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Reparation by Hard Facing of the Damaged Secondary Stone Crushers

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The possibilities for reparation by hard facing of the damaged working parts – the hammers of the secondary stones crusher are investigated in this paper. The analyzed crusher is stationary and it belongs into a group of the process equipment aimed for producing the crushed stone. The produced stone is later used for manufacturing various construction materials like asphalt, concrete, etc. Wear of the crusher's working parts occurs during the exploitation due to operation with very hard materials. That wear is usually abrasive and of high intensity what causes failure of the working parts and consequently the machine's downtimes and appearance of various types of losses, primarily financial ones. To prevent that, and to reduce the downtimes as well, one uses reparation technologies, one of which is hard facing. The analysis of the mass losses of the hard faced parts, after certain number of hours of the crusher's field operation, is performed in this paper.

Keywords: Reparation, Hard facing, Hammer, Secondary crusher

1 Introduction

Stable crushers' plants are the process equipment, which are aimed for manufacturing the rock aggregates that are used for producing various types of construction materials (asphalt, concrete, lime, etc.). To reduce production costs, other plants, like the asphalt base, concrete base, lime and cement producing plants, etc. are placed next to the stable crusher plants. Due to the nature of the production tasks, performed on the stable plants for manufacturing the rock (stone) aggregates, this type of plants are located in quarries, so the complete production of the construction materials represent a whole, the so-called small enterprise. The stable crusher plants are also used on the surface mines in the coal mining and ores' crushing, from which are later obtained various metallic or nonmetallic materials, used in different branches of industry.

When the working part becomes worn, to solve the problem usually the two options are considered. They are (i) purchasing the new part and replacement and (ii) cheaper solution – reparation by hard facing. Application of the hard facing for reparation of various damaged parts was proven useful and reliable technique for returning the damaged parts of different industrial systems back in exploitation. Reparation of graders for terrain leveling was considered in [1], blades for asphalt mixing in [2], gears in [3], forging dies in [4, 5], cranks of guide vane apparatus at hydropower plant in [6], rotational knives in [7], various working parts in [8], dredge teeth in [9], etc. Some other problems were considered in several papers, like influence of the sliding speed and working parts' loadings on the degree of wear of the surface layers [10, 11]; influence of the filler metal on the working life of the hard faced or welded parts [12, 13]; influence of different types of aggregates (stones) on intensity of wear of the working parts. Some papers were devoted to problems like influence of microstructure of material, which is exposed to different types of wear on the material's wear resistance [15-18] or structural factors that could influence reduction or increase of the working parts wear [19].

2 The crusher plant, device and function of the tested part and noticed problems

The stable crusher plant consists of several assemblies, which are connected and mutually dependent and which are completing the rock aggregates production process out of various fractions.

The stable crusher plant, considered in this paper, has the capacity of 120 *t/h*. That is actually a capacity of the primary crusher, which is installed next to the primary grid. Three crushers are installed on this plant, one primary jaw crusher and the two secondary crushers with hammers. The primary crusher's task is to crush stones coarsely, while the secondary crushers are performing the finalizing crushing of the stones already processed in the primary crusher. Material that is chopped in this way is then transported by the belt conveyer to the sieving plant where it is sieved and different fractions are separated. The belt conveyers are driven by an electric motor. The complete stable crusher plant is presented in Fig. 1.

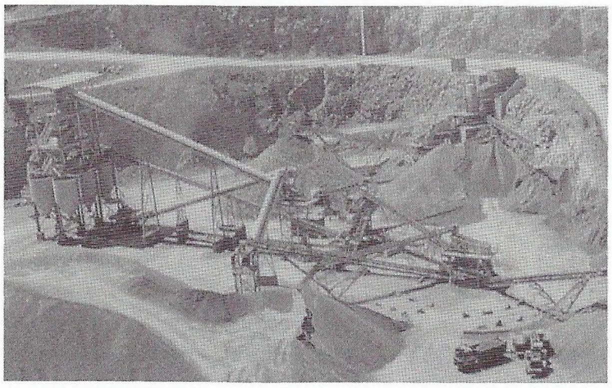


Fig. 1 *Appearance of a stable crusher plant*

The crushers installed in this plant represent a set of mutually dependent devices and they are used for manufacturing the rock aggregates obtained by crushing the limestone. The designed capacity of the two secondary crushers is 150 *t/h*, namely 75 *t/h* per crusher. They are driven by the electric motor of the belt conveyer.

