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INFLUENCE OF PAD WELDING ON THE WEAR OF VIBRATION RIPPER TEETH

WPŁYW NAPAWANIA NA ZUŻYCIE ZĘBÓW ZRYWAKÓW WIBRACYJNYCH

Key words: rock mining, vibration ripper, mining, tooth wear tests.

Abstract Due to the rapid wear of the teeth of the vibration rippers that work to compact and very compact soils, their regeneration by means of pad welding is becoming more and more common. This article presents the technology of pad welding ripper teeth and materials used to pad them. The paper presents the results of comparative research in the wear of new teeth and teeth subjected to the process of pad welding. The research results showed lower wear in welded teeth. The use of padding welds to strengthen the surface of teeth results in prolonging their service life.

Słowa kluczowe: górnictwo skalne, zrywaki wibracyjne, eksploatacja, badania zużycia zębów.

Streszczenie W związku z szybkim zużywaniem się zębów zrywaków wibracyjnych urabiających grunty zwięzłe i bardzo zwięzłe coraz częściej stosowana jest ich regeneracja metodą napawania. W artykule przedstawiono technologię napawania zębów zrywaków oraz materiały stosowane do napawania zębów zrywaków. Praca zawiera wyniki porównawcze badań zużycia nowych zębów z zębami poddanymi procesowi napawania. Wyniki badań wykazały mniejsze zużycie zębów napawanych. Wykorzystanie napoin do wzmacniania powierzchniowego zębów zrywaków prowadzi do wydłużenia ich czasu eksploatacji.

INTRODUCTION

In the Polish rock mining industry, hydraulic hammers, vibration rippers, and milling heads are used increasingly often for mining raw materials. These work to separate from the bed, by breaking the cohesion of the rock mass, of an appropriate batch of rock material, which is then subjected to processing aimed at obtaining the required fraction of the acquired raw material. The equipment listed above does not constitute a separate machine, but the "business end" of single-bucket excavators **[L. 1]**.

Rock mining technologies in Polish rock raw material mines are very diverse and depend mainly on the properties of the mined rock raw materials and the mining and geological conditions characterizing the mined bed. In the case of rock deposits characterized by a high fracture index, where there are a large number of natural cracks, the use of vibration rippers is more efficient.

Vibration rippers were introduced into operation in 2009. Such names as dynamic or hydraulic ripper are also encountered. The device is an exchangeable working accessory with a bucket in a single-bucket excavator and consists of a durable frame structure with a hydraulic motor and an eccentric shaft. During rotation, the shaft causes reciprocating movements of the cutting tool. The cutting tool ends with a ripper tooth, which cuts the rock body directly (**Fig. 1**).

During mining work, rapid wear and tear on components and parts that cut rocks often occurs. Therefore, in order to be able to continue works, worn parts are replaced by new ones or regenerated. Regeneration is not always economically viable, but unavoidable in many cases. Modern pad welding technologies allow for a significant prolongation of service life of new elements subjected to preventive safeguarding measures, as well as for effective restoration of the initial properties of the regenerated elements.

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Fig. 1. XR 42 vibration ripper from Xcentric Ripper in an open-pit mine [L. 2]
Rys. 1. Zrywak wibracyjny XR 42 firmy Xcentric Ripper w kopalni odkrywkowej **[L. 2]**

VIBRATION RIPPERS

The first vibration rippers were developed by the Xcentric Ripper Company **[L. 2]**. They use the company's patented "hydraulic impact accumulation" technology, which resulted in much higher productivity in working the rock medium. The idea behind this technology is to work with vibrations of the ripper tool generated by an eccentric shaft driven by a hydraulic motor. The shaft is supported on two pairs of tapered roller bearings that allow the shaft to transfer significant dynamic loads, and the vibration frequency of the tool can reach up to 25 [1/s]. Thanks to vibrations, the tooth of the ripper penetrates the worked rock deeper, which thus increases the effectiveness of mining **[L. 3].**

Due to their unusual structure, vibration rippers present the following advantages **[L. 3–5]:**

- It is possible to obtain in selected types of rocks efficiencies several times higher than that of hydraulic hammers.
- The reduction of the noise level emitted during the ripper operation is less than the noise level generated by hydraulic hammers.
- The possibility of moving selected rock blocks towards the excavator reduces costs, which is impossible with hydraulic hammers.
- It has a simple structure when compared to hydraulic hammers, resulting in a significant prolongation of the service life of the rippers.
- Rippers are easier to assemble, disassemble, and operate.
- The require minimum maintenance and need little of no daily service.
- They can work in a wide variety of conditions, including water-bearing beds, and under water.

