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INFLUENCE OF THE HARD-FACED LAYER WELDED ON TANGENTIAL-ROTARY PICK OPERATIONAL PART ON TO ITS WEAR RATE**WPLYW WARSTWY NAPAWANEJ CZĘŚCI ROBOCZEJ NOŻA STYCZNO-OBROTOWEGO NA SZYBKOŚĆ JEGO ZUŻYCIA**

Problems related with abrasive wear of tangential-rotary picks during cutting process and its limitations, have been discussed in the present study. Essential for the parameters of cutting process geometrical, kinematic and material parameters of tangential-rotary picks and types of their wear, have been discussed. Testing procedure in aspect of the wear of tangential-rotary picks and their durability estimation, has been described. Manners of the abrasion of pick body and pick edge of the tangential-rotary picks, have been determined. Particular attention was paid to procedure of hard facing of the pick operational part and its influence onto mining process. Results of examination of tangential-rotary picks with hard facing layer on operational part near insert made of abrasion sintered carbide are also cited.

Keywords: tangential-rotary picks, mechanical rock mining, abrasive wear, pad welding

W artykule przedstawiono problemy związane z zużyciem ściernym noży styczno-obrotowych podczas procesu frezowania oraz sposoby jego ograniczenia. Omówiono istotne ze względu na proces skrawania parametry geometryczne, kinematyczne i materiałowe noży styczno-obrotowych oraz rodzaje ich zużycia. Przedstawiona została metoda prowadzenia badań noży w aspekcie szybkości ich zużycia oraz oceny ich trwałości. Przedstawiono sposoby zwiększania odporności na ścieranie korpusów jak i ostrzy noży styczno-obrotowych. Głównie skupiono się na metodzie związanej z napawaniem części roboczej noża oraz jej wpływem na proces urabiania. Przedstawione zostały również wyniki badań noży styczno-obrotowych z wykonaną na części roboczej napoiną w pobliżu wkładki z węglika spiekanego materiałem odpornym na ścieranie.

Słowa kluczowe: noże styczno-obrotowe, mechaniczne urabianie skał, zużycie ściernie, napawanie

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1. Introduction

Exploitation of longwall and roadway excavations is usually made with use of mechanical cutting, which is defined as direct action of pick or set of picks onto rock body. Rock mining with use of shearers or plows is realized with use of cutting picks (shearer picks, plow picks).

Driving of development headings and preparatory headings is made with use of roadheaders equipped with cutting heads armed with cutting picks. Whereas, hard coal exploitation is usually made with use of the longwall system, where the shearer is the main machine usually equipped with two worm-type cutting heads armed also with cutting picks (radial, tangential-flat and tangential-rotary picks).

Actually tangential-rotary picks are used both in case of roadway, longwall and even shaft shearers. Picks replace almost totally the older solutions, i.e. tangential-flat picks and radial picks (Fig. 1), as they are more durable. It has particular meaning for reduction of time needed for their replacement as well as wear of holders and cutting picks (Krauze et al., 2012).

Arrangement of the cutting picks on cutting head is very important, as it decides about mining process efficiency, its power consumption and intensity of pick wear. Wrongly selected arrangement of picks can result in improper operation of the cutting heads, what in turn leads to low efficiency of the cutting machine, overloading of its drive units and generation of unneeded vibrations (Cheluska, 2010). In consequence frequent break downs of the shearer and longwall shut downs occur, so more and more restrictive requirements related with selection of tangential-rotary picks and their fixing on the cutting head, are needed.

