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THEORETICAL AND EXPERIMENTAL ESTIMATION OF THE WORKING LIFE OF MACHINE PARTS HARD FACED WITH AUSTENITE-MANGANESE ELECTRODES

TEORETIČNO IN EKSPERIMENTALNO UGOTAVLJANJE ZDRŽLJIVOSTI STROJNIH DELOV, OPLAŠČENIH S TRDIMI AVSTENITNO-MANGANSKIMI ELEKTRODAMI

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We have investigated the possibility of repairing damaged machine parts by hard facing with austenite-manganese steel electrodes. The subject is a Fe-C-Mn alloy with a microstructure of soft austenite which, after cold deformation, transforms by a shearing mechanism into a hard martensite microstructure. These steels are used mainly for parts exposed to high impact loads and intensive abrasive wear. Depending on the degree of wear, these parts can be replaced by new ones or repaired by hard facing. The selection of the optimal reparation technology for the rotational crusher's impact beams is the subject of this study. Investigations of model samples were conducted first, followed by layers hard faced onto samples with austenite manganese and special electrodes. After this the microstructure and hardness of the welds' characteristic zones were investigated. After reparatory hard facing the impact beams were mounted in the crusher and their behaviour was monitored periodically. Both the new and hard-faced beams' behaviours were monitored and compared under the same working conditions. In this way, the optimal technology for hard facing was established, taking into account not only the technical indicators, but also the economic effects.

Keywords: austenite manganese – hadfield steel, mining engineering equipment, hard facing, reparation

Ta članek predstavlja študij možnosti obnove poškodovanih delov z nanašanjem trdih plasti iz avstenitno-manganskih jekel. Predmet raziskave je zlitina Fe-C-Mn z mehko avstenitno mikrostrukturo, ki se med hladno deformacijo s strižnimi mehanizmi pretvori v trdo martenzitno mikrostrukturo. Ta jekla se uporabljajo predvsem za dele, izpostavljene velikim udarnim obremenitvam in močni obrabi. Odvisno od stopnje obrabe se ti deli nadomeščajo z novimi ali pa se obnovijo s trdimi nanosi. V tem delu je preučevana izbira optimalne tehnologije obnove rotacijskih udarnih drobilnikov. Najprej je bila izvršena preiskava na modelnih vzorcih z nanosom trde plasti iz avstenitno-manganske posebne elektrode, nato pa preiskana še mikrostruktura in trdota značilnih varjenih področij. Po obnovi z nanosom trde plasti so bile udarne plošče nameščene v drobilnik in periodično je bilo spremljano njihovo vedenje. Primerjane so bile lastnosti novih in obnovljenih plošč v enakih obratovalnih razmerah. Tako je bila določena optimalna tehnologija obnavljanja delov z upoštevanjem ne samo tehničnih lastnosti, temveč tudi iz ekonomskega stališča.

Ključne besede: avstenitno-mangansko – Hadfield jeklo, rudarska strojna opreme, nanašanje trdih prevlek, obnavljanje

1 INTRODUCTION

In an investigation of the damage caused to various parts of machines and devices it was established that in more than 50 % of cases the damage occurs due to tribological processes involving more-or-less regular working conditions[1–3]. Accordingly, for the design of the reparation technology for damaged parts, we must first study the possible mechanisms of wear for coupled parts. Here, it should be kept in mind that, besides repairing the parts damaged in normal conditions, hard facing is also used for parts damaged due to failures, as well as for new, flawed cast pieces. Besides, new parts are also hard faced by depositing hard alloys, which can replace the traditional procedures of carburizing and nitriding. All these facts indicate that hard facing is an important advanced technologies.

The key parts of machines, assemblies and devices are frequently produced from very expensive alloys. Thus, by repairing them we are not only shortening the down times due to repairs, but also saving on expensive base materials as well as for the machining of parts. In the majority of cases the economic criterion for applying reparation is that the price of the repair cannot exceed the price of the new part. This is especially important for large-sized parts and batch production, while the reparation of unique machines and devices sometimes has to be performed regardless of the price[4–10].

2 SELECTION AND PROPERTIES OF MATERIALS RESISTANT TO ABRASIVE WEAR

2.1 Base metals

The materials used most frequently for manufacturing the working parts of civil-engineering machines exposed to abrasive wear are cast pieces made from manganese steel. When selecting a material for manufacturing the working parts of such machines, i.e., by selecting the filler metals for their reparation or hard-facing manufacture, we should pay particular attention to the mechanism of abrasive action, since two very different basic cases are met.

In the first case, at the contact surface of the working parts of civil-engineering machines, abrasive and very high specific pressures and local plastic deformation of those parts appear when the external load forces have an impact character. A typical part exposed to abrasive wear of this type is the impact beam of a stone crusher, where the abrasive element is the compact stone. In the second case, the abrasive is in the dispersed state (e.g., a small aggregate). Thus, on the contact surfaces only smaller specific pressures appear and large plastic deformations do not occur. The characteristic parts exposed to this type of wear are the teeth of loading dredger scoops, the storage crates of the transporters, etc.