Companies producing vibration rippers provide approximate operation ranges for rock mining. The measure used for their selection includes mining quality index depending on the R.Q.D. (Rock Quality Designation) cracking index or rock's compressive strength R_c **(Fig. 2)**

PRELIMINARY EXAMINATION OF THE RIPPER TOOTH

A tooth of a XR30 ripper in a brand new condition, purchased from the manufacturer, was prepared for a preliminary examination. The tests consisted of cutting a fragment of the tooth and measuring its hardness at 9 points determined by intersecting perpendicular lines **(Fig. 3)**. Hardness measurements made with WPM and TH170 hardness meters **[L. 7]** at specific points from 1 to 9 are presented in **Table 1**.

Table 1. Hardness in measurement points
Tabela 1. Twardość w punktach pomiarowych

Measurement point	1	2	3	4	5	6	7	8	9
Hardness [HRC]	26	25	28	35	36	35	40	40	44

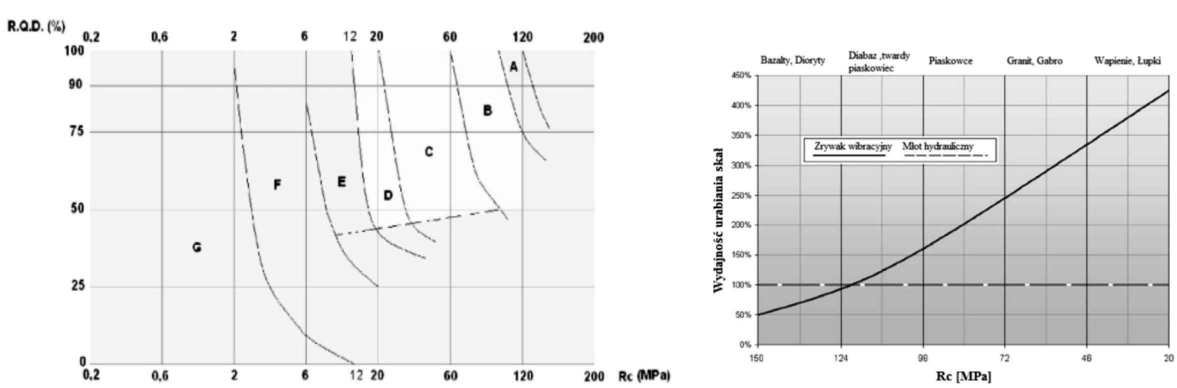


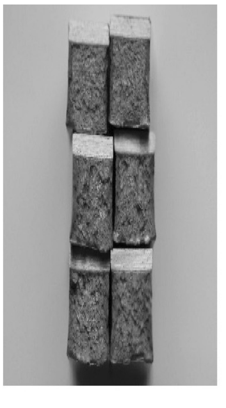
Fig. 2. Efficiency of using vibration rippers when compared to hydraulic hammers [L. 2, 6]
Rys. 2. Efektywność zastosowania zrywaków wibracyjnych w porównaniu z młotami hydraulicznymi **[L. 2, 6]**

Fig. 3. Teeth of the ripper, cut-off point, and hardness measurement points
Rys. 3. Ząb zrywaka, miejsce odcięcia zęba i punkty pomiaru twardości

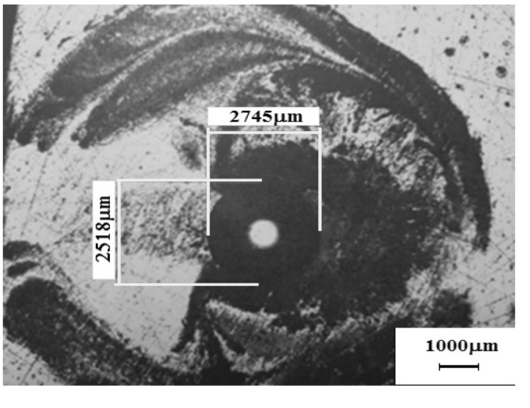
Further studies were carried out to determine the chemical composition of the tooth material and its impact strength, i.e. a tribological examination of the tooth material was also performed.