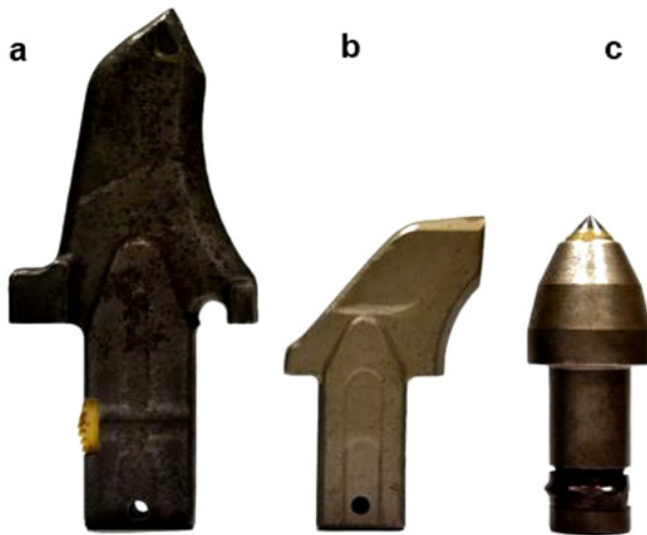


Fig. 1. Cutting tools: a – tangential flat pick, b – radial pick, c – tangential-rotary pick

Tangential rotary pick (Fig. 2) is built of cone-shaped operational part, cylinder-shaped mandrel being holding part of the pick and pick with cutting edge made of sintered carbide or diamond composite (Jonak & Podgórski, 2012).

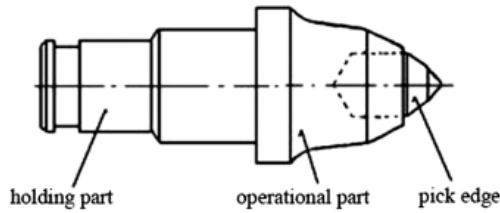


Fig. 2. Structure of tangential-rotary pick

Constructional parameters of the tangential-rotary pick result from cutting process requirements, constructional parameters of the pick holder and cutting head, as well as properties of mined rock body (Jonak, 2002).

Cutting pick is set in its holder under angle with respect to cutting head drum tangent. For such position of the cutting pick together with holder its cutting edge can be determined by pick rake angle α , cutting edge angle β and repose pick rake angle γ (Fig. 3). Moreover, the pick axis can be inclined with angle ρ with respect to line perpendicular to the cutting head axis (Krauze et al., 2012).

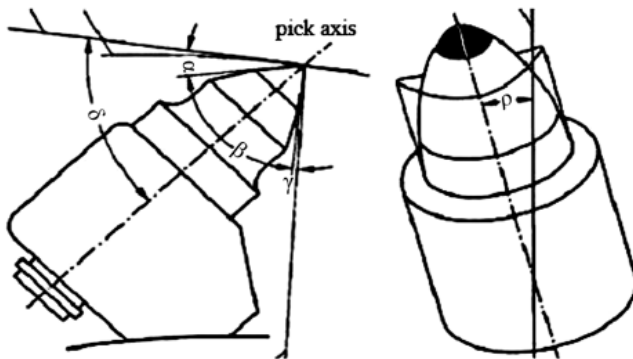


Fig. 3. Angles of repose of the tangential-rotary pick (Jonak, 2002)

Cutting process with use of tangential-rotary picks requires such shape and dimension of the cutting tool that cutting edges inked into rock body to the depth of g_s , obtained suitable operational cutting angles. Particular attention should be paid that the pick cutting angle during cutting process had always positive operational pick rake angle α_r .

Cutting pick fixed in its holder is a part of the cutting head (Fig. 4), so operational cutting angles α_r and γ_r depend not only on the pick constructional parameters but also on cutting rate v_s and advance rate v_p . Thus for cutting head of the diameter D_s , cutting rate v_s and advance rate v_p , height of the holder H_u and angle δ_u , should be selected in such manner that tangential-rotary pick of required length L_n and cutting edge angle $2\beta_u$ were obtained. In such case other parameters of the cutting pick must possess values assuring the best mining conditions (Krauze et al., 2012). Thus constructional and kinematic parameters of the cutting pick allowing minimized cutting resistances and possibly high durability should be calculated (Krauze, 2002).

