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REPARATURA NAVARIVANJEM RAZLIČITIH DELOVA MAŠINSKIH SISTEMA

REPARATORY HARD-FACING OF THE MACHINE SYSTEMS PARTS

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IZVOD

U ovom radu razmatraju se savremene metode obnavljanja pohabanih ili havarijski oštećenih radnih površina različitih delova mašina, uređaja i odlivaka. Reč je uglavnom o navarivanju koje nalazi sve širu primenu pri nanošenju prevlaka otpornih na habanje i koroziju, pri reparaturnim radovima, kao i pri doradi novih odlivaka izrađenih s greškom. Zbog smanjenja troškova zamene, odnosno povećanja veka pojedinih vitalnih delova i sklopova mašina i uređaja, od prvorazrednog značaja je izabrati odgovarajući postupak i propisati optimalnu tehnologiju navarivanja. Na koji se način to ostvaruje ukazuju delom rezultati ovog rada. Smisao optimizacije je da se izaberu takvi postupci, dodatni materijali, parametri navarivanja i termička obrada, da bi se dobile najbolje izlazne karakteristike navara. Iako je opšta procedura ustanovljena za navarivanje čelika za rad na toplo, ona se može primeniti i pri reparaturi delova od drugih vrsta materijala i drukčijeg geometrijskog oblika.

Ključne reči: *reparatura, navarivanje, habanje, mašinski delovi, odlivci, tvrdoća, mikrostruktura*

ABSTRACT

In this paper are considered contemporary methods for regenerating worn or severely damaged working surfaces of various parts of machines, devices and casts. We are predominantly referring to increasingly wider application of hard-facing in deposition of wear- and corrosion-resistant coatings, in reparatory jobs, as well as in additional fishing off of new casts with defects. Due to decrease of replacement costs, i.e. prolonging life span of certain vital parts and assemblies, it is of primary importance to select the adequate procedure and prescribe the optimum hard-facing technology. Manner of realizing the aforementioned is partly highlighted by results of this paper. The essence of optimization is to select procedures, filler metals, hard-facing parameters and thermal treatment, in order to obtain the best output characteristics of the hard-faced layer. The established general procedure for hard-facing steels at elevated temperatures can be applied also in reparation of parts made of different materials and with different geometrical forms.

Key words: *reparation, hard-facing, wear, mechanical parts, cast, hardness, microstructure*

1. OSNOVNI UZROČNICI OŠTEĆENJA MAŠINSKIH SISTEMA

Istraživanjem uzroka oštećenja delova mašina i uređaja ustanovljeno je da u više od 50% slučajeva ona nastaju usled triboloških procesa u manje-više regularnim uslovima eksploatacije. Stoga je za projektovanje tehnologije regeneracije oštećenih delova potrebno poznavati moguće mehanizme habanja spregnutih delova. Pri tome treba imati u vidu da se osim regeneracije delova pohabanih pri normalnom radu, takođe navaruju i delovi oštećeni zbog havarije, kao i novi odlivci izrađeni sa greškama.

1. BASIC CAUSES OF MECHANICAL SYSTEMS DAMAGES

Investigations of causes of mechanical parts damages show that, in more than 50% of cases, those were caused by tribological processes during the more or less standard operating conditions. Hence, selection of the adequate reparation method of the damaged parts requires knowledge of the potential wear mechanisms of coupled sections. It should be taken into consideration that in addition to reparation of parts worn during standard operations, the same process is performed on damaged parts, as well as newly manufactured parts with defects.

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Sve veći značaj ima i navarivanje novih delova, pri čemu se potrebna tvrdoća površinskih slojeva postiže nanošenjem tvrdih legura, umesto klasičnim metodama cementacije odnosno nitriranja. Sve gore navedeno doprinelo je da navarivanje zauzme važno mesto među tzv. naprednim (prestižnim) tehnologijama.

Odgovorni elementi mašina, sklopova, uređaja, najčešće se izrađuju od veoma skupih legura pa se reparaturom, osim skraćenja vremena zastoja zbog popravke, postiže i ušteda kako u skupom osnovnom materijalu tako i u obradi delova na konačne dimenzije. Ekonomski je najopravdanije da se oštećeni elementi regenerišu nanošenjem slojeva nekom od zavarivačkih metoda. U najvećem broju slučajeva kriterijum za izvođenje reparature je taj, da cena regeneracije dela ne prevazilazi cenu izrade novog dela. Posebno je ovo značajno kod delova velikih dimenzija i masovne proizvodnje, dok se kod unikatnih mašina i uređaja izvodi reparatura bez obzira na cenu.

1.1 Oštećenja nastala usled triboloških uticaja

Pod pojmom habanje podrazumeva se gubitak materijala sa kontaktnih površina nastao uglavnom kao rezultat delovanja mehaničkih sila. Hemijski procesi, koji prate ove pojave mogu ponekad biti osnovni uzročnik habanja zbog dejstva korozije. Habanje je posledica delovanja trenja ili zajedničkog delovanja trenja, termičkih, hemijskih, elektrohemijskih i drugih činilaca na elementima tribomehaničkog sistema, tj. na njihovim kontaktnim površinama. Gubitak materijala prouzrokuje promenu oblika i karakteristika elemenata mehaničkih sistema, pa prema tome i promenu njihovih funkcionalnih karakteristika.

Pri razmatranju habanja procenjuju se pre svega oni faktori, koji su u datim radnim uslovima dominantni, kao što su: materijal i osobine radnih površina, kvalitet i osobine kontaktnih površina, osobine medijuma između kontaktnih površina, karakteristike relativnog pomeranja između radnih površina, veličina opterećenja, količina i osobine čestica nastalih u toku habanja i dr. Dakle, habanje utiče na promenu oblika i karakteristika elemenata sistema, pri čemu može biti dominantan jedan od sledećih vidova habanja: abrazivno, adheziono, eroziono, kavitaciono, zamorno, vibraciono i kombinovano.

It is of increased importance using hard-facing on new parts, where required hardness of surface layers is achieved by applying solid alloys instead of classic methods of cementing, i.e. nitridation. All the above´s contributed to hard-facing positioning among so-called advance (prestige) technologies.

The vital elements of machines, assemblies and devices, are the most frequently produced from very expensive alloys, therefore in addition to shortening of the down times of certain devices due to repairs, the reparation achieves both, significant savings in the costs of basic material and in machining parts to the final dimensions. In terms of economics, it is the most justifiable to regenerate the damaged parts by deposing layers by some of the welding methods. In the majority of cases, the criteria for performing the reparation is that the part reparation price does not exceed the price of manufacturing the new part. This is particularly important for the large parts and batch production, while the unique machines and devices are subjected to reparation regardless of respective costs.

