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REPARATION OF THE DAMAGED FORGING HAMMER MALLET BY HARD FACING AND WELD CLADDING

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Professional paper

In this paper the problems related to the maintenance of large forging mallets of pneumatic hammers including hard facing of cracked or worn working surfaces are considered. Actually, the choice of optimum technology for the reparation of hard facing of the broken forging press frame and cracked mallet of the forging pneumatic hammer are taken into consideration.

Key words: *reparation, hard facing, forging mallet, technology of surfacing, thermal treatment, cost analysis*

Regeneracija oštećenog bata kovačkog čekića postupcima zavarivanja i navarivanja

Strukovni članak

U ovom radu se razmatra problematika održavanja velikih batova kovačkih pneumatskih čekića, uključujući tu i navarivanje napuklih i pohabanih radnih površina. Konkretno, ovdje je riječ o izboru optimalne tehnologije reparaturnog zavarivanja napuklog bata. Pored tehno-ekonomske analize, u radu se navodi i energetska analiza, kao dodatni kriteriji za ocjenu primijenjene tehnologije.

Ključne riječi: *reparatura, navarivanje, kovački čekić, tehnologija navarivanja, toplinska obrada, analiza troškova*

1 Uvod
Introduction

During the long-term operation, mallets of the forging hammers are exposed to thermal fatigue due to the cyclic temperature changes and impact loads. Taking into account very high price, and a risk of buying frequently the new parts, the necessity of their reparation becomes obvious. The forging hammer mallet (Figure 1), is primarily exposed to the impact compressive loads, and partially also to a temperature gradient. It is happening due to the thermal stresses caused by unbalanced temperature field [1, 2, 3, 4, 5, 6]. Therefore it is clear that this very intensively loaded mechanical part operates under very complex conditions. During exploitation these parts are used under high intensity of mechanical and thermal loads. As the result of the long duration of operation (high number of load cycles), cracks were observed on the hammer's mallet, as shown in Figure 1.

The technology of manufacturing and reparation requires special efforts, due to the fact that the parts posses large dimensions and complex shape, and are exposed to dynamic and thermal loads.

The pneumatic forging hammer mallet, as one of most highly loaded parts in machinery, is made by forging, using the low alloyed steel for tempering Č4731 - JUS C.B9.021 (34CrMo4 - EN 10083/1) (Table 1).

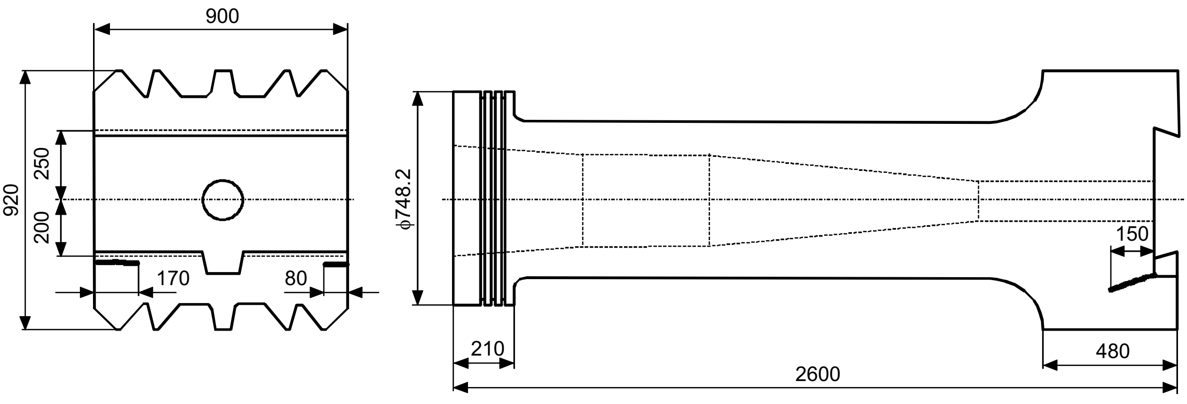

Figure 1 *Appearance of the forging hammer mallet and places of noticed cracks*
Slika 1. *Izgled bata kovačkog čekića i mjesta uočenih pukotina*