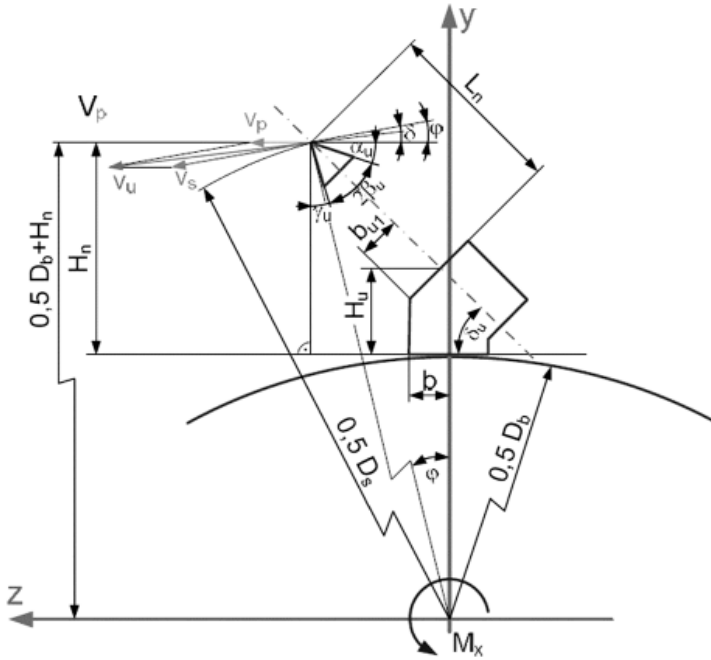


Fig. 4. Parameters of the holder and tangential-rotary pick setting on cutting head (Krauze et al., 2012)

Operational pick rake angle α_r is a sum of angles α_u and φ minus angle δ

$$\alpha_r = \alpha_u + \varphi - \delta = \delta_u - \beta_u + \varphi - \delta \tag{1}$$

Whereas pick rake angle γ_r is a sum of angles γ_u i δ minus angle φ

$$\gamma_r = \gamma_u - \varphi + \delta = 90 - (\delta_u + \beta_u) - \varphi + \delta \tag{2}$$

Angle δ can be calculated from the relations:

$$\delta = \arccos \frac{v_s + v_p \cos \varphi_i}{\sqrt{v_s^2 + v_p^2 + 2v_s v_p \cos \varphi_i}} \tag{3}$$

where: φ_i – angle describing actual pick position on the cutting head.

Angle φ can be described with relation:

$$\varphi = \arctg \frac{R_{nzy} - b_{u2}}{H_n + 0,5D_b} \tag{4}$$

where:

$$R_{nzy} = \frac{H_n}{\operatorname{tg} \delta_u} \tag{5}$$

$$b_{u2} = b_u - b = \frac{H_{u1}}{\operatorname{tg} \delta_u} - b \quad (6)$$

$$H_{u1} = H_u + H_2 - H_{u3} = H_u + \frac{b_{u1}}{\cos \delta_u} - b_{u1} \cos \delta_u \quad (7)$$

$$H_{u1} = H_u + b_{u1} \cos \delta_u \left[(\cos \delta_u)^{-2} - 1 \right] \quad (8)$$

Height of the cutting pick H_n results from the height of the pick holder H_u and pick edge length L_n .

$$H_n = H_u + H'_n = H_u + L_n \sin \delta_u \quad (9)$$

During exploitation, tangential-rotary pick is an element being in direct contact with mined rock body. In result on mining process within zone of the cutting tool contact with mined rock body, phenomenon of wear of the tool in question is observed, commonly in result of abrasion. It is related with changes both of geometrical shape of the pick and its mass loss. Particularly shape change and mass loss of the operational part of the cutting pick leads to the cutting edge drop, i.e. loss of the cutting capabilities. The other problem concerns mechanical damage of the cutting pick resulting from improper exploitation or manufacturing fault (Kotwica, 2012).

Pick wear advance depends on numerous factors, including rock structure, its slotting (cohesion), mineral composition, water saturation and cutting resistances. That is why rock abrasiveness has significant influence onto unit wear of the cutting picks and mining efficiency, what is shown in Fig. 5 (Jonak & Podgórski, 2012).