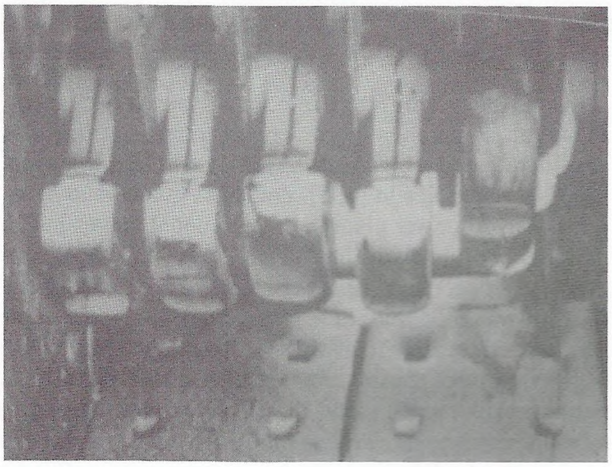


Fig. 2 *Appearance of the interior of the secondary crusher with the worn hammers*

The impact hammers (mallets) are the only crusher's working parts, besides the linings, which are in direct contact with the stones and their aggregates. Their function is to crush and chop the stones down to the required size. They are usually made by casting of the manganese steel, in the shape of the cuboids with dimensions 100×100×200 mm with holes in the middle, which serve for fixing to the supports, which are connected with the crusher's shaft, so the whole assembly represents the crusher's rotor. Mass of one hammer exactly amounts to 16 *kg*, and one set of hammers for one crusher contains 36 pieces. The both surfaces of the hammer are used in exploitation, in the similar manner as the impact beams in the rotational crusher. In Fig. 2 is shown the working area of the crusher's interior with the shaft, supports, hammers, their holders and the lining segments. The hammers are made of the cast steel X120Mn12.

The interior parts of the crusher are primarily exposed to abrasive wear of the so-called closed type, corrosion and constant impact loadings of the high intensity. The wear of the working parts is uneven, in a specific way, Fig. 2. Maximal usage of the hammer's materials is about 60 % of the total mass, usually it is about 50 %, and thus 50 % of the material is discarded as waste.

The noticed problems in exploitation of this stable crusher plant were different; one of the biggest is insufficient usage of the secondary crushers' capacity, though their capacity is significantly bigger than the capacity of the primary jaw crusher. The main reason for that is the short working life of the hammers (mallets), larger mass of the unused material, loss in production due to replacement of the worn parts and allocation of significant funds for purchasing the new spare parts.

3 Applied hard facing technology

The reparation hard facing technology by the REL procedure was used in this case. It was done by the core electrodes, made of various materials E DUR 600, E Mn 14 and E Mn 17 Cr 13 [20]. These filler metals (FM) possess high hardness and favorable microstructure and simultaneously ensure obtaining of the hard faced surfaces with exceptionally good toughness. The FMs E Mn 14 and E Mn 17 Cr 13 belong into a group of the austenitic FMs what is enabled by the high manganese content. During the exploitation, they are subjected to impacts, which cause phase transformation from austenite to martensite, when their hardness and wear resistance are significantly increased. The chemical composition of the base metal (BM) and the filler metals is given in Tab. 1. Preparation of the hard faced working surfaces, applied reparation technology and its execution were performed in the similar manner as for reparatory hard facing of the terrain leveling knives [1]. The technological parameters of the reparatory hard facing, executed on the real working parts (impact hammers) are presented in Tab. 2, while in Fig. 3 is shown the order of the hard faced layers deposition.

The reparatory hard facing was executed directly onto the base metal X120Mn12 (EN 10027-1), without preheating or deposition of the plastic interlayer. After the hard facing, the additional heat treatment was not performed, only the mechanical machining was done, which consisted of grinding of the both working surfaces, until the repaired pieces' mass was not 16 *kg*. The hard faced layer thickness was about 20 *mm* on each of the working surfaces. Total of 12 hammers were repaired in this way, 3 by each of the filler metals.

