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ANALYSIS OF POSSIBILITY OF REPAIRING WELDING OF SELECTED OF THE STEAM TURBINES

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Abstract

The article presents the results of the study on the possibilities of repair by welding methods of exploitation steam turbine bodies. Two hull were investigation after a lifetime of more than 200.000 hours. Repair welding study were carried out on the L17HMF cast steel body in the immediately after exploitation condition, whereas the L21HMF cast steel body underwent a revitalization after the exploitation, and then the welding repair research were performed. On the material taken from the L17HMF cast steel hull, welding repairs were made by welding the previously cut four grooves measuring 200 mm 50 mm 50 mm, which were simulations of material defected. All samples were made in areas where maximum steam temperatures were operating. Welds were tested with destructive and non-destructive methods to determine their quality and define non-compliances detected. The L21HMF cast steel was subjected to a revitalization process, which consisted the hull in subjecting heat treatment in order to obtain favourable structural changes and improve the strength properties. Non-destructive examinations and hardness tests were carried out on the remedial weld, indicating the required quality of repairing remedial weld. Comparative study is aimed at demonstrating the main welding problems during the repair welding of exploitation steam turbine hulls.

Keywords: *regenerative heat treatment, welding, steam turbine*

1. The research of the turbine hull of cast steel the L17HMF

The material used for testing is a steam turbine fuselage made of L17HMF cast steel. This hull has worked over 200,000 hours. Hull samples were taken from the hull and used to perform simulated material losses. In the hull material, significant fatigue-creep changes were found as well as large secretion of chain-shaped carbides on the grain boundary. The chemical composition of the material to be tested is shown in Tab. 1. Four samples were prepared for making overlay weld, in which milling was made, grooves were measuring 200 mm, 50 mm, 50 mm (length, width, depth). The welding groove made in the material that is the subject of the research was filled according to the following basic parameters of the technology is shown in Tab. 2 [1-3, 9].

Tab. 1. The chemical composition of the material

Type of material	Standard	C [%]	Si [%]	Mn [%]	P max [%]	S max [%]	Cr [%]	Mo [%]	Ni [%]	Cu [%]	V [%]
L17HMF	PN-89/ H-83157	0.15- -0.20	0.30- -0.60	0.50- -0.80	0.30	0.30	1.20- -1.50	0.90- -1.10	–	–	0.20- -0.30

Tab. 2. Numbering of welds and basic parameters of welding technology

Sample number	Electrode grades		Heating temperature
	edge stitches	next layers	
1	Nicro ASØ3.2mm.Ø4mm		80-100ºC
2	Nicro ASØ3.2mm	ESV-Cr-MoBØ3.25mm and Ø4mm	80-100ºC
3*	ES2Cr-MoBØ3.25mm	ESV-Cr-MoBØ3.25mm and Ø4mm	300-350ºC
4	Nicro ASØ3.2mm	Wire VALCO-FIL 838B	80-100ºC
* annealing with reforge stitches			

After the welds were performed, the following control and research operations were performed on each of the samples:
1) surface defectoscopy,
2) volumetric flaw detection,
3) macroscopic examination on the cross-section of the connector,
4) microstructural metallographic examinations,
5) measurements of the hardness of the weld metal and the heat affected zone,
6) impact testing of the heat and native material impact zone (excluding sample 4).

Surface defectoscopic examination of welds was made using the magnetic-powder and penetration method. During surface tests, the following indications were identified for the faces of individual paddles (by padding numbering):
1) no cracks or other surface incompatibilities in welding,
2) ten linear indications up to 5 mm long in stitches adjacent to the buffer layer (after removing about 1 mm of the display material partially disappeared),
3) lack of cracks and other surface weld incompatibilities,
4) five linear displays up to 3 mm long, in stitches adjacent to the buffer layer (after removal of approximately 1 mm of the display material, they have partially disappeared).