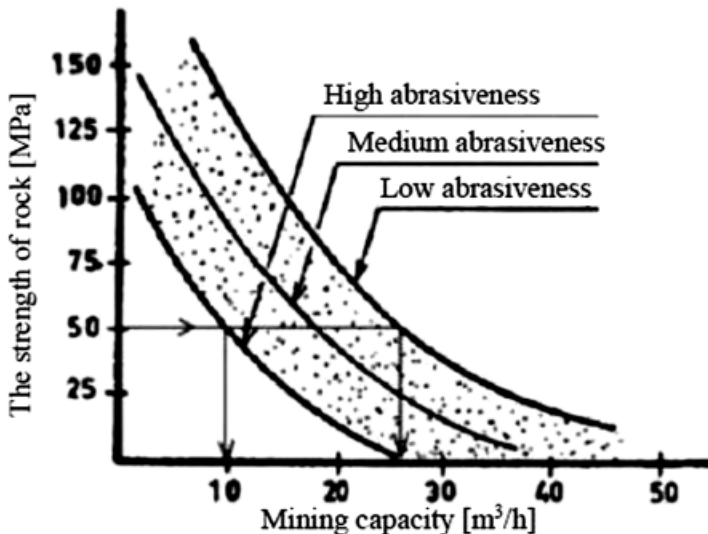


Fig. 5. Influence of the rock abrasiveness and its influence to mining capacity (Jonak and Podgórski, 2012)

Shape of the tangential-rotary pick and mode of fixing in the holder should assure symmetrical wear of the cutting edge and its operational part (body). In such a case cutting pick cuts the rock on its whole length keeping its cutting possibilities. Limit of its usage is determined by symmetrical or asymmetrical wear of the cutting pick (Fig. 6). Phenomenon of resection of sintered carbide insert, when toll body is more quickly worn than the cutting edge, is frequently observed (Fig. 7). It considerably reduces the pick durability and rises exploitation cost (more frequent pick replacement, more frequent shearer stops, output reduction) (Kotwica, 2010). That is why there is need of its surface protection against excessive wear via hardly abraded materials application.

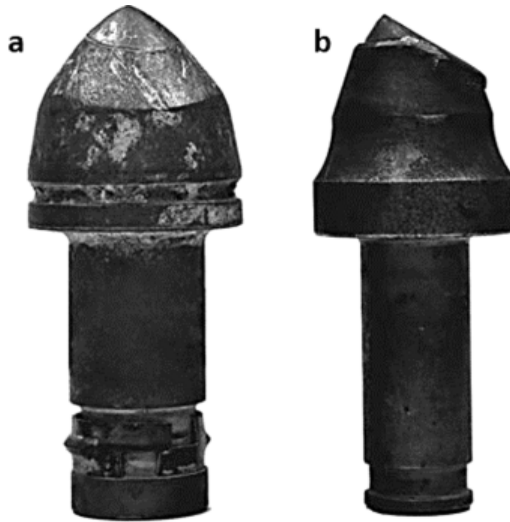


Fig. 6. Wear of tangential – rotary pick: a – symmetrical, b – asymmetrical



Fig. 7. Tangential-rotary picks with broken cutting edge during exploitation

Numerous examinations on new materials for cutting edges and tool bodies production are conducted in order to improve durability of tangential-rotary picks. Actually, cutting edges are usually made of sintered carbides, but cutting edges made of diamond composites or whiskers (fibrous composites) are also conducted (Jonak & Podgórski, 2012). Bodies of tangential-rotary picks are made of high impact resistance steels, which can additionally be exposed to process of carburizing and heat treatment (Kotwica, 2010).

In order to reduce wear, protections of external cone-shaped surface of the cutting pick with a layer resistant to abrasion with use of hard facing method, are applied.

2. Examinations on the abrasive wear of tangential-rotary picks

Abrasive wear is defined as phenomenon of surface layer destruction of co-acting parts during friction process in result of cutting, ridging and shearing interaction of the surface undulations, foreign matters or wear products. Hardness of the matter causing the wear, which is higher than hardness of worn matter is a necessary condition for occurrence of abrasive wear in friction process (Larsen-Basse, 1974).