Table 1 *Chemical composition and mechanical properties of mallet after tempering* [13, 14]
Tablica 1. *Kemijski sastav i mehanička svojstva bata kovačkog čekića poslije poboljšanja* [13, 14]

Position	Chemical composition, %							Mechanical properties				Hardness HB	Microstructure
	C	Mn	Si	Cr	Mo	P	S	R_m, MPa	R_{eH}, MPa	*A*, %	*Z*, %		
Hammer's mallet	0,30-0,37	0,60-0,90	0,40	0,90-1,20	0,15-0,30	0,035	0,03	700-1000	270-380	15	60	≈ 300	Interphase structure
Note: Hammer's mallet was also produced in Poland (Huta Zygmunt).													

According to computation criteria for weldability estimation, this part belongs to the group of conditionally weldable materials. In order to prevent the formation of brittle phases (e.g. cold cracks) due to hardening, the preheating process is necessary. The preheating temperature can be calculated or adopted based on empirical recommendations. In this case the Seferian formula [7, 12] was applied, which takes into account both the chemical composition of the applied steel and the thickness of the welded part. The preheating temperature (somewhat over 300 °C) was obtained, but taking into account the condition that it cannot surpass the temperature of martensitic transformation start, the temperature $\vartheta_p = 300$ °C was adopted [1, 3].

Previous investigations of the reparatory welding have shown that the local preheating has no significant influence for massive pieces due to the heat sink effect which occurs during that process. Therefore, following the preparation of the cracked zones (grooves), massive pieces were preheated up to 350 °C and kept in furnace for several hours (8-12 h). After the removal from a furnace, the piece is covered by isolations cover in a way that only the zone which is repaired by welding is left uncovered. Considering the long reparation period it is sometimes necessary to perform additional heating (using gas burner), in order to sustain the preheating temperature. This additional process has to be controlled, either by thermo-chalks or corresponding digital devices. In the experiment presented in this paper, the preheating temperature was controlled by digital instrument with thermocouple made of Cr-Ni-NiAl, with measuring range -50 to 1200 °C.

2
Selection of the reparation procedure and the filler materials
Izbor postupka reparature i dodatnog materijala

It was decided to apply the procedure of manual metal arc (MMA) welding - hard facing. However prior to the implementation of the procedure on real parts, the corresponding welding tests were performed on models, in order to establish the optimum technology of hard facing.

The coated electrodes used for reparatory hard-facing of the mallet, were manufactured by Piva Plužine: PIVA 351B - DIN 8575/84 - E CrMo1B26 [13, 14] (Table 2). In order to obtain the welds with good mechanical properties, thick shielded metal basic electrodes with controlled content of diffusive hydrogen are dried according to regime 350 °C/2 h [13].

Hard facing of slider guides was performed with coated electrode PIVA 430 B [13]. This electrode is usually used for hard facing of worn surfaces (hardness: 280-330 HB), due to easy mechanical tooling.

3
Experimental investigations of the model
Eksperimentalna ispitivanja modela

In order to select the optimum reparation technology the numerous investigations were conducted on samples made of nominally the same material as in the case of repaired parts. Few models were hard faced in one or several passes (layers), either with preheating (ϑ_p= 300 °C) or without preheating (Figures 2a, 2b and 2c). Metallographic samples (blocks) were produced from the hard faced samples, as shown in Figure 2d. The hardness was measured in several directions and microstructure of characteristic weld zones was estimated. Samples for hard facing were usually chosen according to the geometric similarity with hard faced part and were made of material with the same chemical structure as hard faced mallet [1, 3, 4, 5].

