Marko Ristić[1], Radica Prokić-Cvetković,[2] Boris Katavić[1], Ivana Vasović[1]

SELECTING HARDFACING TECHNOLOGIES FOR VENTILATION MILL SUCTION PLATES AND EXTENDING ITS WORKING LIFE

IZBOR TEHNOLOGIJA NAVARIVANJA USISNIH PLOČA VENTILACIONOG MLINA I PRODUŽETAK NJIHOVOG RADNOG VEKA

Originalni naučni rad / Original scientific paper
UDK /UDC: 621.791.92:621.928
Rad primljen / Paper received: 05.12.2015

Adresa autora / Author's address:
[1)] GOŠA Institute, Belgrade, Serbia, email: marko.ristic@insitutgosa.rs
[2)] University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia

Keywords
- ventilation mill
- coatings
- wear
- suction plate
- hardfacing

Ključne reči
- ventilacioni mlin
- prevlake
- habanje
- usisne ploče
- navarivanje

Abstract

This paper presents results of the suction plate surface modification by hardfacing, of the ventilation mill in the Kostolac B power plant. Before applying hardfaced suction plates to exploitation conditions, it is necessary to study model hardfaced samples for determining the optimal technology and filler material for revitalization. Experimental tests of revitalized mill suction plates in real exploitation conditions show that the proposed modification, hardfacing technologies and filler materials give good results. The relative weight loss of the suction plates after 1440 h period of exploitation in real conditions is 1-3%. The application of this approach can reduce the number of possible repairs and extends the period between them, resulting in significant economic effects.

Izvod

Ovaj rad prikazuje rezultate modifikacije usisnih ploča ventilacionog mlina na Termoelektrani Kostolac B pomoću tehnologije navarivanja. Pre nego što se primeni tehnologija navarivanja usisnih ploča i njihovo stavljanje u eksploataciju potrebno je uraditi modelna ispitivanja radi određivanja optimalne tehnologije navarivanja i određivanja odgovarajućeg dodatnog materijala. Eksperimentalna istpitivanja usisnih ploča u realnim eksploatacionim uslovima je pokazalo da je predložena modifikacija, tehnologija navarivanja i dodatni materijal daju dobre rezultate. Relativni maseni gubitak usisnih ploča nakon eksploatacije od 1440 č je 1-3%. Ovakav pristup rešavanju problema može dovesti do smanjenja broja redovnih remonta i produženja perioda između njih, a veliki uticaj će imati na ekonomsku uštedu.

INTRODUCTION

Wear is one of main failure mechanisms of materials and equipment and exists in many industrial fields, such as metallurgy, mining industries, energy sources and construction industry. Hardfacing coatings have been used widely in these industries because of the coatings' excellent abrasive wear resistance, /1-3/. The wear rate of hard coatings is controlled by several factors like the size and distribution of carbide particles, hardness of the carbide particles relative to the abrasive, properties of the matrix and its volume fraction and the coating process, which determines coating characteristics as phases, density and microhardness, /2-4/.

The main aim of this paper is to increase the wear resistance of the suction plates of ventilation mill for coal grinding in power plants, in order to define the optimal technology of revitalization by hardfacing. Working parts of the device, during exploitation are dominantly exposed to wear, resulting in the reduction of mill production capacity and its ventilator effects compared to the designed value, as well as frequent delays due to parts replacements, that significantly affects the productivity, economy and energy-efficiency of the system, /2-4/.

Multidisciplinary research of ventilation mills of thermal power plants includes a variety of theoretical, numerical, empirical and experimental methods of flow research, /6-10/.

In order to protect suction plates of the ventilation mill and extend their life, the process of hardfacing is selected to revitalize the components. This is a very useful procedure and an economical way to improve the performance of components submitted to severe wear conditions, /11-15/. Revitalization processes are unique, and this is why in practice there are no standard procedures for defining and applying the most optimal technology of reparation by hardfacing or the assessment of the remaining life of repaired components.

Previous experimental research indicates a linear dependence of abrasive wear resistance and mechanical properties of materials. Based on the mechanical properties, especially hardness, the behaviour of metals in conditions of wearing can be predicted, but hardness is not the only characteristic that affects the wear resistance and wear in general. Parameters which also affect the wear resistance, are the structure, shape, size and distribution of micro-constituents in the hardfaced coating. This experiment uses a wide area of resistance-to-wear complex materials alloyed with Cr, Mo, Nb, W, V, Ti, B, Co and other elements that create carbides, /12/.

