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Effects of Steel Cast GS30Mn5 Hardening Parameters on Dredger`s Sheave Edge Properties

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Dredgers are special sea floating vessels used for removing sea bottom material in order to: reshape harbor underwater areas and waterways, assembling pipelines, preparing sand beaches and coasts to handle with erosion impact, oil resources exploitation, forming man-made islands… This paper is based on selection of heat treatment parameters of sheaves, surface errors determination method and surface damages recovery. Om test samples made out of same material (GS30Mn5) built—up welding test was carried out of (SMAW procedure) by fluting prepared damage area. Next step was induction hardening using various parameters. Determination of cracks appearance was done by magnet method. By recording cross section structure as well as hardness measuring it has been determined that besides certain level of energy input (electrical current frequency) surface layer properties of sheave edge depend also about choosing proper cooling medium. Satisfying hardness values (320÷400 HB) were achieved combining air and water cooling simultaneously with avoiding cracks appearance. Parameters selected that way should ensure long working period of ropes (hardness 500÷550 HB) as well as safe dredgers performance.

Utjecaj parametara kaljenja čeličnog lijeva GS30Mn5 na svojstva utora užnica broda jaružara

Izvornoznanstveni članak

Jaružari su specijalna morska plovila kojima se materijal s morskog dna uklanja u cilju: oblikovanja - produbljivanja lučnih pristaništa i plovnih puteva, polaganja cjevovoda, održavanja pješčanih plaža i obale od erozije, exploatacije naftnih izvora, formiranja umjetnih otoka nasipavanjem pijeska… Na ispitnim uzorcima izrađenim od istog materijala kao i užnice (GS30Mn5) izvršene su probe navarivanja (REL postupkom). Nakon toga izvršeno je indukcijsko kaljenje, različitim parametrima. Kontrola pojave pukotina utvrđivana je magnetskom metodom. Snimanjem strukture poprečnog presjeka i mjerenjem tvrdoće utvrđeno je da osim o odgovarajućem unosu energije (frekvencija struje) svojstva površinskog sloja utora užnice ovise i o izboru sredstva za hlađenje. Zadovoljavajuće tvrdoće (320÷400 HB) postižu se kombinacijom hlađenja zrakom i vodom uz istovremeno izbjegavanje pojave pukotina. Takav bi izbor parametara trebao omogućiti zadovoljavajući vijek užadi (tvrdoće 500÷550 HB) te pouzdanu exploataciju jaružara.

1. Introduction

Dredgers are special sea floating vessels used for removing sea bottom material in order to: reshape harbour underwater areas and waterways, assembling pipelines, preparing sand beaches and coasts to handle with erosion impact, oil resources exploitation, forming man-made islands... The main feature of the vessel, that singles it out to a separate category, is the way that the working hand used for digging (the digger) is connected to floating vessel, the ship. To ensure mobility of the ship, working hand used for digging is, while travelling from one work-site to another, adapted to ships form. At the dig site, dredger must reach the dig depth of 37 meters from single work position, while in shallow conditions is able to work in different work position. Digging is done by work hand operated by the complex system of steel ropes and sheaves.

Symbols/Oznake

$R_{p0,2}$	- yield strenght, MPa - granica razvlačenja	A_5	- elongation, % - istezljivost
R_m	- tensile strength, MPa - vlačna čvrstoća	KV (-20°C)	- impact energy, J - udarni rad loma

Rotational and reversible points are formed by keying, while the steel ropes and sheaves are used to manipulate (lift or lower) the digging work hand from one work position to another, or the work hand itself is placed to berth during the sail to destination.

Generally speaking, all the sheaves on the dredger are used to guide the rope from the reel to the hard spot – the lug. Sheaves are subjected to high encumbrance and wear, because they are constantly in contact with steel ropes which are used to manipulate the work hand, especially when digging the sea bottom.

Material used to build the sheaves is steel cast GS30Mn5. It is regulated that the rope hardness is between 500-550 HB. About 50 sheaves are mounted on dredger, with sheave edge cross section of 1250 mm up to 1400 mm.

Emphasis in this paper will be detection, determination of cause and recovery of errors occured while casting the sheaves, and selection of parameters of induction hardening of sheaves with the goal to achieve regulated hardness without unallowed mistakes. Technical documentation defines not only the dimensions of sheaves but also the hardness of sheaves (320-400 HB) and allowed size of cracks. Therefore, it is necessary to determine the extra material for crack recovery on casts of raw sheaves using tests, and make selection of parameters of induction hardening, to satisfy the given demands concerning hardness and quality of sheave egde surface, after the final machine treatment.

