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Investigations of Wear Resistance of Hardfaced Layers on Steel 40X

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Abstract **– The article discusses a fundamental problem in the shipbuilding industry related to the repair of critical and expensive components directly related to the operation of ships in the global fleet. Methodology and technology for repair by welding of workpieces made of 40X steel have been developed and applied. Hardfacing electrodes of the brands OK 83.28 and OK 61.20 were used. The developed welding technologies include both buffered and non-buffered layers. For one of the specimens, preheating to a temperature of 200 degrees Celsius was performed, which proved to be optimal for the metal. The measured macro stresses are below the elastic limit of the examined metal. The measured residual stresses are insignificant at +62 MPa. The microhardness results show an increase in microhardness to about 450HV in the weld metal zone. The dry friction wear test performed on the welded layer showed a relatively uniform metal loss in both specimens due to the slight increase in temperature.**

Keywords **– Hardfacing, macro stresses, microstructure, microhardness Vickers, wear resistance.**

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1. Introduction

In present times where prices for goods, services, and irregular deliveries are changing constantly, it is economically justified to seek ways to efficiently restore components in ship repair. One such method is welding worn-out details or parts of machinery and mechanisms, with the exception of crankshafts for main engines, as a possible quick and effective approach.

In essence, welding is the process of depositing metal onto the worn-out part of the component. The choice of welding electrodes and wires is closely related to the chemical composition of the base metal and the operating conditions of the component.

In the industry, there are various methods for welding components. In [4], an analysis of the advantages and disadvantages of the most commonly used methods in ship repair has been conducted. The analysis has revealed that the most commonly used and suitable methods for this industry are manual shielded metal arc welding (SMAW) and welding in a protective gas environment with consumable electrodes.

In the welding process, in addition to parameters, settings, and consumables, which are of primary importance, the parameters of the electric arc are also crucial. For welding with shielded electrodes of various diameters (3.25-4.0mm) and current sizes ranging from 80-150A, an analysis has been carried out and presented in [2].

The study of the structural characteristics following the deposition of specimens with austenitic-nickel wire for the buffer layer and Fe-Cr-C for the deposited layer, as well as wear resistance tests are presented in [7]. During the deposition process, the method used is arc welding in a protective gas environment with a consumable electrode. The combination of the buffer and deposited layers influences the diffusion of elements and the ratio of Fe and Cr crystals. Judging from the results after wear testing, it has been found that thermal and gas treatment provide excellent wear resistance [3], [8], [9].

In [6], the researchers investigated the impact of the buttering layer (18.5% Cr + 9% Ni) and the chemical composition of the hardfacing filler materials on the microstructure and wear behavior of structural steel (S355JR).

A similar study was conducted in [2]. In that study, the authors proposed two railtrack repair technologies for the turnouts. One technology involved the application of a buffer layer, while the other did not. The electrodes used were OK 83.28 and OK 68.23. The hardness established in the heat-affected zone during welding without a buffer layer using OK 83.28 electrodes was around 340-380 Vickers units, whereas when welding with a buffer layer and OK 67.45 electrodes, it was approximately 270-340 units. In this case, it was found that welding without a buffer layer is preferable.

2. Methodology

The methodology of the experiment includes the development of technology for hardfacing specimens made of 40X steel. To evaluate the proposed technology, two specimens were produced. Dimension of specimens is shown in Figure 1.

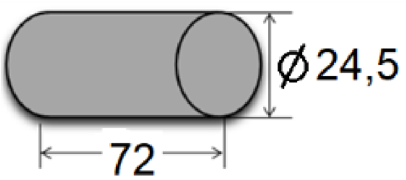

Figure 1. Dimension of specimens

Two cylindrical specimens cut by a machine tool were subjected to a preliminary heat treatment to change the structure into a granular sorbit, which gives toughness to the steel. High core toughness was sought for the initial test pieces before welding. Fig. 2 shows a cyclorama of preliminary heat treatment of specimens.

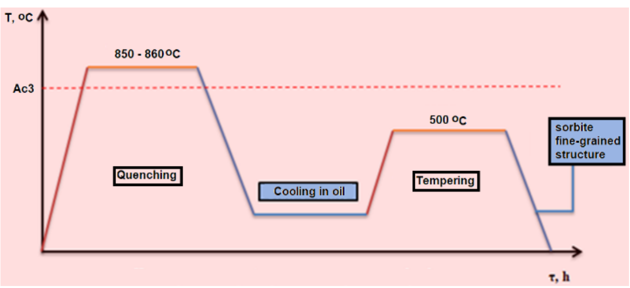

Figure 2. Heat treatment cyclogram of quenching-tempering of specimens

For the purposes of the study, two methods were chosen for hardfaced, shown in Table 1.