By selecting a group of filler materials, before testing in the exploitation conditions, it is necessary to model test hardfaced samples in order to test the recommendations. Filler materials have been tested with standard test methods (mechanical and structural tests). After selecting optimal filler materials and technologies, it is implemented in the functional testing of revitalised parts of the ventilation mill.

The subject of this paper is the selection of optimal hardfacing procedures, filler material and hardfacing technology, based on results of numerical simulation, tribological, structural, and mechanical properties of samples from experimental hardfacing models. By applying these technologies it would reduce the number of possible emergency repairs and would prolong the period to complete necessary repairs.

MODEL STUDIES OF HARDFACING PROCESSES

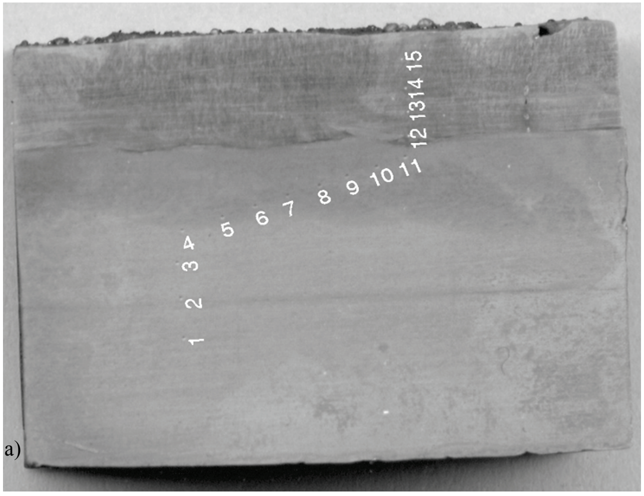
Before applying filler materials in exploitation conditions, it is necessary to test model hardfaced samples in order to verify the recommendations. One of the aims of the experiment, besides the known hardfacing alloys from the Fe-Cr-C system, is the application of new additional complex materials alloyed with Cr, Mo, Nb, W, V, Ti, B, Co and other elements, and to define technical requirements and procedures for the revitalization, and to expand the knowledge in the field of repair hardfacing of components in ventilation mills. Experimental research indicates an approximately linear dependence of abrasive wear resistance and mechanical properties of materials, /3/. Especially, hardness can predict the behaviour of metals in conditions of wear. The depth of penetration of abrasive particles and high hardness value is inversely proportional, /3, 19/. However, hardness is not the only characteristic that affects wear resistance and wear in general. Parameters also effecting the wear resistance besides hardness are the structure, shape, size and distribution of micro constituents in the hardfaced layer /3, 12-23/. The wear resistance of a hardfacing alloy depends on many other factors such as the type, shape and distribution of hard phases, as well as the toughness and strain hardening behaviour of the matrix, /4/. It is necessary to select an appropriate hardfacing alloy with optimal properties, great hardness and optimal resilience, that leads to reducing wear. In previous research, a wide scale of filler material resistance to wear is analysed, /12/, and for the purpose of this experiment, one group of filler material for model testing is selected, and a potential implementation in the functional testing is analysed.

Model testing of macrostructure is done. Diagrams of hardness distributions are plotted (Fig. 1, a and b), the zone of the surface layer and the HAZ, as well as the degree of mixing for all hardfaced samples are defined. In addition, microstructural analyses obtained by scanning electron microscopy (SEM) and EDS analysis, also present the results of tribological tests. The choice of applied filler materials and hardfacing procedures in the hardfacing of ventilation mill suction plates is made based on the results of this research.

The optimization of ventilation mill performances is achieved by correlating the technological process and the state of the main working parts. Numerical simulation of multiphase flow, based on the available parameters, has indicated the modes of failure of system components, and facilitates in eliminating the causes. Model studies are based on results of tribological, structural and mechanical properties of samples from experimental hardfacing model.

EXPERIMENTAL PROCEDURE OF MODEL TESTING

Samples of dimensions 250×200×15 mm, made of hot-rolled S355J2G3 (EN 10025-2) steel sheet, are prepared and used as substrates. In order to prevent the inclusion formation in weld deposits, prior to the welding operation, the oxide layers are removed from the substrate surface by means of grinding. Before hardfacing, samples are preheated to T_p = 160-170 °C. Conventional welding processes are used: manual metal arc welding (MMA); shielded metal arc welding (SMAW); and gas welding (G). Upon hardfacing, coatings are air-cooled down to room temperature.



