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Research paper
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ANALYSIS OF SAVINGS POTENTIAL THROUGH THE APPLICATION OF WELDING REPAIR FOR THE REVITALIZATION OF PARTS IN CONSTRUCTION MACHINERY

Abstract: *In modern industrial production, due to rigorous working conditions, machine parts frequently fail or wear out, leading to production downtime and financial losses. When a machine part becomes damaged, there are two options: replace the worn part with a new one or repair the damaged part through welding. Although purchasing a new part initially seems like a simpler and more reliable solution, many large industrial systems today opt for the regeneration of damaged components.*

This choice is driven by the multiple advantages that welding offers, not only from a technical perspective but also from an economic standpoint. This paper presents a procedure for determining the optimal technology for repairing various technical systems and provides an overview of potential monetary and time savings achievable through this technology. Costs and savings will be analyzed using the cost-effectiveness (profitability) method for different complex machine parts.

All analyzed components were revitalized through welding. Along with restoring the operational capacity of machine parts, significant savings in both money and time were achieved. The welding technology quality was evaluated and verified through experimental research and monitoring the performance of repaired parts during operation. The savings achieved were calculated using the cost-effectiveness method and expressed in specific monetary values for each analyzed part compared to the costs of purchasing a new one.

Overall, this paper represents a comprehensive techno-economic analysis of welding in the repair of various machine systems.

Keywords: *welding, repair, costs, savings, profitability*

1. Introduction

In modern industrial production, wear and sometimes even failure of working components occur very frequently. The causes of such failures can vary (Arsić, D. et al., 2015; Arsić, M., et al. 2014; Hawryluk et al., 2014), but the ultimate result is often the malfunctioning of different systems and production downtimes, which can lead to significant costs. When a component fails,

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there are usually two options: replacing the damaged part with a new one or repairing the existing one. Although the first option seems to be a faster, better, and more reliable solution, numerous examples of repairs presented in the literature (Lazić, V., et al. 2016a, 2016b, 2011) suggest that this is not always the case.

The aim of this paper is to highlight the potential economic savings that industrial systems can achieve by using welding as a technology for revitalizing damaged components. The savings will be presented in concrete monetary values, which are often the primary motivation for employers to adopt this technology. However, additional positive effects will also be emphasized, including reduced machine or plant downtime, shorter procurement time for new parts, decreased delays in product delivery, reduced inventory levels, and more.

The cost savings analysis will be conducted using a cost/benefit approach applied to three technical systems in construction machinery:

1. Excavator bucket teeth
2. Mixer blades for asphalt production
3. Rotary beams for stone crushing

On the other hand, it should be noted that welding technology has a significant and decisive impact on the characteristics of the welded layers (surfaces). Therefore, defining the appropriate welding procedure is not a simple task. To ensure the adequacy of the prescribed technology, numerous factors must be considered, along with high-quality equipment and well-trained, experienced personnel. The authors of this paper have extensive experience in defining welding technologies for various components, as verified through previous studies (Arsić, D. et al., 2015, Arsić, M., et al. 2014, Lazić et al. 2016a, 2016b, 2011). If properly defined and implemented, welding technology can even result in better overlay characteristics than those of a new component.

Since this paper focuses on the techno-economic aspect of repairs rather than the technological aspect, the welding technology for the mentioned components will not be discussed in detail here. However, more information can be found in (Nedeljković et al. 2008).

2. Calculation methods

When it comes to economic advantages, they are reflected in cost reduction, decreased downtime of production facilities, reduced spare parts inventory, and other factors (Wasserman, 2003).

This paper presents an analysis of achieved savings using the cost-effectiveness method, comparing the costs of performed repairs with the costs of purchasing new parts. Besides this method, various other approaches can be used to assess techno-economic feasibility, such as (Čukić, 2010): the Cost-Effectiveness Method (CEM), Profitability Improvement Analysis (PIA) Method, Machinery and Allied Products Institute (MAPI) Method, Life Cycle Costing (LCC) Method, and Net Present Value (NPV) Method.