2. Tribosystem sheave – steel ropes

Figure 1 shows the dredger appearance. Combined lenght of steel ropes on dredger is approximately 6 kilometres. Due to special circumstances when working on sea, away from the dry dock, interventions on ropes are very complicated. Because of that, in this tribosystem, it is determined that the softer triboelement should be the sheaves, because their replacement is much easier [2].

Declared material of sheaves is steel cast GS30Mn5 [3]. Table 1 shows results of chemical analysis of sheaves structure. In delivered, casted state, when measured with portable hardness measure device, it is determined that sheave edge hardness is between ~180 and ~200 HB.

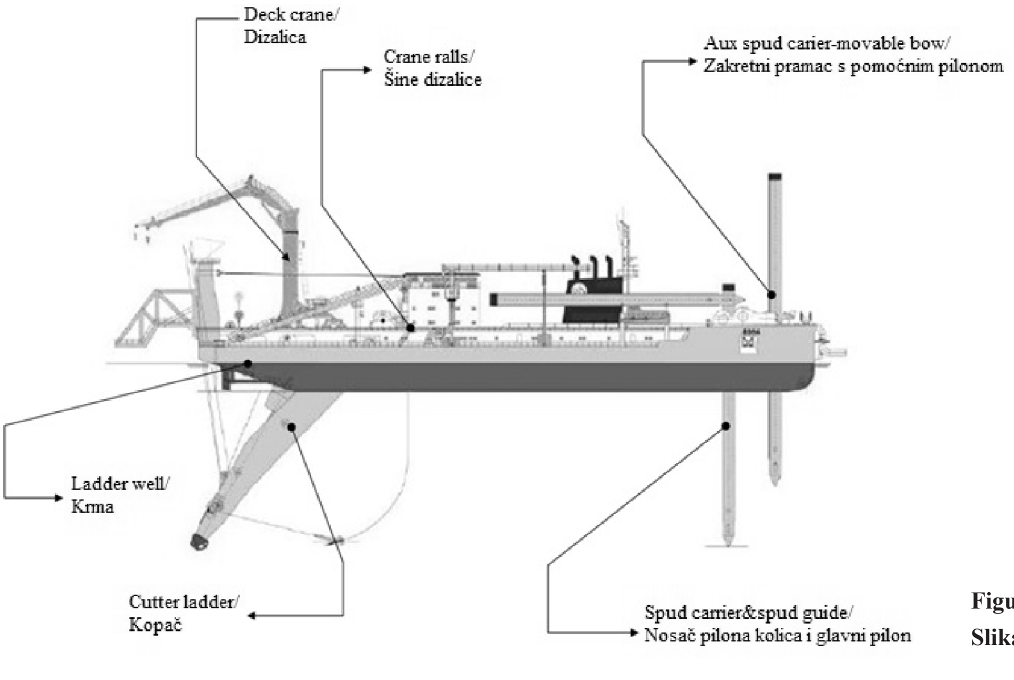


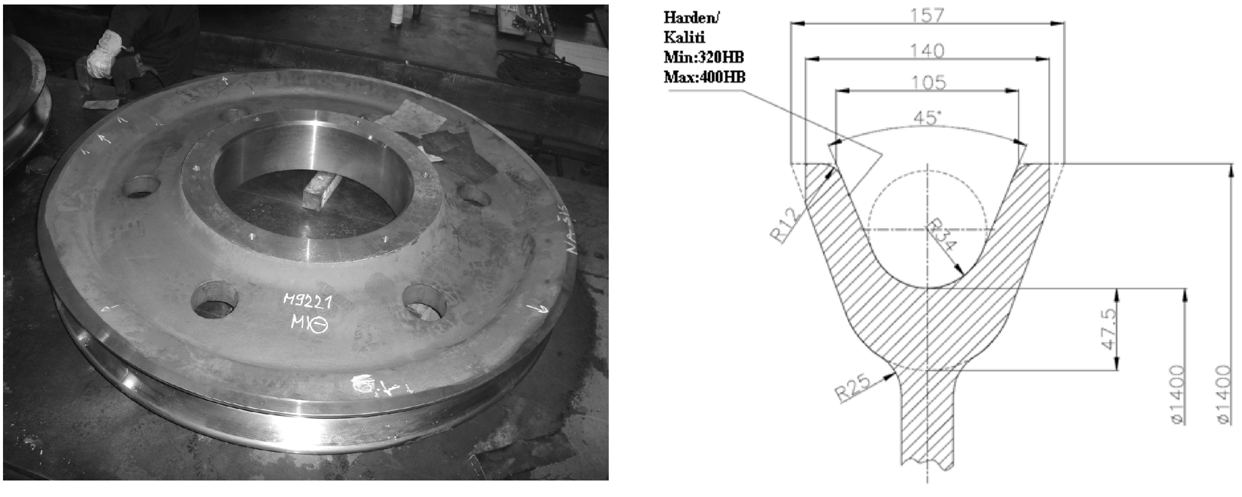
Figure 1. Dredger ship [1]
Slika 1. Dredger ship [1]