Non-destructive examinations were performed by ultrasound taking the recording level equivalent to Ø1.5 mm (for ERG). During ultrasonic tests, for welds made of high-nickel weld metal (welds No. 1, 2, 4), the ultrasonic beam was not reflected from the bottom and the reproducibility of indications for individual test conditions was obtained. Ultrasonic test results for individual repair welds:
1. No indications exceeding the registration level were detected in the weld, while in the native material discontinuities of 150 mm length were detected, penetrating to a depth of about 8 mm along the ridge under the weld.
2. In the central zone of the weld on the length of 120 mm there are 11 flat transverse indications (ERG ≈ Ø3-6 mm), in the home material 5 scattered spot discontinuities under the weld were detected (ERG ≈ Ø1.8-2.0 mm).
3. Two point discontinuities were detected in the weld – ERG ≈ Ø1.7 mm and ERG ≈ Ø1.3 mm in layers at 32 and 42 mm depth from the face, while in the native material 3 ERG ≈ Ø1.2-1.7 mm in the band were found away from the bottom of the weld 7-13 mm.

No indications were detected in both the weld and the native material [1, 7, 8].

The areas in which surface indications were found or located inside the repair joint were subjected to detailed macroscopic and microscopic examination. Macroscopic metallographic examinations were performed on transverse and longitudinal cross-sections from areas in which discontinuities were detected during defectoscopy. The results of metallographic examinations are shown in Tab. 3 and the photographs below [1, 7, 8].

Within the illustrated sections, there are differences in the morphological structure of individual components, such as granularity or conformity of bainite and martensite, and the presence of carbides on the grain boundary of the former austenite. The most intensive carbide separations occur mainly in welds No. 1, 2 and 4. In weld No. 3, carbide separations at the grain boundary have been detected only at the padding weld [1, 7].