Table.1. Information for hard facing process

№	Hardface electrode	Electrode buffer layer	Preheating
1	OK83.28	-	200◦C
2	OK83.28	OK61.20	

In the hardfacing process, it is crucial to make the correct selection of consumables and manufacturing technology, Table 2 and Table 3, show the chemical composition of base metal and electrodes.

Table 2. Chemical composition of base metal [1]

C	Si	Mn	Ni	Cr	Cu	P	S
0.36 - 0.41	0.17 – 0.37	0.5 – 0.8	≤ 0.3	0.8 – 1.1	≤ 0.3	≤ 0.035	≤ 0.035

Table 3. Chemical composition of electrodes [1]

Electrodes	C	Si	Mn	Cr	Ni	N
OK 83.28	0.1	< 0.7	0.7	3.2	-	-
OK 61.20	0.02	0.4	1.9	19.8	9.8	0.05

On the first test specimen, presented in Fig.3, preheating was performed in an electric resistance furnace to the calculated temperature of 200°C, as determined by the carbon equivalent. Subsequently, in the heated state to prevent the formation of cold cracks, layers were hardfacing using electrode type OK83.28. According to the technical data sheet, this electrode imparts good wear resistance to the welded layers.

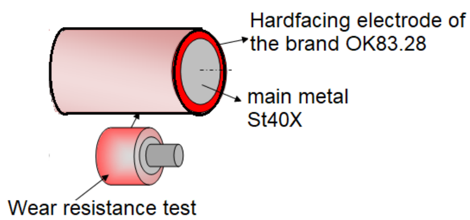

Figure 3. Treatment of the first specimen

On the second test specimen, in Fig.4, as per the experimental plan, no preheating was carried out. Instead, an intermediate layer of buffer electrode type OK61.20, composed of austenitic steel with lower hardness, was applied on the cold base metal. Then, a final layer using electrode type OK83.28 was deposited on top.

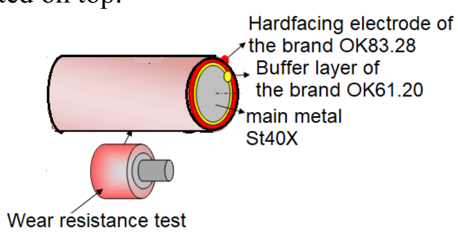

Figure 4. Treatment of the first specimen of second specimen

In order to reduce the deformations in the test samples, a laboratory setup for deformation-free welding was designed, Fig.5.

During the welding process, an indicator clock is used to monitor the deformation of the specimen, recording its behavior at each stage of hardfacing. In order to minimize subsequent deformation resulting from the recovery process Fig.6 illustrates the sequence of hardfacing of the seams.

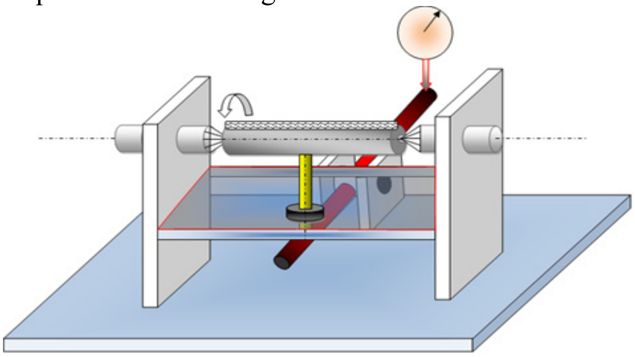

Figure 5. Scheme of the hardfacing stand

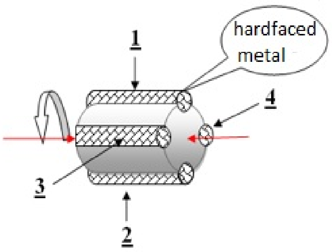

Figure 6. Sequence of application of the hardfaced layers

After the welding process, the test specimens were machined using a metal-cutting machine to level the surface and reduce roughness.