Table 1. Characteristic chemical composition material of sheave

Tablica 1. Karakteristični kemijski sastav materijala užnice

Material / Materijal: GS30Mn5	Elements portion/ Udjel elemenata, %							
Batch mark / Oznaka šarže	C	Mn	Si	P	S	Cr	Ni	Cu
S156	0,30	1,37	0,28	0,010	0,004	0,23	0,31	0,17
S267	0,31	1,41	0,34	0,010	0,004	0,19	0,25	0,14
S270	0,31	1,30	0,40	0,014	0,005	0,22	0,26	0,21
S324	0,28	1,45	0,33	0,010	0,006	0,22	0,23	0,17
Request / Zahtjev DIN 17205	0,27÷0,34	1,20÷1,50	≤0,60	≤0,020	≤0,015	-	-	-

Sheave making process is consisted of following operations: raw sheaves casting, pre-treatment by particle separation, control without destruction (magnet control), damage recovery (if any damage presented) by welding, induction hardening of sheave groove, control without destruction (magnet control), recovery by welding if new damage occures, final machining on measure followed by magnet control. Figure 2.a shows sheave after machine pre-treatment on overmeasure of 1 mm. Figure 2.b shows characteristic dimensions of single sheave edge.



a) b)

Figure 2. Characteristic view of sheaves: a) After machine pre-treatment (before induction hardening); b) Dimensions of single sheave edge

Slika 2. Karakteristični izgled užnice: a) Nakon strojne predobrade (prije kaljenja); b) Dimenzije utora

The criteria of acceptability as also method of indication irregularities examination are defined in standard: ASME VIII, Division 1, Apendix 6, Metods for Magnetic Particle Examinnation A17.2.2 [4]. All defects (cracks, porosity, inclusion…) which are unacceptable to demands above standard, must bring out state of acceptability. Also, it is defined that the sheave edge hardness between 320 and 400 HB is allowed. The reason is that hardness of steel rope is somewhat higher, between 500–550 HB. That means it is important to achieve that after final machine treatment and inductional hardening, there are no unallowed cracks inside the sheave edge, but also that the whole hardened surface of the sheave edge is within the limits of regulated hardness. To accomplish this, the following tests are required:

- tests on sheaves before recovery of surface cracks,
- tests on laboratory samples, and
- tests on sheaves recovered by welding.

3. Results of experiments

Besides that sheaves have to be satisfactory concerning dimensions and surface treatment quality, from the tribological aspect, as more replaceable element of tribosystem [4], they also have to satisfy determined criteria of hardness and surface cracks. Therefore, it is specified that sheaves are controlled by methods without destruction: magnet, hardness measuring and structural impressions method.

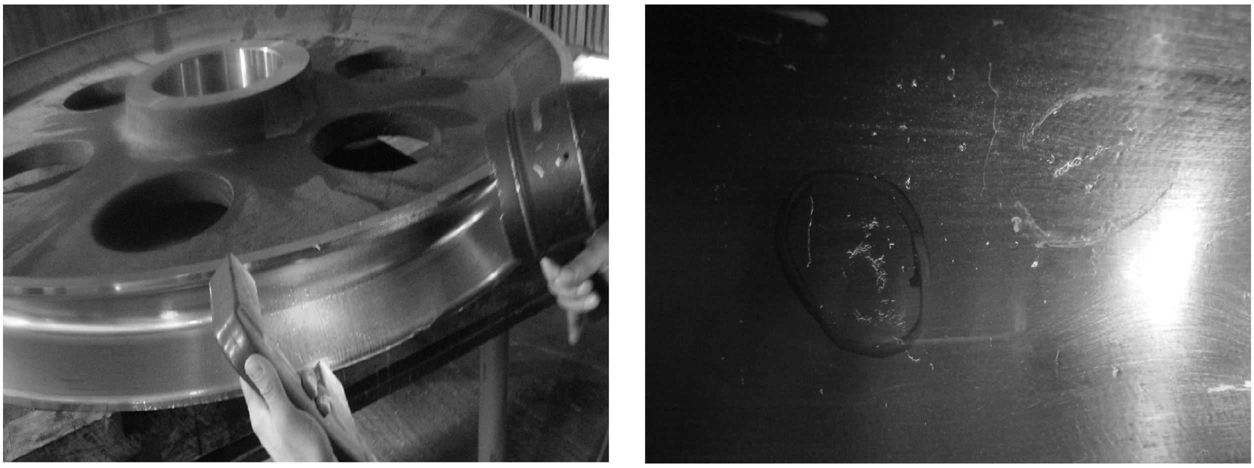
Control of indication of surface cracks is done by magnet method. First magnet control is performed after machine pre-treatment of sheave on overmeasure, Figure 3.a. Magnetic forces are deformed on irregularities, so by application of feromagnetic particles onto the test surface, crack indication is formed, Figure 3.b. Damage can appear in characteristic forms: inclusions of impurities, inclusions of residual gases, and cracks of different shapes as a consequence of quick cooling of the cast [5].