Manganese austenite steels, also Hadfield steels[11–15], exhibit good resistance to the first type of abrasive action. They are usually supplied in the cast, hot- or cold-deformed states. Besides the basic Hadfield steel (ČL3160-JUS, G-X120Mn12-DIN), which contains 1.20 % C, 12 % Mn, 0.50 % Si, 0.35 % P and 0.10 % S, the following multi-alloyed manganese steels are applied steels: (ČL3161-JUS), (ČL3460-JUS), (ČL3462-JUS) and (ČL3463-JUS), which possess good resistance to impact wear because, besides the high contents of manganese (w(Mn) = 12–17 %) and carbon (w(C) = 1–1.4 %), they are also alloyed with chromium (w(Cr) = 1–1.8 %). The hard facing reparation of these steels is usually performed by the application of basic manganese electrodes. The good resistance to abrasive wear by dispersed materials is exhibited by heat-treated, low alloyed steels, rapidly cooled cast steels and ledeburite tool steels[12,15,16].

The chemical composition and instructions for the application of the base metals (ČL3160 and ČL3460) are given in **Table 1**, while the comparative marks by the JUS and DIN Standards, as well as the mechanical properties and microstructure of those materials, are given in **Table 2** [4–6,17].

2.2 Filler metals

In the experimental investigation, various filler metals were applied (E Mn14, E Mn17Cr13, E DUR 600, ABRADUR 58 and INOX B 18/8/6) [17]. In **Table 3** the chemical composition and the comparative Standards' marks are presented, and in **Table 4** are the hardness and applications of tested electrodes.

The most frequently recommended filler metals for the hard facing of the parts for civil-engineering machines subjected to impact abrasive wear and the

Table 1: Chemical composition and application of ČL3160 and ČL3460
Tabela 1: Kemijska sestava in uporaba ČL3160 in ČL3460

Base metal	Chemical composition, mass fraction, w/%	C	Si	Mn	Cr	P	S	Application
ČL3160	Prescribed	1.20	0.50	12.00	–	0.035	0.10	Suitable for manufacturing the parts exposed to abrasive wear and high impact loads, such as the working parts of mills, crushers, civil engineering machines, for work with raw materials of high hardness, etc.
	Analyzed	1.20	0.48	12.35	–	0.025	0.10	
ČL3460	Prescribed	1.20	0.50	13.00	1.00	0.040	0.10	
	Analyzed	1.20	0.55	13.14	1.12	0.035	0.15	

Table 2: Comparative Standard marks, some mechanical properties and microstructure of ČL3160 and ČL3460
Tabela 2: Primerjalne oznake po standardih, nekatere mehanske lastnosti in mikrostruktura ČL3160 in ČL3460

Comparative marks		Mechanical properties		Microstructure
JUS	DIN	Tensile strength, R_m/MPa	Hardness, HB	
ČL3160	G-X120Mn12	200	≈ 200 after fast quenching	Austenite
ČL3460	G-X120Mn12	210	≈ 210 after fast quenching	Austenite

Table 3: Comparative Standard marks and chemical composition of the tested electrodes
Tabela 3: Primerjava oznak po standardih in kemijska sestava preizkušenih elektrod

Comparative marks		Chemical composition, mass fraction, w/%						
SŽ Fiprom Jesenice	DIN8555	C	Mn	Cr	Ni	W	Mo	V
E Mn14	E7-UM-200-KP	1.20	12.50	–	–	–	0.70	–
E Mn17Cr13	–	0.60	16.50	13.50	–	–	–	–
E DUR 600	E 6-UM-60	0.50	–	7.50	–	–	–	–
ABRADUR 58	E 10-UM-60-GR	3.60	–	32.0	–	–	–	–

Table 4: Mechanical properties and application of the tested electrodes
Tabela 4: Mehanske lastnosti in področje uporabe preizkušenih elektrod

Electrode mark SŽ Fiprom-Jesenice	Hardness	Application
E Mn14	220 HB – after hard-facing 48 HRC – after forging	For hard-facing of manganese steels of thickness up to 10 *mm* which are applied for the manufacturing of parts in railroad engineering and parts of the stone crushers
E Mn17Cr13	220 HB – after hard-facing 48 HRC – after forging	For hard-facing of hydraulic presses' mallets, parts of the loading scoops of the civil engineering mechanization, parts of crushers, rails and railway-crossings
E DUR 600	57–62 HRC	For depositing of the hard welds from which the high wear resistance in the hot and cold states is expected, as well as good toughness and impact resistance
ABRADUR 58	57–62 HRC	For hard-facing of tools subjected to intensive abrasive wear in contact with minerals in a cold state
INOX B 18/8/6	-	For welding of the Cr- and Cr-Ni steels, for welding of two different types of steels, for depositing of welds resistant to corrosion and for depositing of the plastic inter-layer.

action of impact loads are austenite manganese electrodes with a large content of manganese and carbon, and the addition of other alloying elements, usually chromium, and then Ni, Mo, V and W[11–13,15,17].