The wear resistance of the hardfaced layers was tested with a machine, a scheme of which is shown in Fig. 7

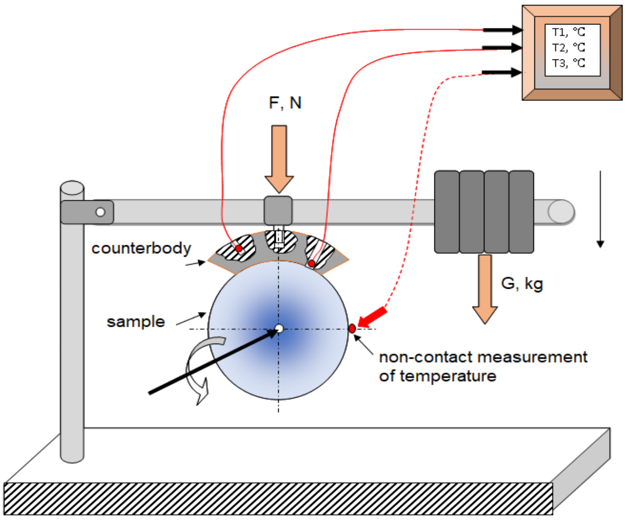

Figure 7. Scheme of the wear stand

The inner cylindrical surface of the counterbody (CuAl8Fe3) contacts the surface of the rotating, constant frequency (1400rpm) specimen. The load F is applied at the center of gravity of the contact area between the specimen and the counterbody and is set by a lever system. The test was conducted under identical conditions for all specimens in dry friction mode and examining the temperature in the specimen body, counterbody, and non-contact on the specimen surface.

3. Results and Discussion

The investigation of the macro and microstructure is conducted using a metallographic microscope NEOFOT-2; Hanemann 100 attachment to a metallographic microscope for measuring Vickers microhardness, EUROMEX steriomicroscope for macro research.

The macrostructures of the two specimens are shown in Fig. 8. It is particularly noticeable that there is a wide heat-affected zone in the specimen without a buffer layer, i.e., the one preheated to 200°

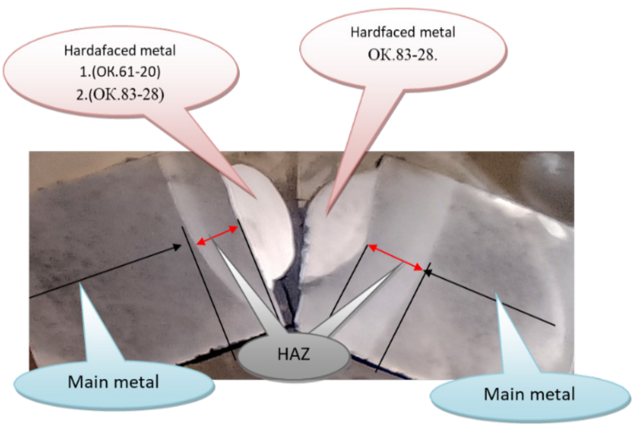

Figure 8. Macrostructure of hardfaced bodies

After hardfacing of specimen 1 according to the selected process parameters and using electrode OK 83.28, a dendritic layer with needle-shaped martensitic crystals forming towards the martensitic region of the Schaeffler diagram is obtained as demonstrated in Figures 9 and 10.