$$C_{ekv} = C\% + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15. \quad (1)$$

After adding the element share:

$$C_{ekv} = 0{,}31 + 1{,}41/6 + (0{,}19 + 0 + 0)/5 + +(0{,}25 + 0{,}14)/15 = 0{,}61\ \%. \quad (2)$$

Considering that C_{ekv} is above 0,6 – material has to be pre-heated to a temperature of 200 – 300 °C (8).



a) b)

Figure 3. Determining the crack formation indication: a) Surface crack indication control using magnetic particles; b) Damage appearance

Slika 3. Utvrđivanje formiranja indikacija pukotina: a) Kontrola indikacija površinskih pukotina magnetskim česticama; b) izgled oštećenja

Regarding the individual – local presence of unallowed cracks, recovery will be made using the welding SMAW procedure. Welding is a procedure in which extra material is applied onto the surface of work object to achieve desirable properties, dimensions and shapes. Welding can restore worn out material, can weld up new layer of material and therefore ensure longer lifetime of the machine part or the construction, recover cracks, recover corrosion effects, repair casting defects [7]. Succesful welding requires: understanding the chemical structure and mechanical properties of material; types and causes of damage, material defects, shape, depth, type of crack; determining the quality of surface and thickness of material layer, determining the type of material treatment before and after welding; selecting the type or types of extra welding material; determining the types of material wear in exploatation and determining parameters and welding procedure [8].

Considering that sheave material GS30Mn5 has carbon share of 0,31 %, there is a need for pre-heating before welding [9]. Temperature of pre-heating depends on chemical structure and thickness of material. When applying multiple layers, temperature between the layers should be the same as pre-heating temperature. Pre-heating temperature is determined based on chemical structure, by calculating C_{ekv} using the formula:

In order to test the possibility of sheave damage recovery, coated electrode mark E 46 4 B 32 H5 Conarc 49C is selected as an extra material. Reason why this electrode has been selected is its chemical structure (Table 2), but also its mechanical properties (Table 3).

Table 2. Chemical structure of electrode E 46 4 B 32 H5 Conarc 49C [9]

Tablica2. Kemijski sastav elektrode oznake E 46 4 B 32 H5 Conarc 49C [9]

~ %C	~ %Mn	~ %Si	~ %P	~ %S
0,06	1,4	0,3	0,015	0,01

Table 3. Mechanical properties of electrode E 46 4 B 32 H5 Conarc 49C [10]

Tablica 3. Mehanička svojstva elektrode oznake E 46 4 B 32 H5 Conarc 49C [10]

Yield strength/ Granica razvlačenja $R_{p0,2}$, MPa	Tensile strength/ Vlačna čvrstoća R_m, MPa	Elongation/ Istezljivost A_5, %	Impact energy/ Udarni rad loma KV (-20 ºC),J
min. 480	min. 580	min. 28	min. 200

From the values shown in Table 2 and 3, it is important to notice that the declared carbon share is very low (0,06

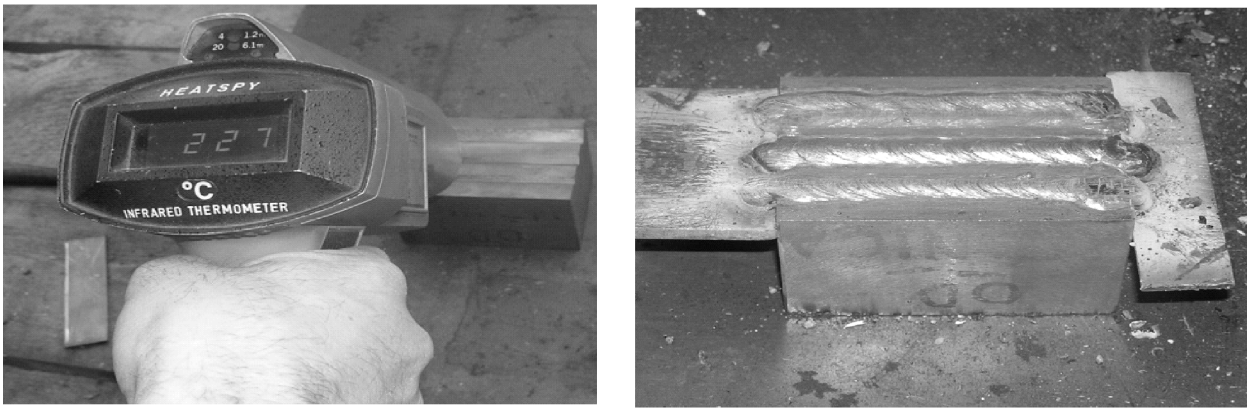
%), that the regulated minimal elongation is 28 %, with impact energy higher than 200 J. Low carbon share is prerequisite for lowering the danger of martensite excretion, and excessive hardness. Above stated, along with relatively high elongation, should lower the danger of crack occurrance.