3 ESTIMATION OF THE WELDABILITY OF MANGANESE STEELS

Manganese steels with an austenite structure are prone to overheating and, with the deposition of multi-layer welds, the appearance of cracks is possible. Thus, it is necessary to know the behaviour of those materials when a significant amount of heat is being brought in, which would enable measures preventing the growth of austenite grains and the formation of brittle phases. Depending on the content of manganese and carbon, during a slow enough cooling of a Fe-C-Mn alloy we can obtain the following: perlite, perlite-martensite, martensite-austenite and austenite microstructures. Perlite and austenite manganese steels have practical applications; however, they have a low plasticity and, due to rapid hardening, they are difficult to machine mechanically. An increase of the plasticity of manganese austenite steels is achieved by the thermal treatment of rapid quenching, which consists of heating up to a temperature of 1093 °C [15], then heating through that temperature, followed by rapid water cooling. In this way, a pure austenite microstructure and high toughness are obtained. After the cooling, from casting or from the hot-deformation temperature, we obtain an austenite microstructure with particles of complex iron manganese carbides precipitated at the boundaries of the austenite grains. In contrast to this, after slow cooling some martensite will also appear, i.e., a predominantly martensite or austenite-martensite microstructure.

To achieve a satisfactory weldability of these manganese austenite steels it is necessary to prevent the abrupt growth of austenite grains due to the excessive quantity of heat that is introduced. This is why it is recommended that the hard facing is performed with short welds, the careful selection of hard-facing parameters and forced rapid cooling. In the opposite case, the abrupt growth of austenite grains can occur, which would worsen its weldability and mechanical properties. The tendency of welds that are applied with manganese electrodes to crack is significantly reduced by the addition of a certain quantity of nickel and chromium, usually up to 4 % [13,15].

4 MODEL INVESTIGATIONS

4.1 Selection of the hard-facing technology

The tests were conducted on samples made of low-carbon steel (Č0361) with a thickness s = 10 mm for the purpose of selecting the technological parameters of the hard-facing procedure. The samples were welded using the REWL procedure. Depending on the type and the diameter of the used electrode, the hard-facing parameters were within the limits given in **Table 5** [4–6,16]. The method of depositing the weld layers, the order and the number of deposited layers and the appearance of the model are presented in **Figure 1**.

It is necessary to emphasize that, for further metallographic and other investigations, the samples were chosen to be welded using an electrode of diameter d_e = 3.25 mm. Single-pass welds had a width b = 6–12 mm and a height h = 3.2–4.6 mm. The two-layered samples were only welded with the electrodes E Mn14 and E Mn17Cr13 (**Figure 1b**), while the three-layered samples were welded with electrodes E DUR 600 and ABRADUR 58 (**Figure 1c**) with the prior deposition of the inter-layer with the electrode INOX B 18/8/6. For model investigations, neither a prior nor a posterior thermal treatment was applied. After the hard facing the samples were rapidly cooled and then with grinding a

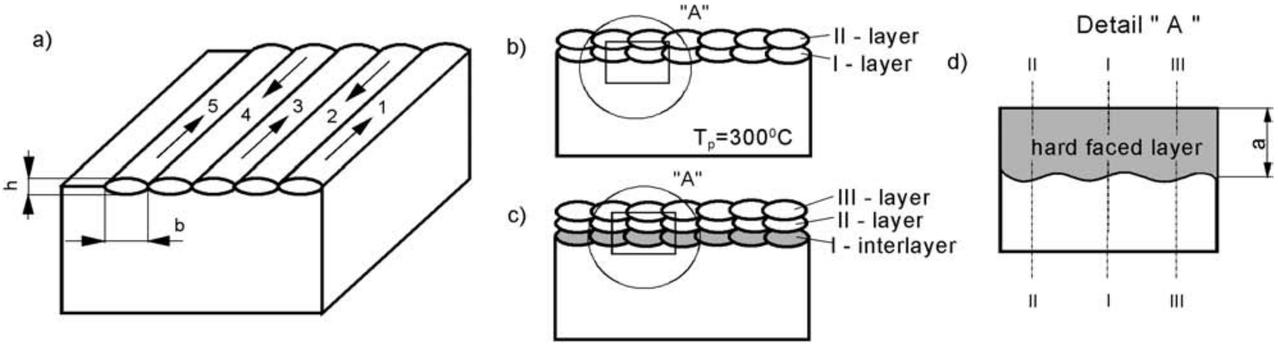


Figure 1: Order of weld layers' depositing: a) 1 layer, b) 2 layers (E Mn14, E Mn17Cr13), c) 3 layers (INOX B 18/8/6-E DUR 600, INOX B 18/8/6-ABRADUR 58), d) metallographic ground piece (block)