Wear rate of tangential-rotary pick can be determined during exploitation or in the laboratory. However, considering changeable operational conditions in natural rocks, laboratory tests are recommended for the pick durability assessment. In such conditions assuring constant kinematic parameters of the cutting process as well as constant properties of the cut rock is assured.

Empirically, potential user can only determine quality of the cutting pick, or picks, with reference to volume of the obtained winning output. The most often number of worn (replaced) picks per 1000 Mg of the winning or per its volume is taken under consideration. However, these results refer to definite place and time, and they can be changed according to changes of the properties of mined rock. Thus if we want to preserve properties of mined rock body and cutting parameters (advance rate v_p , cutting head rotation n), laboratory testing is recommended (Krauze et al., 2009).

Measurement of the abrasive wear rate of the tangential-rotary picks is aimed at assessment of their durability and it must be realized always in the same conditions in manner allowing their reliability, repeatability and comparability. Abrasive wear rate is defined as the pick total mass loss with respect to volume of the obtained winning.

Assumed requirements concerning the wear rate of the tangential-rotary picks call for adaptation of suitable measurement procedure. Thus as was already mentioned, cutting of artificial or natural rock sample of constant properties with use of pick or picks of constant cutting parameters (v_p , n), is required. In such case measurement of the pick mass before and after cutting allows calculation of the mass loss with respect to mass of the mined sample. Thus special laboratory testing stand was designed, where mining of the rock sample by cutting, as well as measurement of cutting parameters is possible (Krauze et al., 2012).

Laboratory testing stand accessible in the Department of Mining, Dressing and Transport Machines of the AGH University of Science and Technology in Kraków – Poland (Fig. 8) comprises two subassemblies: cutting head drive and advance system of the mined block. Special disc with tangential-rotary picks holders, single and two stage, play role of the operational element.



Fig. 8. Laboratory testing stand for examination of quality of tangential-rotary picks

Cutting head rotation forced by drive unit and rectilinear rock sample movement allow cutting with given cutting depth (web). Hydraulic advance system allows shift of the laboratory table together with cut block. Motor rotations are controlled via control system located in control cabinet, whereas the advance system is controlled during cutting and slotting via hydraulic cylinder.

Sample made of natural or artificial mineral is placed on the laboratory table. Cutting of artificial rock (cement – sand sample), which possess strong abrasive resistance and uniform and isotropic properties is recommended in case of the examination of the wear rate of tangential-rotary picks. The laboratory testing stand is equipped with measuring system being its integral part (torque meter, pressure converters, distance converters, measuring computer). It allows measurement of cutting element load and rate and pressure of the advance system, what in turn allows calculation of cutting resistances or cutting process power consumption (Krauze et al., 2012).

The testing results illustrate mass losses of individual cutting picks fixed in holders on the operational disc. The cutting picks are weighted before and after testing with accuracy up to 1 gram. Ratio of the pick mass loss and mass of the mined rock sample is a parameter describing its wear rate allowing pick durability assessment. Parallel examination of various picks is also possible (Krauze & Mucha, 2016).

3. Possibilities of the improvement of operational tangential-rotary pick operational part resistance to abrasion

Abrasive properties of rocks considerably influence wear of the tangential-rotary picks. That is why the picks are made mainly of steel having high resistance to abrasion, as well as high impact resistance and high strength. Usually steels of high content of manganese, molybdenum, nickel and boron are used. Depending on the tool destination, steels of the type 12HN3A, 40H, 40HN, 36 HNM or 35 HGS, are used (Kotwica, 2012).

Whereas, the pick cutting edges are usually armed with inserts of sintered carbides with the cobalt matrix. Such pick cutting edge passes high durability, under condition that pick operational part is properly fixed. Several methods limiting wear rate of the pick body and protecting sintered carbides are used.

In order to improve abrasive resistance of pick bodies, they can be exposed to carburizing process or heat treatment, what improves abrasive resistance of its surface layer. Application of the heat treatment of steel used for pick production comprising processes of hardening and tempering allows obtaining the hardness of over 45 HRC, and in consequence higher abrasive resistance (Klimpel & Dziubiński, 1985).