Analysis of the chemical composition of a tooth using an emission optical spectrometer (OES) -Foundry Master Smart - Oxford Instrument indicated the following elements: 0,30%C, 0.61%Si, 1.00%Mn, 0.036%P, 0.02%S, 1.00%Cr, 0.08%Mo, 0.02%Ni, and 0.004V, which corresponds to chemical composition of 30HG steel. In the impact strength test carried out according to the standard **[L. 8]**, the following values were obtained for three consecutive tooth material samples on the Charpy hammer: 63.74 J/cm^2, 53.94 J/cm^2, 50.26 J/cm^2 **(Fig. 4a)**. Samples for tribological studies were cut with a band saw and then encapsulated in resin. The tribological tests were performed with the ball-cratering method **[L. 9]**. The sample was pressed with the force of 50N against a steel ball rotating at a speed of 250 [rpm]. An abrasive suspension in the form of an aqueous solution of silicon oxide was applied to the friction pair. In the wear test according to PN EN ISO 26424:2016-05 made with the Elbit tribotester, which took 1800 seconds, the recorded weight loss was 36.29363g - 36.29271g = 0.00067g. Such a precise mass loss measurement was performed with an automatic vacuum mass comparator in the Foundry Research Institute in Kraków. The dimensions of the imprint measured in perpendicular directions were 2.75mm×2.52mm, **(Fig. 4b)**. Microscopic examination of the tooth material revealed its bainitic structure with carbide separation, which is characteristic for tempered steels, (**Fig. 4c**).

a)



b)



c)

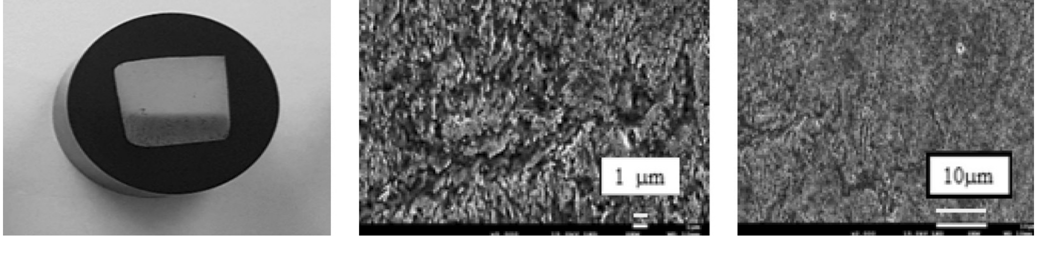


Fig. 4. Ripper material: a) fractures after impact test, b) print diameter after ball-cratering abrasion test, c) microsection and microscopic images
Rys. 4. Materiał zrywaka: a) przełomy po próbie udarności, b) średnica odcisku po próbie zużycia metodą ball-cratering, c) zgład i zdjęcia mikroskopowe

The results obtained from the analysis of the ripper tooth material showed that the selection of standard ripper tooth materials is not, at least in our opinion, optimal. This is the main cause of premature wear of the tooth during work in the rock mass. Manufacturers of these teeth strive for a large sales volume. However, we try to prove that preventive safeguarding of the discussed elements allows for a significant increase in their durability.

SELECTION OF ELECTRODES AND PAD WELDING TECHNOLOGY FOR THE RIPPER TOOTH

We selected electrodes for pad welding taking into account the exact chemical composition and selected mechanical properties of the ripper tooth material. The selection of electrodes was based on the experience of one of the authors, who, for 25 years, has been dealing with choosing electrodes for welding and pad-welding as the sole representative of a reputable world company producing specialized welding consumables. For making the buffer layer, we chose an electrode in line with EN 14700: E Fe 14-60-cg, DIN 8555: E 10-UM-60-GRZ, and AWS: E FeCrA1 with the following chemical composition: carbon C 3.5–4.2%, chromium Cr 28–32% and iron Fe for the remaining part.

For making the operation layer, we chose an electrode in line with EN 14700: E Fe 15-60-cg, DIN 8555: E 10-UM-65-GRZ. The chemical composition (according to the manufacturer) of the electrode for pad welding is the following: carbon C 4.7–5.2%, chromium Cr 32–35%, and Fe iron. The buffer layer made with an electrode with lower iron and chromium content is intended for better connection with the native material of the tooth. Subsequent layers contain more carbon and chromium, which results in a gradual increase in the hardness as the thickness of the padded weld increases. This combination reduces the risk of cracks leading to chipping. It is not recommended to use multiple layers with only electrode No. 2, because the padded weld layer could peel off as the difference in hardness would be too great. In addition, the probability of cracking is high.