Slika 1: Zaporedje navarjenih slojev: a) 1 sloj, b) 2 sloja (E Mn14, E Mn17Cr13) c) 3 sloji (INOX B 18/8/6-E DUR 600, INOX B 18/8/6-ABRADUR 58), d) kos za metalografske preiskave

Table 5: Technological parameters of hard-facing

Tabela 5: Tehnološki parametri nanašanja trdih plasti

Base metal thickness s, *mm*	Electrode mark	Electrode core diameter d_e/mm	Current intensity I/A	Working voltage U/V	Welding speed v_z/(cm/s)	Welding driving energy, J/cm
10	E Mn14	3.25	120	25	≈ 0.148	16216
	E Mn14	5.00	180	27	≈ 0.162	24000
	E Mn17Cr13	3.25	130	25	≈ 0152	17105
	E Mn17Cr13	5.00	200	28	≈ 0.168	26667
	INOX B 18/8/6	3.25	100	24	≈ 0.136	14118
	INOX B 18/8/6	5.00	160	26	≈ 0.178	18697
	E DUR 600	3.25	120	25	≈ 0.119	20168
	ABRADUR 58	3.25	130	25	≈ 0.124	20968

portion of the material was removed from the back layer[4–6].

4.2 Metallographic investigations and hardness measurements on models

Manganese austenite steels have a relatively small hardness in the range from 180 HB to 250 HB (usually 200–229 HB). They are highly resistant to abrasive wear only when their working surface layers are intensively plastically cold deformed with effect of strong impact loads or of slow pressure as a result of the pressing load. However, in these steels the hardening of the surface layers is not due to the strain hardening of the austenite, but the plastic deformation initiates the phase transformation of austenite to martensite. After local transformation of the austenite to martensite, a hardness of the surface layers as high as 500–520 HK can be achieved (the usual hardness range is between 330 HK and 480 HK). For this reason, these steels are hard to machine by cutting and are usually treated by hot or cold plastic deformation or by casting.

In some references[4–6,8] the limiting depth was established at which we can still observe an increase in the surface layers' hardness due to the austenite-to-martensite transformation initiated by the plastic cold deformation. The maximum measured hardness was 460 HK, and the width of the transformed zone was 0.50

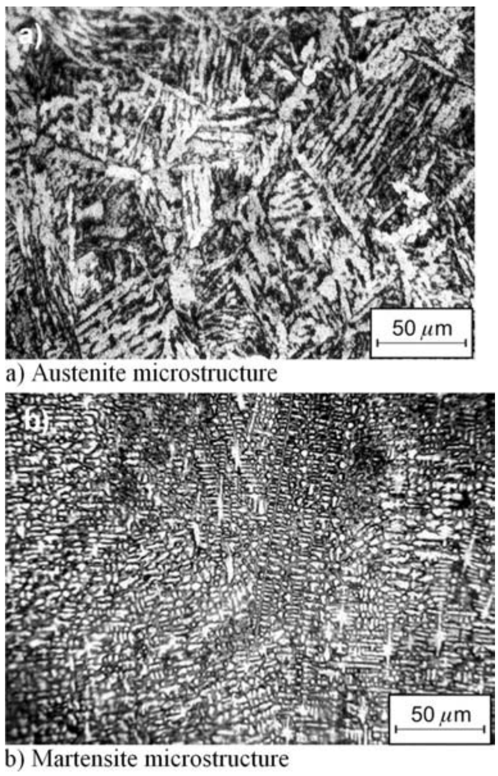


Figure 2: Microstructure of the Hadfield steel (ČL3160): a) before the plastic deformation and b) after the plastic deformation

Slika 2: Mikrostruktura Hadfield jekla (ČL3160): a) pred plastično deformacijo, b) po plastični deformaciji mm. In **Figure 2** the microstructure of the Hadfield steel (ČL3160), before and after plastic deformation, is presented[4–6].

In **Figure 2** we can see that the microstructure of the Hadfield steel before the plastic deformation was purely austenite, while after the plastic deformation the needles of martensite can be seen in the austenite matrix.

In some investigations[1–3] it was shown that the austenite-carbide microstructure has the highest wear resistance, rather than the martensite-carbide, as would be expected from their hardness values. The reason lies in the stronger austenite-carbide, grain-boundary bonds due to the smaller difference of the lattices parameters, rather than in the martensite-carbide combination. In other words, abrasive particles are pulling out the carbide particles from the martensite matrix more easily than from the austenite.