1.1 Damages due to tribological influences

The term ˝wear˝ means that loss of material from contact surfaces originated mainly due to effects of mechanical forces. Chemical processes accompanying these occurrences may sometimes prove to be primary cause of wearing due to corrosion effects. Wear is a result of friction exertion or joint exertion of friction, thermal, chemical, electro-chemical and other factors on tribomechanical system elements, i.e. respective contact surfaces. Loss of material causes alternation of shape and properties of mechanic system elements, and consequently their functional characteristics.

Wear assessment is primarily guided by estimating the prevailing factors in given operating conditions, like material and properties of the working surfaces, quality and properties of the contact surfaces, characteristics of the medium between the contact surfaces, characteristics of the relative displacement between the working surfaces, magnitude of load, quantity and properties of the wear particles, etc. Thus, wear effects alternation of shape and system elements properties, with one of the following dominant type of wear: abrasive, adhesive, pitting, cavitational, fatigue, pulsational and combined.

Svi tipovi habanja obično su praćeni i hemijskim efektima, koji mogu uticati kako na tok tako i na intenzitet pojave. Naročito su poznata dva slučaja. U prvom slučaju nastaju na površini delova veoma tvrde oksidne skrame kao korozioni produkti koji mogu usporiti dalji tok habanja. Suprotno tome, ako se razori taj sloj, ove čestice mogu ubrzati habanje radnih površina. U drugom slučaju nastaju na površini delova korozioni produkti mekši nego osnovni materijal te mogu imati dobre klizne osobine i time smanjiti habanje. Ako nemaju dobre klizne osobine, lako se pri relativnom kretanju delova odstranjuju te se dalje habanje odvija veoma intenzivno.

U slučaju kada su delovi izloženi različitim vrstama habanja, onda se pojava tako i označava (npr. eroziono-kavitaciono habanje u hemijski aktivnoj sredini). Veoma je teško predvideti efekte kombinovanog habanja.

Hemijski procesi, koji deluju pri eksploataciji raznih uređaja, mogu biti sastavni ili prateći deo procesa habanja, odnosno osnovni uzročnik gubitka metala, tj. korozije.

2. PREGLED POSTUPAKA NAVARIVANJA

Uopšteno posmatrano različitim postupcima navarivanja mogu se izvesti sledeći radovi:

- *regeneracija delova i uređaja* oštećenih usled trenja, različitih vidova habanja, korozije ili preloma - *reparaturno navarivanje*;
- *navarivanje površine* ili delova površine novih elemenata - *proizvodno navarivanje*;
- *dorada* novih odlivaka od legura gvožđa ili neželeznih metala, ako se završnom kontrolom otkrije neka od spoljnih livačkih greški.

Posebno treba istaći navarivanje tvrdim legurama koje može da zameni površinsko otvrdnjavanje termičkom obradom (cementacijom, nitriranjem), čime se produžava radni vek tretiranih komponenata ali se cena povećava.

Navarivanje, bilo *proizvodno* ili *reparaturno*, može biti tehno-ekonomski opravdano samo pri racionalnom izboru postupka navarivanja, dodatnog materijala, tehnologije i metode kontrole.

All types of wear are usually accompanied by chemical effects, which can influence both the appearance and the intensity of the phenomenon. Two cases are particularly distinguished. In the first case, very hard oxide layers as the corrosion products are formed on the part's surfaces, which can slow down further wear process. Contrary to that, if that layer is destroyed, these particles can accelerate wear of working surfaces. In the second case, on part's surfaces can appear the corrosion products softer than the base metal; having good sliding properties they can decrease wear. Lack of good sliding properties allows their facilitated removal during the relative motion of parts, which is followed by intensive wear.

In the case when the parts are simultaneously exposed to different types of wear, the phenomenon is named accordingly (like pitting-cavitational wear in chemically active environment). It is very difficult to predict effects of combined wear.

Chemical processes acting during exploitation of different devices, can be the immanent or accompanying process of wear, namely the basic cause of metal loss, i.e. corrosion.

2. REVIEW OF THE REPARATION PROCEDURES

In general, different hard-facing procedures may be use for executing the following:

- *regeneration of parts and devices* damaged due to friction, different types of wear, corrosion or fracture– *repairable hard-facing*,
- *hard-facing of entire surface* or respective parts – *production hard-facing*
- *repairing* of new cast parts made of iron or other nonferrous metals, if final control show cast imperfections.

Hard-facing with solid alloys should be particularly pointed out because it can replace surface hardening by thermal processing (cementation, nitridation), hence prolonging life span of treated components, but increasing overall price.

Hard-facing, *manufacturing* or *reparable*, can be justifiable in technical and economical terms, only with right selection of hard-facing, filler metal, technology and control method.

Svi postupci zavarivanja topljenjem mogu se primeniti i za navarivanje (gasno, ručno elektrolučno, u zaštiti gasa, pod prahom, pod troskom, plazmeno, elektrovibraciono), a u poslednje vreme navarivanje se izvodi i elektronskim snopom, laserskim zracima i trenjem.

Pri navarivanju, neophodno je kod većine postupaka uzeti u obzir i stepen mešanja, koji je najveći u prvom sloju, a u drugom i trećem je znatno manji što najčešće nameće potrebu višeslojnog navarivanja (troslojnog).

Oblast primene navarivanja danas je znatna. Navaruju se alati (za obradu deformisanjem, livenjem i rezanjem), zupčanici, kolenasta vratila, delovi motora SUS, radni delovi mašina za obradu zemlje i razni delovi transportnih uređaja, valjci valjaoničkih stanova, obloge sudova u hemijskoj industriji i dr. Isto tako, navarivanjem se popravljaju neke livačke greške na čeličnim odlivcima, odlivcima od livenog gvožđa, aluminijuma, mesinga, bronze i sl.

Navarivanje se zasniva na polaganju slojeva dodatnog materijala koji je obično različitog hemijskog sastava od podloge kada je u pitanju regeneracija, a približno istog sastava kada se popravljaju livačke greške na odlivcima ili repariraju kokile i kovački alati. Naneta prevlaka odnosno navaren sloj se kao i kod plakiranja ne uzima u obzir pri dimenzionisanju odgovarajućih delova konstrukcije, tj. ne smatra se nosećim presekom.

Posle navarivanja delovi se mašinski obrađuju da bi se dobio traženi oblik i potrebne dimenzije. U tom pogledu, navarivanjem TIG postupkom ostvaruju se najkvalitetnije površine navara, a najgrublje elektrolučnim navarivanjem obloženim elektrodama. Za neke delove kao što su vedrice bagera, čeljusti drobilice za kamen, radni elementi nekih poljoprivrednih mašina nije potrebna nikakva naknadna mašinska obrada, ali se npr. pri navarivanju zupčanika, sedišta ventila, blokova motora i sl., mora birati legura za navarivanje koja se može mašinski obrađivati. Posle navarivanja masivnih alata (npr. kovačkih matrica), u nekim slučajevima, se izvodi omekšavajuće žarenje (kriterijum 350 *HV*) radi mašinske obrade; konačna tvrdoća alata postiže se naknadnom termičkom obradom - poboljšanjem.