***Tab. 1** Chemical composition of the base and filler metals*

Material	Alloying elements, %								Hardness, HRC
	C	Si	Mn	P	S	Cr	W	Mo	
X120Mn12	1.20	0.50	12.00	0.035	0.10	-	-	-	~ 45
E DUR 600	0.50	-	-	-	-	7.50	4.00	-	~ 58
E Mn 14	1.20	-	12.50	-	-	-	-	0.70	~ 48
E Mn 17 Cr 13	0.60	-	16.50	-	-	13.50	-	-	~ 50

***Tab. 2** Technological parameters of the impact hammer reparatory hard facing by the REL procedure*

BM thickness s, mm	Electrode mark "SŽ - Electrodes Jesenice"	Electrode core diameter d_e, mm	Hard facing current I, A	Hard facing voltage U, V	Hard facing speed v_Z, mm/s	Hard facing heat input $q_l = (U \cdot I) \cdot \eta_l / v_Z$, J/mm
180	E DUR 600	3.25	120	25	1.19	2016.8
	E Mn 14	3.25	120	25	1.48	1621.6
	E Mn 17 Cr 13	3.25	130	25	1.52	1710.5

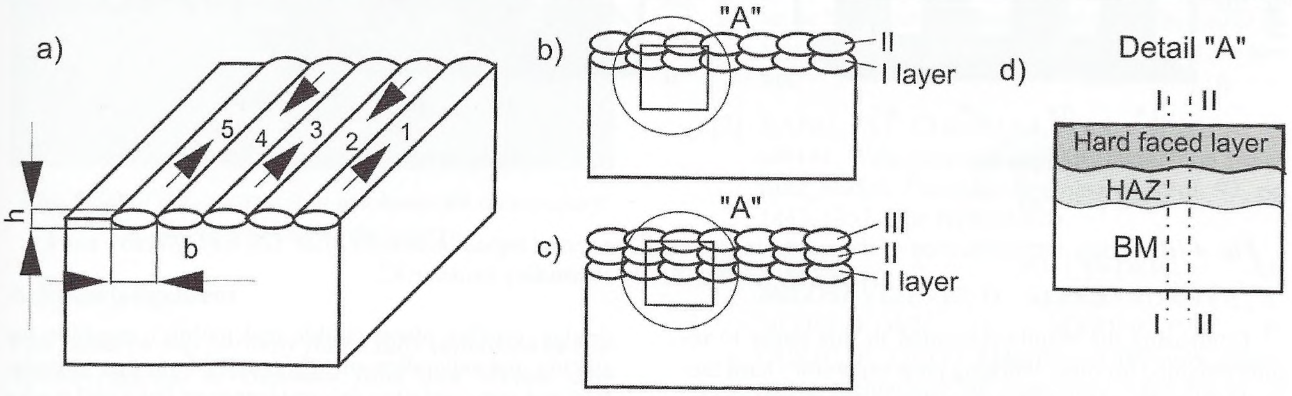


***Fig. 3** Layers deposition order: a) – I, b) – II, c) – III, d) metallographic ground sample*

4 Wear resistance determination

Mounting of the repaired impact hammers was done on the secondary crushers in the following way: 6 pieces were mounted on the first crusher in one row, (2 pieces hard faced with each of the FMs), while on the second crusher 6 pieces were mounted – one in each row; for both crushers they were mounted in the middle, one behind the other. The remaining places were occupied by the new impact hammers, 30 per each crusher.