Despite the evident difficulties associated with hardness measurements and in dterming the hard-faced layers' microstructure, we were able to determine the width of the austenite-to-martensite transformation zone and were also able to record the microstructure of that zone. These data can be of special importance in the hard facing of various working parts of technical systems that operate in such or similar working conditions. In Figures 3 and 4 are the distributions of the welds before and after the plastic deformation. The following filler metals were used: E Mn14 and E Mn17Cr13 [4–6,8].

From **Figures 3** and **4** it is clear that there is an increase in the hardness after the plastic deformation in both tested filler metals. By comparing the results (**Figure 4**) related to the filler metals E Mn14 and E Mn17Cr13, it is clear that a somewhat higher hardness was obtained for the second filler metal. Also, it can be concluded that the width of the transformed austenite-to-martensite zone is larger for the welds deposited by the E Mn17Cr13 electrode. The maximum measured hardness after the cold hardening in the welds deposited by the E Mn14 electrode was about 520 HK, while the width of the transformed zone was 0.60 mm. In the same conditions for welds deposited by the E Mn17Cr13 electrode the maximum obtained hardness was 560 HK and the width of the transformed zone was 1.20 mm [4–6,8].

The microstructures of the surface layer of the back weld before and after the cold plastic deformation are shown in **Figures 5** and **6** [4–6,8].

The hardness distributions and the appearance of the formed structures in the characteristic zones of the filler metals E DUR 600 and ABRADUR 58 are presented in[4–6,8].

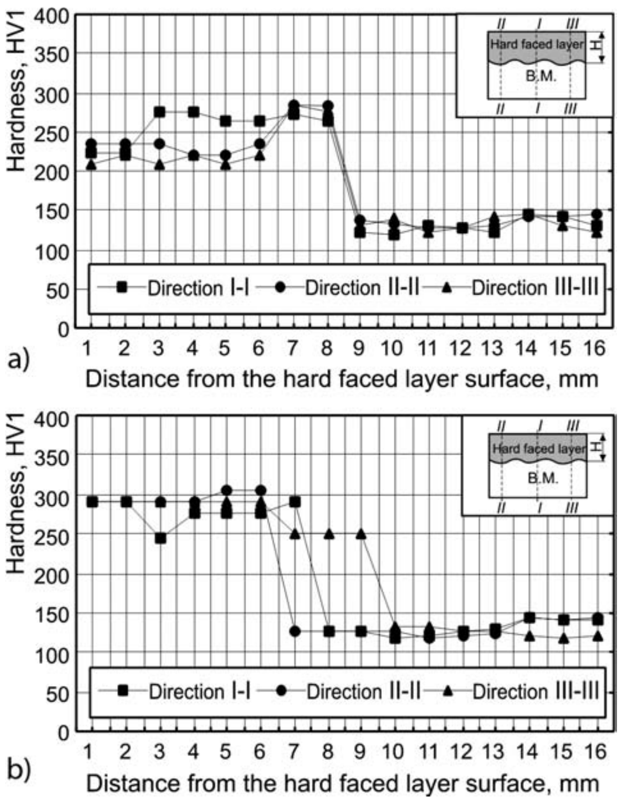


Figure 3: Micro hardness distribution along the welds' cross-section before the plastic deformation: a) E Mn14 and b) E Mn17Cr13

Slika 3: Razporeditev mikrotrdote v prečni smeri vzdolž zvara pred plastično deformacijo: a) E Mn14 in b) E Mn17Cr13

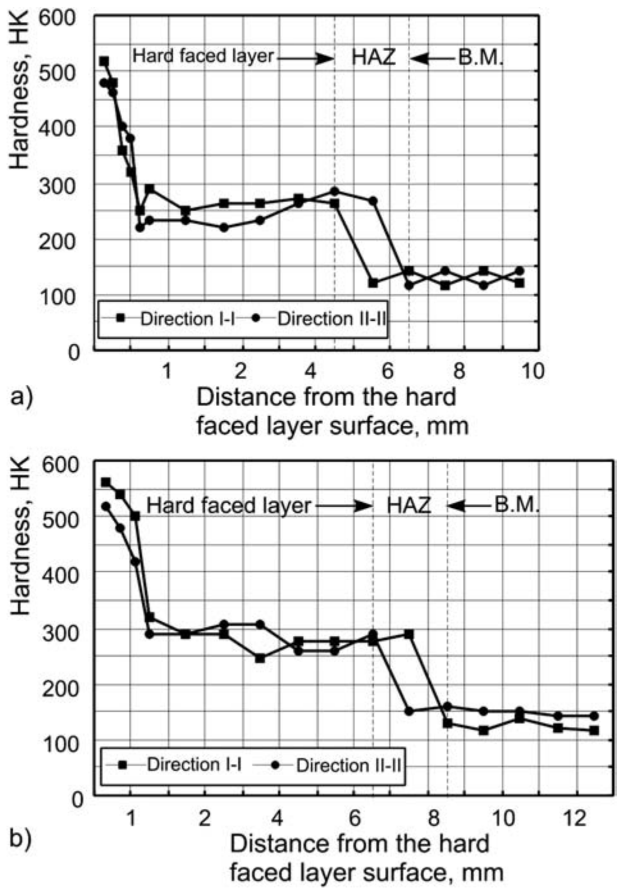


Figure 4: Micro hardness distribution along the welds' layer cross-section after the plastic deformation: a) E Mn14 and b) E Mn17Cr13

