](https://www.researchgate.net/publication/283568934_A_REVIEW_OF_HIGH-STRENGTH_WEAR-RESISTANT_STEEL_-_HARDOX).
- [13] KONAT, Ł., BIAŁOBRZESKA, B., BIAŁEK, P. (2017). Effect of Welding Process on Microstructural and Mechanical Characteristics of Hardox 600 Steel In: *Metals*, 2017 7(9), 349; [cit. 16-07-2020] Available from: <https://doi.org/10.3390/met7090349>.
- [14] SSAB HARDOX Wear plate, Hardness [cit. 16-07-2020] Available from: <https://doi.org/10.3390/met7090349> <https://www.ssab.com/products/brands/hardox/hardness>.
- [15] BREZOVÁ, E., MÄSIAR, H., RADIČ, P. (2014). Welding of high strength materials used in the manufacture of special equipment [online]. 28.07.2020. Available from [http://ur.tnuni.sk/fileadmin/dokumenty/UR\\_V8\\_ISS3-4\\_51to61.pdf](http://ur.tnuni.sk/fileadmin/dokumenty/UR_V8_ISS3-4_51to61.pdf)
- [16] NOVAKOVA, I., MORAVEC, J., SVEC, M., KIK, T., KORECEK, D. (2019). Influence of the Welding Process on the Change of Mechanical Properties in the HAZ of Welds at Alloy AW 6005 and Possibilities of Their Renewal by Heat Treatment In: *Manufacturing Technology* 2019, Vol. 19, No 5 pp. 823-830 FME JEPU. Czech Republic.
- [17] SEJČ, P., BELANOVÁ, J. (2019). The Effect of Welding Parameters on the Properties of Join between Studs and Steel Sheet USIBOR Type 22MnB5 In: *Manufacturing Technology*, Vol. 19, No. 3, pp. 492-498 FME JEPU. Czech Republic.
- [18] ISO 6507-1:2018 Metallic materials – Vickers hardness test - Part1: Test method.
- [19] ISO 6508-1:2016 Metallic materials - Rockwell hardness test - Part 1: Test method.
- [20] ISO 6506-1:2004 Metallic materials - Brinell hardness test - Part 1: Test method.

- [21] NÁPRSTKOVÁ, N., ŠRAMHAUSER, K., CAIS, J., STANČEKOVÁ, D. (2018). Using of the Electron Microscope to Evaluate the Tool Wear for a Selected Cutting Insert In: *Manufacturing Technology*. Vol. 18, No. 4 pp. 635-640. FME JEPU. Czech Republic.
- [22] ESAB [online] 28.07.2020. Available from <https://www.esab-slovakia.sk/sk/sk/products/filler-metals/covered-stick-electrodes-smaw/low-hydrogen-electrodes/ok-48-00.cfm>.
- [23] ISO 9692-1:2013 Welding and allied processes - Types of joint preparation - Part 1: Manual metal arc welding, gas-shielded metal arc welding, gas welding, TIG welding and beam welding of steels.
- [24] KOVÁČ, I., MIKUŠ, R., ŽARNOVSKÝ, J., DRLIČKA, R., ŽITŇANSKÝ, J., VÝROSTKOVÁ, A. (2014). Creation of wear resistant boride layers on selected steel grades in electric arc remelting proces. In: *Kovové materiály*. 2014, vol. 52, no. 6, pp. 387-394.