Hard facing of the pick operational part is the other method of the abrasive resistance improvement of tangential-rotary picks. This procedure comprises protection of the external cone-shaped surface of tangential – rotary pick with abrasion resistant layer. The following hard facing methods are actually used in order to increase pick operational part hardness and in consequence reduce its wear rate:

- electric-arc method
- flame method
- alloying
- plasma welding method
- HVOF
- nanoHVOF
- laser method (deposition, hardening, alloying).

These methods allow considerable improvement of the abrasive resistance and in consequence elongate exploitation time of tangential-rotary picks (Klimpel, 1999). Photos of two picks, one with its operational part protected with abrasion resistant padding weld, and the second pick, which operational body was exposed only to heat treatment, are shown in Fig. 9. Pick marked with symbol „a” is a pick with abrasion resistant padding weld prepared to operation. Whereas picks marked with symbol „b” and „c” are picks after two days of operations of the cutting head of roadway shearer. As seen, surface of the pick body with abrasion resistant padding weld is considerably less worn than in case of picks exposed only to heat treatment.

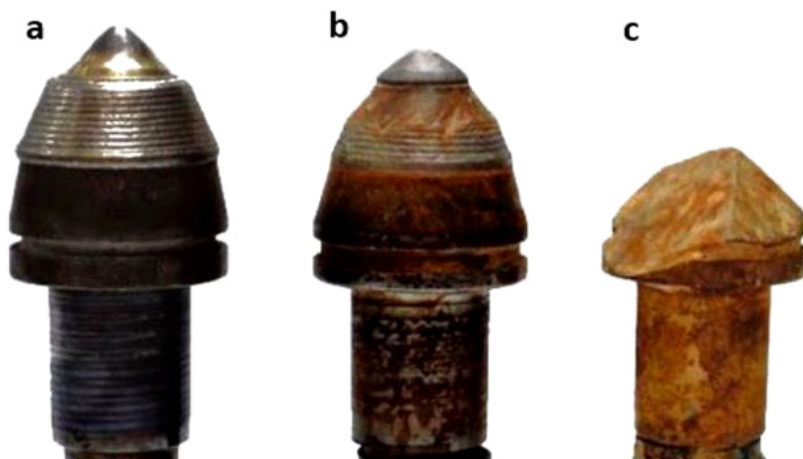


Fig. 9. Comparison of the wear of hard faced and not hard faced cutting picks:
 a) new pick protected with abrasion resistant padding weld, b) pick protected with abrasion resistant padding weld after two days of operation, c) pick not protected with abrasion resistant padding weld after two days of operation (Krauze & Mucha, 2016)

It was also proved that protection of the pick body with protective layer has no negative influence onto mechanical and strength properties, hardness and material structure of original pick. The protective layer do not increase cutting resistances, as diameter of protected segment is not considerably enlarged. Parameters of the pick body in its operational part are not deteriorated in result of coating it with protective layer and they preserve their properties, such as: impact resistance, tensile strength and elasticity limits. In this case, only materials admitted for use in conditions occurring in underground mines were used hard facing.

Described pick with hardly abrasive padding weld is one of examples of improvement of its durability. It is obtained in result of application of various type padding welds, which posses high hardness and are abrasion resistant. Use of defined type of the padding weld depends also on original material type and place of the pick operation.

4. Examinations on tangential-rotary picks with hard faced layer

In order to check improvement of the abrasion resistance, i.e. elongation of the durability of tangential rotary picks, abrasion resistant padding wells on the pick operational part near sintered carbonate inserts, were made. The padding welds were coated on picks made of steel 36HNM (Fig. 10) using electric-arc welding, with use of coated electrodes and welding rectifier BESTER SPF 315. Electrodes of the type EN600B and ABRADUR 54, were used and their chemical composition is shown in Table 1.