Navarivanje čeličnih delova od kojih se traži koroziona otpornost izvodi se pomoću dodatnog materijala koji po hemijskom sastavu odgovara nerđajućem čeliku. Čelici skloni ka zakaljivanju i delovi velike krutosti se predgrevaju do 400°C pri navarivanju električnim lukom i do 600°C pri navarivanju gasnim plamenom [1, 4].

All welding by melting procedures can be applied to hard-facing as well (gas, manual arc welding, gas metal welding, submerged arc welding, electro-slag welding, plasma arc welding and electro-pulsed arc welding), and more recently hard-facing is performed by electronic beam, laser beam and friction.

During hard-facing, most procedures imply encompassing the degree of mixing, with the highest in the first layer, and further descending order, very often imposing necessity of the multi-layer hard-facing (three-layer).

Hard-facing implementation scope is vast. It is used for tools (processing by deforming, casting and cutting), gear-wheels, crankshafts, SUS engine parts, operating parts of machines for land ploughting and various parts of transportation devices, roller bearings, vessel coatings in chemical industry and similar. Likewise, hard-facing is used for repairing casting defects on iron, aluminum, brass, bronze, etc. casts.

In case of regeneration, hard-facing is based on deposition of layers of additional material (filler metal), usually with different chemical composition than base, and approximately of the same composition in case of reparation of casting defects. The deposited coating, i.e. the hard-faced layer is, like in plating omitted from calculating dimensions of respective parts of construction, i.e., it is not considered as a part of the carrying cross section.

After the hard-facing, parts are machined in order to achieve required shape and dimensions. In that regard, hard-facing by the TIG procedure results in the highest quality of the hard-faced layer, while in hard-facing by the shielded-metal arc welding the roughest surfaces are obtained. For some parts, like buckets of the dredge, jaws of the stone mill, working elements of some agricultural machines, no additional machining is needed, but for hard-facing of gears, valve seats, engine blocks, etc., an hard-facing alloys supporting machining must be selected. In hard-facing of tools, e.g., forging dies, prior to machining, the hard-faced layer is usually softened by annealing (350 *HV* criteria), and final hardness is achieved by additional thermal treatment of tempering.

Hard-faced corrosion-resistant layers are achieved with filler metal, whose chemical composition corresponds to stainless steel. Parts prone to self-hardening and of high stiffness are preheated up to 400°C for electric arc hard-facing and up to 600°C in hard-facing by gas flame-welding [1, 4].

Ručno elektrolučno navarivanje

To je još uvek dominanantan postupak kako za reparaturne radove, tako i za nanošenje tvrdih navara na radne površine novih delova i alata. Pri reparaturi pohabanih delova, ili ponovnom navarivanju, potrebno je brušenjem odstraniti oštećeni metal, naročito ako su u pitanju prsline koje mogu delovati kao koncentratori napona. Ovim postupkom navaruju se delovi od čelika, LG, legura Cu, legura Al, legura Ni, i dr.

REL navarivanje može se u većini slučajeva izvesti i bez predgrevanja, ali se to procenjuje od slučaja do slučaja. Pri polaganju, npr. debelih navara na masivne čelične podloge sa sadržajem ugljenika iznad 0.35% predgrevanje je obavezno. Suprotno tome, predgrevanje nije potrebno kad se navaruje austenitni Mn čelik, koji ojačava složenim mehanizmima pri radnim udarnim opterećenjima na hladno. Ovaj Hadfieldov čelik navaruje se kratkim navarima, minimalnim unosom toplote i brzim hlađenjem deponovanog sloja.

Reparatura lokalno oštećenih delova, kao što su zupčanici, zupčaste letve, kuke dizalica, valjci i sl., izvodi se bazičnom elektrodom legiranom molibdenom uz potpuno ili lokalno predgrevanje.

Kod materijala sklonih pojavi prslina u ZUT-u, nanose se kratki zavari širine 1-2 prečnika elektrode što umanjuje "razblaživanje" dodatnog materijala, sopstvene napone i deformacije. Suprotno tome, kod materijala dobre zavarljivosti nanose se široki zavari i navaruje strujom veće jačine. Posebno se pri navarivanju velikih površina tvrdim legurama preporučuje nanošenje plastičnog međusloja u obliku rastavljenih zavara od niklovih ili austenitnih elektroda. Naredni slojevi izvode se sa maksimalno dopuštenom jačinom struje, širokim zavarima (10 d_e) koji se preklapaju. Uopšteno se plastičan međusloj preporučuje ne samo kada se navaruju tvrdi materijali, već i u slučajevima većih razlika u termo-fizičkim osobinama legura za navarivanje i podloge.

Predmeti otporni na abrazivno habanje od Hadfieldovog austenitnog čelika ili čeličnog liva, repariraju se bazičnom manganskom elektrodom. Navar austenitnih manganskih elektroda u početku rada nema veliku tvrdoću već ona raste martenzitnom transformacijom zbog deformacije površinskih slojeva. Potrebna deformacija ponekad se postiže u radnim uslovima, a u nekim slučajevima iskivanjem navara na hladno.

Manual arc hard-facing

Application of the manual arc welding for hard-facing is still predominant, both for reparatory operations and for deposition of the hard layers on the working surfaces of new parts and tools. In reparation of the worn parts or repeated hard-facing, it is necessary to grind-off damaged spots, particularly cracks which can act as the stress concentrator. By this procedure are hard-faced parts made of steel, cast iron, Cu alloys, Al alloys, Ni alloys, etc.

In majority of cases, arc welding can also be performed without preheating, depending on case. In deposition of, e.g., thick layers on the massive steel substrates, with carbon content over 0,35%, the preheating is mandatory. Contrary to that, preheating is not necessary in hard-facing of the austenitic manganese steels, given it hardens by complex mechanisms with impulsion load on cold. This Hadfield´s steel is hard-faced by short hard-faced layers, minimal heat input and rapid cooling on deposited layer.

Reparation of the locally damaged parts, like gears, racks, cranes hooks, rollers, etc., is done by basic electrode alloyed with molybdenum with complete or local preheating.

For materials that are prone to appearance of cracks in the HAZ, the short hard-faced layers are deposited, in 1 to 2 electrode diameter width, which reduces dilution, self-stresses and deformation. Contrary to that, for materials of good welding properties, the wide hard-faced layers are deposited and the welding is done by the higher intensity current. In hard-facing large surfaces by hard alloys it is particularly recommended to deposit the plastic inter-layer in the form of separated layers of nickel or austenitic electrodes. The consecutive layers are deposited with maximum current intensity, wide overlapping hard-faced layers (10 d_e). Generally, the plastic inter-layer is recommended not only when the hard materials are hard-faced, but also in cases of greater differences in thermal and physical hard-facing alloys properties and the substrate.