After the hard facing, model samples (total 4) were slowly cooled in the furnace. Two samples were tempered at 650 °C/2 h, with slow heating in the furnace and then slowly cooled. The other two samples were not thermally treated. Samples which were preheated and tempered by the use of PIVA 351 B electrodes had the hardness under 350 HV. That indicates that there is no concern of brittle martensite phases formation in hard faced zones, if prescribed technology is followed. In some characteristic zones of these samples the following facts were observed: hard faced layer interphase carbide, HAS interphase sorbite, and base material (BM) mainly sorbite. In the case of samples that were preheated without tempering, hardness over 350 HV was obtained. In

Table 2 *Filler metal properties* [13, 14]
Tablica 2. *Svojstva dodatnog materijala* [13, 14]

Electrode sign mark		Chemical composition of the pure hard-faced layer, %						Mechanical properties			
FEP Plužine	Standard DIN 85875/84	C	Mn	Si	Mo	Ni	Cr	R_m, MPa	R_{eH}, MPa	A_5, %	KV, J $\vartheta = 20$ °C
PIVA 351B	ECrMo1B26	0,08	0,85	0,5	0,5	-	1,20	560-660	460-560	22-26	100-140

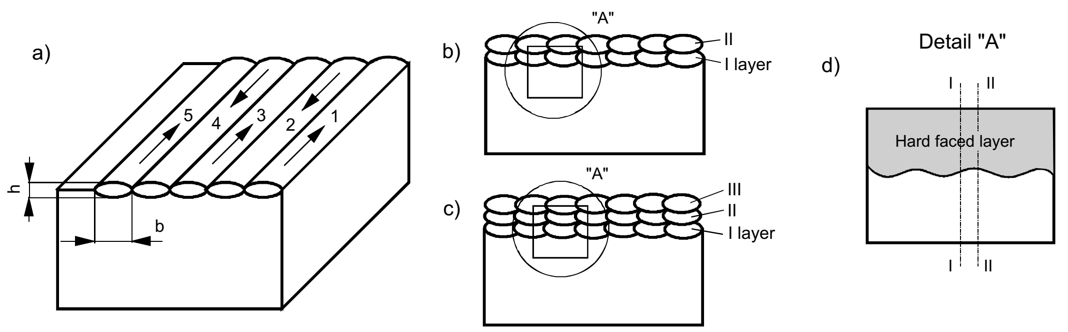

Figure 2 *Order of hard-faced layers deposition* [1, 3]
Slika 2. *Redoslijed polaganja navara* [1, 3]

Table 3 *Hard facing reparation parameters for the MMA procedure F.M. PIVA 351 B and PIVA 430 B*
Tablica 3. *Parametri reparaturnog navarivanja REL postupkom D.M. PIVA 351 B i PIVA 430 B*

Repaired position	Electrode diameter, d_e, mm	Welding current, I, A	Working voltage, U, V	Welding speed, v_z, cm/s	Input heat, $q_l = \frac{U \cdot I}{v_z} \cdot \eta$, J/cm
Mallet model	3,25	75	23	0,085	13 000
	4	170	27	0,160	22 950
	5	200	28	0,169	26 508

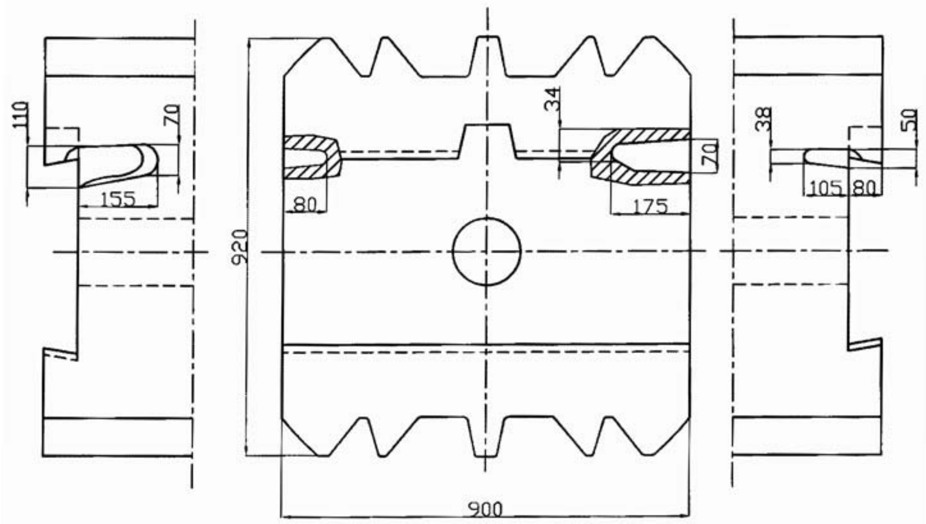

Figure 3 *Shape and geometry of prepared grooves*
Slika 3. *Oblik i geometrija pripremljenih žljebova*

addition, appearance of brittle phases – martensite and lower bainite was detected [1, 3].