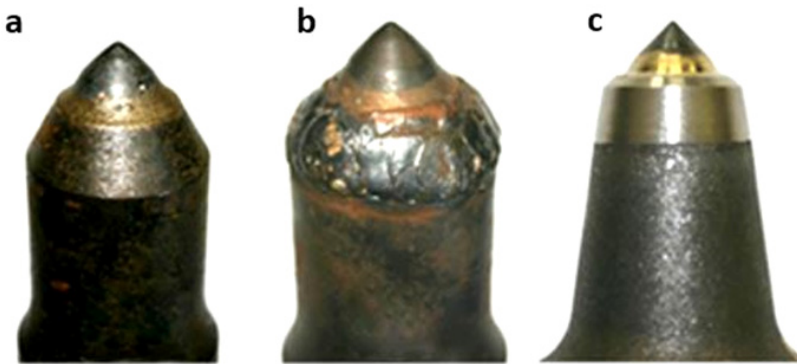


Fig. 10. Tangential-rotary pick: a) before hard facing, b) after hard facing, c) after hard facing and surface treatment

TABLE 1

Chemical composition of used electrodes

Electrode \ Element	C	Si	Mn	Cr
	% mas.			
EN 600B	0,6	1,2	1,4	5,6
ABRADUR54	3,6	2,0	—	9,5

Pick marked with symbol „a” is prepared to padding weld coating. Whereas pick marked as „b” shows pick after coating with padding weld. Pick was exposed to mechanical treatment, what allowed reduction cutting resistance – see pick marked with symbol „c”.

Some picks after padding weld coating were cooled in water, and the other were exposed to heat treatment, what resulted in the padding weld impact resistance improvement, including original material of the pick body operational part, keeping its high hardness and resistance to abrasion.

Thus hardness measurements of these picks within hard faced segments have been executed and results are presented in Tables 2 and 3. Hardness measuring results for picks cooled in water are presented in Table 2 and measuring results of picks after heat treatment are presented in Table 3. As seen, higher hardness values were obtained in case of picks cooled in water. However, it is hard to state that increased hardness do not cause deterioration of impact resistance. We can only state lack of distinct padding weld structure and original material (Fig. 13) on the basis of microscope examination (Fig. 11-12).

TABLE 2

Padding and original material hardness after water cooling

Electrode	Hardness of padding weld	Hardness of original material
EN 600B	63 HRC	53 ±1 HRC
ABRADUR54	63 HRC	42 ±1 HRC

TABLE 3

Padding and original material hardness after heat treatment

Electrode	Hardness of padding weld	Hardness of original material
EN 600B	43 ±4 HRC	43 ±1,5 HRC
ABRADUR54	40 ±1 HRC	39 ±1 HRC

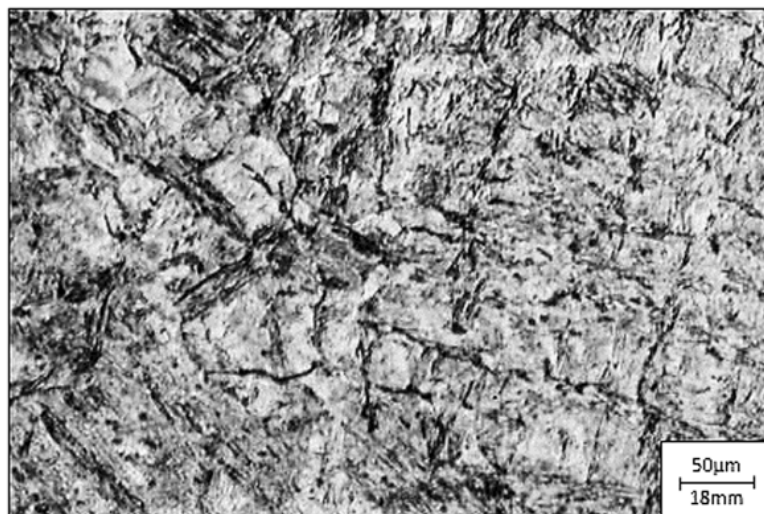


Fig. 11. Martensite microstructure of the padding weld made with use of electrode EN600B



Fig. 12. Martensite microstructure of the padding weld made with use of electrode ABRADUR54