Abrasive wear-resistant objects resistant made of Hadfield austenitic steel or cast steel, are being repaired by base manganese electrode. The hard-faced layer by austenitic manganese electrodes initially doesn't have high hardness, yet it increases through martensitic transformation in the surface layers. The necessary deformation is sometimes achieved in the working conditions and in some cases by cold forging the hard-faced layer.

Alatni čelici za rad na toplo i na hladno, kao i brzorezni čelici takođe se mogu uspešno navarivati obloženim elektrodama. Za reparaturu kovačkih matrica za rad na toplo primenjuju se legirane elektrode koje daju metal navara približan osnovnom metalu. Pre navarivanja neophodno je predgrevanje, te navarivanje uz eventualno dogrevanje, zatim sporo hlađenje i otpuštanje, i najzad mehanička obrada na konačne dimenzije.

Alati za obradu rezanjem se, po pravilu, ne repariraju navarivanjem, ali se ponekad ovim postupkom obnavljaju samo oštrice noževa, npr. za sečenje papira (rezne ivice su od brzoreznog čelika, a podloga od ugljeničnog čelika).

Navarivanje cilindričnih površina može se izvesti polaganjem uzdužnih, ili kod delova većeg prečnika, kružnih navara. Po pravilu se kod rukavaca, osovina i sl., prvi navari nanose na dijametralno suprotnim stranama da bi se uravnotežile termičke deformacije.

Treba takođe istaći mogućnost navarivanja, kako nerđajućim tako i stelitnim elektrodama, kada je neophodna visoka tvrdoća na povišenim temperaturama, velika otpornost na koroziju i vatrootpornost. Osim toga stelitni navari imaju visoku otpornost na abraziju, termičke udare, kao i dobre klizne osobine i mogućnost poliranja [1, 4].

3. OSNOVNI PRINCIPI ZA IZBOR DODATNIH MATERIJALA

Dodatni materijal za navarivanje bira se u najvećem broju slučajeva na osnovu traženih osobina navarivanog dela i raspoložive opreme. U slučaju kad se ne može izvesti termička obrada posle navarivanja, potrebne osobine navarenog sloja mogu se postići pogodnim izborom hemijskog sastava dodatnog materijala. Na osnovu poznatih mehanizama habanja i analize procesa habanja svakog konkretnog elemenata, može se zaključiti da oštećenja načešće nastaju zbog trenja, mada ponekad deluju i drugi činioci kao što su korozija, termički i termo-mehanički zamor i sl. U slučaju da uređaj radi u uslovima pojačanog dejstva korozije, materijali za regeneraciju se biraju isključivo na osnovu hemijskog sastava u zavisnosti od vrste korozije, dok je u slučaju delova izloženih dejstvu sile trenja, problem izbora dodatnog materijala znatno složeniji. Ipak, tvrdoća i hemijski sastav ne mogu biti jedini kriterijumi za ocenu pogonosti materijala prevlake.

The tool steels for hot and cold working and high-speed steels can also be successfully hard-faced with shielded-metal arc welding. For reparation of forging dies for hot working are used the alloyed electrodes providing hard-faced layer metal of similar quality to base metal. Prior to hard-facing the preheating is necessary, followed by hard-facing with eventual additional heating, slow cooling and tempering, and finally the mechanical machining to final dimensions.

Tools for metal cutting are, usually, not repaired by hard-facing, but sometimes this procedure is used only for repairing the knife blades, for instance for paper cutting (cutting edges are made of high-speed steel, and base metal is carbon steel).

Hard-facing of cylindrical surfaces can be done by deposition longitudinal and, for larger diameter parts, circular layers. Usually, for sleeves, axles, etc., the first hard-faced layers are deposited on diametrically opposite sides to balance the thermal deformation.

The possibility of arc welding should also be emphasized, both with stainless electrodes and electrodes made of stellite, when the high hardness at elevated temperatures, high corrosion resistance and refractoriness are required. In addition to this, stellite hard-faced layers have high resistance to abrasion, thermal impacts, as well as good sliding properties and possibility of polishing [1, 4].

3. BASIC PRINCIPLES FOR FILLER-METAL SELECTION

Filler metals for hard-facing are, in majority of cases, selected based on the required properties of the hard-faced part and available equipment. In cases additional thermal treatment after hard-facing cannot be performed, required properties of the hard-faced layer can be achieved by suitable selection of filler metal. Based on the known wear mechanisms and elements wear analysis, it can be concluded that, to the largest extent, damages occur due to friction, though sometimes corrosion, thermal and mechanical fatigues have effects. In case when device operates in corrosion-intensive conditions, regeneration materials are to be chosen solely based on chemical composition depending of the corrosion type, while in cases of parts exposed to action of the friction force, the problem of the filler metal selection is significantly more complex. However, hardness and chemical composition can not be sole criteria for estimation of suitability of the coating material.

Stoga se u tabeli 1 daje sažet pregled najčešće primenjivanih dodatnih materijala i to posebno onih otpornih na habanje, koroziju i oksidaciju. Dodatni materijali za navarivanje otporni na habanje i koroziju mogu se u osnovi grupisati u šest klasa: čelici, livena gvožđa (bela), karbidi volframa, legure kobalta, legure nikla i legure bakra. Pošto se najveći broj industrijskih delova povlači iz eksploatacije iz razloga habanja (53% *abrazivno,* 24% *adheziono*, 10% *udar* i ostale vrste) i *korozije* (13%), to se i dodatni materijali klasifikuju prema tom kriterijumu (tabela 1) [4].

Tabela 1: Uticaj strukture dodatnog materijala na izlazne osobine prevlake

STRUKTURA	GLAVNE OSOBINE
1. Perlitna struktura	Otpornost na udarno opterećenje, abrazivno habanje
2. Karbidi W u mekoj osnovi	Velika otpornost na abrazivno habanje, navar je relativno krt
3. Austenitna struktura (Cr≥12%)	Dobra otpornost na eroziju, oksidaciju i koroziju
4. Austenitne legure sa većim sadržajem Co	Dobra otpornost na visokim temperaturama (500-1000ºC), oksidaciju, koroziju i abrazivno habanje
5. Austenitne legure (sa većim sadržajem Ni	Dobra otpornost na koroziju i oksidaciju
6. Martenzitna struktura	Velika otpornost na abrazivno habanje, kao i otpornost na pritisak (gnječenje)
7. Martenzitni čelici	Dobra otpornost na abrazivno habanje, udarno opterećenje, na dejstvo pritiskujućih sila i dr.
8.1 Austenitni čelici -Otporni na kiseline CrNi	Dobra otpornost na koroziju i oksidaciju, srednje otporni na abrazivno habanje
8.2 Austenitni čelici-Manganski (≈ 13% Mn)	Velika otpornost na udarno opterećenje, posebno posle sabijanja na hladno
9. Fosforne bronze	Otporne na adheziju i koroziju
10. Aluminijumske bronze	Otporne na udar, kavitaciju i koroziju
11. Nikal-aluminijumske bronze	Otporne na udar i kavitaciju

4. IZBOR I PROVERA TEHNOLOGIJE NAVARIVANJA KOVAČKIH ALATA

4.1 Materijali za izradu kovačkih alata i njihove osobine

Pre izbora tehnologije navarivanja kao redovnog tehnološkog procesa, potrebno je na probnim uzorcima ustanoviti vezu između postignutih rezultata i ulaznih parametara navarivanja uključujući i termičku obradu. U tom smislu, dalje se daje primer kako se taj problem rešava pri regeneraciji alata za kovanje u kalupima.