Slika 4: Razporeditev mikrotrdote v prečni smeri vzdolž zvara po plastični deformaciji: a) E Mn14 in b) E Mn17Cr13

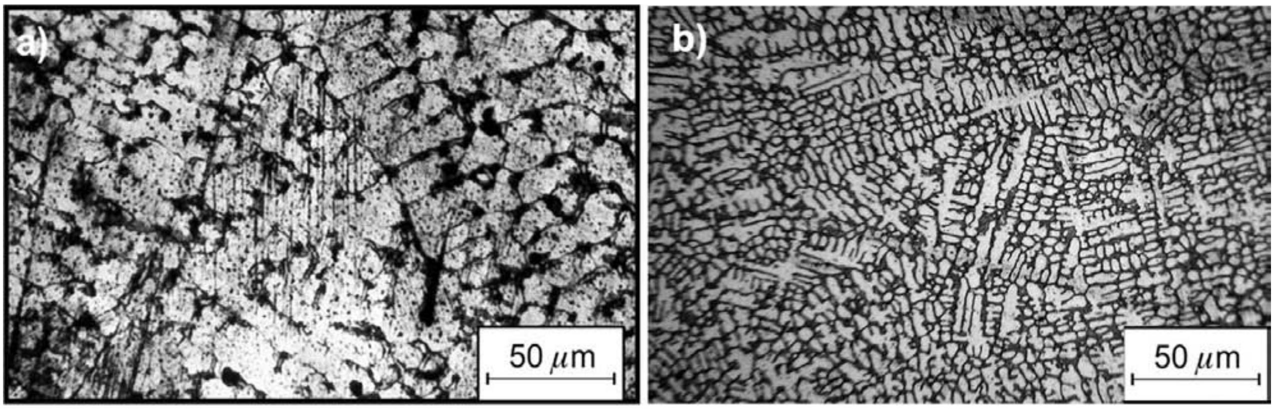


Figure 5: Microstructure of the weld's back layer: a) before the plastic deformation and b) after the plastic deformation; Filler metal: E Mn14
Slika 5: Mikrostruktura zvara: a) pred plastično deformacijo in b) po plastični deformaciji; material elektrode: E Mn14

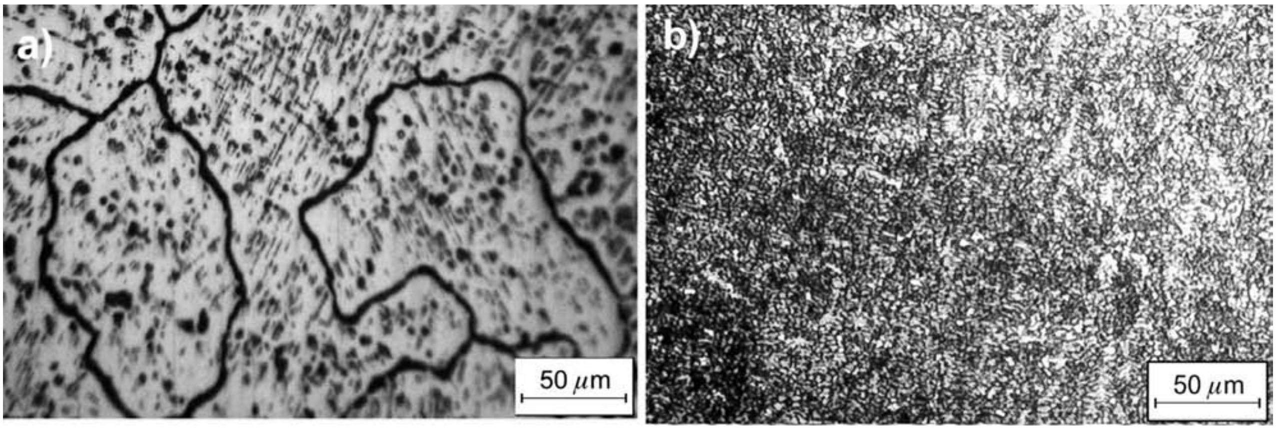


Figure 6: Microstructure of the weld's back layer: a) before the plastic deformation and b) after the plastic deformation; Filler metal: E Mn17Cr13
Slika 6: Mikrostruktura zvara: a) pred plastično deformacijo in b) po plastični deformaciji; material elektrode: E Mn17Cr13

5 EXPERIMENTAL HARD FACING OF IMPACT BEAMS AND A DETERMINATION OF THEIR WEAR RESISTANCE

5.1 Description of the crusher plants' operation

The impact beams of crushers are simultaneously exposed to large impact loads and intensive abrasive wear since they are in working contact with rocks. In fact, the rocks are being crushed, minced and ground in order to obtain various fractions of the granules for direct insertion into roads or buildings. Besides being used for grinding rocks, similar crushing plants are also being used for the mincing of ores and coal.

