Serbian Tribology Society

SERBIATRIB '13

13th International Conference on Tribology

Faculty of Engineering in Kragujevac

Kragujevac, Serbia, 15 – 17 May 2013

TECHNO-ECONOMIC JUSTIFICATION FOR REPARATORY HARD-FACING OF MACHINE SYSTEMS' WORKING PARTS

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Abstract: *Research in the field of hard-facing of various parts of mechanical systems is being done for technical and techno-economic reasons. The reasons for introducing the new reparation technologies by hard-facing are numerous: three quarters of all the mechanical parts of engineering systems could be regenerated or manufactured by hard-facing; the working life of the repaired part reaches or even exceeds the working life of a new part, while the working life of the hard-faced manufactured part surpasses several times the working life of the new part manufactured by some other technology. Large number of damaged and, frequently even broken parts causes terminations of the working process. Thus, due to difficulties in procurement of new, mainly imported parts, the alternative solution must be applied and that is regeneration by hard-facing.*

It is shown that the a proper choice of the hard-facing technology is related to the complex procedure of checking the quality of the hard-faced layer, what indicates that the reparatory operations could be performed only in specialized regeneration workshops, which are furnished with adequate equipment and corresponding expert and skilled staff. The estimated net benefit for the analysed parts is exceptionally high, regardless of the fact that the additional external and internal effects have not been quantified. After the successful application of these new manufacturing hard-facing technologies it would be possible to create the knowledge base and apply it in maintaining the parts of civil engineering machinery, forging equipment and other similar mechanical parts.

Key words: *regeneration, wear, hard-facing, costs, techno-economic analysis.*

1. INTRODUCTION

The reasons for the introduction of technology for manufacturing and reparatory hard-facing are numerous: research indicates that three-quarters of all the mechanical parts can be regenerated and manufacturing hard-faced, service life of repaired part reaches or exceeds the service life of the new part, service life of new in production hard-faced part exceeds several times that of the new part, which was not hard faced, repair costs are reduced as well as the downtime due to purchasing a new part, which increases productivity, financing costs and cost of storage are also reduced [1- 4]. A large number of damaged, and often broken, parts cause termination of the process, and the difficulties in the procurement of new, mostly imported parts, must use an alternative such as hard-facing-regeneration. In addition, the maintenance of the technical system should take in consideration manufacturing of new parts by hard-facing, what is expected to extend their service life with respect to the new working parts.

To perform the modelling of hard-facing of working parts, i.e., to prescribe general regeneration procedures, it is necessary to perform previous studies on a number of models and real working parts made of various types of steel and cast iron. While the surfacing almost every time is a unique job, because it requires the technology customized to each working part, it is possible to establish general procedure for groups of similar parts and then to apply it [2,5-6].

2. SELECTION OF THE OPTIMAL HARD-FACING TECHNOLOGY

In examining the state of the damaged parts one should first determine: whether the wear occurred during the normal exploitation or it appeared due to some mechanical damage; what is the degree of the part's wear is crucial for the decision whether it is cost-effective and safe to use it in furter exploitation (to apply regeneration or the part) or should it be rejected. The size of expected deformation and residual stresses are also important factors in making such a decision [7-8]. After determination of the chemical composition of the base metal and working conditions, it is possible to create the basic conditions for the design of technological processes. Based on those facts and previously conducted detailed techno-economic analysis, the method of regeneration should be chosen, taking into account the local possibilities of the company. The basic requirement is to obtain the required properties of the regenerated part and, ofcourse, the reliability of the part during the estimated working life.

To achieve the above requirements it is necessary to make the proper selection of filler material for hard-facing. In some cases of reparation of working parts it is necessary to apply two or more kinds of additional material to insert an intermediate layer, the so called buffer layer, between the layer and the substrate. This reduces the large differences in the chemical composition, structure and, consequently, the thermo-physical properties, of the substrate and the deposit. Next follows the selection of the regeneration process parameters, resulting from the properties of the base and filler metal, and form demands concerning the size and shape of regenerated parts. The final stage of planning, before the experimental surfacing, is the assessment of the necessity for implementation of special measures and the previous, current and subsequent heat treatment.

For verification of the proposed technologies, the comparative tests in laboratory and in working conditions have been performed, and, in some cases, comparative test of imported parts, which were not hard-faced and the new-hardfaced parts. Laboratory tests are related to the microstructure, hardness distribution and tribological tests and working tests of comparing the working life of the new and repaired parts installed in the same machine [2-3,9].

From the point of view of techno-economic analysis, reparation welding technology is a complex set of different types of mandatory procedures, which take into account: the conditions of work, damage identification, estimation of weldability, welding process, filler material, welding and hard-facing regimes, heat treatment applied, model and real tests. Having in mind the complexity of the process, it is necessary to determine the optimal technical-technological solutions to bring the reparation process to a stage when it is possible to make a final decision, wheter to buy a new part or to repaire it.