The proposed electrodes are characterized by high resistance to abrasion, good resistance to dynamic loads, and very good properties at temperatures above 600˚C, which occur during the operation of the ripper's teeth when they sink into the rock **[L. 10].**

Before the buffer layer was applied, the entire surface of the ripper's tooth was mechanically cleaned until metallic gloss was achieved. Then the tooth was preheated to 80–100°C and the buffer layer was applied (**Fig. 5a** and **Fig. 5b**). The buffer layer was made with an electrode with a diameter of Ø3.25 mm, 120A current, and 25V voltage. Deviations in current and voltage values must not exceed ±10% of the nominal values.

Then, subsequent layers of padding welds were applied with electrodes of the same diameter at a current intensity of 125A and the voltage was increased to 26V. For all layers, the pad welding speed did not exceed 0.25 m/min. After making each layer of padded weld, the surface was thoroughly cleaned of chips and slab by means of grinding. The sequence and direction of making individual padded welds are shown in **Fig. 5a** and **Fig. 5c.**

During the pad welding process, the temperature between the runs was 250˚C. Therefore, it was necessary to hold the welded surface at the temperature of 300–350˚C for two hours **[L. 11, 12]. Figure 6** shows the view of a brand new tooth and a ripper tooth with padding weld.

Fig. 6. Ripper with padding weld (top) and without padding weld (bottom)
Rys. 6. Zrywaka z napoiną (na górze) i bez napoiny (na dole)

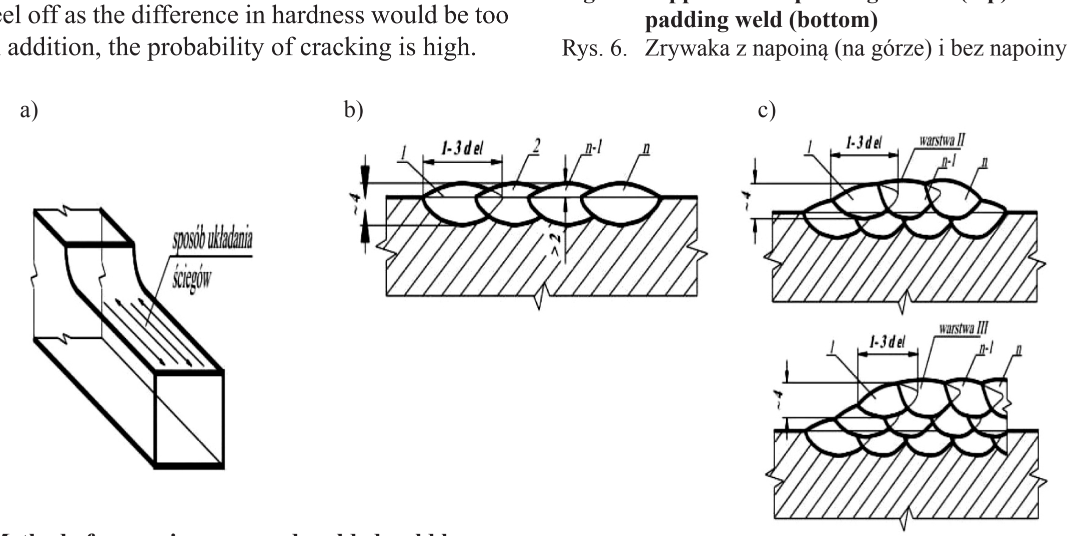


Fig. 5. Method of arranging runs and padded weld layers
Rys. 5. Sposób układania ściegów i warstw napoiny

EXAMINATION OF THE RIPPER TOOTH AFTER PAD WELDING

In order to determine the hardness of ripper after pad welding, the same steps as for the brand new ripper tooth were performed. The drawing shows the points of hardness measurement for the tooth material after pad welding and the imprint after the tribological wear test **(Fig. 7a)**.

In spots marked with consecutive digits, the hardness was higher, as shown in **Table 2**:

Table 2. Hardness in measurement points
Tabela 2. Twardość w punktach pomiarowych

Measurement point	1	2	3	4	5	6	7	8	9
Hardness [HRC]	55	53	53	53	56	56	57	59	60

The tribological tests were carried out under the same conditions as in the analysis of a non-welded tooth.