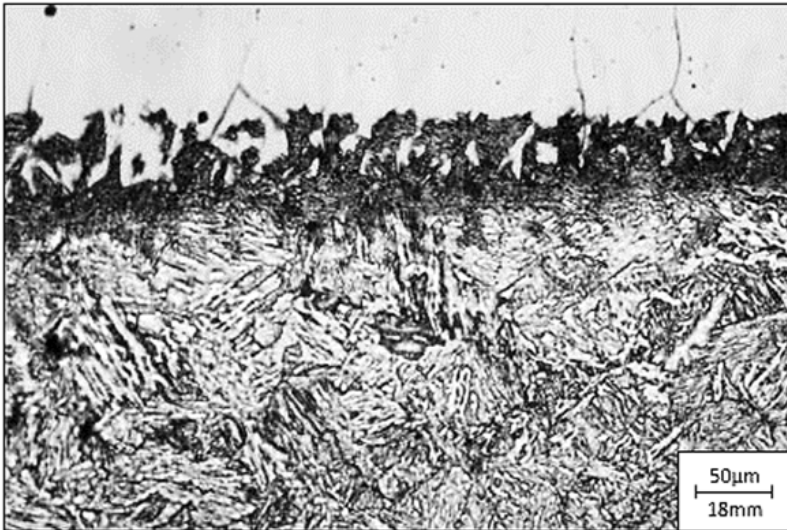


Fig. 13. Martensite micro-structure of original material with visible welding line

Influence of the hard faced layer onto pick wear rate and its damage was checked in conducted laboratory examinations executed according to described procedure, using specialty constructed laboratory testing stand. Examination of all picks were executed in the same conditions what assured reliable, repeatable and comparable results. It allows assessment of durability of tested picks and their comparison.

Pick wear was defined as ratio between pick mass loss and volume of obtained winning. Relative mass loss can be calculated with use of one of the following formulas:

$$C_1 = \frac{\Delta m}{m} \cdot \frac{v}{v_u} \quad (10)$$

$$C_2 = \frac{\Delta m_{\max} - \Delta m}{m} \cdot \frac{v}{v_u} \quad (11)$$

$$C_3 = \frac{m}{\Delta m} \cdot \frac{v}{v_u} \quad (12)$$

where:

- C_1, C_2, C_3 — relative mass loss of picks after examinations [-],
- Δm — pick mass loss [g],
- m — pick mass loss before testing [g],
- V — volume of sample before testing [m³],
- V_u — winning volume [m³],
- Δm_{\max} — maximal pick mass change from all series [g] (Krauze et al., 2015).

Four picks exposed to heat treatment and four picks with padding weld layer, have been tested. Cement-sand block of strength $R_c = 12$ MPa and bulk density 2,1 Mg/m³, has been cut. Testing results are shown in Table 4.

TABLE 4

Results of tangential-rotary picks wear testing

Pick No	Picks after thermal treatment of their operational parts			Picks after hard welding with use of abrasion resistant electrode		
	Pick mass loss, Δm , g	Winning volume; V_u , m ³	Relative mass loss of picks after testing C_2	Pick mass loss, Δm , g	Winning volume; V_u , m ³	Relative mass loss of picks after testing C_2
1	12,44	0,0258	1,381	8,07	0,0269	1,329
2	16,46	0,0258	1,820	9,49	0,0269	1,556
3	5,80	0,0258	0,640	1,94	0,0269	0,319
4	3,51	0,0258	0,388	1,10	0,0269	0,181
	Mean of the parameter of relative mass loss of picks after testing		$C_2 = 1,058$	Mean of the parameter of relative mass loss of picks after testing		$C_2 = 0,845$

On the basis of obtained results, reduction of the wear of picks with hard faced protective layer has been proved. Comparison with mined mineral mass allows assessment of the wear of picks at the level of 20%. As grindability of the cement-sand sample is high we can state positive influence of the padding weld onto wear of cutting picks and elongation of their durability.

5. Final conclusion

Hard facing of operational part of tangential-rotary pick improves its durability and wear rate. No influence of the padding weld onto original material and padding weld mechanical properties was observed. Further continuation of examinations on durability of cutting picks coated with padding weld and cost reduction of their production are recommended.

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