

Chapter 8

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POSSIBILITY FOR REALIZING SAVINGS BY APPLICATION OF THE HARD-FACING AS THE REVITALIZATION TECHNOLOGY OF VARIOUS MACHINE PARTS

Abstract: This Chapter is aimed in presenting the importance of hard-facing as the manufacturing technology, which nowadays is used increasingly for revitalization of the responsible plants and the machine parts. The reason for such development lies in multi-folded advantages that the hard-facing could provide, which could be observed from both the technical and economical point of view. Here is presented a procedure for prescribing the optimal technology for reparation of various technical systems with special reference to possible savings in money and time that could be realized by application of that technology. Costs and savings for reparation of various complex machine parts are analyzed by the profitability method. All the analyzed machine parts were revitalized by hard-facing, with substantial savings in money and machines' downtimes. Evaluation and verification of the hard-facing technology quality was done both experimentally and by monitoring the performance of the repaired parts in exploitation. The realized savings, calculated according to the profitability method, are presented by concrete monetary amounts for each analyzed working part, compared to costs of procuring the respective new part. In general, this Chapter can be considered as the voluminous techno-economic analysis of hard-facing as the revitalization technology of various machine systems.

Keywords: revitalization, technology, hard-facing, costs, savings, profitability.

8.1. Introduction

The objective of this Chapter is to point out the possibilities for application of hard-facing as one of the leading technology in

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revitalization of the damaged parts. Thereby, besides the returning the part back into exploitation, many accompanying positive effects are realized, primarily related to savings of money. Those savings are not always as concrete as the difference between the price of the new part and the reparation costs, but they can be related to shortening of the machine's or the plant's downtime, of the time necessary for procuring the new part, of delays in delivery of the new part, reduction of supplies, etc.

Besides prescribing the procedure of the optimal hard-facing technology for various machine parts, here is presented a large number of concrete examples of the revitalized machine parts and systems and analysis of savings realized by application of the reparatory hard-facing. This survey of the regenerated parts serves as the proof for economic justification of the reparation technologies as compared to purchasing of the new parts.

The hard-facing technology has the large and decisive influence on characteristics of the hard-faced layers (surfaces) and consequently the prescribing of the hard-facing/welding technology is everything but a simple task. That was the subject of previous research by authors of this Chapter, as well as by other authors. Results of revitalization of various machine parts and systems were presented in numerous papers: parts of the construction mechanization (MUTAVDŽIĆ M. 2015, LAZIĆ V. et al. 2011, MUTAVDŽIĆ M. et al. 2008), forging hammers' mallets (LAZIĆ V. et al. 2009) and forging dies (LAZIĆ V. et al. 2014, ARSIĆ D. et al. 2016c, MUTAVDŽIĆ M. et al. 2012, ARSIĆ D., et al. 2015, HAWRYLUK M., et al. 2014), gears (MARKOVIĆ S. et al. 2011), hydraulic power plant blades (ARSIĆ M. et al. 2014), rotational device knives for terrain leveling (NEDELJKOVIĆ B. et al. 2008), impact beams of the rotary milling machine (MUTAVDŽIĆ M. et al. 2007), bucket teeth (LAZIĆ V. et al. 2015a), secondary stone crushers (LAZIĆ V. et al. 2016c), snow plough blades (LAZIĆ V. et al. 2015a).

The prescribed technologies and executed revitalizations were verified in different ways. Some technologies, i.e. the working parts, were tested experimentally, in the laboratory conditions (ARSIĆ D. et al. 2015,

MUTAVDŽIĆ M. et al. 2012, MARKOVIĆ S. et al. 2011, WASSERMAN R. 2003); some on the working parts in the real exploitation conditions (LAZIĆ V. et al. 2015b, ARSIĆ D. et al. 2016b), while some were verified both experimentally and "in the field" (LAZIĆ V. et al. 2010-MUTAVDŽIĆ M. et al. 2015, MARKOVIĆ S. et al. 2011, LAZIĆ V. et al. 2015a). Analyzing of results, presented in those papers, leads to conclusion that parts hard-faced by the adequate technology exhibit better results than the new parts, in the majority of cases.

As already emphasized, besides the better characteristics of the hard-faced parts working surfaces, a series of the economic advantages is realized by hard-facing. Those advantages are related to decrease of costs and downtimes of various machines and plants, reduction of necessary spare parts supplies, etc. (WASSERMAN R. 2003, ČUKIĆ R. 2010). Here is presented an analysis of the executed revitalizations in comparison to the new parts purchasing costs, performed by the profitability method.

Authors of this paper have worked on the equipment maintenance in industry and the construction mechanization for over fifteen years and have encountered numerous problems related to revitalization of the damaged parts of various technical systems. Generally, the objective was to extend the working life of parts, which can be very expensive and/or imported. During that period, a very large number of reparatory works was executed on various parts of the construction mechanization and forging tools that were made of different types of high quality steels. The constant dilemma was: replacement of the damaged parts with the new ones or revitalization by some reparation technology. Of course, the easiest way for solving such a problem is to buy the new part. However, that would require spending of significant funds and certain purchasing time, which sometimes could be very long, what would increase already long mechanization downtime and create great losses in construction works. The other alternative is to repair the damaged parts, what would require significantly lower funds. It is only fair to notice that such a solution would also require engaging of some additional manpower.

Nevertheless, the part(s)' downtime would be significantly reduced and the men and mechanization working hours would be much better exploited.

The positive techno-economic effects of the reparatory and manufacturing hard-facing should be expected only if those procedures were executed according to designed optimal technologies, which must provide for all the necessary conditions for successful execution of those processes. Selection of the optimal hard-facing technology and its verification on models and real parts in exploitation conditions was presented in previous works by authors of this paper (LAZIĆ V. et al. 2011- HAWRYLUK M. et al. 2014).