3.1. Large figures and figure captions

For metalografic structure analysis and hardness control, panels were obtained, dimensions ≈50×150×300 mm (L×W×H), of the steel cast that matches the chemical structure of sheaves. Before welding, panel is pre-heated. Chosen pre-heating temperature of panel was 230 °C. Control of reached temperature was made by appropriate portable digital device, Figure 4.a. After the pre-heating, welding is performed on three places along the panel, making sure that all the instructions and parameters for chosen extra material are satisfied [10], Figure 4.b. Welding is perforemed in one, two and three layers. The goal is to comprehend all possible sizes (depths) of surface damage.

Surface hardness wass measured on three places along the welded layer and three places in heat impact zone. Measured values of hardness are scetched in Figure 5a. Test samples have been cut from the panel and hardness measures of cross section were performed. It was impossible to measure HV1 on cross sections of samples because the values of hardness in the weld are less than 188 HV. Therefore, values of HV5 were measured. Results are scetched in Figure 5b.

After testing the samples for hardness, microstructural tests were performed. Differences, that would lead to conclusion that the number of welded layers significantly changes the structural characteristics, were not obvserved. It was performed by assesment of metallurgical purity of the basic material and welded layers. In basic material, presence of inclusions type D were observed along with globulat type oxid, heavy series number 3, ASTM E45, while inclusions type D and globulat type oxid – light series number 5 [11]. Figure 6.a shows characteristic microstructure of weld, eroded state. Structure is fine-grained, dendritic, with no anomalies such as microcracks and cracks. Figure 6.b shows characteristic microstructure



a) b)

Figure 4. Welding test panels: a) Pre-heating temperature control; b) Welded layers

Slika 4. Navarivanje ispitne ploče: a) Kontrola temperature predgrijavanja; b) Navareni slojevi

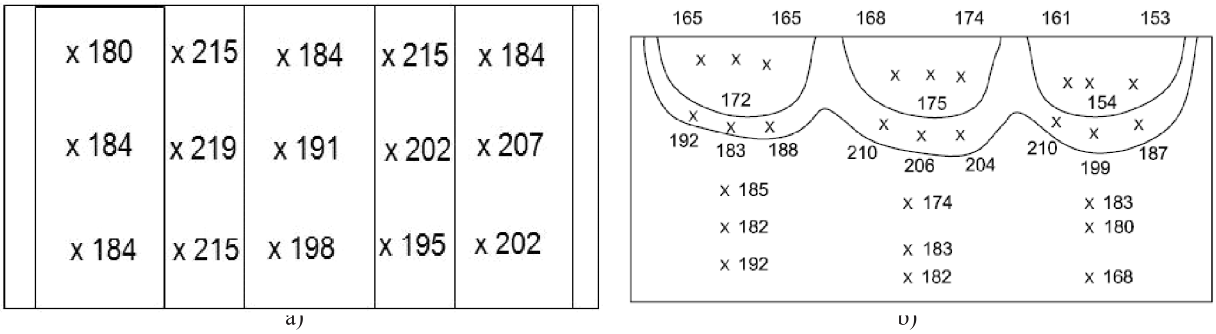


Figure 5. Sketch of measuring surface hardness results (HB) on welded test panel (a); Sketch of measured hardness results (HV5) by cross sections of welded test panel (b)

Slika 5. Skica rezultata mjerenja površinske tvrdoće (HB) na navarenoj ispitnoj ploči (a); Skica rezultata mjerenja tvrdoće (HV5) po poprečnom presjeku navarene ploče (b) of heat impact zone. Structure is fine-grained, without anomalies.