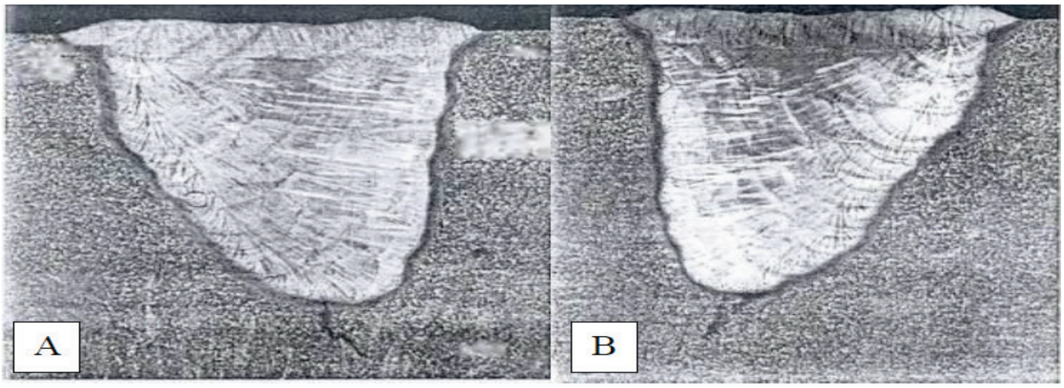

Fig. 1. Macrostructure of weld No. 1 – cross-section A and B

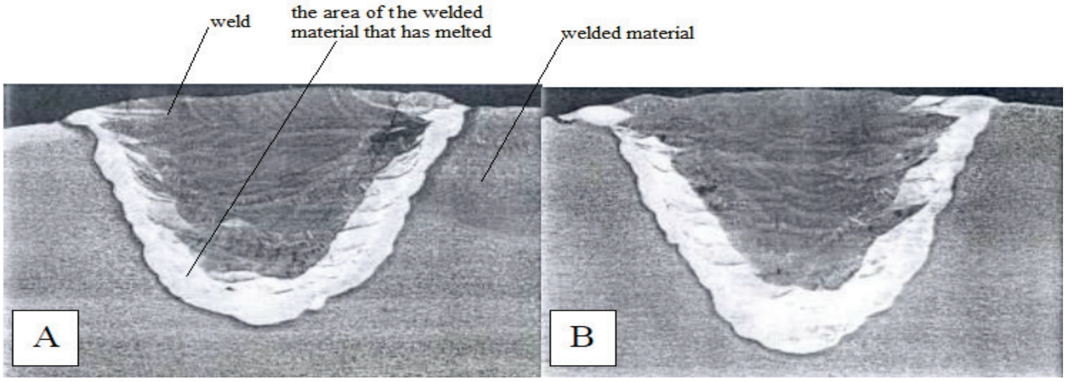

Fig. 2. Macrostructure of weld No. 2 – cross-section A and B

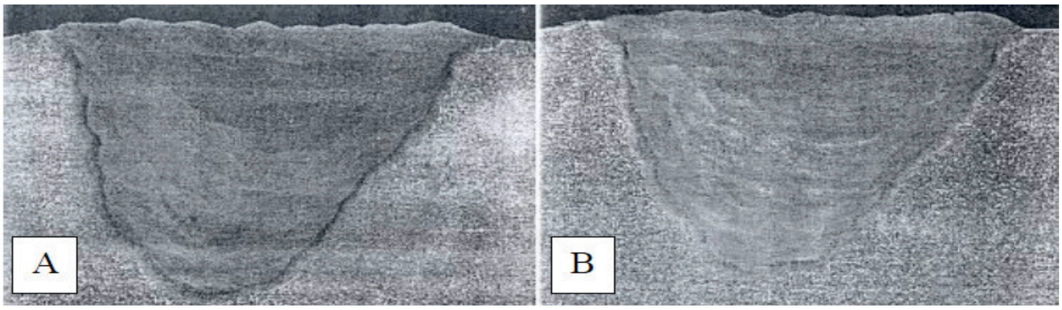

Fig. 3. Macrostructure of weld No. 3 – cross-section A and B

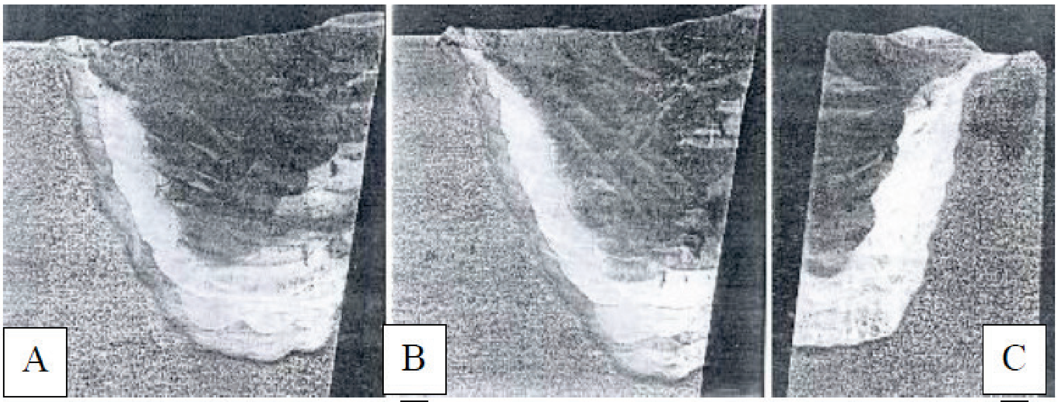

Fig. 4. Macrostructure of weld No. 4 – cross-section A, B and C

Tab. 3. Results of metallographic tests

The type of linear discontinuity		Weld number			
		1	2	3	4
Of sticking and cracking between stitches	Quantity (pieces)	–	2	2	1
	Size [mm]	–	To 0.5	To 2.2	To 0.5
Cracks and tears in stitches	Quantity (pieces)	–	≥25	1	≥20
	Size [mm]	–	To 2.2	To 1.2	To 3.0
Transversal cracks in the weld face layer	Quantity (pieces)	–	5	–	3
	Size [mm]	–	To 21	–	To 1.5
Transverse cracks in the weld	Location	–	1/3 of the length of the weld	–	–
	Size [mm]	–	To 40	–	–
Cracks in the heat affected zone	Location	From the root of the weld to the heat affected zone	–	–	–
	Size [mm]	150 x 0.5 – heat affected zone	–	–	–
Cracks in the native material	Location	From the root of the weld to the heat affected zone	–	–	At the surface
	Size [mm]	150 x 11	–	–	To 10

The results of hardness measurements are presented in diagrams describing hardness distribution at individual distances from the weld line.