Calculations and evaluation of the techno-economic justification of certain procedure can be done by various methods, like the method of economic efficiency (MEE), Profitability Improvement Analysis method (PIA), Machinery and Allied Products Institute method (MAPI), the Life Cycle Cost (LCC) method and the Net Present Value method (NPV) (MUTA VDŽIĆ M. et al. 2012, ČUKIĆ R. 2010). Each of the mentioned methods has different criteria according to which the estimates are done of the techno-economic justifiability of certain technologies for revitalization of the damaged elements of technical systems and the decision is brought on application of the optimal one. Those methods can also be used for decision making on the optimal technology for manufacturing of the new parts. Selection of the most profitable version/technology is performed based on the economic justification indicators. Calculation of economic effects, obtained by application of some alternative reparation methods and by reparatory/manufacturing hard-facing (RMHF), belongs to two different groups of economic categories. The form of the economic effects, by which the contribution of a certain technology is evaluated, must be in accordance with criteria that are requirements, which express the tendency to realize certain outcome effects (ČUKIĆ R. 2010, LAZIĆ V. et al. 2015a).

Economic effects of the two different technologies for renewal of various working parts are considered in this paper:

1. *Replacing the damaged parts by the new spare parts,*
2. *Reparatory hard-facing (welding) of the damaged – used parts.*

Prior to starting the revitalization procedure of a certain part, one must keep in mind that the process is always conducted depending on the current restrictions, i.e. depending on availability of needed technologies and the financial resources (ČUKIĆ R. 2010).

From the aspect of *available technologies*, one compares the two alternatives – to purchase the new part and to revitalize the damaged one.

From the aspect of *available financial resources* one acts respecting the criterion of maximal rationality.

Since the subject of this research is analysis of application of the two available technologies, the advantage is always given to technology which provides for the better techno-economic effects. The parameters *higher profitability* and *absolute rentability* are used as criteria for evaluation of investments into either of the two alternative technologies, i.e. for determination of the amount of money to be spent (ČUKIĆ R. 2010).

8.2. Procedure of prescribing the hard-facing technology

Prescribing of the welding technology and selecting of the filler metals belongs into a group of the most complex tasks within the revitalization process of the damaged parts. This is why the fact is, that within that process, the largest amount of money is allocated for salaries of the highly expert staff performing those tasks during the revitalization of the damaged parts by hard-facing/welding.

When prescribing the technology, one starts from analysis of the damaged part, its material type, purpose and function, etc. The next step is selecting the filler metal (FM). This is one of the crucial steps, since wrongly selected FM would not provide for the required properties of the hard-faced part. The FM is being selected based on type of the base metal (BM), purpose and function of the part, the required mechanical properties, etc.

The previous research and reparatory hard-facings, performed by this group of authors (MUTAVDŽIĆ M. et al. 2015, ARSIĆ D. et al. 2015, NEDELJKOVIĆ B., et al. 2008, ARSIĆ D., et al. 2016a, b, c, LAZIĆ V. et al. 2015a, b, c), were mainly related to parts for which the primary requirement was increased wear resistance, though there are also some examples of hard-facing or coatings deposition, where the required properties were anti-corrosion protection and changes of material's electrical or thermal properties. Thus, the used materials mainly were the high-alloyed filler metals, which possessed the high hardness. Material's hardness imposes great influence on the wear resistance, though that must not always be the case, i.e. that the materials with high hardness also have the high wear resistance.

The filler metals that are mostly used for revitalization of parts exposed to abrasive and erosive wear, like the parts of the construction mechanization, are the FMs with high content of Cr, W and Mn, as well as some other alloying elements (MUTAVDŽIĆ M. et al. 2015, LAZIĆ V. et al. 2015a, ARSIĆ D., et al. 2016a): E DUR 600², CrWC 600³, ABRADUR 58⁴, E Mn 14⁵ and E Mn 17 Cr 13⁶. Notation of the filler metals is presented according to the internal standards of the FMs' manufacturer "Electrode–SIJ–Slovenian Steel Industry", Jesenice, Slovenia (Catalogues of base and filler metals). The numerated FMs are aimed for hard-facing of parts subjected to intensive abrasive wear, which is a result of collisions of machine parts' working surfaces with various rock materials of high hardness (LAZIĆ V. et al. 2015b). Out of all the mentioned materials, it is not possible to single out certain material as the optimal one, since each of them has some advantages for operation in different conditions. Thus, for instance, E DUR 600 is optimal for hard-facing of the snow-plough knives (LAZIĆ V. et al. 2015a), E Mn 17 Cr 13 for hard-

² EN 14700: E Fe 8; DIN 8555: E 6-UM-60.

³ EN 14700: E Fe 14; DIN 8555: E 10-UM-60-C.

⁴ EN 14700: E Fe 14; DIN 8555: E 10-UM-60-G2.

⁵ EN 14700: E Fe 14; DIN 8555: E 7-UM-200-KP.

⁶ EN 14700: E Fe 9; DIN 8555: E7-UM-200 KNP.

facing of the secondary crusher's hammers (LAZIĆ V. et al. 2016c), ABRADUR 58 for hard-facing of loader's teeth (LAZIĆ V. et al. 2015a), while CrWC 600 exhibited the best results in laboratory testing of the hard-faced test pieces on tribometer (ARSIĆ D. et al. 2016a).

On the other hand, revitalization of other kinds of parts, like the forging tools (forging mallets (LAZIĆ V. et al. 2009, LAZIĆ V. et al. 2010), forging dies (LAZIĆ V. et al. 2010c), frame of the forging press (LAZIĆ V. et al. 2014b)) and hard-facing of the thermo-resistant steels in general, is done with filler metals with content of Cr, Mo and smaller content of V, like UTOP 38⁷, UTOP 43⁸ and UTOP 55⁹.