Table 1 shows brief review of the most frequently applied filler metals, particularly wear- and corrosion-resistant. Hard-facing filler wear- and corrosion-resistant metals, can essentially be grouped in six classes: steels, cast irons (white), tungsten carbides, cobalt alloys, nickel alloys and copper alloys. Since the largest number of industrial parts is withdrawn from exploitation due to wear (53% *abrasive* wear, 24% *adhesive* wear, 10% *impact* and other types) and *corrosion* (13%), the filler metals are classified according to that criterion, Table 1 [4].

Table 1: Influence of filler metal structure on output characteristics of the hard-faced layer

STRUCTURE	MAIN PROPERTIES
1. Pearlite structure	Resistance to impact load, abrasive wear
2. Tungsten carbides in soft matrix	High resistance to abrasive wear, hard-faced layer is relatively brittle
3. Austenitic structure (Cr ≥ 12%)	Good resistance to erosion, oxidation and corrosion
4. Austenitic alloys with higher Co content	Good resistance at elevated temperatures (500 - 1000°C), oxidation, corrosion and abrasive wear
5. Austenitic alloys with Ni content	Good resistance to corrosion and oxidation
6. Martensite structure	High resistance to abrasive wear, as well as to compression (kneading)
7. Martensite steels	Good resistance to abrasive wear, impact load, action of compressive forces, etc.
8.1 Austenitic steels resistant to CrNi acids	Good resistance to corrosion and oxidation, medium resistant to abrasive wear
8.2 Manganese austenitic steels (≈ 13% Mn)	High resistance to impact load, especially after cold compression
9. Phosphorus bronzes	Resistant to adhesion and corrosion
10. Aluminum bronzes	Resistant to impact, cavitation and corrosion
11. Nickel-aluminum bronzes	Resistant to impact and cavitation

4. SELECTION AND CONTROL OF THE FORGING TOOLS HARD-FACING TECHNOLOGY

4.1 Base materials for manufacturing forging tools and their properties

Prior to selection of hard-facing technology as regular process, it is necessary to use testing samples for establishing correlation between output results and input parameters of hard-facing, including the thermal treatment. In that sense, we present solving the problem of forging dies tools regeneration.

Kovački alati su u eksploatacionim uslovima izloženi udarnom opterećenju i cikličnom zagrevanju u određenom intervalu povišenih temperatura. Čelici namenjeni za izradu alata za obradu metala deformisanjem, moraju da izdrže visoka udarna opterećenja, i da imaju dobre mehaničke osobine na povišenim temperaturama radi otpornosti na habanje i termički zamor. U vezi sa pomenutim razlozima, primenjuju se legirani čelici što otežava reparaturno navarivanje oštećenih delova.

4.2 Izbor tehnologije navarivanja i dodatnog materijala

Za izbor optimalne tehnologije navarivanja neophodno je izvesti probna ispitivanja na uzorcima od odgovarajućeg čelika. U radu je istraživana mogućnost navarivanja dva tipična čelika za alate koji rade na toplo; 56NiCrMoV7 (DIN) - namenjenog za kovačke alate svih vrsta i 38CrMoV51 (DIN) - namenjenog prvenstveno za livačke kalupe neželeznih metala. Budući da kovački kalupi rade u termički poboljšanom stanju, to su svi uzorci podvrgavani toj termičkoj obradi, da bi se što više približili eksploatacionim uslovima. Na izabranim uzorcima je posle navarivanja i odgovarajuće obrade (termičke, mehaničke), merena tvrdoća i ocenjivana mikrostruktura [4, 5].

Kao dodatni materijal korišćene su visokolegirane bazične elektrode UTOP 38 (E3-UM-40T ∅3.25 mm - DIN 8555) i UTOP 55 (E6-UM-60T ∅5.00 mm - DIN 8555) (tabela 2). One su namenjene za navarivanje alata, kao što su: utopi, čelični kalupi, matrice i trnovi za presovanje.

S obzirom na sklonost osnovnog materijala ka zakaljivanju (C > 0.35%), bilo je neophodno njegovo predgrevanje do $T_p \approx 300°C$. Tehnološki parametri navarivanja određeni su prema odgovarajućim literaturnim preporukama [1], (tabela 3), a navarivanje je izvođeno sa dva i tri prolaza da bi se uzelo u obzir i razblaživanje, tj. da bi se ustanovilo u kom sloju se postižu deklarisane osobine elektroda. Merena je brzina navarivanja pri svakom prolazu, a takođe je pre nanošenja svakog narednog prolaza, odnosno sloja, proveravana temperatura predgrevanja, odnosno međuprolazna temperatura (interpass). Struja navarivanja bila je niža za oko 10% nego pri zavarivanju radi umanjenja stepena mešanja, odnosno razblaživanja [1].

In exploitation conditions, forging dies are exposed to impact load and cyclic heating up in assigned interval of elevated temperatures. Steels aimed for manufacturing tools for processing metal by deformation, have to sustain high impact loads, and maintain good mechanical properties at elevated temperatures for wear- and thermal fatigue resistance. In connection to aforementioned reasons, alloyed steels are used, what makes the regeneration of the damaged tools by hard-facing procedures more difficult.

4.2 Selection of both hard-facing technology and filler materials

In order to select optimum hard-facing technology, it is necessary to performs testing on samples made of adequate steel. In this paper are investigated hard-facing options for two typical forging dies steels: 56NiCrMoV7 (DIN) - aimed for forging dies of all types, and 38CrMoV51 (DIN) - aimed primarily for casting dies for non-ferrous metals. Given that forging dies operate in tempered state, all the samples were subjected to that type of thermal treatment, in order to simulate the exploitation conditions as close as possible. After hard-facing and appropriate treatment (thermal, mechanical), hardness was measured and microstructure evaluated [4, 5].

As the filler metals were used the high alloyed basic electrodes UTOP 38 (E3-UM-40T ∅3.25 *mm* - DIN 8555) and UTOP 55 (E6-UM-60T ∅5.00 *mm* - DIN 8555) (Table 2). They are aimed for hard-facing of tools like: dies, steel moulds, pressure dies and mandrels.