As before, the test lasted 1800 seconds at ball revolutions of 250 [rpm] and 50N pressure. In the Elbit tribotester, an aqueous solution of silicon oxide was also introduced into the friction pair. The wear test showed a reduction in weight of: 33.08285g -33.08275g -33.08275g = 0.00010g (measured with a vacuum mass comparator). In this case, the dimensions of the imprint, measured in mutually perpendicular directions, were 2.09mm×2.00mm, (**Fig. 8b)**. Then, we performed a microsection and microscopic photos of the pad-welded ripper tooth (**Fig. 8)**.

The next stage of the tests of the obtained padding weld included testing their microstructure with a JSM 7100 F scanning electron microscope. These tests were carried out on metallographic microsections etched with Mi19Fe reagent. Padding weld microstructure is shown in **Fig. 9**.

a) b)

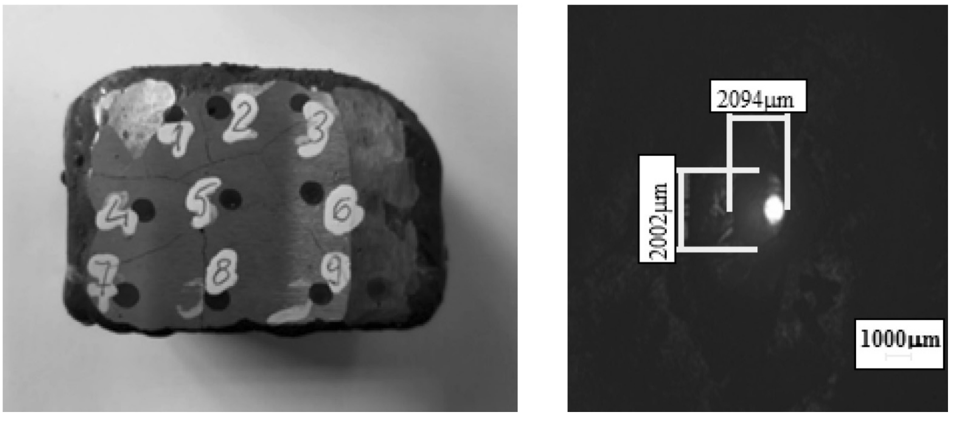


Fig. 7. Hardness measurement locations (a) and imprint measurement after wear test (b)
Rys. 7. Miejsca pomiaru twardości (a) i pomiar odcisku po teście zużycia (b)

a) b)

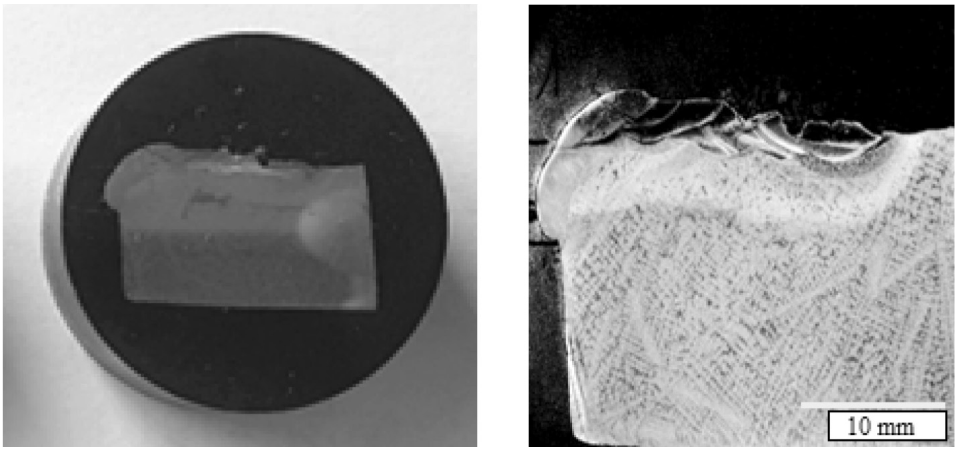


Fig. 8. Metallographic microsection of the pad welded ripper tooth and microstructural image
Rys. 8. Zgład metalograficzny napawanego zęba zrywaka i obraz mikrostruktury