Filler metals alloyed with Cr, Mo and V, like 5HCr, 7.5HCr, 8HCr and 12HCr are used for hard-facing of the rotary tiller blades (KANG S. et al. 2014). Investigations have shown that FMs with higher content of Cr possess better wear resistance, in this case that is 12HCr, which has 2.5 times better wear resistance than the FM 5HCr. It should be noticed that Cr has the largest influence on the wear resistance; the reason for that is its high hardness and favorable micro structure, which allows for forming of carbides and their uniform distribution within the material.

Hard-facing of parts is almost always done in several layers (passes) in order to obtain the necessary thickness of the hard-faced layer, whether that is done to extend the working life of the revitalized part or to cut out the sample for various tribological tests (ARSIĆ D., et al. 2016a, ZAVOS A. et al. 2015). Hard-facing can be done according to scheme shown in Fig. 1 (a to c), what is already presented in several papers (LAZIĆ V. et al. 2011, ARSIĆ D. et al. 2016c, Mutavdžić M. et al. 2008). The caterpillars should be deposited alternately, one next to the other to obtain the FM layer as compact as possible, without voids or gaps, which can later become the places of the stress concentration and influence the premature part's failure. Further, in Fig. 1d is shown the way of cutting out the slits for tribological and metallographic tests.

⁷ EN 14700: E Fe 3; DIN 8555: E 3-UM-40-T.

⁸ EN 14700: E Fe 3; DIN 8555: E 3-UM-40-PT.

⁹ EN 14700: E Fe 4; DIN 8555: E 6-UM-60-T.

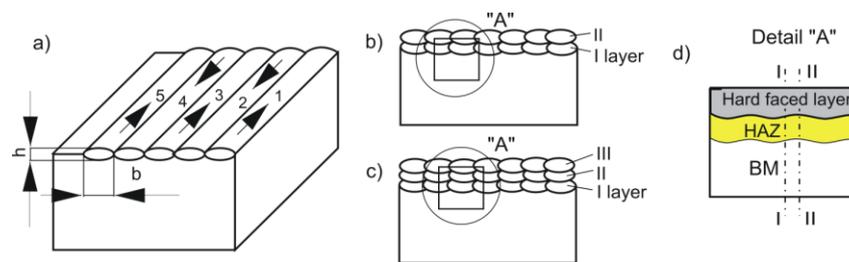


Fig. 8.1. Layers deposition order (a, b, c) and metallographic ground sample (d) layers deposition order (a, b, c) and metallographic ground sample (d).

For hard-facing parameters, current, voltage, speed and heat input, one should primarily apply recommendations of the FMs' manufacturers or experience from previous researches. Generally speaking, the conclusion drawn based on the long-term experience is that the hard-facing of construction mechanization parts should be done with the following parameters: current $I = 110-130$ A, voltage $U = 25-28$ V, speed $v_{HF} = 1.4-1.9$ mm/s and heat input $q_l = 1.6-2.0$ kJ/mm. For the hard-facing of forging dies (hot working tool steels), the hard-facing parameters are the following: $I = 115$ A for FM UTOP 38 and 190 A for FM UTOP 55, $U = 26$ for UTOP 38 and 29 V for UTOP 55, $v_{HF} = 2.5-2.8$ mm/s and q_l of about 0.9 kJ/mm for UTOP 38 and about 1.7 kJ/mm for UTOP 55.

The welding parameters have to be selected also in accordance with the material's weldability. For materials with the good weldability one can use the lower current and heat input and the hard-facing could be successful even without application of the prior, concurrent or the post hard-facing heat treatment. If the base metal were poorly weldable, it is necessary to apply the preheating as the type of the additional heat treatment (usually at about 200°C), then drying of the BM to eliminate the moisture (for 1 to 2 h at 300°C) and tempering (if necessary) for obtaining the better mechanical properties (ARSIĆ D. et al. 2016c, MUTAVDŽIĆ M. et al. 2012). It is very important to emphasize here that in the case when it is not possible to apply the preheating, deposition of a

plastic inter-layer of stainless austenitic FM can serve as an alternative. That layer is deposited directly to the BM and the hard-facing is done with another FM. Analyses of such executed hard-facings have shown that this plastic inter-layer could even improve the wear resistance (ARSIĆ D. et al. 2016a, b), since it could act as the buffer layer and alleviate the action of the hard materials during the exploitation.

After the hard-facing, one continues with testing of the hard-faced layers. The tests consist of determination of hardness of the hard-faced layers, as well as their wear resistance. The latter can be done directly, "in the field", by measuring the worn material mass of the working part after certain number of operating hours of the part and comparing those results to results obtained in exploitation of the not hard-faced parts (LAZIĆ V. et al. 2011, LAZIĆ V. et al. 2016c), or to results obtained in laboratory by tribological tests on tribometer (ZAVOS A. et al. 2015, ARSIĆ D., et al. 2016a, ARSIĆ D. et al. 2016b), or to both (MUTAVDŽIĆ M. 2015).

Numerous factors influence the wear resistance, the most important being material's hardness and microstructure. The wear degree depends on the working conditions and it could be said that the wear mechanism the most affects the decrease of the wear resistance. For example, it is quite natural that the loader dredge's teeth would be far more worn than the plough for plowing the soil.