For estimation of the structural changes, with respect to temperature and cooling rate, the corresponding diagrams of continuous cooling (ARA diagrams), were used, [13, 14]. This process made it possible to establish the relationship between the preheating temperature and selected energetic welding parameters. Mallet model was repaired with electrodes ∅3,25, 4,0 and 5,0 mm. The order of the hard faced layers deposition is presented in Figures 2a, 2b and 2c. In this way the optimum reparation technology, suitable for real part, was determined (Table 3). Microstructure analysis, hardness measurements and visual inspection confirmed that the repaired layers did not have pores, cracks, ruptures and other failures and that the bond between base material and filler material was of good quality.

4 Hard facing of considered part
Reparatura originalnog dijela

Before applying the optimum technology of hard facing, a detailed control of observed damages was performed. Damage investigation was conducted by visual inspection of corresponding zones, magnetic defectoscopy, ultrasonic control and penetrating liquids. This process made it possible to perform the adequate preparation of welding grooves in a way that the groove root reaches the crack (Figures 3 and 4).

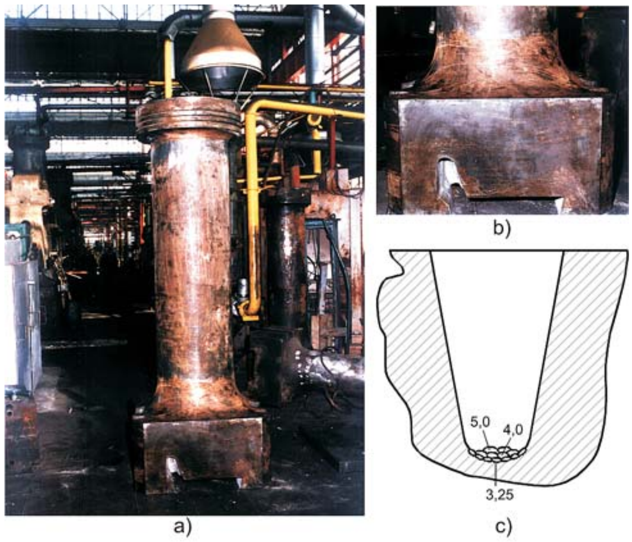

Figure 4 *Appearance of grooved mallet (a, b) and weld pattern (c)* [1, 8]
Slika 4. *Fizički izgled ižljebljenog bata (a, b) i shematski redoslijed polaganja zavara (c)* [1, 8]

Based on the previously developed model investigations, [1, 3, 4, 5, 9, 11] and other reports [2, 6, 7, 8, 10], the decision to start this complex and risky reparation was made. The complexity of this process was directly influenced by very hard operating conditions, high impact and frequently repeated mechanical loads, elevated temperatures, etc. Also, the reparation procedure conditions were very unfavorable due to the locations of the grooves and cracks, complex cross sections and difficulties during the manipulation with these massive and heated parts (about 6 000 kg).

In order to perform sanitation of the larger cracks, the prediction of making the minimum volume of grooves was made (Figures 3 and 4). Tooling of grooves was primarily performed on two spindle milling copy machines while finishing was completed manually [1, 8].

After the preparation of grooves, the damaged part was placed into the horizontal furnace with electro-resistance heater (Figure 5). The sample was first preheated and then heated through to the final temperature for about 11 h ($\vartheta_p \approx$ 300 °C). After that the mallet was partially pulled out from the furnace chamber followed by reparation process. With respect to the requirements the sample was either additionally heated with gas heater and burner, or was placed back into furnace, if the temperature of hard faced zones dropped down below 250 °C. The reparation procedure was conducted according to the scheme given in Figure 4c. Root weld layers and fillers were welded first according to the prescribed sequence. The non cooled welds (except for the root and cover layers), were forged by the tool with round head. During the surface forging of the weld, one has to be careful that grooving does not cut over depth. In addition, one must take into account the strain hardening, mainly in order to preserve the impact toughness. For that purpose the hot weld was forged only above the recrystallization temperature (ϑ>480 °C). The total time for frame reparation was about four days (with two workers). The appearance of the repaired parts is given in Figure 6.