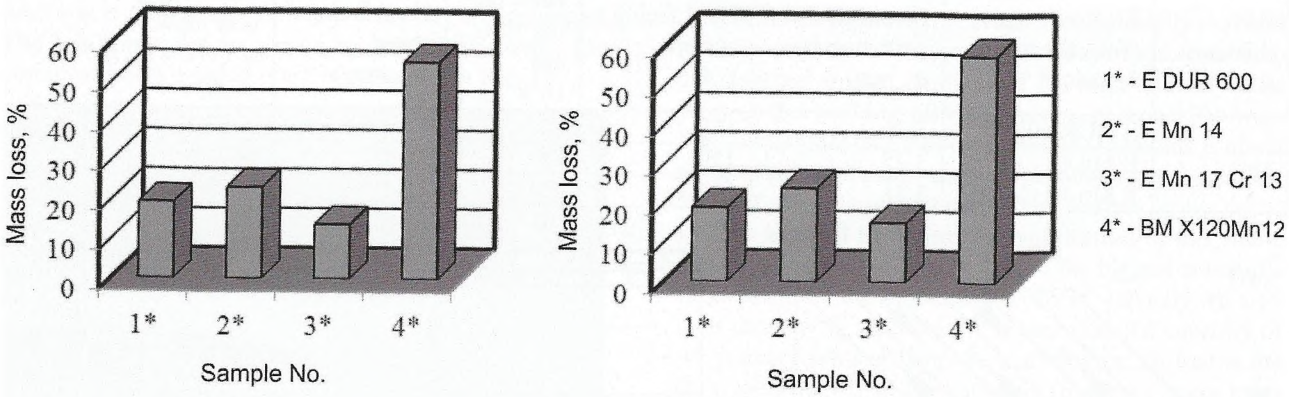
Based on the exploitation research of the new, non-hard faced impact hammers, the conclusion was reached that the maximal working life in crushing the organogenic limestone, with usage of both working surfaces, is about 320 *h* of effective operation [14]. Determination of the wear resistance of the hammers was done in several phases, by measuring their material's mass, on the precision scale, before and after certain exploitation time. The mass loss of the tested pieces, in all the test phases was almost proportional, thus the investigation results are presented as average values for each group of the tested materials. In addition, it is important to mention that in some cases the real process could be simulated in the laboratory conditions, which was proven as relatively reliable for the sake of comparison of results [1, 2, 8, 9]. The average values of the wear resistance of the tested materials, after 320 *h* of the effective work, are presented in Tab. 3, for each type of the tested materials.

In Fig. 4 are shown the graphical representations of the percentage materials' mass losses of the reparatory hard faced and the new non-hard faced impact hammers of the secondary crushers of the stable crusher plant, after 320 *h* of effective work.

According to results of tests on samples taken from the impact hammers of the secondary crushers, one can conclude that the best wear resistance was exhibited by the reparatory hard faced samples with manganese FM – E Mn 17Cr13 (almost 4 times better than the BM); then follow samples hard faced by FM – E DUR 600 (almost 3 times better than the BM) and finally the worst wear resistance was exhibited by samples hard faced with the FM E Mn 14 (almost 2.5 times better than the BM). Though the base metal X120Mn12 is predicted for manufacturing the parts exposed to abrasive wear, where the impact loads appear as well, all the tested pieces hard faced by the different filler metals exhibited better resistance to this type of wear. Some earlier laboratory investigations have confirmed that materials, which were considered as the best for manufacturing of this type of parts and these working environments, did not show the best results in tests on the tribometer [10]. Similarly, when the problem of hard facing of the loader's teeth was investigated [9], it was noticed that wear resistance is also affected by the direction in which the caterpillar were hard faced, besides the working environment and the contact conditions.

***Tab. 3** Results of experimental investigations of the impact hammers' wear resistance after 320 h of effective work*

Tested pieces mass, kg	Crusher # 1				Crusher # 2			
	1*	2*	3*	4*	1*	2*	3*	4*
At the tests' start, kg	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
At the tests' end, kg	12.90	12.30	13.80	7.20	13.00	12.20	13.60	6.80
Mass loss, kg	3.10	3.70	2.20	8.80	3.00	3.80	2.40	9.20
Mass loss, %	19.38	23.13	13.75	55.00	18.75	23.75	15.00	57.50



a) b)

***Fig. 4** Histogram representation of the wear resistance of the tested impact hammers after 320 h of effective work: a) Secondary crusher #1; b) Secondary crusher #2.*

Comparing the results presented in this paper to results obtained for other working parts reparatory hard facing [1-4, 7, 8], one could notice that they are quite compatible. It turned out that wear resistance of the hard faced parts in all the cases is similar, with the only difference being the fact that in this case the wear resistance against the abrasive wear is twice higher. There are several reasons for obtaining such results. The first one is that here the processed materials were rock materials (namely the organogenic limestone and calcite-dolomite limestone) and various base materials from which the tested pieces were manufactured (X120Mn12 and X120Mn12.1). The second reason is that in this case the crushers are secondary and they crush already chopped stones, while in the other examples the crusher was primary and it processed significantly larger pieces of stones. The third reason is that the abrasive wear occurs according to somewhat different mechanism, though in all the cases the type of wear was the same – abrasive wear.