The next factor that influences the wear resistance is the micro structure as shown in (VARGA M. et al. 2011), as well as the presence, quantity and distribution of carbides in the material (LAZIĆ V. et al. 2010a, LAZIĆ V. et al. 2010b). Those researches have shown that the best wear resistance is obtained by the chromium carbide distributed in the martensitic substrate. CHANG et al. 2010 and CHUI et al. 2015 have shown that chromium exhibits the strongest influence on the wear resistance, by investigating the filler metals based on the Fe-Cr-C alloys while, ŽUROVSKI et al. 2012 have shown that, besides the micro structural and mechanical properties of material, there exist the construction factors that influence the degree of wear of the machine

parts' working surfaces, and that those factors must be taken into account in design, manufacturing and revitalization of those parts.

8.3. Methodology for determination of the hard-facing profitability

The profitability method was used in the further analysis, where the procedures, which are the most frequently used, are applied as the justifiability measures for application of a certain technology. Those procedures are: (i) comparison of profitability as the ratio of incomes and expenses, (ii) comparison of costs and realized savings due to their decrease and (iii) increasing of the financial results by income increase due to costs decrease.

In quantitative economic analysis one estimates the direct (net) gain, as well as the unexpected costs, internal effects and multiplication effects (MUTAVDŽIĆ M. 2015, ČUKIĆ R. 2010, WILD J. et al. 2014, LAZIĆ V. et al. 2015a). Such a calculation of the net profit has, as a goal, to express the general rationality principle for the new technologies introduction.

The new part procuring costs (C_{np}) represent the sum of all the costs accompanying the purchase (new part's costs, part's transportation costs, customs costs if the part was imported, the VAT costs, keeping and storage costs, etc.). These costs are reduced for the amount obtained by selling the damaged part (C_{ld}). However, those costs are increased for amount of additional costs (C_a) that stem from downtimes in production, penalties for the overdue deliveries, etc. The new part procuring costs are being determined based on the company's documentation.

The analysis of the techno-economic justifiability of the reparatory hard-facing revitalization of certain working parts of the construction mechanization, conducted in this Chapter, was performed according to the profitability method, comparing that technology to costs of replacement of the damaged parts by the new spare ones. Those parts are usually purchased and kept in the maintenance storage as the spare parts. When a certain working part is damaged in exploitation, it is being

replaced by the spare part, while the damaged part itself is deducted and discarded. The techno-economic analysis is conducted also under the assumption that organization of the maintenance function is at the exceptionally high level, so the purchasing of the new part is always done in time, as well as the reparation of the damaged part; thus, there is always sufficient number of working parts in storage ready to be used for replacement of the damaged one. This somewhat idealized approach is selected since in that way one obtains the least economic effects of the reparatory technology application; in any other case those economic effects could be significantly higher, i.e. more positive.

In this techno-economic analysis, additional costs, due to downtimes during the single replacement of the damaged part by the new or the repaired one, were not taken into account since those costs are almost the same for the two technologies and do not significantly influence the final conclusion of the analysis. However, those costs must be taken into account in the analysis, if the larger number of replacements is done, since the new parts have shorter working life than the repaired ones. This means that number of replacements is bigger if the parts are being replaced by the new ones, than by the repaired ones, what then significantly increases the replacement costs and that strongly influences the final conclusion of the techno-economic analysis. Those additional costs, which are pretty high, are usually being calculated per annum, what is usually done in determination of the economic effects of certain technology (LAZIĆ V. et al. 2015a).

Therefore, this techno-economic analysis has as an objective to present, thoroughly and transparently, the savings realized by application of a certain reparatory hard-facing procedure, with respect to purchasing of the new part, which can be generalized to all the types of regenerated parts; here are presented results of savings realized by reparation of the parts of the construction mechanization and the forging tools.

8.4. Analysis of profitability of the damaged parts revitalization

This techno-economic analysis included the following parts' hard-facing revitalization: the loader's teeth, blades for asphalt mixing, impact beams of crushers for grinding the rock materials, blades for removing and cutting of vegetation overgrowth, knives for terrain leveling, knives of the trenching machine, knives of the snow ploughs, hammers of the secondary crushers, the forging press frame and toothed hub of the eccentric press. Here is presented only the techno-economic analysis of justifiability of the damaged parts revitalization, while the complete procedures of those revitalizations by hard-facing are presented in separate papers (LAZIĆ V. et al. 2011, ARSIĆ D. et al. 2015, NEDELJKOVIĆ B. et al. 2008, MUTAVDŽIĆ M. et al. 2007).

The analyzed working parts are, according to the purchasing plans, being procured several times per annum, i.e. the savings realized per one piece should be multiplied by the number of replacements and thus the savings per annum would be obtained. Results obtained by this analysis are presented in Tables 1 to 10.

The techno-economic effects were calculated according to the following parameters:

- Total costs of the new part purchasing C_{np} , €
- Total costs of the damaged part repair C_{rp} , €
- Profitability coefficient

$$c_e = \frac{C_{np} - C_{rp}}{C_{np}} \quad (8.1)$$

- Exploitation reliability coefficient

$$c_{ex\ rel} = \frac{t_{e\ rp}}{t_{e\ np}}, \quad (8.2)$$

where $t_{e\ np}$ and $t_{e\ rp}$ are the effective operational time of the new and repaired part, respectively,

- Economic rationality coefficient

$$c_{ec\ rat} = \frac{C_{np} \cdot i_{h\ np}}{C_{rp} \cdot i_{h\ rp}}, \quad (8.3)$$

where $i_{h\ np}$ and $i_{h\ rp}$ are the limiting wear of the new and repaired part, respectively.

- Total costs per annum C_{ann} , €
- Direct savings per piece S , €
- Direct savings per annum S_{ann} , €.

8.4.1. Loader's teeth

Basic parameters for profitability calculation of the compared revitalization technologies are:

- Base metal – steel cast iron 50Mn7 (DIN)
- Teeth mass – 8.6 kg/piece (average value)
- Number of teeth – 10 pieces (one set)
- Purchase price – 113.5 €/piece
- Filler metal – ABRADUR 58 and INOX B 18/8/6
- Purchase price – 15 €/kg
- Reparatory work price (N.H.¹⁰) – 10 €/h
- Applied reparation procedure – MMA surfacing.