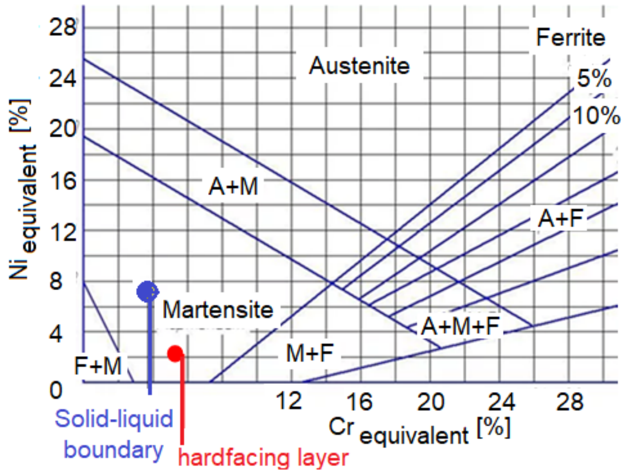

Figure 9. Schaeffler diagram [5] of specimen 1

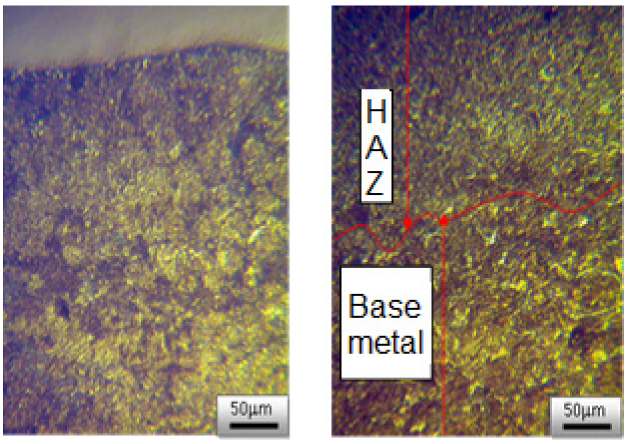

Figure 10. Microstructure of specimen 1

During the welding of the second specimen with a buffer layer, a martensitic structure is formed in the weld zone deposited with OK 61.20 and the buffer layer deposited with OK83.28. An austenitic-martensitic structure is obtained at the solid-liquid boundary between the buffer and the base metal. In this structure, the obtained sorbitic grain structure and ferrite enhances the strength of the welded layer, which in turn improves the operational qualities of the product.

The crystals in the dendritic zone of the weld with OK 83.28 electrode metal are properly oriented. Additionally, the crystals in the weld with OK 61.20 metal are also oriented, with the melting boundary between the buffer layer and the welded layer clearly defined as presented in Figures 11 and 12.

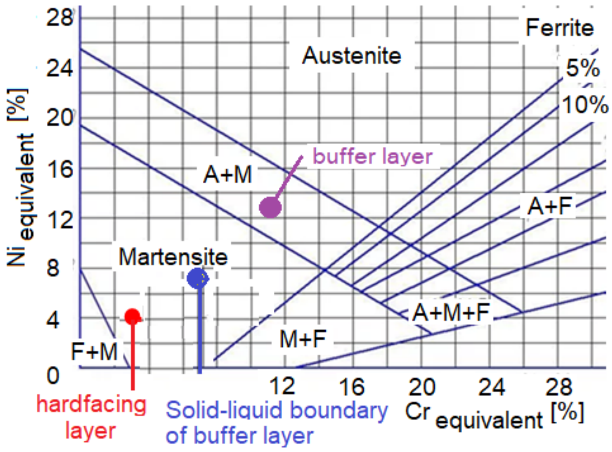

Figure 11. Schaeffler diagram [5] of specimen 2

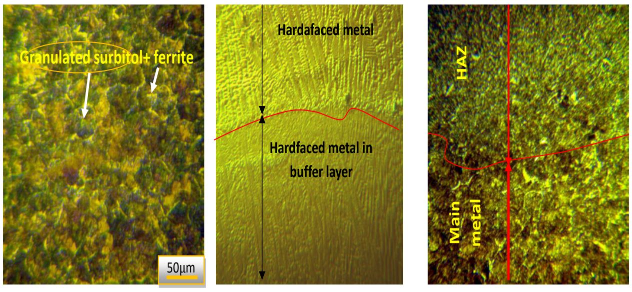

Figure 12. Microstructure of specimen 2

To determine the residual macro stresses obtained after welding and finishing hardening treatments, an X-ray diffractometer SIMENS was used.

The results obtained are presented in the histogram shown in Fig. 13. It can be seen that large compressive stresses-891MPa-are obtained during the buffer layer welding (sample 2).

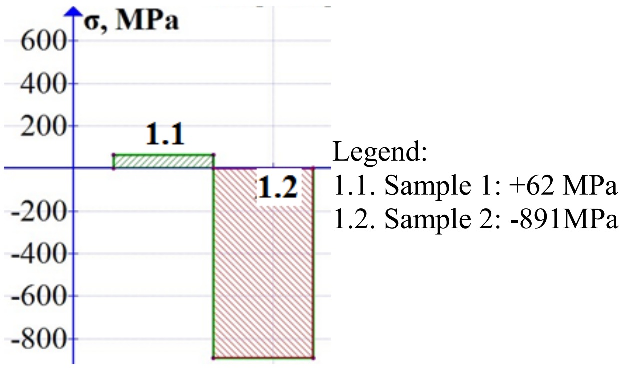

Figure 13. Histogram-graph of X-ray stress measurement

Vickers microhardness testing was performed to determine the degree of hardening of the specimens. The test results are shown graphically in Fig. 14