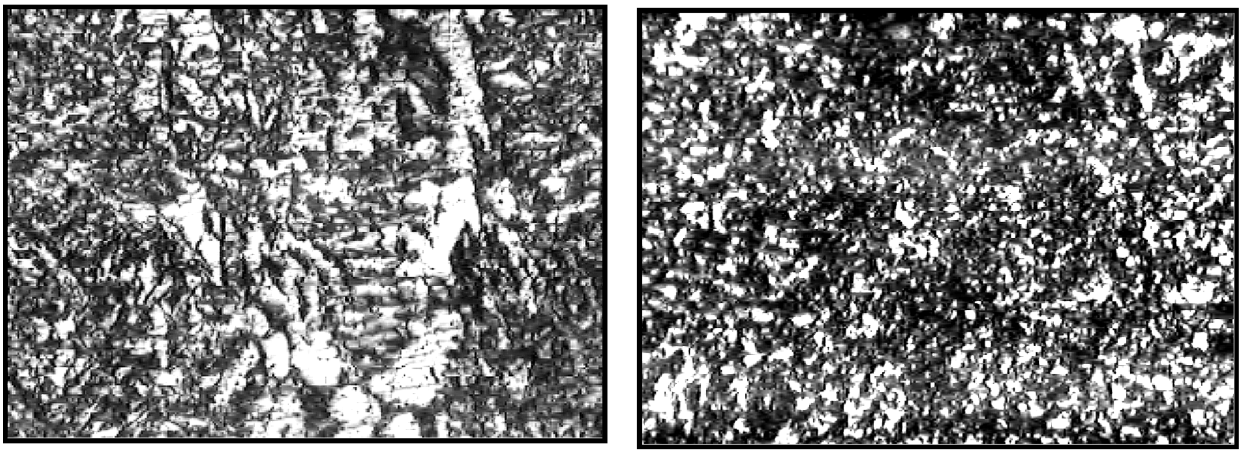

a) b)

Figure 6. Characteristic microstructure of test samples, eroded with nital 3 % (magnification 400 ×): a) Weld structure; b) Heat impact zone structure

Slika 6. Karakteristična mikrostruktura ispitnih uzoraka, nagrizeno nitalom 3 % (povećanje 400 ×): a) Struktura navara; b) Struktura zone utjecaja topline

3.2. Sheave edge tests

Sheave with unallowed damage, determined by magnet method, has been chosen for test purposes, Figure 7.a. After the recovery by welding and machine treatment, structural imprint was taken (replica). Prepared spot for obtaining the replica is shown in Figure 7.b.

a) b)

Figure 7. Sheaves with marked recovery spot by welding (a) and surface detail for replica (b)

Slika 7. Užnice s označanim mjestom sanacije navarivanjem (a) i detalj površine za repliku (b)

On the spot where the structural imprint (replica) was taken, hardness control HV 10 was performed using the moderate portable hardness measuring device. Measured hardness values of basic material and weld, are shown in Figure 4.

It is observed that the hardness values of basic material and welded layer are lower than demanded values (margins are 320-400 HB). Therefore, it is neccesary to perform induction hardening of the sheave edge.

3.3. Induction hardening of the sheave edge

In the phase one of the testing, conducted on cut panel samples, surface heating with straight inductor along with water cooling was performed. Appearance of straight inductor is shown in Figure 8.a. Metalographic analysis of all three welds were performed. Characteristic structure of transition between basic material / heat impact zone, is shown in Figure 8.b. Based on detailed inspection of prepared samples, it is important to emphasise that martensite is detected in heat impact zone.

Table 4. Results of hardness control on welding recoverd place of single sheave edge

Tablica 4. Rezultati kontrole tvrdoće na navarivanjem saniranom mjestu utora užnice

Location/ Lokacija	Hardness HV 10/ Tvrdoća HV10	Hardness HB calculated to EN ISO 18265 [12]/ Tvrdoća HB preračunata prema EN ISO 18265 [12]
Basic material/ Osnovni materijal	182 − 194	173 − 184
Hiz/ ZUT	291 − 399	277 − 379
Welded layer/ Navareni sloj	207 − 223	187 − 212

Same samples were also subjected to surface hardness measurements, using the Brinell method, both the welded layer and the basic material. Obtained values were between 528 HV and 560 HV.

Hardness measurement HV1, on cross section of the sample was performed. It is determined that the depth of hardened layer is approximately 5 mm, also that measured hardness values within that depth are much higher than the hardness values of basic material. Based on the comparison with regulated or allowed sheave edge hardness values (320 – 400 HB), it is concluded that cooling parameters should be changed. Because of the fast heat drainage, when quenched with water in the surface layer, regardless to very low carbon share in the electrode (C≤0,06 %), as a consequence of mixing with the basic material, martensite is partially excreted [13]. It results in significantly exceeded allowed values of hardness after the induction hardening and water quenching. Therefore, inductor with dual „cooling“ system, with the goal to cool off heated surface and achieve slower quenching rate, was built:

- First cooling system cooles off the surface by air
- second cooling system cooles off the surface by water.