Important parameters for comparison of the two technologies:

- Exploitation time of the set of the new teeth working with stones and aggregates is, on average, $t_{exp\ np} = 1200$ h of effective operation (determined in authors' own experimental investigations);
- Exploitation time of the surfaced teeth in the same operation conditions, on average $t_{ex\ rp} = 4\ 200$ h (determined in authors' own experimental investigations);
- Liquidation value of the worn teeth scrapped material is $T_{lo} = 0.2$ €/kg; Quality (primary and secondary) of the repaired teeth is at least the same or better than that of the new teeth.

¹⁰ N.H. norm-hour(s)



Fig. 8.2. The damaged (above) and repaired (below) loader's teeth.

Significant costs for comparison of alternative technologies:

- Total costs of purchasing of one set of the new teeth $C_{np} = 1210$ €;
- Total costs of reparation of one set of worn teeth $C_{rp} = 320$ €;
- Total costs due to downtime (losses) in present conditions for this machine amount to $C_{dt} = 20$ €/h.

Table 1. Loader's teeth revitalization

Applied technology	C_{np}, C_{rp} €	c_e	$c_{ex\ rel}$	$c_{ec\ rat}$	C_{ann} €
Replacement	1210	0.735	3.500	13.226	6021
Reparation	320				1060
Direct savings	$S = 890$ € (73.50 %)		$S_{ann} = 4961$ € (82.40 %)		

8.4.2. Blades for asphalt mixing

Basic parameters for profitability calculation of the compared revitalization technologies are:

- Base metal – steel cast iron GX210Cr12
- Blades mass – 3.6 kg/piece (average value)
- Number of blades – 64 pieces (one set)
- Purchase price – 43.6 €/piece
- Filler metal – E DUR 600 and INOX B 18/8/6

- Purchase price – 15 €/kg
- Reparatory work price (N.H.) – 10 €/h
- Applied reparation procedure – MMA surfacing.

Important parameters for comparison of the two technologies:

- Exploitation time of the set of the new blades working in asphalt production is, on average, $t_{exp\ np} = 360$ h of effective operation (determined in authors' own experimental investigations);
- Exploitation time of the surfaced blades in the same operation conditions, on average $t_{ex\ rp} = 1080$ h (determined in authors' own experimental investigations);
- Liquidation value of the worn blades is $T_{lo} = 0.21$ €/kg;

Quality (primary and secondary) of the repaired blades is at least the same or better than that of the new blades.

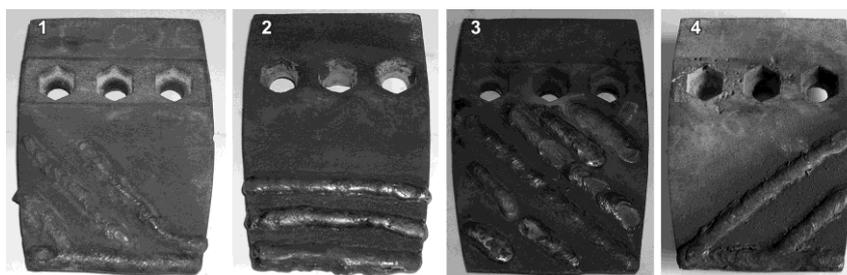


Fig. 8.3. Repaired blades for asphalt mixing.

Table 8.2. Asphalt mixer blades revitalization

Applied technology	C_{np}, C_{rp} €	c_e	$c_{ex\ rel}$	$c_{ec\ rat}$	C_{ann} €
Replacement	2790	0.609	3.000	7.677	560336
Reparation	1090				183980
Direct savings	$S = 1700$ € (60.90 %)		$S_{ann} = 376356$ € (67.17 %)		

Significant costs for comparison of alternative technologies:

- Total costs of purchasing of one set of the new blades $C_{np} = 2\,790$ €;
- Total costs of reparation of one set of worn blades $C_{rp} = 320$ €;
- Total costs due to downtime (losses) in present conditions for the asphalt base machine amount to $C_{dt} = 3000$ €/h.

8.4.3. Impact beams of the rock materials crusher

Basic parameters for profitability calculation of the compared revitalization technologies are:

- Base metal – steel cast iron GX120Mn12.1
- Impact beam mass – 300 kg/piece (average value)
- Number of beams – 4 pieces (one set)
- Purchase price – 2187.5 €/piece
- Filler metal – E Mn 17 Cr 13
- Purchase price – 15 €/kg
- Reparatory work price (N.H.) – 10 €/h
- Applied reparation procedure – MMA surfacing.



Fig. 8.4. The rock crusher's impact beam.

Important parameters for comparison of the two technologies:

- Exploitation time of the set of the new impact beams of the stone crusher working in producing the rock aggregates from the limestone, on average, is $t_{exp\ np} = 150$ h of effective operation, using both working

surfaces; this is the maximum possible number of hours since the beams work with limestone; when operating with other types of harder stones the time is significantly shorter (determined in authors' own experimental investigations);

- Exploitation time of the surfaced impact beams in the same operation conditions, on average $t_{ex\ rp} = 320$ h, using both working surfaces (determined in authors' own experimental investigations);
- Liquidation value of the worn beams is $T_{lo} = 0.42$ €/kg;

Quality (primary and secondary) of the repaired beams is at least the same or better than that of the new beams.

Significant costs for comparison of alternative technologies:

- Total costs of one set of new impact beams $C_{np} = 8750$ €;
- Total costs of reparation of one set of worn beams $C_{rp} = 2040$ €;
- Total costs due to downtime (losses) in present conditions for the asphalt base machine amount to $C_{dt} = 1050$ €/h.