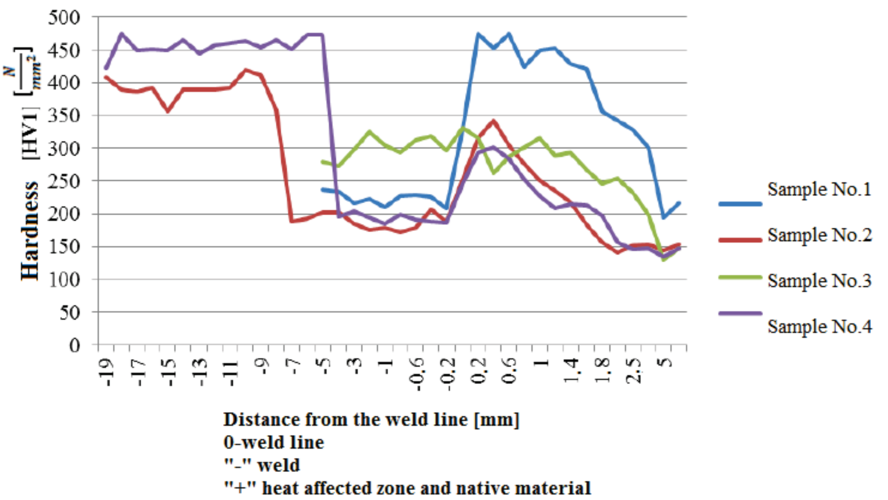

Fig. 5. Diagram of hardness dependency [HV1] from the distance from the weld line [mm] on the face of welds

2. The research of the turbine hull of cast steel the L21HMF

The examination of the hull of a L21HMF steel turbine was qualified to carry out the revitalization process. This hull has worked over 200.000 hours. The chemical composition of the tested G21CrMoV4-6 cast steel (L21HMF) is shown in Tab. 4.

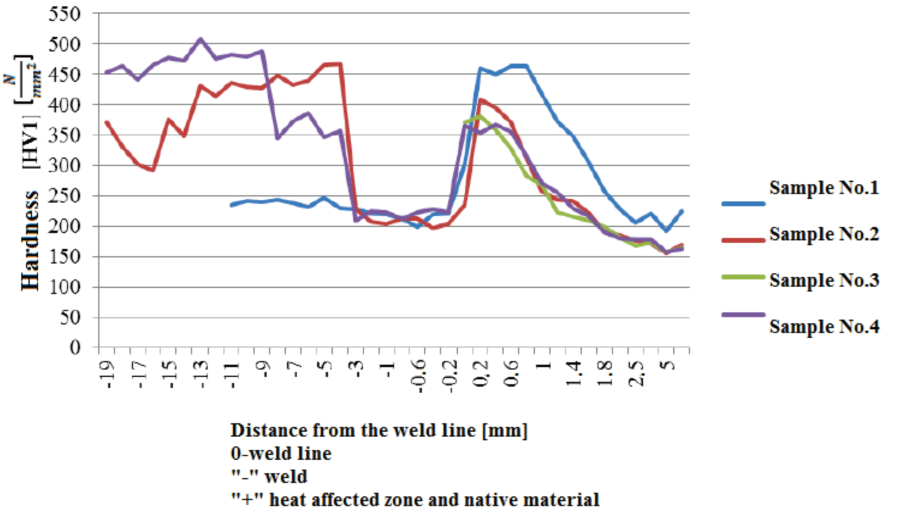

Fig. 6. Diagram of hardness dependency [HV1] from the distance from the weld line [mm] to ½ of the weld height