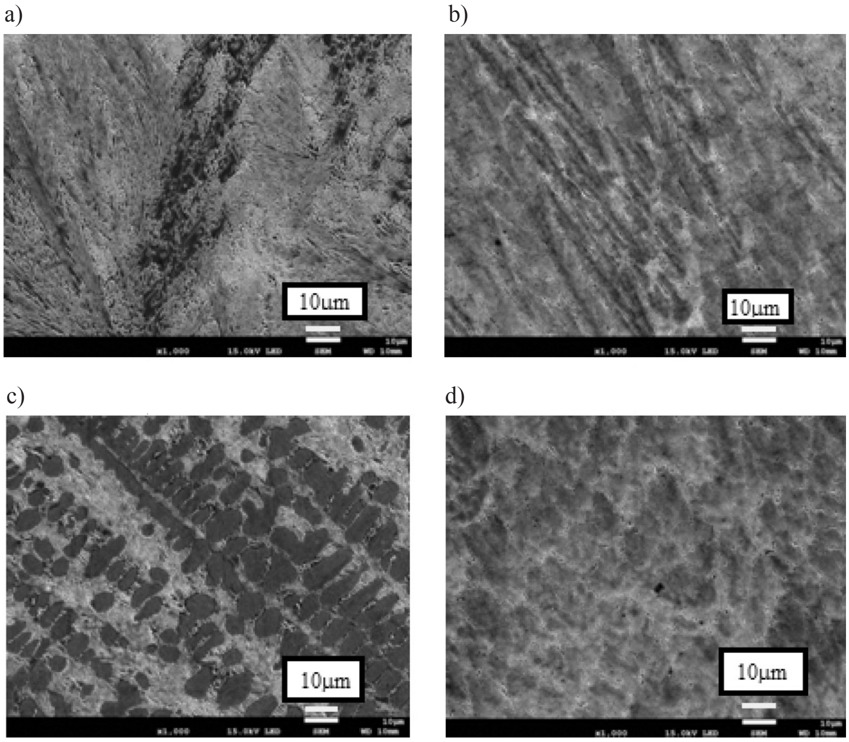


Fig. 9. Padding weld microstructure: a, b) growth of crystals in the direction of heat dissipation, c, d) change of padding weld microstructure depending on the distance from the next welded layer

Rys. 9. Mikrostruktura napoiny: a, b) wzrost kryształów w kierunku odprowadzenia ciepła, c, d) zmiana mikrostruktury napoiny w zależności od odległości od kolejnej warstwy napawanej

The padding welds made did not show any welding defects or inclusions. Directional crystal growth conforming to the direction of heat dissipation can be observed (**Figs. 9 a, b**). Depending on the run position, the microstructure of padding weld kept changing under the influence of the heat coming from the next welded layer (**Figs. 9 c, d**). No welding imperfections were observed in the fusion line.

At the final stage of testing the obtained padding weld, the linear distribution of selected elements in the padding weld – the base tooth material area was examined. Linear analyses were performed using the EDS (Energy Dispersive Spectrometer) detector. **Figure 10** shows the view of the measurement section of the tested padding weld, and **Figure 11** shows the linear distribution of selected elements in the measurement section in the padding weld – tooth material matter.

Photographs of the microstructure and linear distributions of selected elements confirmed the correct character of padding weld's fusion into the base material of the tooth. There are no welding discontinuities at the padding weld–base material joint. A narrow zone of heat influence determines a smooth transition between the padding weld and the base material, which is confirmed by linear distributions of selected elements.

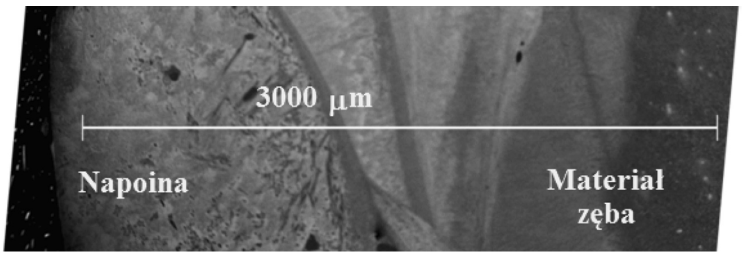


Fig. 10. Measurement section for investigating the distribution of elements in padding weld – tooth base material area

Rys. 10. Odcinek pomiarowy do zbadania rozkładu pierwiastków w obszarze napoina – materiał podstawowy zęba