3. EXAMPLES OF IMPLEMENTED REPAIRS

Here is considered the justification for application of the production and reparation hard-facing and it is pointed to profitabilityof repairs on examples of damaged forging hammer, forging press frame and large gear of eccentric presses. The subject matter is the reparatory welding and surfacing of the damaged or cracked forging hammers, broken and cracked frames, forging presses and large gear eccentric presses [10-11]. To determine the optimal technology of hard-facing, it was necessary to carry out tests on model and real working parts. Test hard-facing and testing of models have served to establish the initial reparation technology, and to "transfer" thus approved technologies to the working parts, which are then further checked under actual working conditions.

This paper mainly deals with the techno-economic advantages of the hard-facing technology, while the complete procedures of determining the optimal technology for each particular part were presented in papers [2-3,5,9-11].

3.1. Regeneration equipment's for forging hammer and press frame

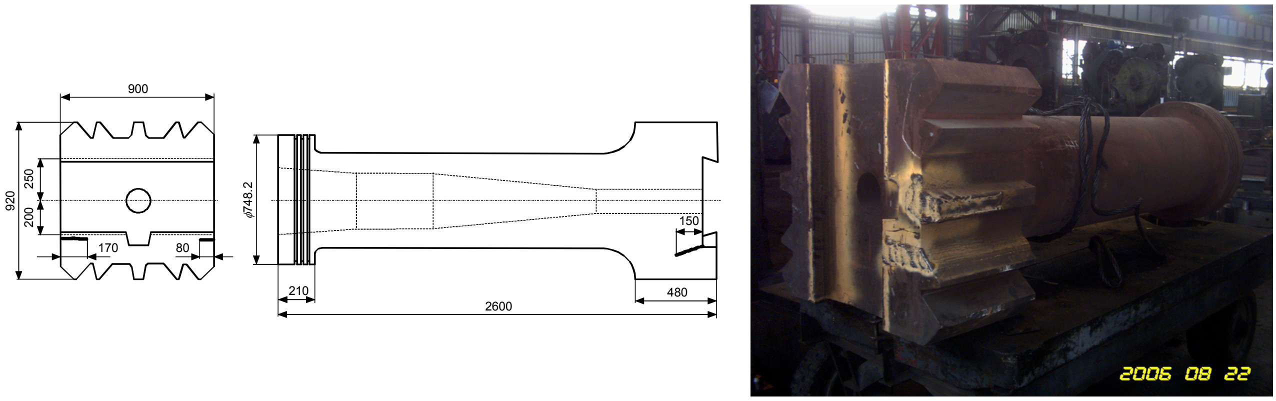
For regeneration of responsible parts with complex geometries and large masses, made of material sutible for tempering, a detailed analysis of the working parts is required as well as the precisely proposed reparation technology.

Hammers mallets and presses frames are exposed, during the long operation, to thermal fatigue due to cyclic temperature changes and to impact loads. Due to the high costs and often to impossibility of purchasing the new working parts, it is necessary to evaluate the possibility of their repairs. Harsh working conditions sometimes lead to a complete fracture of the part and endangering the workplace safety. Figure 1 shows fracture of a forging mallet, which has originated from fatigue crack propagation.

Mallet of forging's hammer, shown in Fig. 2, and frame forging press, shown in Fig. 3, are primarily subjected to impact compression loads, and, in partially to temperature gradient, that is thermal stresses caused by uneven temperature field [2,7-8]. After a long work of these parts, i.e., large number of repeated cycles on hammer mallet and on the press frame, visible cracks were observed, and on one portion of the frame and on a single occurred the complete fracture (Fig. 1 and 3).

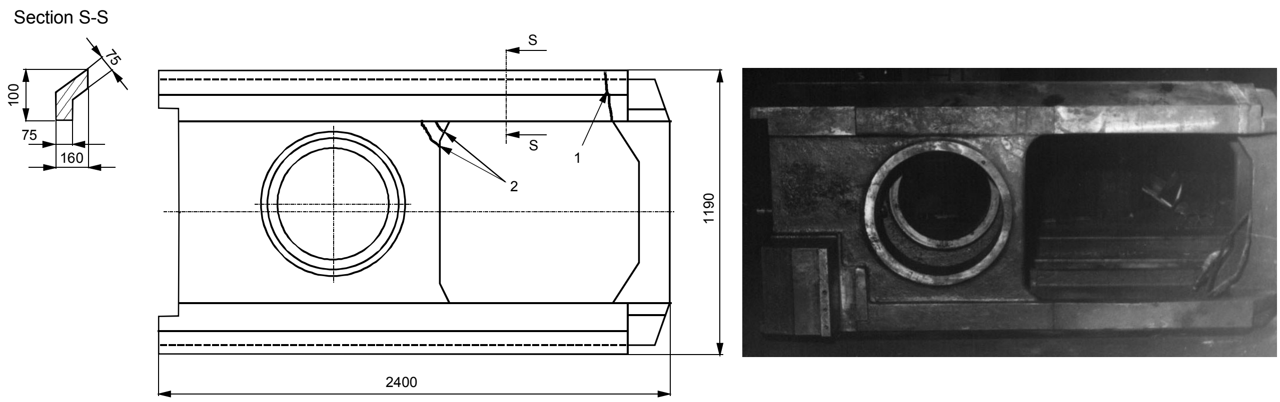
Taking into account that these are parts of large dimensions and complex shapes, and that components are subjected to dynamic and thermal loads, they are dimensioned on the basis of the increased safety degrees; thus the special measures are required for the manufacturing and reparatory technologies, as well. Forging press frame is made
by casting in sand, from the medium carbon cast steel. On the other hand, pneumatic forging hammer mallet, as one of the most loaded mechanical parts, is made of low alloyed steel for tempering.