Considering tendency of the base metal to self-hardening (C > 0,35%) the preheating was necessary up to $T_p \approx 300°C$. Technological hard-facing parameters were determined according to respective reference recommendations [1], (Table 3), and hard-facing was performed with two or three inter-passes in order to take decrease mixing into consideration, i.e., to establish in which layer are achieved properties declared by the electrode manufacturer. The hard-facing speed was measured at each inter-pass. Likewise, prior to each following inter-pass, namely layer, the preheating temperature was checked, i.e. the inter-pass temperature. Hard-facing current was lower about 10% then with hard-facing for decrease mixing [1].

Tabela 2: Osobine dodatnog materijala [8]
Table 2. Filler metal properties [8]

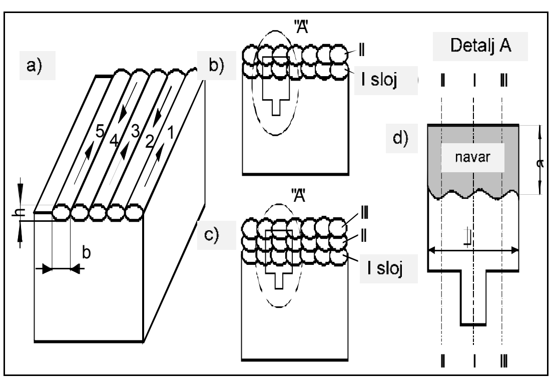
Red. br. *(No.)*	**Oznaka elektrode** *(Electrode mark)*		**Hemijski sastav, %** *(Chemical composition, %)*					**Vrsta struje** *(Current type)*	**Tvrdoća navara,** *(Hardness,* ***HRC***	**Namena** *(Remark)*
	SŽ Fiprom	DIN 8555	C	Cr	Mo	V	W			
1.	UTOP 38	E3-UM-40T	0.13	5.0	4.0	0.20	+	= (+)	36-42	Navarivanje alata za rad u toplom i hladnom stanju *(Hard-facing of tools for cold and hot working)*
2.	UTOP 55	E6-UM-60T	0.50	5.0	5.0	0.60	+	= (+)	55-60	- II -

Tabela 3: Parametri navarivanja REL postupkom [1, 4]
Table 3: Arc welding hard-facing parameters [1, 4]

Red. br. *(No.)*	**Oznaka elektrode** *(Electrode mark)*		Prečnik jezgra *(Core diameter)* d_e, [mm]	Struja zavarivanja *(Welding current),* I, [A]	Napon, *(Voltage)* U, [V]	Brzina navarivanja *(Hard-facing speed),* v_z, [cm/s]	Pogonska energija *(Input heat),* q_l, [J/cm]
	SŽ Fiprom	DIN 8555					
1.	UTOP 38	E3-UM-40T	3.25	115	26	≈ 0.28	8543
2.	UTOP 55	E6-UM-60T	5.00	190	29	≈ 0.25	17632

Redosled i smer nanošenja prvog navara dat je na slika 1a, s tim što je pre narednog prolaza odstranjivana troska čeličnom četkom. Prema ovoj shemi nanošeni su i ostali slojevi (drugi (slika 1b) i treći (slika 1c)). Rezultati dobijeni posle navarivanja i završne termičke obrade odnose se na: raspodelu tvrdoće u poprečnom preseku (slika 1d), mikrostrukturu navara, zonu uticaja toplote i osnovni materijal.

Order and direction of depositing the first hard-faced layer is given in Figure 1a, where the slag was removed by steel brush prior to each new inter-pass. Other layers were deposited according to this scheme (the second Figure 1b, and the third, Figure 1c). Results obtained after the hard-facing and thermal treatment refer to: hardness distribution over the cross section (Figure 1d), microstructure of the hard-faced layer, heat affected zone and base metal.



Slika 1.- Redosled polaganja navara: (a - 1 sloj, b - 2 sloja, c - 3 sloja, d- metalografski izbrusak)

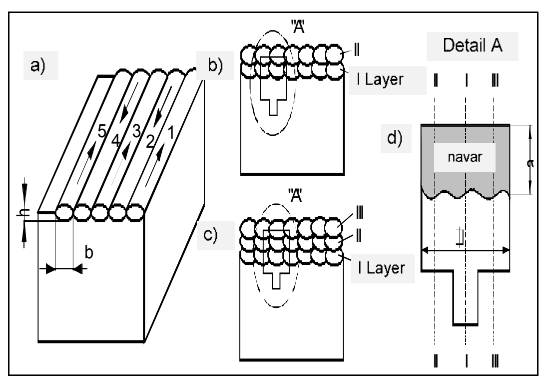


Figure 1.- Order of hard-faced layers deposition: (a - 1st layer, b - 2nd layer, c - 3rd layer, d - pin appearance)

Pored povezivanja izlaznih–korisnih osobina navarenih slojeva sa primenjenom tehnologijom, bilo je potrebno odrediti novo formirane strukture i meriti tvrdoću u karakterističnim zonama navarenih slojeva posle navarivanja i hlađenja.

Ulazni parametri objedinjeni pogonskom energijom navarivanja omogućuju da se izračuna brzina hlađenja (vreme hlađenja-$t_{8/5}$) čijim se unošenjem u odgovarajući dijagram kontinualnog hlađenja-KH (ARA) dijagram (slika 2) može očitati struktura i tvrdoća navarenog sloja. Vreme hlađenja- $t_{8/5}$ najpre je određivano eksperimentalno, a potom na osnovu raspoloživih empirijskih formula. Eksperimentalni rezultati poslužili su za ocenu tačnosti navedenih formula. Osim vremena hlađenja-$t_{8/5}$, unete su i eksperimentalno snimljene grane hlađenja temperaturskih ciklusa (npr. 11/1- v_h= 13.04ºC/s i 21/1- v_h= 18.18ºC/s, slika 2). Novonastale strukture i tvrdoća ZUT-a očitane iz KH- dijagrama, mogu se uporediti sa eksperimentalno dobijenim rezultatima (slika 3) [4, 5].