Table 8.3. Stone crusher's impact beams revitalization

Applied technology	C_{np}, C_{rp} €	c_e	$c_{ex\ rel}$	$c_{ec\ rat}$	C_{ann} €
Replacement	8750	0.767	2.133	9.149	303940
Reparation	2040				105000
Direct savings	$S = 6710$ € (60.90 %)		$S_{ann} = 198940$ € (65.45 %)		

8.4.4. Blades for clearing the vegetation overgrowth

Basic parameters for profitability calculation of the compared revitalization technologies are:

- Base metal – steel 42CrMo4 (DIN)
- Blades mass – 300 kg/piece (average value)
- Number of blades – 40 pieces (one set)
- Purchase price – 23.8 €/piece

- Filler metal – E DUR 600 and INOX B 18/8/6
- Purchase price – 15 €/kg
- Reparatory work price (N.H.) – 10 €/h
- Applied reparation procedure – MMA surfacing.



Fig. 5. The hard-faced and sharpen blade for vegetation overgrowth.

Important parameters for comparison of the two technologies:

- Exploitation time of the set of the new blades is $t_{exp\ np} = 150$ h of effective operation (determined in authors' own experimental investigations);
- Exploitation time of the surfaced blades in the same operation conditions, on average is $t_{ex\ rp} = 600$ h, using both working surfaces (determined in authors' own experimental investigations);
- Liquidation value of the worn blades is $T_{lo} = 0.21$ €/kg;
- Quality (primary and secondary) of the repaired blades is at least the same or better than that of the new blades.

Significant costs for comparison of alternative technologies:

- Total costs of purchasing of one set of new blades $C_{np} = 957$ €;
- Total costs of reparation of one set of worn blades $C_{rp} = 304$ €;
- Total costs due to downtime (losses) in present conditions for this machine amount to $C_{dt} = 12.5$ €/h.

Table 8.4. Blades for clearing the overgrowth revitalization

Applied technology	C_{np}, C_{rp} €	c_e	$c_{ex\ rel}$	$c_{ec\ rat}$	C_{ann} €
Replacement	957	0.682	5.000	15.735	17537
Reparation	304				1550
Direct savings	$S = 636 \text{ € (60.20 \%)}$		$S_{ann} = 15987 \text{ € (91.16 \%)}$		

8.4.5. Terrain-leveling machine knives

Basic parameters for profitability calculation of the two compared revitalization technologies are:

- Base metal – steel 58CrV4 (DIN)
- Knives mass – 1.7 kg/piece (average value)
- Number of knives – 14 pieces (one set)
- Purchase price – 118.8 €/piece
- Filler metal – E DUR 600 and INOX B 18/8/6
- Purchase price – 15 €/kg
- Reparatory work price (N.H.) – 10 €/h
- Applied reparation procedure – MMA surfacing.

Important parameters for comparison of the two technologies:

- Exploitation time of the set of the new knives is $t_{exp\ np} = 240$ h of effective operation (determined in authors' own experimental investigations);
- Exploitation time of the surfaced knives in the same operation conditions, on average $t_{ex\ rp} = 520$ h (determined in authors' own experimental investigations);
- Liquidation value of the worn knives is $T_{lo} = 0.2$ €/kg;

Quality (primary and secondary) of the repaired knives is at least the same or better than that of the new knives.



Fig. 8.6. The hard-faced and sharpened blade for terrain leveling.

Significant costs for comparison of alternative technologies:

- Total costs of purchasing of one set of the new knives $C_{np} = 1663 \text{ €}$;
- Total costs of reparation of one set of the worn knives $C_{rp} = 426 \text{ €}$;
- Total costs due to downtime (losses) in present conditions for this machine amount to $C_{dt} = 12.5 \text{ €/h}$.

Table 8.5. Terrain-leveling machine knives revitalization

Applied technology	C_{np}, C_{rp} €	c_e	$c_{ex\ rel}$	$c_{ec\ rat}$	C_{ann} €
Replacement	1571	0.744	2.167	8.460	16178
Reparation	426				2168
Direct savings	$S = 1145 \text{ € (74.40 \%)}$		$S_{ann} = 14010 \text{ € (86.14 \%)}$		

8.4.6. Trenching machine blades

Basic parameters for profitability calculation of the compared revitalization technologies are:

- Base metal – steel 60SiMn5 (DIN)
- Blades mass – 10.6 kg/piece (average value)
- Number of blades – 24 pieces (one set)
- Purchase price – 118.8 €/piece

- Filler metal – E DUR 600
- Purchase price – 15 €/kg
- Reparatory work price (N.H.) – 10 €/h
- Applied reparation procedure – MMA surfacing.



Fig. 8.7. Hard-faced and sharpen blade of the trenching machine.

Important parameters for comparison of the two technologies:

- Exploitation time of the set of the new blades is $t_{exp\ np} = 300$ h of effective operation (determined in authors' own experimental investigations);
- Exploitation time of the surfaced blades in the same operation conditions, on average $t_{ex\ rp} = 1600$ h (determined in authors' own experimental investigations);
- Liquidation value of the worn blades is $T_{lo} = 0.21$ €/kg;

Quality of the repaired blades is better than that of the new blades.

Significant costs for comparison of alternative technologies:

- Total costs of purchasing of one set of new blades $C_{np} = 3080$ €;
- Total costs of reparation of one set of worn blades $C_{rp} = 970$ €;
- Total costs due to downtime (losses) in present conditions for this machine amount to $C_{dt} = 16.7$ €/h.