Figure 1. Appearance of fractured forging hammer mallet.



a) **b)**

Figure 2. Forging hammer mallet
a) Sketch of mallet with observed crack; b) Apperance of the regenerated mallet of mass of 6000 kg



a) **b)**

Figure 3. Frame of vertical forging press.
a) sketch of the frame (1 – fracture site; 2 - observed cracks); b) regenerated, heat treated and machined part

The complete technology for regeneration of damaged forging hammers' mallets and presses' frames is shown in [6, 10-11]; here are presented only the techno-economic indicators for the mallets' regeneration.

The following data are relevant for comparison:

A. The price of the new part is: **83987 €**

(This price includes price of a new part - 67470 €, tax -12144 €, the customs 3373 € and the cost of shipping and transportation services - 1000 €);

B. The total real costs of reparation of **4912 €** include:

- Identification and damage detection:

3 days × 8 (nh*/day) × 10 (€/nh) = 240 €;

- Machining of damaged area:

10 days × 8 (nh/day) × 12 (€/nh) = 960 €;

- Selection of the optimal hard-facing technology:

8 days × 8 (nh/day) × 15 (€/nh) = 768 €;

- Model testing:

4 days × 8 (nh/day) × 12 (€/nh) = 384 €;

- Surfacing of real working parts:

20 days × 8 (nh/day) × 10 (€/nh) = 1600 €;

- The costs of machining operations of surfaced areas:

10 days × 8 (nh/day) × 12 (€/nh) = 960 €.

nh = norm-hour

Based on these data one can conclude that the total reparation costs are far lower than the costs of a new part (less than 6%). Therefore, the "buy" or "repaire" dilemma is apparently resolved without more detailed analysis of the positive effects that mallet regeneration allows.

3.2. Reparation of large gears - toothed hub of an eccentric press

The techno-economic analysis of reparatory welding and hard-facing of the damaged teeth of a coupling hub with mass of 500 *kg*, shown in Fig. 4, is performed after the repair has already been performed, because it is a unique part that could not be easily obtained. The coupling is exposed to harsh environmental conditions and is made of alloyed steel for tempering. Since it is a conditionally weldable steel, it was necessary to prescribe a particular reparation technology. It was established through previous model tests [5,10]. The analysis of obtained results leads to the optimal hard-facing technology which is then "transferred" to the real part.

Figure 4. Appearance a coupling hub

In economic "buy" or "repaire" analysis, an estimate of the more complete effects was not conducted, which should be performed by the *benefit-cost* (BC) analysis, or more precisely by using the *life-cycle-cost* (LCC) analysis, which would point to more precise and more clear advantages of application of this advanced technology [3]. A comparative analysis was performed after two and a half years of the hard-faced rack hub couplings operation.

As relevant for comparison the following data were taken:

A. Purchasing price of the new part: **26500 €**

(This price includes price of a new part, the cost of taxes, customs duties, freight forwarding services and transport).

B. The total real reparation costs of **3380 €** include:

- Identification and damage detection: 1

day × 8 (nh/day) × 10 (€/nh) = 80 €;

- Machining of damaged area:

2 days × 8 (nh/day) × 12 (€/nh) = 192 €;

- Selection of the optimal hard-facing technology:

1 day × 8 (nh/day) × 15 (€/nh) = 120 €;

- Model testing:

3 days × 8 (nh/day) × 12 (€/nh) = 288 €;

- Surfacing of real working parts:

10 days × 8 (nh/day) × 10 (€/nh) = 800 €;

- Costs of production services (processing hard-faced teeth and transport)

1900 €.

Based on these data one can conclude that the total cost of repairs is significantly lower than the cost of purchasing a new part (less than 13%).

4. CONCLUSION

Through the proper selection and application of the reparatory and manufacturing hard-facing technologies, it is possible to achieve a number of advantages compared to the installation of new parts. This is primarily related to the extension of the service life of the analyzed parts, increase of productivity, reduction of downtimes, reduction of inventory costs and other benefits derived by applying the welding technology.

It is shown that a proper choice of hard-facing technologies is associated with the complex procedure of checking the quality of deposits, what indicates that the repair work can be performed only in specialized workshops for regeneration, which have adequate equipment and appropriate skilled staff. The expected net benefit for the analyzed parts is very high, regardless of the fact that additional external and internal effects have not been quantified. After the successful implementation of these new manugacturing surfacing technologies in presented areas, it is possible, by applying the similar procedure, to form a knowledge base and to use it for maintenance of equipment for forging, and other similar mechanical parts.

ACKNOWLEDGEMENT

This research was partially financially supported by Ministry of Education and Science of Republic of Serbia through grants TR35024, TR35021, TR34002 and OI174004.

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