These two systems operate within the short time period, one after another. Because of that, air nozzel is built ahead of water nozzel. Figure 9.a shows the inductor appearance. Figure 9.b shows its position during the induction hardenind of the sheave edge. Prior tests to determine the influence of air, followed by water quenching, were conducted on the samples made of previously described test panel. Using the hardness control, it is determined that measured values on the sample surface are between ~380 and 420 HB. Results of surface hardness measurements and a fact that there were no unallowed cracks noticed during magnet control, were a good indicator that inductor with two coolers can be used for sheave edge hardening.

Sheave that has been recovered by welding the unallowed cracks, was chosen. Application was performed on the sheave after pre-treatment on measure. After the final machine treatment of sheave edge on final measure, structural tests on the location that was recovered by welding, using replica, were conducted [14]. Figure 10.a shows microstructure of the basic

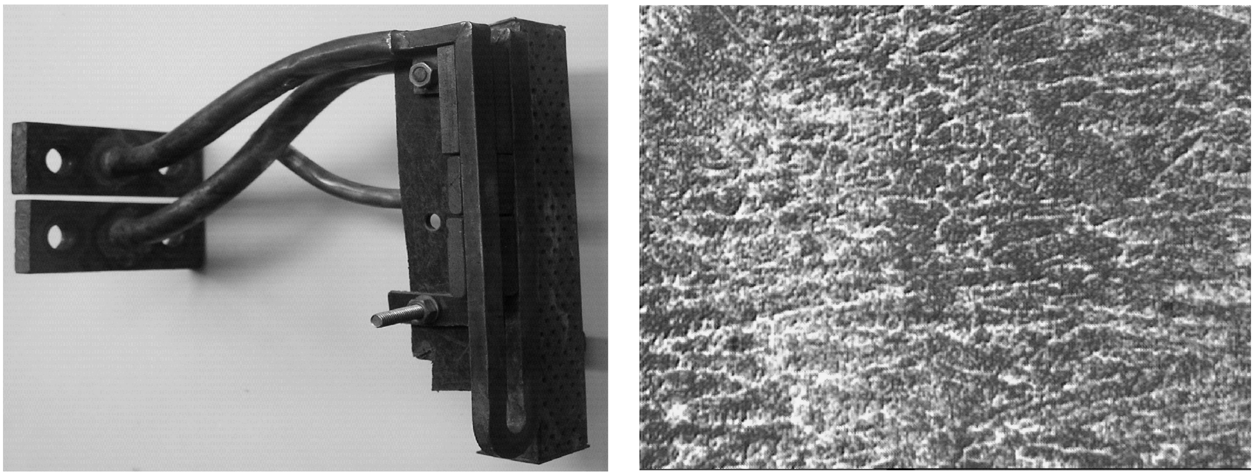

a) b)

Figure 8. Appearance of classical inductor for the purposes of hardening panel samples, water quenching (a); Characteristic microstructure of hardening part weld/heat impact zone (b)

Slika 8. Izgled klasičnog induktora za potrebe kaljenja ispitne ploče, gašenje vodom (a); Karakteristična mikrostruktura zakaljenog dijela navar/zona utjecaja topline (b)