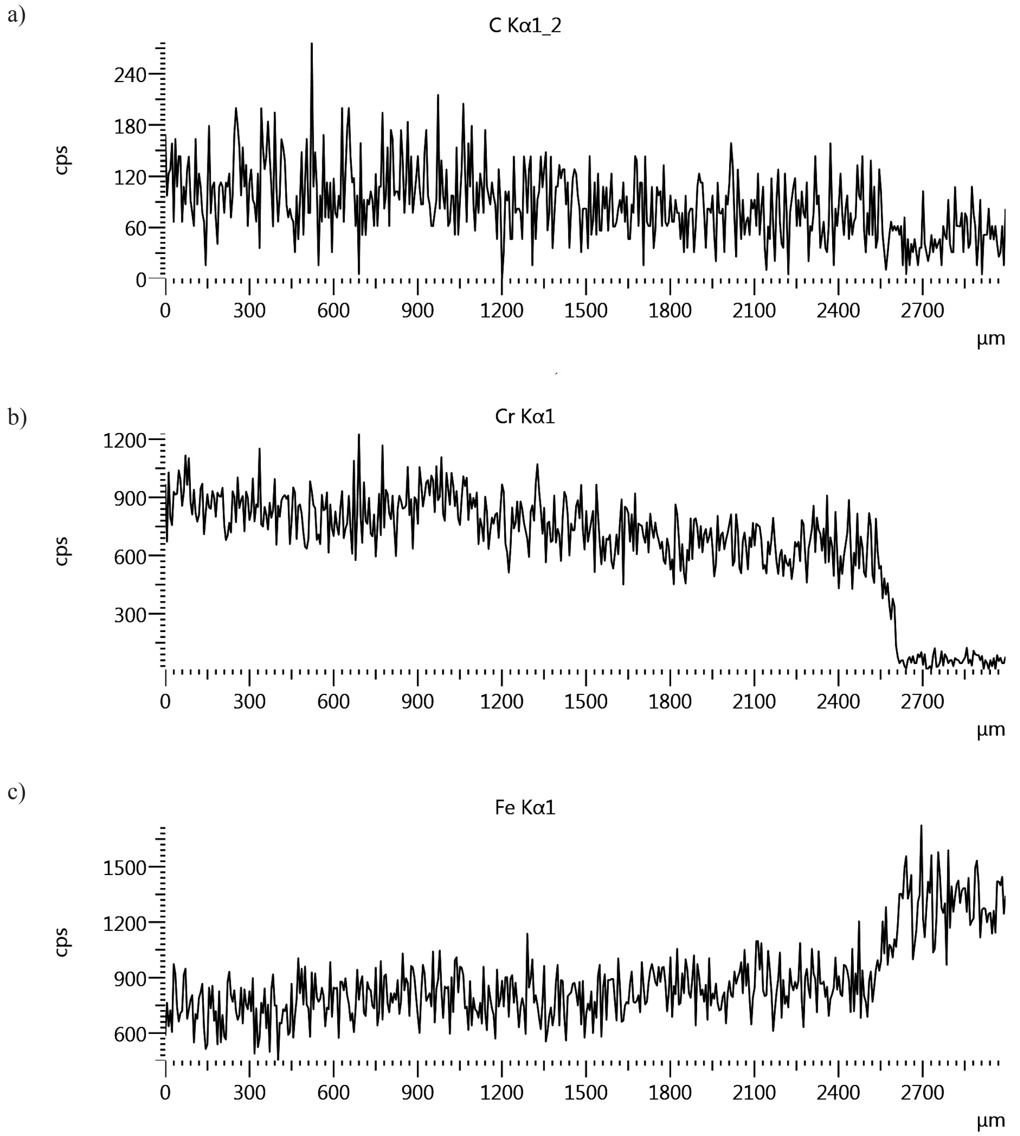


Fig. 11. The linear distribution of elements in the padding weld – tooth base material area: a) carbon C, b) chromium Cr, c) iron Fe

Rys. 11. Liniowy rozkład pierwiastków w obszarze napoina – materiał podstawowy zęba: a) węgla C, b) chromu Cr, c) żelaza Fe

OPERATION TESTS OF THE TEETH

The KOMATSU 800LC **[L. 13]** excavator was used to test teeth wear in industrial conditions. The XR 30 vibration ripper by Xcentric Ripper **[L. 2]** was connected to the excavator as an accessory (**Fig. 12**).

The tests were carried out in limestone beds, which were characterized by different compressive strength of the rocks amounting to Rc = 62–104 MPa. The worked beds were characterized by a very high R.Q.D fracture index rate resulting not only from the natural causes but also from the blasting works carried out previously **[L. 14].** Limestone mined from the bed constituted the raw material used for cement production.