Each of these methods has specific criteria for evaluating the techno-economic feasibility and deciding on the most cost-effective technology for restoring damaged elements in technical systems. These methods and criteria can be used not only to select the most favorable repair technology but also to determine the most appropriate technology for manufacturing new working components. They serve as a basis for ranking repair technologies and making decisions regarding the selection and implementation of the optimal solution. The choice of the most economical option is based on relevant indicators of economic feasibility.

In this study, the authors focused on the economic effects of two alternative repair technologies for different damaged components in technical systems:

1. Replacing damaged parts with new spare parts
2. Repair welding (overlay welding) of damaged parts

Before initiating the revitalization of a specific part, it is essential to consider that the process is always carried out within the constraints of the production facility, i.e., depending on the availability of human resources, technical capabilities, and financial resources (Wasserman, 2003). In this paper, it is assumed that all technical and human resource requirements are met and that repairs can be performed within the facility's own capabilities. Furthermore, due to the scope of the study, the detailed welding technology for the analyzed damaged components will not be presented here; instead, the authors refer readers to relevant literature where such data have been previously published (Lazić et al. 2016a, 2016b, 2011, Nedeljković et al. 2008).

Given that this research examines multiple available technologies, priority is given to the one that provides better techno-economic effects. As criteria for evaluating investments in these two alternative technologies, i.e., for quantifying the financial investment, the parameters of higher cost-effectiveness and absolute profitability are used (Wasserman 2003).

In the cost-effectiveness method, which will be applied in the subsequent analysis, three main procedures are commonly used to justify the application of a particular technology: comparing cost-effectiveness as the ratio of revenue to expenses, comparing costs and achieved savings by their reduction, and increasing financial results by improving revenue through cost reduction. In qualitative economic analysis, direct (net) benefits are assessed, as well as unforeseen costs, internal effects, external effects, and multiplier effects (Wasserman, 2003). The goal of such net profit calculations is to express the general principle of rational technology application.

The cost of acquiring a new part (C_{np}) represents the sum of all costs associated with procurement, including the purchase price of the new part, transportation costs, customs duties (if the part is imported), tax payments, storage and warehousing costs, and others. This cost is reduced by the resale value of the damaged part (C_{op}) but increased by additional costs (C_a) arising from production downtime, lost business due to contract cancellations, penalty fees for exceeding contractual deadlines, and more. The cost of acquiring a new part is determined based on the company's financial documentation.

The techno-economic effects were calculated according to the following parameters (Čukić, 2010):

- total costs for purchasing of the new part C_{np}, €;
- total costs for reparation of the damaged part $_{Crp}$, €;
- the profitability coefficient
$$c_e = (c_{np} - C_{rp})/C_{np}$$
- the exploitation reliability coefficient:
$$c_{ex\,rel} = t_{e\,rp}/t_{e\,np}$$

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

- the economic rationality coefficient:
$$c_{ec\,rat} = (c_{np} \cdot i_{h\,np})/(c_{rp} \cdot i_{h\,rp})$$

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, € and
- direct savings per annum S_{ann}, €.

In conducting a comparative techno-economic analysis for these cases, additional costs due to downtime during a single replacement of damaged parts—whether replacing them with new or repaired components—were not considered, as these costs are nearly identical and do not significantly impact the final economic analysis results. However, additional costs resulting from a higher number of replacements and downtimes due to the shorter service life of new parts compared to repaired ones had to be taken into account, as they have a significant influence on the final outcome. These additional costs, which are quite high, were calculated for an operational period of one year, as is commonly done when determining economic effects (Čukić, 2010).

Therefore, the goal of the techno-economic analysis is to provide a detailed and comprehensive presentation of the savings achieved through the application of a particular welding process compared to purchasing a new part. This methodology can be applied to all types of regenerated components, while this study specifically focuses on analyzing the achieved savings in construction machinery components.

3. Cost-Effectiveness Analysis of Performed Revitalization of Damaged Parts

The techno-economic analysis in this study includes loader bucket teeth, asphalt mixing blades, and impact beams for crushers used in grinding rock materials (stone). This paper primarily focuses on analyzing the economic benefits of applying welding technologies, while the complete technological procedure for determining the most suitable repair technology and the welding technology for each specific part has been presented in some of our previously published works (Lazić et al. 2016a, 2016b, 2011).