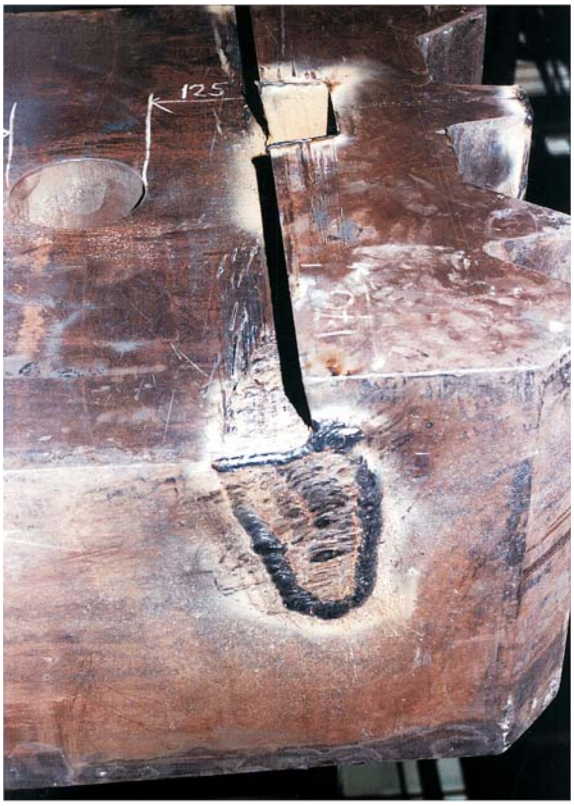

Figure 6 *Appearance of mallet after hard facing*
Slika 6. *Izgled bata poslije reparaturnog zavarivanja*

Figure 5 *Preheating of the mallet in horizontal electro resistance furnace*
Slika 5. *Predgrijavanje bata u horizontalnoj komornoj elektrootpornoj peći*

5 Selection of additional thermal and mechanical treatment
Izbor naknadne toplinske i strojne obrade

Immediately after the welding operations, the mallet was returned into the furnace and cooled down to the room temperature. In addition the thermal treatment was performed according to regime $\vartheta_ž$ = 650 °C/11 h (Figure 7). After the tempering relaxation process, it was necessary to perform the slow cooling of mallet, in the furnace that was switched off. The reason for such a thermal treatment procedure (prior, current and additional), was primarily due to the function of the mallet. The specific function of the mallet imposed the necessity to minimize the unfavorable changes in the vicinity of the weld. It was done by reduction of the residual stresses, decrease of hardness, obtaining of the unfavorable structure, easier diffusion of hydrogen, etc.

Following the thermal treatment, all joints were tested for compactness by ultrasonic defectoscopy and penetrating liquids. No defects were detected by these types of inspection. After additional thermal treatment, hammer mallet was produced to its original dimensions and shape by machining.

6 Techno-economical analysis of realized reparation
Tehničko-ekonomska analiza izvedene reparature

The importance of hard facing is widely recognized. Hard facing technology consists of complex set of different obligatory procedures in which many factors, which may impact the cost of the job, should be considered. The most important factors that should be considered for any hard facing application are: working conditions of the part that has to be repaired, damage identification, estimated weldability, consumable costs (flux, gas, power, welding material, labor and overhead), process to be used, volume of material to be deposited, filler material, deposit efficiency, operating efficiency, applied thermal treatment, final machining, model and actual parts examination. Having in mind the complexity of process it is necessary to establish the most suitable technical-technological solution in order to make right decision either to purchase a new part or to repair it.