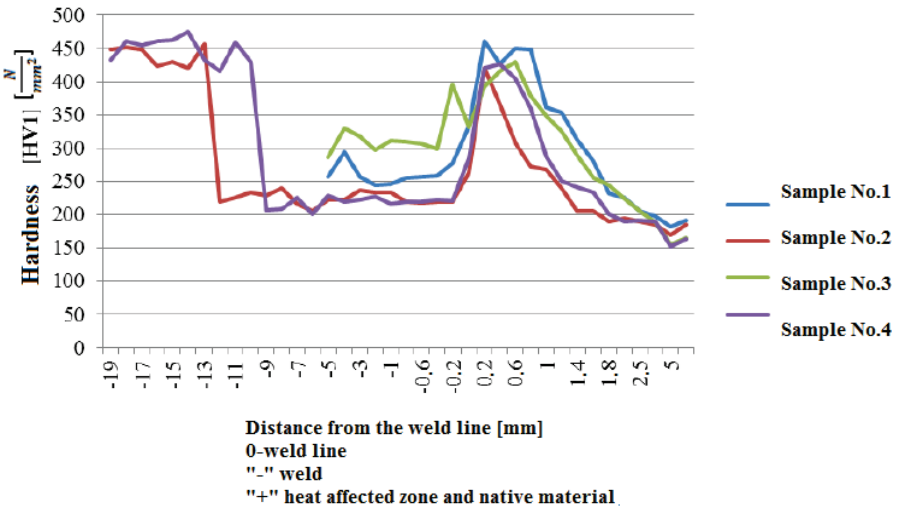

Fig. 7. Diagram of the hardness dependency [HV1] from the distance from the weld line [mm] in the ridge of the welds

Tab.4. Chemical composition of cast steel of the L21HMF

Type of material	C [%]	Si [%]	Mn [%]	P max [%]	S max [%]	Cr [%]	Mo [%]	Ni [%]	Cu [%]	V [%]
L21HMF G21CrMoV4-6	0.18- -0.25	0.20- -0.50	0.40- -0.70	0.030	0.030	0.90- -1.20	0.50- -0.70	≤ 0.30	≤ 0.30	0.20- -0.35

The purpose of heat treatment in the revitalization process of the steam turbine hull is to remove after-care changes of the microstructure, to obtain a sufficiently high impact resistance, and to enable the correct repair performance by welding the material after removed, after-cracked cracks. Tempering was carried out by heating to the temperature of austenite and heating at this temperature and subsequent cooling to obtain non-equilibrium structures – martensite, bainite or a mixture of martensite and bainite. The use of heat treatment to revitalize the steam turbine hulls resulted in favourable changes in microstructure and mechanical properties. As a result of the heat treatment, a significant increase in the energy of breaking Charpy V samples was obtained. In the after-care condition, the average impact strength was 13 J, and after the revitalization process, the average value reached 52 J. It can therefore be concluded that the energy of breaking the Charpy V samples of the steam turbine's hull after revitalization has increased by five times.

After carrying out the revitalization process, attempts were made to weld defects in the material resulting from the removal of the detected cracks in accordance with the developed welding instructions. The four different welding technologies were developed depending on the use of repairs in the given stage of the revitalization process, including the possibility of preheating the material for welding, the possibility of performing stress relief annealing after welding and the type of welds: material defects and structural weld.

The due to the inability to take a sample for impact and microstructural tests of the weld cross-section, due to the further suitability of the hull, only hardness tests were carried out on a randomly selected weld that determined the general condition of the welds throughout the hull.

The Tab. 5 presents the results of hardness tests on a randomly selected repair weld in the upper part of the hull [1, 4-8].