Impact-beam wear occurs according to the mechanism of abrasive wear of the so-called closed type. The rock is brought into the working space between the beams and the stationary crusher housing where the kinetic energy of the rotational beams is transferred to the work, which is being spent on breaking the cohesive and adhesive bonds of the rock material.

The rock materials for building roads are usually of high hardness, and thus the crushers' working parts must have high toughness and wear resistance[4–7]. The experimental investigations presented in this paper were conducted on impact beams and segments of the housing forming the crusher's jaw, **Figure 7**. The wear of the beams and the housing was monitored during the crushing of lime stone in a crusher with a capacity of 350 t/h. This is a rotational crusher with four impact beams, which are mounted onto the rotor and are driven by an electric or IC engine, with a pulley and v-belts. Such transmissions enable the belts to slide if overloading occurs, which protects the crusher's vital parts against fracture.

Impact beams have two alternative working surfaces, which allows the beam to be turned over and the second surface used after the first one is worn out. The crusher housing is made of flat spherical segments that are also being worn during the working process.

The crusher impact beams, on which the experimental hard-facing was performed, are made of manganese steel. Their dimensions were 300 mm × 120 mm × 1000 mm and their mass was around 300 kg. The same cast steel sheets were used for manufacturing the housing elements of thickness 30 mm and mass of around 20 kg.

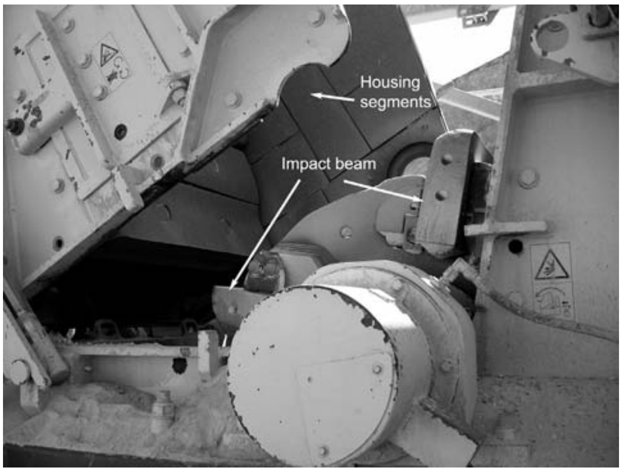


Figure 7: Appearance of the impact beams and crusher housing segments
Slika 7: Videz udarnih plošč in deli ohišja drobilnika

5.2 Experimental hard facing

The hard facing of impact beams was performed by technologies that are similar to the model investigations, but with changed working conditions. The reason for this is the large mass of the impact beams, as the hard facing was done in real working conditions, i.e., in a quarry. This means that the welds were deposited in the most unfavourable conditions, which gives special importance to the obtained results.

In the reparatory hard facing of the damaged impact beams, four beams were hard-faced, each one with a different filler metal (E Mn14, E Mn17Cr13, ABRADUR 58 and E DUR 600). The welds were deposited onto one of the two working surfaces of the impact beams, while the other working surface was brand new and unworn, and in this way a comparison of the working life of new and repaired beams was possible. The welds were deposited longitudinally on the working surface and the necessary weld thickness was achieved by multilayer hard facing with the thickness of each layer ranging from 10 mm at the ends to 35 mm in the middle of the impact beams where the wear was the greatest. The hard facing of the impact beams with electrodes E Mn14 and E Mn17Cr13 was done without the deposition of a plastic inter-layer. On the contrary, the weld layers realized by the ABRADUR 58 and E DUR 600 electrodes were deposited over the previously deposited plastic inter-layer of INOX B 18/8/6. After the hard facing, no faults of the crack type were spotted during a visual control of the large, hard-faced working surfaces (1200 mm × 100 mm).

In the reparatory hard facing of impact beams, two new beams were hard faced by depositing lateral multi-layers consisting of single-pass welds with the electrodes ABRADUR 58 (one impact beam) and E DUR 60 (the other impact beam). The distance between the deposited layers was about 100 mm, and partial welds were deposited all over the working surface. Two other impact beams were hard faced by depositing partial cross-like (honeycomb) welds over the whole working surface in such way that one impact beam was hard-faced with the E Mn14 electrode while the E Mn17Cr13 electrode was used for the other beam. The maximum weld thickness allowed is up to 10 mm, for construction reasons, since thicker welds would touch the housing during rotation. As in the first case, the hard facing with the ABRADUR 58 and E DUR 600 welds was deposited over the previously deposited plastic layer of INOX B 18/8/6, while the hard-facing welds of the electrodes E Mn14 and E Mn17Cr13 were directly deposited over the base metal. In this way, the second set of impact beams was prepared.