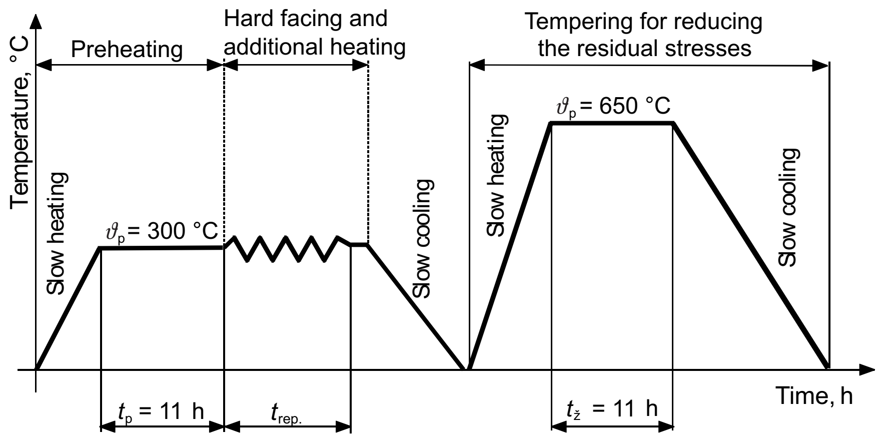

***Figure** 7 Complete cycle of hard facing of hammer mallet* [1, 3]
***Slika** 7. Kompletan ciklus reparature bata kovačkog čekića* [1, 3]

In this paper, techno-economical indicators of hard facing of forging hammer mallet were considered. Factors relevant for the decision were both cost of new part and cost of the hard facing.

6.1
Cost of new part
Troškovi nabavke novog dijela

According to the latest information, import of a new part would cost as follows:

- Price of new part 67 470,00 €/mallet
- VAT (18 %) 12 144,60 €/mallet
- Customs duty (5 %) 3 373,50 €/mallet
- Transportation 1 000,00 €/mallet.

Which gives total cost of 83 988,10 €/mallet.

6.2
Cost of repaired part
Ukupni troškovi reparature

Considered part was not in operating condition and repair expenditure may be broken into following parts:

- Damage identification 240,00 €/mallet,
- Machining of damaged surfaces 960,00 €/mallet,
- Hard facing technology determination 768,00 €/mallet,
- Model verifying 384,00 €/mallet,
- Hard facing of operating part 1 600,00 €/mallet,
- Cost of hard faced surface machining 960,00 €/mallet.

Which gives total cost of 4 912,00 €/mallet.

This leads to the conclusion that total cost of hard facing, including costs of energy, is significantly lower (less than 6 %) than the purchase of the new part. Therefore the question if either reparation or hard facing should be used is not necessary, even without considering additional advantages that hard facing gives [1, 3, 9, 10]. In this study the considered hard faced bat was used in production since the beginning of the year 2002.

7
Energy saving
Ušteda energije

Electrical power has been mainly used for hard facing of forging hammer mallet. Depending on a hard facing phase, electrical power consumption may be separated into phases such as making of grooves, machining of worn sliding guides, preheating (Figure 6), filling of two pre-arranged channels (Figure 3), hard facing of worn sliding guides of tool core, additional tempering (Figure 6) and additional machining.

All of ways of energy consumption will be further analyzed.

7.1
Consumption of energy in pre-machining (Q_1)
Utrošak energije pri prethodnoj strojnoj obradi (Q_1)

Ultrasound defectoscopy registered two chaps (Fig. 1), which were processed to make grooves that need minimum deposited material (Figures 3 and 4). Damaged bat sliding guides were also machined. Tooling time, of two axle milling machines with the power P_1 = 20 kW, was t_1= 30 h. Thus, energy consumption was $Q_1 = P_1 \cdot t_1$ = 600 kWh.

7.2
Consumption of energy during pre-heating (Q_2)
Utrošak energije pri prethodnoj toplinskoj obradi (Q_2)

After pre-machining, tooling mallet was slow-heated in horizontal chamber electrical heater for approximately 9 h, before the preheating temperature, $\vartheta_p \approx 300$ °C was reached. This temperature level was held for approximately 11 h, with additional heating when temperature dropped below 250 °C, which was about 20 h. Power capacity of heater was P_2 = 120 kW, which led to consumed energy $Q_2 = P_2 \cdot \Sigma t_i$ = 4 800 kWh.