Table 8.6. Trenching machine blades revitalization

Applied technology	C_{np}, C_{rp} €	c_e	$c_{ex\ rel}$	$c_{ec\ rat}$	C_{ann} €
Replacement	3080	0.685	5.333	16.934	29400
Reparation	970				2090
Direct savings	$S = 2110 \text{ € (68.50 \%)}$		$S_{ann} = 27310 \text{ € (92.89 \%)}$		

8.4.7. Snow plough blades

Basic parameters for profitability calculation of the compared revitalization technologies are:

- Base metal – steel C45
- Blades mass – 46 kg/piece (average value)
- Number of blades – 2 pieces (one set)
- Purchase price – 413.3 €/piece
- Filler metal – E DUR 600
- Purchase price – 15 €/kg
- Reparatory work price (N.H.) – 10 €/h
- Applied reparation procedure v MMA surfacing.



Fig. 8.8. The worn (left) and repaired (right) snow-plough blade.

Important parameters for comparison of the two technologies:

- Exploitation time of the set of the new blades is $t_{exp\ np} = 150$ h of effective operation (determined in authors' own experimental investigations);
 - Exploitation time of the surfaced blades in the same operation conditions, on average $t_{exp\ rp} = 900$ h (determined by authors);
 - Liquidation value of the worn blades is $T_{lo} = 0.21$ €/kg;
- Quality of the repaired blades is better than that of the new blades.

Significant costs for comparison of alternative technologies:

- Total costs of purchasing of one set of the new blades $C_{np} = 810$ €;
- Total costs of reparation of one set of the worn blades $C_{rp} = 270$ €;
- Total costs due to downtime (losses) in present conditions for this machine amount to $C_{dt} = 15$ €/h.

Table 8.7. Snow plough blades revitalization

Applied technology	C_{np}, C_{rp} €	c_e	$c_{ex\ rel}$	$c_{ec\ rat}$	C_{ann} €
Replacement	810	0.667	6.000	18.000	22800
Reparation	270				1640
Direct savings	$S = 540$ € (66.70 %)		$S_{ann} = 160$ € (92.81 %)		

8.4.8 Stone crushers hammers

Basic parameters for profitability calculation of the compared revitalization technologies are:

- Base metal – steel cast iron GX120Mn12 (DIN)
- Hammer mass – 36 kg/piece (average value)
- Number of hammers – 16 pieces (one set)
- Purchase price – 140 €/piece
- Filler metal – E Mn 17 Cr 13
- Purchase price – 15 €/kg

- Reparatory work price (N.H.) – 10 €/h
- Applied reparation procedure – MMA surfacing.

Important parameters for comparison of the two technologies:

- Exploitation time of the set of the new hammers is $t_{exp\ np} = 320$ h of effective operation (determined in authors' own experimental investigations);
- Exploitation time of the surfaced hammers in the same operation conditions, on average $t_{ex\ rp} = 1200$ h (determined in authors' own experimental investigations);
- Liquidation value of the worn hammers is $T_{lo} = 0.42$ €/kg;

Quality of the repaired hammers is better than that of the new hammers.

Significant costs for comparison of alternative technologies:

- Total costs of purchasing of one set of new hammers $C_{np} = 5040$ €;
- Total costs of reparation of one set of worn hammers $C_{rp} = 1860$ €;
- Total costs due to downtime (losses) in present conditions for this machine amount to $C_{dt} = 333.3$ €/h.

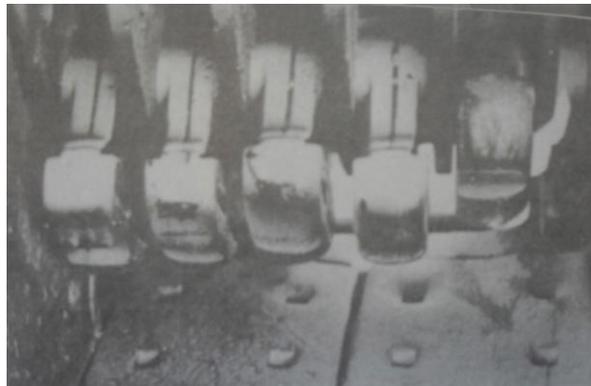


Fig. 8.9. Stone crusher's hammers.

Table 8.8 Stone crusher hammers revitalization

<i>Applied technology</i>	C_{np}, C_{rp} €	c_e	$c_{ex\ rel}$	$c_{ec\ rat}$	C_{ann} €
<i>Replacement</i>	10080	0.630	3.750	10.160	103600
<i>Reparation</i>	3720				16880
<i>Direct savings</i>	$S = 6360\ \text{€} (63.00\ \%)$		$S_a = 86720\ \text{€} (83.71\ \%)$		

8.4.9. Forging press frame

Basic parameters for profitability calculation of the compared revitalization technologies are:

- Base metal – 34 CrMo4 (EN);
- Frame mass – 6000 kg;
- Number of frames – 1 piece;
- Purchase price – 84000 €;
- Filler metal – E CrMo1B26 (DIN 85875/84);
- Applied reparation procedure – MMA welding/hard facing.

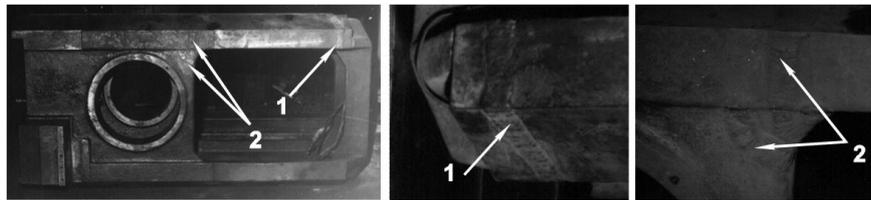


Fig. 8.10. The forging press frame – the hard-faced points.