In the first research phase, teeth purchased directly from the ripper manufacturer were used as the tip of the ripper and we tested the duration of their efficient

Fig. 12. Vibration ripper before installing on the KOMATSU 800LC excavator

Rys. 12. Zrywak wibracyjny przed zainstalowaniem na koparce KOMATSU 800LC operation until achieving significant wear. We assumed that, for all the tested teeth, significant wear was equivalent to achieving tooth lengths of 440 to 450 mm, with initial tooth lengths of 570 to 580 mm. The obtained research data allowed the determination of the correct operation life of the teeth made by the ripper's manufacturer. The results of the experiment for two teeth batches with two teeth each are presented in the collective **Table 3**.

In the second stage of the research, new teeth were assembled in the ripper, pad welded in line with the above-mentioned technology immediately after purchase from the manufacturer. In this case, a given tooth was also used until its length dropped to 440–450 mm.

The research was complemented with measurements of the durability of regenerated teeth. These were end-of-life teeth with various length losses. They were regenerated using the pad welding technology described above, but for some of the teeth, it was necessary, due to the degree of wear, to make more padding weld runs.

Determination of the effective operation time of particular types of teeth proved a significant problem during this research. This was related to the fact that the volume of limestone mined from the bed depended on the actual demand for raw material in the cement plant, its location in the bed, and on the time of operation of a mobile processing unit crushing the mined limestone into the desired fraction size. For this reason, we decided to determine the average operation time of a given type of the tested ripper and express it in terms of one-shift operation in a monthly period. The operation time was determined on the basis of the records in the mine's work reports.

Table 3 presents the results for an operation time of a standard tooth (brand new), a brand new tooth strengthened with a padding weld and a tooth regenerated with the use of pad welding technology until they are completely worn down. Additionally, the table presents unit prices of individual teeth, taking into account the costs pad welding new teeth amounting to PLN 700 and the costs of pad welding regenerated teeth amounting to PLN 1200.

Table 3. Comparison of the operation period of the tested ripper teeth

Tabela 3. Porównanie czasu pracy badanych zębów zrywaków

No	Tooth type	Operation time [months]	Net unit price [PLN/pc]
1	Standard	1.5	2500
2	New strengthened	2.5	2500+700=3200
3	Regenerated	2.0	1200

SUMMARY

The pad welding technology for vibration ripper teeth presented in this article was developed in order to reduce the costs of their operation.

Analysis of the data showing the relationship between operation time and the ripper tooth price **(Table 3)** indicates that the use of standard (brand new) teeth is not economically viable. The use of additional tooth strengthening consisting of a padding weld made according to the technology presented in the article, which costs only PLN 700, extends the life of the tooth by another month. If the tooth is regenerated three times, its service life may increase by another 6 months. Therefore, assuming that a new tooth will be accepted for operation and strengthened with a padding weld, which will then be regenerated three times, the total service life of such tooth may amount to 8.5 months. The use of the strengthening measures protection and regeneration of teeth according to the proposed pad welding technology may result half of the cost when compared to the purchase of new, standard teeth.

It is worth noting that the electrodes proposed for pad welding the ripper's teeth are easily available, and the technology of making these padding welds does not pose any major technical difficulties. However, the padding welds must be made in compliance with all the requirements concerning the sequence of making, taking into account the thermal processes occurring during their making and the requirements concerning the purity of subsequent padding weld layers superimposed one upon the other. The presented pad welding technology is far from being easy, because it is necessary to know how to apply buffer layers, how to heat the material, and how to carry out heat treatment of the padding welds. Moreover, in Polish mines, the commonly used material for pad welding includes the EN600B electrode, which fails in these conditions.

The performed padding weld tests have shown an increase in hardness on the surface of the tooth material which exceeded (depending on the place of measurement) even 100% of the hardness value for material of a brand new tooth. The impact strength was tested only for the tooth material. These tests are not used for the examination of pad welded layers as they only make up for up to 1% of the tooth thickness. It is important to be aware that, due nature of a ripper's work, it is exactly the hardness of the tooth's surface material with a soft centre that determines the length of its service life.

Although we believe that satisfactory values for padding weld hardness have been obtained, it is possible to increase these hardness values, but it would require the use of electrodes with much higher unit prices.

The aim of the article is to encourage machine users to use technologies at least somehow different from the generally accepted standards. The use of EN600B or even EB150 electrodes for pad welding is unjustified or even harmful in this case.

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