The analyzed working parts are procured multiple times a year according to the procurement plan, meaning that the savings on a single unit can be multiplied by the number of units needed per year to determine the annual savings. The results obtained from the cost-effectiveness analysis are presented in Tables 1 to 3.

3.1 Loader Bucket Teeth

Basic Parameters for Economic Calculation of Compared Alternative Technologies for Restoring Loader Bucket Teeth:

- Base Material – Cast Steel 50Mn7 (DIN)
- Tooth Mass – 8.6 kg/piece (average value)
- Number of Teeth – 10 pieces (one set)
- Purchase Price – €113.5/piece
- Additional Materials – ABRADUR 58 and INOX B 18/8/6
- Purchase Price – €15/kg
- Repair Work Cost (standard hour) – €10/hour
- Applied Method – Manual Metal Arc (MMA) Welding/Hard Facing

Key Parameters for Comparing Alternative Technologies:

- Service Life of a Set of New Teeth when working with stone and its aggregates:
  - Average C_{erp} = 1200 hours of effective operation (determined through own experimental research)
- Service Life of Hard-Faced Teeth under the same working conditions:
  - Residual Average C_{erp} = 4200 hours
- Value of Worn Teeth Material:
- C_{dp} = €0.2/kg

Significant Costs for Comparing Alternative Technologies:

- Total Procurement Cost of One Set of New Teeth: C_{np} = €1210
- Total Repair Cost of One Set (10 pieces) of Teeth: C_{op} = €320
- Total Downtime Costs (Losses) in Current Production Conditions for this machine: C_a = €20/hour

Table 1. Techno-economic analysis of the regeneration of damaged bucket teeth

Applied technology	Direct costs of alternative technologies C_{np} and C_{rp}, €	Profitability coefficient $k_p = \frac{C_{np} - C_{rp}}{C_{np}}$	Exploitation reliability coefficient $k_{ep} = \frac{C_{erp}}{C_{enp}}$	Economic rationality coefficient $k_{er} = \frac{C_{np} \cdot i_{hnd}}{C_{rd} \cdot i_{hrp}}$	Total annual costs, €
Replacement (2 sets)	1210	0.735	3.500	13.226	6021
Reparation (2 sets)	320				1060
Direct savings	890 € (73.50 %)		Annual savings	4961 € (82.40 %)	

3.2 Blades of Asphalt Mixing Plants

Basic parameters for the economic calculation of alternative technologies for renewing the blades of asphalt mixers:

- Base material – Steel casting X210Cr12
- Blade mass – 3.6 kg/piece (average value)
- Number of blades – 64 pieces (one set)
- Purchase price – 43.6 €/piece
- Additional material – E DUR 600 and INOX B 18/8/6
- Purchase price – 15 €/kg
- Repair work cost (standard hour) – 10 €/h
- Applied method – MMA welding/hard facing
- Important parameters for comparing alternative technologies are:
- Service life of a set of new blades in asphalt production is on average C_{enp} = 360 hours of effective operation
- Service life of welded blades under the same working conditions is on average C_{erp} = 1080 hours of effective operation
- Residual value of material from worn-out blades is C_{op} = 0.21 €/kg
- Significant costs for comparing alternative technologies are:
- Total cost of acquiring one set of new blades C_{np} = 2790 €
- Total cost of repairing one set of blades C_{rp} = 1090 €
- Additional costs due to downtime (production losses) under current production conditions for the asphalt plant are C_a = 3000 €/h

Table 2. Techno-economic analysis of the regeneration of damaged asphalt mixing blades

Applied technology	Direct costs of alternative technologies C_{np} and C_{rp}, €	Profitability coefficient $k_p = \frac{C_{np} - C_{rp}}{C_{np}}$	Exploitation reliability coefficient $k_{ep} = \frac{C_{erp}}{C_{enp}}$	Economic rationality coefficient $k_{er} = \frac{C_{np} \cdot i_{hnd}}{C_{rd} \cdot i_{hrp}}$	Total annual costs, €
Replacement (2 sets)	2790	0.609	3.000	7.677	560336
Reparation (2 sets)	1090				183980
Direct savings	1700 € (60.90 %)		Annual savings		376356 € (67.17 %)

3.3 Rotary bars for stone crushing

Basic parameters for the economic calculation of compared alternative technologies for the restoration of impact bars in crushers for the production of stone aggregates:

- Base material – X120Mn12.1 (EN);
- Mass of impact bar – 300 kg/unit (average value);
- Number of impact bars – 4 units (one set);
- Purchase price – 2187.5 €/unit;
- Additional material – E Mn 17 Cr 13;
- Purchase price – 15 €/kg;
- Cost of repair work (standard hour) – 10 €/h;
- Applied method – MMA welding/hard facing.