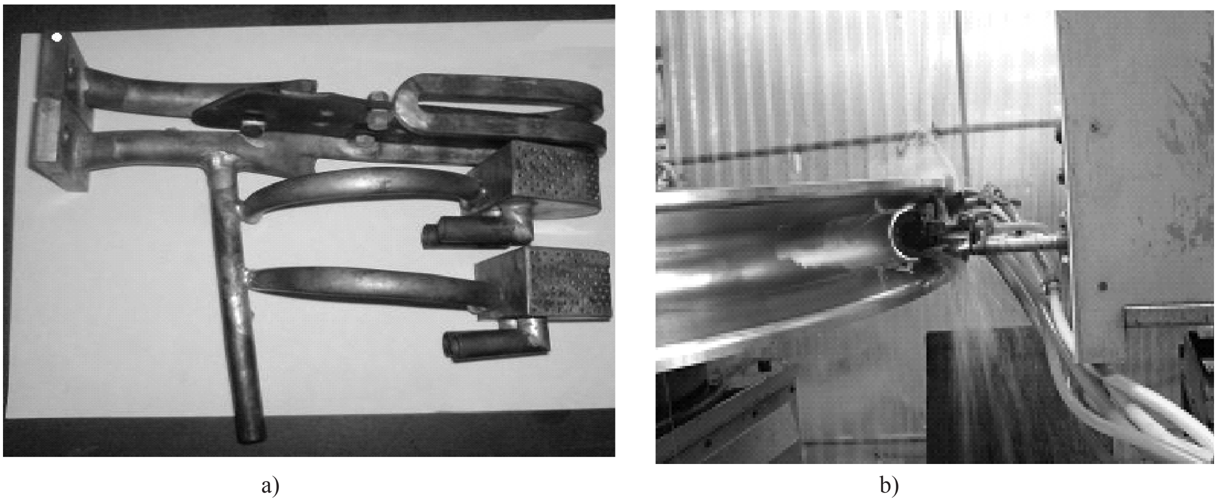

a) b)

Figure 9. Induction hardening of the sheave edge; a) Inductor with dual cooling systems; b) Hardening of the sheave edge

Slika 9. Indukcijsko kaljenje utora užnice; a) Induktor s dvije hladilice; b) Kaljenje utora

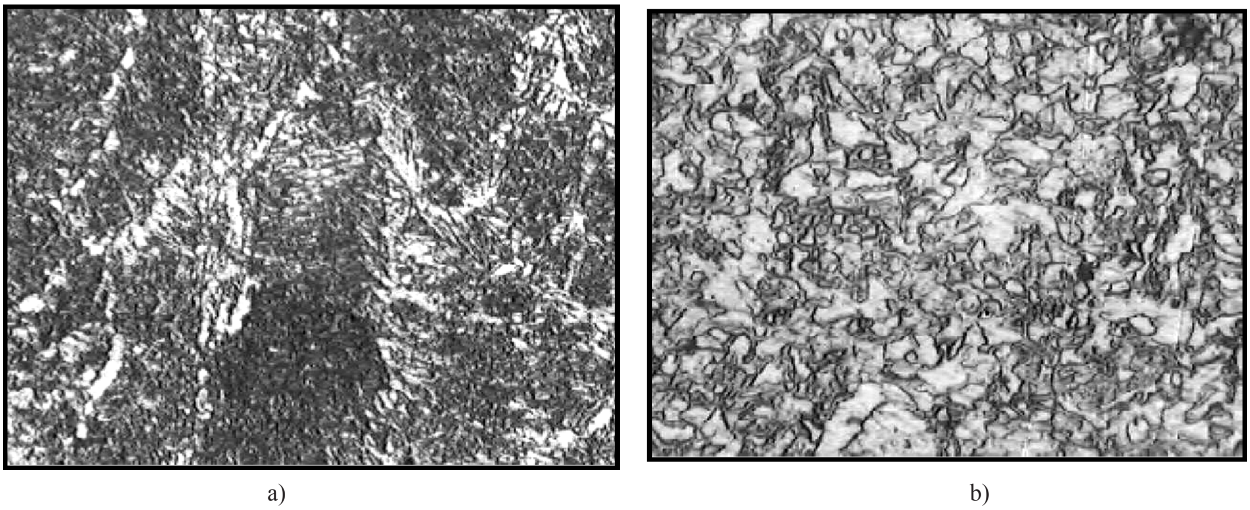

a) b)

Figure 10. Microstructure of sheave edge damage recovered by welding, eroded with nital 3 % (magnification 400 ×): a) Basic material; b) Heat impact zone

Slika 10. Mikrostruktura navarivanjem saniranog oštećenja na utoru užnice, nagrizeno nitalom 3%, (pov. 400 ×): a) Osnovni materijal; b) Zona utjecaja topline

material. It is characterised by relatively large grain, but also it is visible that the material has been heat treated. Anomalies, such as cracks, are not presented in the structure. Microstructure of heat impact zone is extremely fine-grained, without anomalies, such as microcracks, Figure 10.b. Microstructure of the weld is also typicaly dendritic, also without visible microcracks, very similar to the weld structure shown in Figure 6.a.

4. Result analysis and conclusion

Satisfying values of sheave edge hardness (320-400 HB) are acieved by combination of air and water cooling. That way, by achieving the adequate structure while avoiding the tension, it is accomplished that no unallowed anomalies appear in the form of microcracks, on the location recovered by welding. Parameters selected that way should ensure long working period of ropes (hardness 500÷550 HB) as well as safe dredgers performance. It is a good example that use of scientific methods in tribosystem element analysis and selection of treatment parameters, can contribute to necessary acceptance of approach that leads to efficient “economic science”. Research should be continued by monitoring of the sheave use, monitoring of the wear intensity and dominant mechanism. The goal is to, based on the feedback information, achieve not only demanded properties of the sheave edge, but also to ensure longer lifetime and quality in order to boost manufacturers reputation.

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