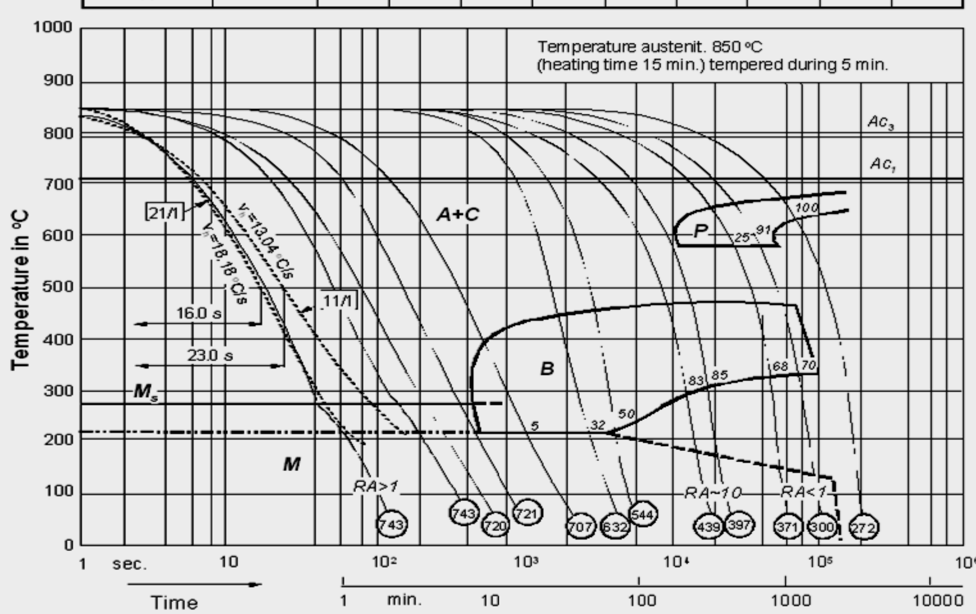
Ovako određena veza ulazno-izlaznih parametara pri modelskim istraživanjima omogućuje rangiranje različitih dodatnih materijala (za usvojeni kriterijum kvaliteta) i izbor optimalne tehnologije navarivanja.

In addition to correlating output - useful characteristics of the hard-faced layers to the applied technology, it was also necessary to determine the newly created structures and to measure hardness in characteristic zones of the hard-faced layer after hard-facing and cooling.

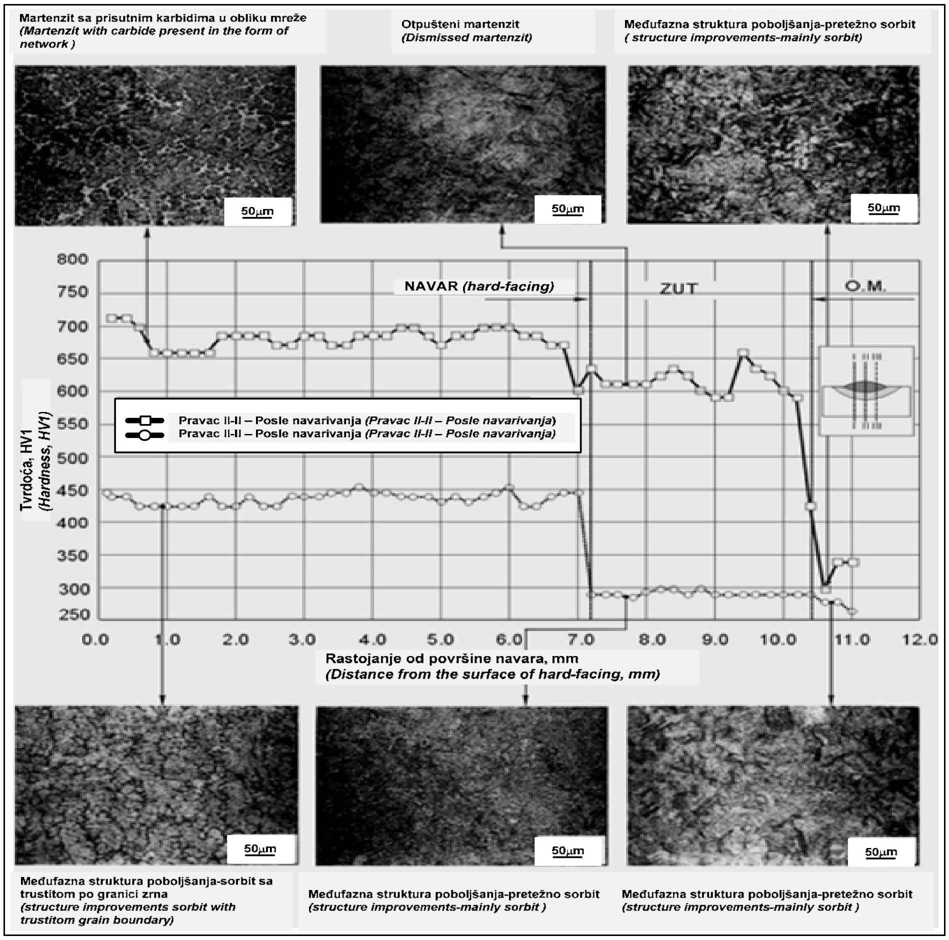
The input parameters of hard-facing, gathered by hard-facing driving energy, enable determination of cooling rate (cooling time - $t_{8/5}$), which imported in corresponding diagram of continual cooling – ARA diagram (Figure 2) enable reading of structure and hardness of the hard-faced layer. The cooling time - $t_{8/5}$ was first determined experimentally, and then based on available empirical equations. Experimental results are used for estimating accuracy of named equations. In addition to cooling time $t_{8/5}$ experimental obtained branches of cooling temperature cycles are input (for example 11/1- v_h= 13.04ºC/s i 21/1- v_h= 18.18ºC/s, Figure 2). Newly formed structures and hardness HAZ read from ARA diagrams, may be compared with experimental obtained results (Figure 3) [4, 5].

The established correlation of the input and output parameters in model experiments enables rating of different filler metals (for adopted quality criteria) and selection of the optimum hard-facing technology.

Chemical composition, %	C	Si	Mn	P	S	Cr	Mo	Ni	V	W
	0.52	0.29	0.70	0.01	0.01	1.09	0.43	1.72	0.74	-



Slika 2.- KH - dijagram za 56NiCrMoV7 [8]
Figure 2.- ARA diagram for 56NiCrMoV7 [8]



Slika 3.- Raspodela tvrdoće i mikrostruktura zona navara (O.M. Č 5742-D.M. UTOP 55, s= 29 mm)
Figure 3.- Hardness distribution and microstr. of hard-facing zone (O.M. Č 5742-D.M. UTOP 55 s=29 mm)

5. PRIMERI IZVEDENIH REPARATURA

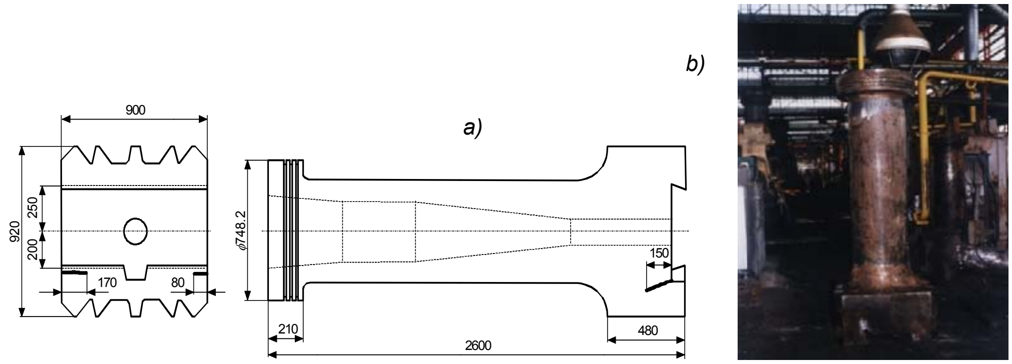
Ova procedura omogućuje izvođenje, na sličan način, repariranje drugih delova, što je izvedeno na više realnih delova. Na slikama 4, 5, 6 i 7 prikazani su samo neki primeri izvedenih reparatura na delovima od različitih materijala i složenih geometrijskih oblika, kao što su: bat kovačkog čekića, ram kovačke prese, zubi utovarne kašike i zubi zupčanika velike mase [2, 3, 6, 7, 9 10].