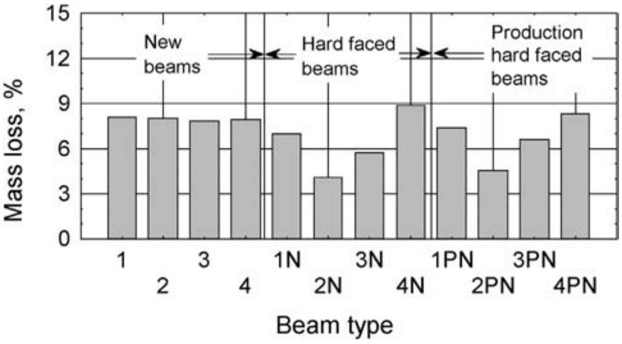
With monitoring of the impact beams' wear it was established that, after continuous work for 72 h, the damage to the working surfaces of the new impact beams was very severe and it was not possible to continue the crushing and adjustment of the crusher and that beams must be turned over to use their second working surface. The material losses of the hard-faced impact beams were obtained by monitoring the manufacturing process during 60 effective working hours so the two could be compared. The results of these examinations are presented in **Table 6** and in **Figure 8** [4,6,16].

Based on obtained results of the wear-resistance investigations in real working conditions we can conclude that the highest resistance was achieved with the hard faced layer of the E Mn17Cr13 (4.12 %) electrode, followed by the layer deposited with the E DUR 600 (5.73 %) electrode, then the layer deposited with the E Mn14 (7.0 %) electrode, while the layer deposited with the ABRADUR 58 (8.87 %) electrode exhibited wear resistance even lower than that of the base metal – ČL3460 (7.87–8.12 %). Clearly, ABRADUR 58 is not suitable to be used for this type of wear.

Table 6: Material losses of crushers' impact beams in real working conditions after 60 h of operation
Tabela 6: Izguba materiala na udarnih ploščah drobilnika po 60-urnem delovanju v realnih razmerah

Tested samples mass (impact beams)	Non hard-faced beams				Reparatory hard-faced beams				Production hard-faced beams			
	1	2	3	4	1*	2*	3*	4*	1*	2*	3*	4*
At the test beginning, kg	300	300	300	300	300	300	300	300	305	305	305	305
At the test end, kg	275.6	276.0	276.4	276.2	279.0	287.6	282.8	273.4	282.2	291.0	284.8	279.5
Mass loss, kg	24.4	24.0	23.6	23.8	21.0	12.4	17.2	26.6	22.5	14.0	20.2	25.5
Mass loss, %	8.12	8.00	7.87	7.93	7.00	4.12	5.73	8.87	7.38	4.59	6.62	8.36

*Note: *1- E Mn14; 2- E Mn17Cr13, 3- E DUR 600, 4- ABRADUR 58.*



1, 2, 3, 4 – New beams; 1N, 2N, 3N, 4N – Reparatory hard-faced beams; 1PN, 2PN, 3PN, 4PN – Production hard-faced beams

Figure 8: Graphical representation of the crushers' impact beams material losses after 60 h of operation

Slika 8: Grafična predstavitev izgube materiala udarnih plošč drobilnika po 60-urnem delovanju

The whole hard-facing process could have been performed automatically by robots. However, for the crushers' impact beams this is still not possible, especially because the main economic effect of introducing robots into the hard-facing and welding process, increasing the economic efficiency, i.e., lowering the process costs, cannot be achieved on small batch products like beams. For smaller parts and in batch manufacturing, however, the introduction of robots for the hard-facing process would be justified[18–20].

6 CONCLUSION

The extended experimental investigations have shown that the working life of properly hard-faced impact beams significantly exceeds the working life of the original beams. In this way large savings in material costs are realized, the crusher's down-time is reduced, and the range and quantity of the necessary spare parts is smaller. In terms of days, the working life of the new impact beams was about 15 d, while the working life of the repaired beams was reaching about 30 d, on average, depending on the applied filler metal. By analysing the costs of the filler metals and the price of the welders' labour, data were obtained which have shown that the costs of the reparatory hard facing of one impact beam are 25 % lower than the costs of a set of the new beams. This means that by applying the reparatory hard facing, four damaged impact beams (one set) can be renewed for the price of one new beam. By application of reparatory hard facing (primarily with the E Mn17Cr13 electrode) the working life of parts is extended and the down time of the manufacturing process is reduced. All these positive effects came as a result of a complex theoretical model and the investigations of this paper's authors, realized in collaboration with the user company. One of the tasks that remains for future work is how to exploit the advantages of the robotization of the welding and hard-facing process for large parts such as the crusher's impact beams.

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