Important parameters for comparing alternative technologies:

- The service life of a new set of impact bars in the production of stone aggregates from limestone is C_{enp} = 150 hours of effective work using both working surfaces. This is the maximum number of effective working hours when processing limestone, and for harder rock types, the number of effective working hours is significantly lower.
- The service life of welded old impact bars in the same working conditions is an average of C_{erp} = 320 hours of effective work using both working surfaces.
- The liquidation residual value of the material of worn-out impact bars (high-alloy manganese steel) is C_{op} = 0.42 €/kg.

Significant costs for comparing alternative technologies:

- Total cost of purchasing a new set of impact bars C_{np} = 8750 €;
- Total cost of repairing one set of impact bars C_{rp} = 2040 €;
- Additional costs due to downtime (losses) in the current production conditions at the crushing plant are C_a = 1050 €/h.

Table 3. Techno-economic analysis of the regeneration of damaged rotary bars for stone crushing

Applied technology	Direct costs of alternative technologies C_{np} and C_{rp}, €	Profitability coefficient $k_p = \frac{C_{np} - C_{rp}}{C_{np}}$	Exploitation reliability coefficient $k_{ep} = \frac{C_{erp}}{C_{enp}}$	Economic rationality coefficient $k_{er} = \frac{C_{np} \cdot i_{hnd}}{C_{rd} \cdot i_{hrp}}$	Total annual costs, €
Replacement (2 sets)	8750	0.767	2.133	9.149	303940
Reparation (2 sets)	2040				105000
Direct savings	6710 € (60.90 %)		Annual savings	198940 € (65.45 %)	

4. Conclusion

The aim of this paper was to demonstrate the potential of extending the service life of damaged components and delaying the replacement of damaged parts with new ones through the use of welding technology, without compromising the functionality of the technical system. The analysis covered the repair of three complex parts of technical systems used in construction machinery or plants for producing construction materials.

The problem is often most easily solved by purchasing new parts, but this requires a significant financial outlay and an unacceptably long procurement time, which significantly prolongs plant downtime and results in large production losses. The cost for repairs was considerably lower, but on the other hand, it required the engagement of additional human and technical resources. Through the applied regeneration process, downtime was significantly reduced, and the working hours of the workers and the entire plant were better utilized.

The results of the cost-effectiveness analysis for the characteristic examples of repairing different damaged working parts, presented in section 4 of this paper, show that by applying the optimal welding technology, almost all machine parts can be repaired. Even for smaller parts, which do not require high procurement costs, the direct net savings can reach amounts of several tens of thousands of euros annually, excluding other factors through which additional savings can be realized. For the three examples presented, net savings achieved annually are:

1. Excavator bucket teeth – 4961 EUR,
2. Asphalt mixing blades – 376,356 EUR,
3. Rotary hammers for stone crushing – 198,940 EUR.

In addition to the above data, the conclusion is that vital working parts of construction machinery should always be repaired because downtime always leads to significant additional costs. Furthermore, by applying welding technology, it is possible to perform multiple repairs, i.e., to repair already repaired parts again, thus further increasing economic benefits.

For the analyses presented in this paper, only the cost-effectiveness method was used, and the results obtained are reliable enough to make decisions about the feasibility of applying the welding repair technology in the revitalization of damaged working parts of construction machinery. The techno-economic analysis was performed after the successful repair and confirmed the results obtained using the cost-effectiveness method.

It is crucial to accurately define the input parameters necessary for economic calculations when applying this method. In this case, for all analyzed examples, this was done with great precision using current data from each company's documentation.

The presented cost-effectiveness analysis showed that the net benefit for the analyzed parts can be very significant, even though additional internal and external effects, which could further increase the net benefit, were not considered.

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