Na slikama 4, 5, 6, and 7 su prikazani primeri primene izvedenih reparatura, u kojima je primenjena optimalna tehnologija navarivanja, koja je određena posle odgovarajućih ispitivanja na specijalno pripremljenim modelima. To se odnosi uglavnom na merenje mikrotvrdoće i ocenu mikrostrukture karakterističnih zona navara, odnosno po potrebi i na određivanje nekih mehaničkih karakteristika na sobnoj ili povišenim temperaturama. Završna kontrola navarenih delova izvedena je ultrazvukom, penetrantima i dinamičkim ispitivanjima na pulzatoru (zupčanici) [2].

5. EXAMPLES OF CREATED REPARATIONS

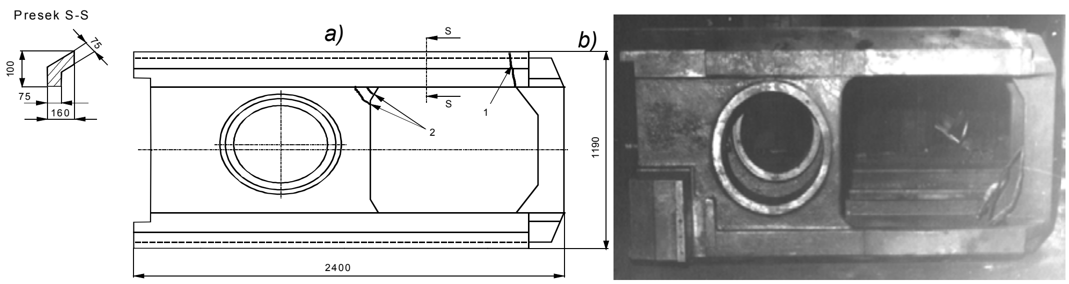
This procedure enables performing, reparation of other parts, in the similar manner, which was realized on several actual parts. In Figures 4, 5, 6, and 7 are shown some examples of created reparations of different materials and complex geometric shapes, such as: mallet of forging hammer, forging press frame, loading bucket tooth, toots of heavy gears [2, 3, 6, 7, 9, 10].

Figures 4, 5, 6, and 7 show examples of applications of the performed reparations, where the optimum hard-facing technology was applied, determined after corresponding investigations on the specially prepared models. This is related mainly to measurements of micro-hardness and estimation of the microstructure of the hard-faced layer characteristic zones, namely according to need also to determination of certain mechanical characteristics at room or at elevated temperatures. Final control of hard-faced parts was performed by ultrasonic methods, penetrating liquids and dynamic investigations on a pulsator (gears). [2].



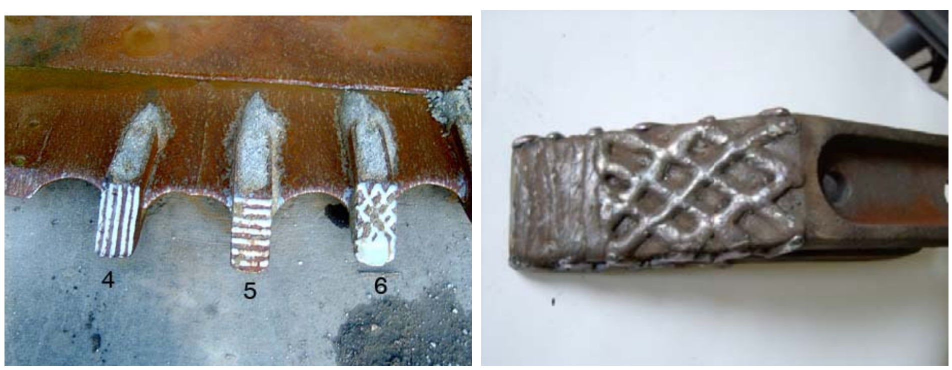
Slika 4.- Bat kovačkog čekića: a- skica bata sa uočenim prslinama i b- fizički izgled bata mase 6000 kg [4]

Figure 4.- Mallet of forging hammer: a- Mallet draft with noticed cracks, b- real mallet appearance of 6000 kg mass [4]



Slika 5.- Ram vertikalne kovačke prese: a- skica rama (1- mesto preloma i 2- uočene prsline) i b- regenerisani, termički i mašinski obrađen deo [7]

Figure 5. The forging vertical press frame: a- Frame draft (1- position of crack and 2- noticed cracks) and b- Repaired, temper treated and machine processed part [7]



Slika 6.- Zubi utovarne kašike [9]

Figure 6.- Loading bucket tooth [9]

Slika 7.- Zupčanik ekscentar prese [10]

Figure 7.- The gear of excenter press [10]

6. ZAKLJUČAK

Cilj ovog istraživanja je bio da se postavi reparacioni model mašinskih delova oštećenih u eksploataciji. Da bi se došlo do opšteg modela reparature neophodno je bilo izvesti brojna eksperimentalna ispitivanja i pri tome pratiti uticaj nekih bitnih ulaznih parametara na rezultat reparature u svim slučajevima navarivanja. To se u prvom redu odnosi na unos toplote i brzinu hlađenja u kritičnom temperaturskom intervalu.

Predloženi model reparature, zasnovan na prethodno ustanovljenom rangu uticaja pojedinih parametara navarivanja na izlazne-korisne osobine navara, praktično je overen uspešnom regeneracijom različitih delova mašinskih sistema. Osim toga, ovaj model reparature omogućuje da se izabere postupak i tehnologija navarivanja prema traženim radnim zahtevima navarenih delova i uređaja.

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6. CONCLUSION

Objective of this research was to establish the reparation model of machine parts damaged during exploitation. For that purpose, it was necessary to perform numerous experimental investigations while monitoring influence of certain important input parameters on the reparation result for all cases of hard-facing. Those are, primarily, input heat and cooling rate within the critical temperatures interval.

The proposed reparation model, based on previously established range of influence of hard facing parameters on output-useful properties of the hard-faced layers, was practically proven with successful reparation of different parts of mechanical systems. In addition to this, the proposed reparation model enables selection of hard facing procedure and technology according to the required operating criterion of hard faced parts and devices.

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