On these two examples it was shown that the successful processing of the rock materials could be done only by mechanization whose working parts are either made of, or repaired by, the high quality materials; the best wear resistance was exhibited by austenitic manganese steels that possess high toughness, with uniformly distributed carbides in the soft metal substrate. The construction mechanization is made powerful by its working parts and assemblies which are in the direct contact with the construction materials, especially the rock materials (stones). In Figure 5 is show a part of the construction mechanization for quarry operations, for processing the rock materials and manufacturing of their aggregates.

The complete set of the construction mechanization for quarries consists of bulldozer, loader, trencher, dredge, crusher plants (stable and mobile), machine for sieving and separation of aggregates of various granulation and transportation means (conveyer belts and trucks of high loading capacity).

5 Conclusions and comments

Investigation on the impact hammers of the secondary crushers for stone crushing and manufacturing of the stone aggregates was done for the sake of determination of the wear resistance, where one base metal was used (X120Mn12), from which the new pieces were manufactured, and the three filler metals (E DUR 600, E Mn 14 and E Mn 17 Cr 13), which were used for reparatory hard facing the worn pieces (damaged impact hammers) made of that BM. All the tested FMs were exhibiting the better wear resistance to this type of wear than the base metal, in the range 2 to 4 times. Similarly, in investigation of the impact beams of the rotational crusher, the best wear resistance was exhibited by hard facing the same BM with FM E Mn 17 Cr 13, whose wear resistance is almost 4 times bigger than that of the base metal (Tab. 3 and Fig. 4). Application of the optimal hard facing technology enables extension of the tested parts working life several times, while by application of the multi-reparation by hard facing the purchasing and maintenance costs could be reduced to minimum.

Investigations on the real working parts of the construction machinery, aimed for operations in different working conditions, have multifold significance, since, besides checking of results obtained on models, they provide clear directives on justification for application of various materials for manufacturing those parts and especially on justification of reparation of the parts damaged by the various types of wear, corrosion processes or fracture. The other benefit of these investigations is that adequacy of application of certain filler metals in the hard facing reparation of parts, exposed to various types of wear, could be clearly defined. For reparation of the construction mechanization working parts, one could use other filler metals, as well, however it is necessary to keep in mind the requirements about the working surfaces properties of those parts.

Fig. 5 *Set of the construction mechanization necessary for operations in the quarry*

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Analysis of Heat Transfer Conditions in the Sand and Metal Moulds and Their Effect on the Solidification of the Casting

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The article deals with heat transfer in the casting - mould system. There are characteristics of sand and metal mould. The sand mould is a dispersion system, respectively - a capillary-porous body. In sand mould are heat transfers shared by all three ways: conduction, convection and radiation. These individual elementary processes of heat transfer are only theoretical significance, as very often processes are taking place simultaneously in different intensities or interact. The maximum effects of these processes are in a certain temperature range. From temperature 200 °C dominates conduction heat transfer. Between of temperatures 200 to 600 ° C is the effective convection heat transfere. At higher temperatures above 600 ° C prevails radiation heat transfer. This is the consequence, why the sand mould has a lower value thermal accumulation than a metal mould. The metal mould as a result of its character and compactness has a high heat accumulation value. Therefore, in the metal mould cast solidifies faster than the in sand mould. Based on the Newton´s and Fourier´s laws, there were indicative calculated times of solidification cast of shape plate in the sand and metal moulds. Concurently were made simulations calculations performed solidification of shaped plate through simulation software MAGMA 5. To obtain the corresponding results of simulation calculations, it is important to use the respective temperature-dependent of the thermophysical variables, including temperature dependence heat transfer coefficient.

Keywords: Sand mould, Metal mould, Solidification, Heat transfer, Thermo-physical quantities.

1 Introduction

The production of castings in foundry moulds is a very complex thermal process. This is related to the fact that the sand mould, respectively wall of sand mould constitutes a dispersion system. Sand mould is basically capillary porous body filled with air. Therefore, the heat