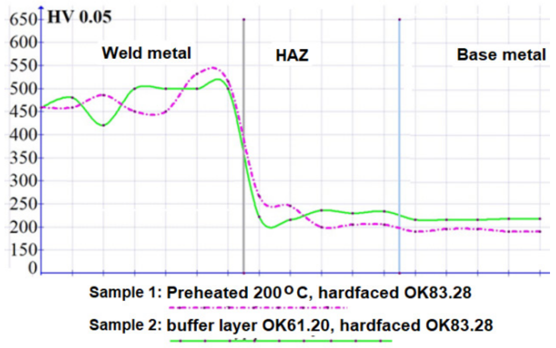

Figure 14. Microhardness Vickers $HV_{0,05}$

The graph shows the hardness changes in the depth of the surface-welded layer and in the heat-affected zone.

The measured microhardness in the zone of the surface welded metal is about 450-550 HV0.05. In the zone of thermal influence the hardness decreases to 250 hardness units and equalizes with the base metal (40X improvement steel). This makes it reasonable to assume that the welded layer is wear resistant, and in the heat-affected zone has a higher toughness, which is an indication of the absence of cold cracks.

To establish the actual wear resistance, dry friction tests were also performed on the two sample bodies and the weight loss was measured with a precision scale.

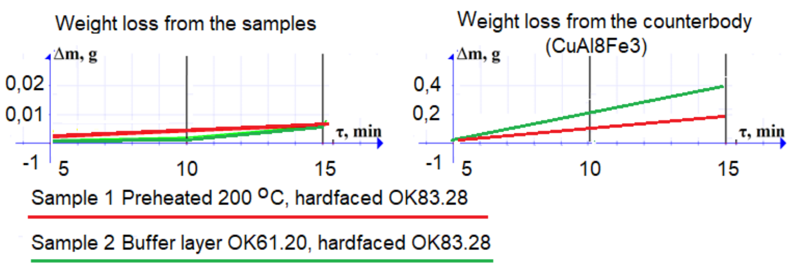

Figure 15. Weight loss from the samples and conterbody

The graphs show a uniform mass loss during the wear tests on both test specimens. The more intense wear of the counterbody (aluminium bronze) in specimens welded with a buffer layer (OK61.20) is likely caused by adhesive wear mechanisms.

During the dry friction wear tests, a record was also made of the temperature variation due to friction between the rotating sample bodies and the stationary counterbody of (CuAl8Fe3).

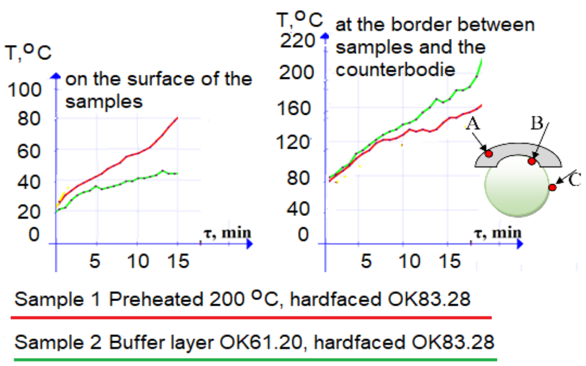

Figure16. Temperature recorded with thermo K-couples on the surface of the samples (C) and at the boundary between the samples and the counter body (B)

No significant temperature increase was recorded for the recorded test times, probably due to the good tribological properties of the contact bodies. The temperature in the counterbody (A) and the contact area (B) were found to be in similar ranges, so no graphical expression of the result is shown in Fig. 16.

4. Conclusion

The article addresses a current issue in heavy engineering and, in particular, ship repair related to the wear and restoration of components made from 40X steel. Based on the developed hardfacing technology, macro and microstructures of specimens have been created, and the conclusions can be summarized as follows:

An optimal preheating temperature (200°C) has been established before hardfacing, and the measured macro stresses are below the elastic limit of the examined metal.

It has been found that in the specimen with a buffer layer (OK 61.20), the thickness of the heat-affected zone is significantly narrower and finer-grained compared to the specimen welded without preheating.

Needle-like martensitic crystals are observed in the dendritic zone of the welded metal (OK 83-28).

Regarding the dry friction wear test, it can be concluded that the technology with preliminary heat treatment and without buffer layer (sample 1) shows better performance and warrants future research.

Regarding the structure of the welded layer, the buffer layer technology (specimen 2) shows a narrower heat affected zone and hence better mechanical performance due to the finer grain size of the structure in the HAZ.

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