7.3
Consumption of energy during hard facing (Q_3)
Utrošak energije pri reparaturnom zavarivanju (Q_3)

Deposition of filler material was performed using MMA technique with the electrodes with three different

diameters. Application of standard procedure for calculation of consumed energy leads to:
$Q_3=U_{sr3}\cdot I_{sr3}\cdot t_3$=27,3·181,5·9,7=48 063 kWh, where U_{sr3}, I_{sr3}, and t_3 are average voltage, average current intensity, and deposition time, respectively [1, 10, 15].

7.4 Consumption of energy during hard facing of sliding guides (Q_4)
Utrošak energije pri reparaturnom navarivanju pohabanih kliznih vođica (Q_4)

Deposition of filler material was performed with two different diameters of shielded electrodes. Application of standard procedure for calculation of consumed energy leads to
$Q_3=U_{sr3}\cdot I_{sr3}\cdot t_3$=27,6·184·4,046=20 547,2≈20,5 kWh, where U_{sr4}, I_{sr4}, and t_4 are average voltage, average current intensity, and deposition time, respectively [1, 10, 15].

7.5 Consumption of energy during annealing process (Q_5)
Utrošak energije pri izvođenju naknadne toplinske obrade - otpuštanja (Q_5)

After hard facing, mallet underwent slow cooling in horizontal chamber electrical heater until the room temperature was reached. In the next step slow heating for approximately 19 h was conducted before preheating temperature, ϑ_{ann} ≈ 650 °C was reached. This temperature was held for approximately 11 h, and then slowly cooled. Power capacity of heater was P_2 = 120 kW, which leads to consumed energy $Q_5 = P_2\cdot\Sigma t_i$ = 3 600 kWh.

7.6 Consumption of energy during additional tooling process (Q_6)
Utrošak energije pri naknadnoj strojnoj obradi (Q_6)

After cooling of hard faced mallet, damaged sliding guides were machined. Tooling time, of two axle milling machines with the power P_1 = 20 kW, was t_6 = 20 h. Thus, energy consumption was $Q_6= P_1\cdot t_6$ = 400 kWh.

7.7 Consumption of energy during total reparation process (Q_T)
Ukupni energetski troškovi reparature (Q_T)

Total consumption of electrical energy Q_T during reparation process of hammer forging mallet is:

$$Q_T = \sum_{i=1}^{i=6} Q_i = 9\,468{,}5 \text{ kWh}.$$

The mallet has mass of M_T = 6 000 kg and unit consumption of energy during total reparation process is $Q_{Ts} = Q_T/M_T$ = 1 5781 kWh/kg.

7.8 Consumption of energy during primary processing of steel Č4731
Ukupni energetski troškovi dobivanja čelika - Č4731 primarnom preradom

Total consumption of energy during processing of one kg of steel for tools, according to producer's information, is 4,12 kWh/kg of electrical power and 0,496 m^3/kg of natural gas, which is about 2,6 times of necessary energy Q_T for hard facing of considered mallet [13].

Therefore, it is easy to conclude that the hard facing of damaged hammer forging mallet is justified with respect to energy consumption and consequently beneficial in ecological aspects.

8 Concluding remarks
Zaključna razmatranja

Complex examination of model and final testing of hard faced mallet indicate that the proposed technology of hard facing may give satisfactory results in real operating conditions. It was necessary to perform pre heating and additional thermal treatment, such as annealing, to lower the level of residual stresses. Metallographic examination and hardness measurements did not indicate quench structures in proposed hard facing. Furthermore with the utilization of based dry electrodes, the risk of cold fractures development was decreased, which made hard faced part operationally reliable.

Economical aspects of application of these new advanced hard facing technologies are obvious and lead to large savings in comparison with the new part prices. Economical savings are clear considering the fact that the cost of hard facing is approximately 6 % of the cost of new mallet production. It has been shown that the best way to promote some new technology were the measurable techno-economical results. It should be noted that the repaired mallet described in this paper was in continuous operation in the last seven years and that it highly exceeded warranty period of a new mallet. It should be noted that the repaired mallet has been in operation 15 hours per day, 5-6 days per week, during the above mentioned period.

Detailed analysis of energy consumption has shown the justification of hard facing. The energy consumption in hard facing was much less than the consumption of energy necessary for production of new part. Consequently, hard facing beside all technical, economic, and energetic advantages has a positive effect to the protection of environment.

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