Tab. 5. The hardness test result on a randomly selected repair weld in the upper part of the hull

Hardness HV5		
Hull material	Heat affected zone	Weld
180-190	185-196	168-182

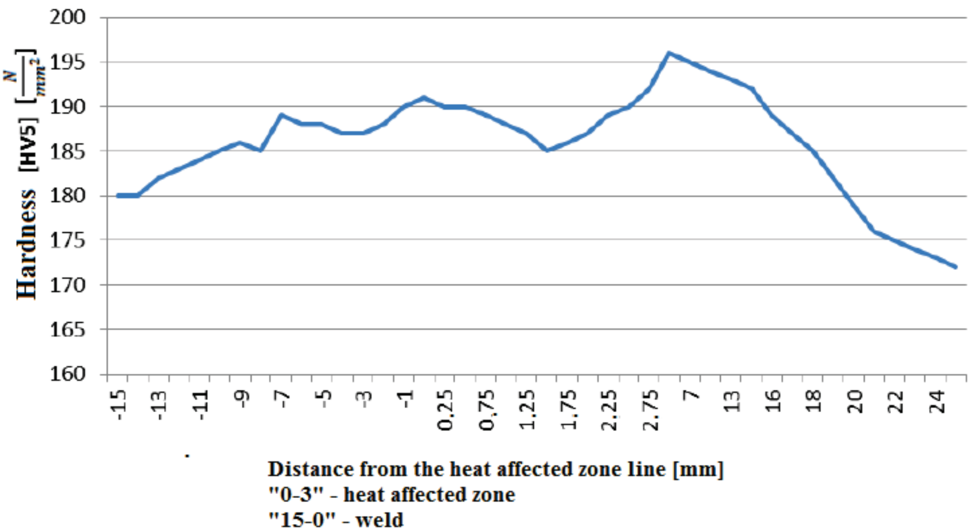

Fig. 8. Diagram of the hardness dependency [HV5] from the distance from the fusion line [mm] on the weld surface

3. The summary of the research of the turbine hull of cast steel the L21HMF and L17HMF

The final defectoscopic and metallographic tests, hardness measurements on welds, hardness measurements on the hull material and impact tests prove that the revitalization process has been carried out correctly. As a result, the material's ability to plastic deformation has been restored. Defectoscopic tests as well as hardness tests confirm the required quality of repair welds made on the revitalized steam turbine hull.

The hardening of the heat-affected zone of all tested welds is a consequence of the martensitic transformation. In all welds, the hardening of the heat-affected zone is highest at the root. The most hardened (> 450HV) is the heat affected zone around the entire circumference of the No. 1 weld. In welds No. 2, 3 and 4, the hardening of the heat affected zone at 400-450 HV occurs only at the root of weld. There are cold cracks in the entire cross section of the No. 2 weld. The cracking intensity is the highest in the central zone of the weld length. The cracking of the heat and parent material zone occurs under the No. 1 weld. A band of material adjacent to the root is fractured by ca. 85% of the length of the weld. Cracks are initiated on the inside-grain surface of the splitting, which results from the post-exploitation fragility of the material, [1, 4, 6, 7].

4. Summary and conclusions

The considering the results of the repair process, in which there are significant fatigue-creep changes and significant carbide separation at the grain boundary, we can conclude that such a process is not feasible. We note that despite the use of special welding technologies developed for the implementation of repair joints on samples, similar results were observed in each case. None of the welds fulfils any criterion allowing for further processes or operation. The most common defects occur in the area of repairs, in the heat-affected zone and in the domestic material directly adjacent to the repairs area. It can be concluded that the cracks have a course from the parent material.

Through the use of the revitalization process, the macrocracks found on the surface of the casting were removed from the material; all carbide precipitates were fragmented and obtained uniform distribution in the material. According to the assumptions of the revitalization process, post-mining stresses were also removed from the material. Thanks to these factors, the problem of welding rupture during welding was eliminated. In addition, the revitalization process also assumes the removal of stresses resulting from the surfacing and, consequently, the elimination of another factor causing the joints to break.

Considering samples from L17HMF material, it can be concluded that the obtained hardness is very diverse, in particular, the hardness of the weld, which reaches even 450HV1, and the hardness of the native material oscillates within 190HV1. In the case of welding of L21HMF material, we obtain hardness within the tolerances between the weld, the heat affected zone and the native material.

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