Important parameters for comparison of the two technologies:

- Exploitation time of the set of the new forging press frame is $t_{exp\ np} = 1280$ h of effective operation (determined in authors' own experimental investigations);

- Exploitation time of the surfaced hammers in the same operation conditions, on average $t_{ex\ rp} = 2900$ h (determined in authors' own experimental investigations);

Significant costs for comparison of alternative technologies:

- Total costs of purchasing of the new frame $C_{np} = 84000$ €;
- Total costs of reparation of the damaged frame $C_{rp} = 4900$ €;
- Total costs due to downtime (losses) in present conditions for this hammer amount to $C_{dt} = 300$ €/h. The hammer operates cca 15 h per day.

Table 8.9. Forging press frame revitalization

Applied technology	C_{np}, C_{rp} €	c_e
Replacement	84000	0.941
Reparation	4900	
Direct savings	$S = 79100$ € (≈ 94.00 %)	

8.4.10 Toothed hub of the eccentric press

Basic parameters for profitability calculation of the compared revitalization technologies are:

- Base metal – 34 CrMo4 (EN);
- Hub mass – 500 kg;
- Number of hubs – 1 piece;
- Purchase price – 26500 €;
- Applied reparation procedure – MMA welding/hard facing.

Important parameters for comparison of the two technologies:

- Exploitation time of the new toothed hub is $t_{exp\ np} = 500$ h of effective operation (determined in authors' own experimental investigations);

- Exploitation time of the surfaced hub in the same operation conditions, on average $t_{ex\ rp} = 1400$ h (determined in authors' own experimental investigations);



Fig. 8.11. The toothed hub.

Significant costs for comparison of alternative technologies:

- Total costs of purchasing of the new hub $C_{np} = 26500$ €;
- Total costs of reparation of the damaged hub $C_{rp} = 3380$ €;
- Total costs due to downtime (losses) in present conditions for this press amount to $C_{dt} \approx 250$ €/h.

Table 8.10. Eccentric press toothed hub revitalization

Applied technology	C_{np}, C_{rp} €	c_e
Replacement	26500	0.873
Reparation	3380	
Direct savings	$S = 23120$ € (≈ 87.00 %)	

8.5. Conclusions

The objective of this paper was to present the economic aspects of the hard-facing reparation technology only, as well as to and to emphasize its numerous advantages, with respect to purchasing the new parts.

Results of the techno-economic analysis, presented in this paper, for all the ten examples of performed revitalizations of the damaged parts of the construction mechanization and forging tools, lead to the following conclusions:

- In majority of cases the reparation technology produces better techno-economic effects than replacement of the damaged parts by the new spare ones;
- Practically all working parts of the construction mechanization could be repaired by adequate hard-facing technology;
- When observing the techno-economic aspect, it is safe to say that more than 70 % of all the damaged parts of the construction machinery should be repaired;
- Working parts that are the so-called *bottlenecks* in the manufacturing process should always be repaired, since the downtimes cause excessively high additional costs;
- Reparation of the large size and complex shape parts should be done even if it does not produce immediate savings, since the savings would be realized later in exploitation by extending the working life of such parts (with respect to the new parts);
- In the case when the reparation of the small parts is considered, whose revitalization would not require high costs (per unit), the direct net savings could reach tens of thousands of Euros per annum, since those parts are usually used in large quantities and are replaced frequently (at least several times a year);
- Reparation by hard-facing could be applied even for revitalizing of the completely broken-down parts of construction mechanization;
- Reparation of the parts should be done in time, i.e. before the large loss of material occurs due to the wear process, since that would

produce much better techno-economic effects and higher quality of the repaired parts;

- By applying the reparatory hard-facing it is possible to execute the multiple reparations, i.e. to again repair the already repaired parts, what increases the positive economic effects;
- The better techno-economic effects are achieved if the reparation of large number of parts is organized simultaneously, due to decreasing of the preparation and finalization times (i.e. costs);
- Reparation by hard-facing can frequently be done without dismounting (disassembling) the parts either in the workshop or at a construction site, what is extremely important for the construction mechanization, since the downtimes are practically eliminated and the additional positive economic effects are realized;
- Application of the welding and hard-facing procedures for the reparation jobs frequently produces better effects than some other known reparation techniques, since the former enable improvement of the quality of parts and increase of the working life of parts for several times, as well as increase of their reliability.

The profitability method was the only one used for analysis presented in this paper. Even so, the obtained results are reliable enough for decision making on justification for applying the reparatory hard-facing and welding of the damaged parts of the construction mechanization and forging tools. In applying this method, it is important to determine the input parameters for economic calculations, as best as possible. In all the presented examples that was done with high accuracy, since the used data were obtained from the documentation from practice.

A great importance is assigned nowadays, in developed countries, to manufacturing costs and costs of maintenance of technical systems. The serious analyses of causes and ways to decrease the costs in production and services were done. Some detailed analyses have shown that, for instance, the car assembled of the spare parts would be two to three times more expensive than the newly manufactured one. In addition, by

applying the reparation, besides the direct savings, some indirect savings can be realized, as well. How important is the problem of reparation of the damaged parts is best stated by data presented in (WASSERMAN R. 2003) where it is stated that by application of the reparatory welding and hard-facing of parts of the technical systems, saving on the annual level in all the branches of economy, could reach millions of Euros, what cannot be neglected in the times of the world economic crisis.

From the standpoint of the techno-economic analysis, the technology of reparatory hard-facing is a complex set of mandatory procedures, which must be followed to the letter, if the reparation is to be successful.

The expected net benefits for the analyzed parts presented in this Chapter were exceptionally high, despite the fact that all the additional external and internal effects were not taken into account, which could even increase those benefits.

Note: Results of this research were partially presented at the "Welding 2015" Conference, reference (LAZIĆ V. et al. 2015a).

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