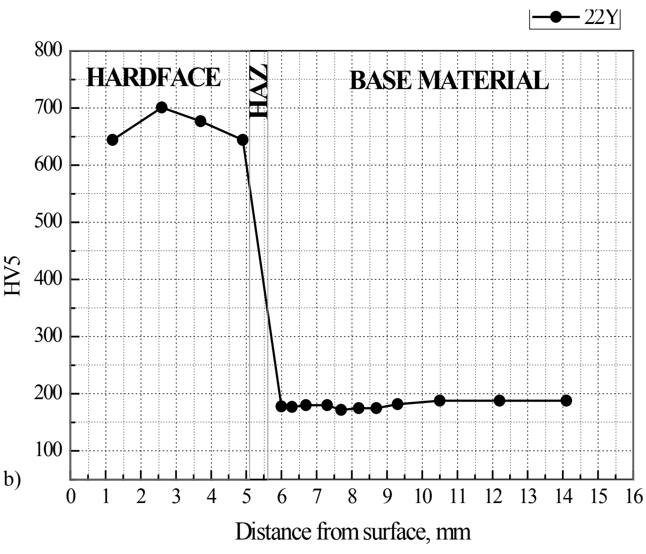


Figure. 1. a) Macrostructure of 5006, b) Distribution of hardness in cross section of sample hardfaced with Fe-Cr-C-Si (5006).

The filler materials used are presented in Table 1, with hardfacing procedures, nominal chemical compositions and commercial name, manufactured by Castolin Eutectic Co, Ltd, Vienna. The most important condition for the MMA, SMAW and G processes is the weld plate low degree of mixing and the manufacturing cost of welding consumables. Hardfacing is carried out by technological lists with defined parameters (power, voltage, welding speed, line energy, preheating of materials and coatings, and application method of coatings), /12/.

Table 1. Filler materials and hardfacing procedures.

Hardfacing electrode	Nominal chemical compositions	Process hardfacing
Xuper AbraTec 5006	Fe- Cr-C- Si	MMA
ULTIM112	Fe-C-W- Co-Ni-Si	MMA
390 NDO	Fe-Cr-W-B-Nb-Mo-C	SMAW
7888T	WC-Ni-Cr-Si-B, matrix with WC	G

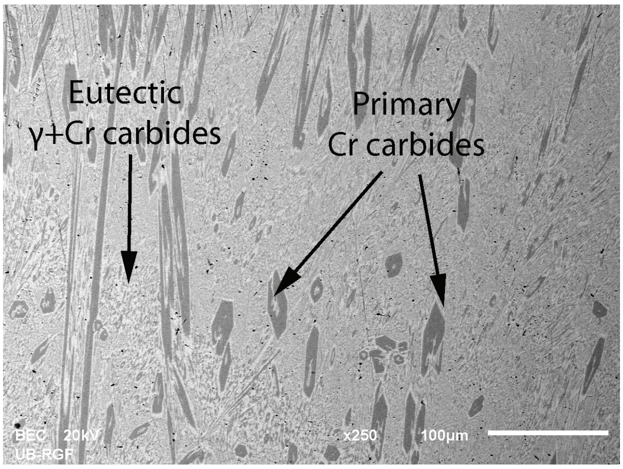
RESULTS AND DISCUSSION OF MICROSTRUCTURAL ANALYSIS AND HARDNESS TESTS

The numbers of layers, the average thickness of hardfaced coating and the degree of mixing and hardness values of the hardface are given in Table 2, depending on the type of filler material and hardfacing process.

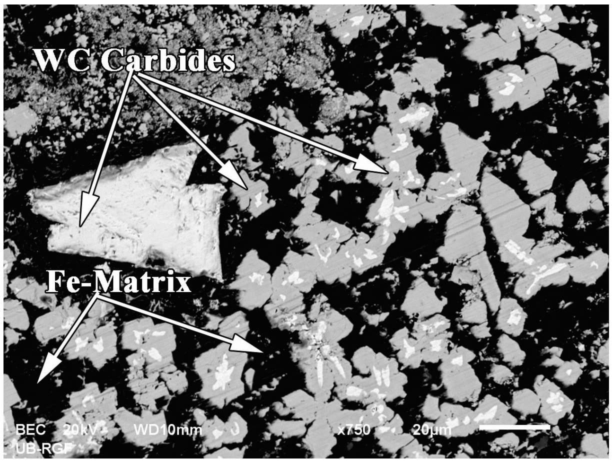
Table 2. Characteristics of hardface coating.

Filler material	No. of layers	Thickness (mm)	Degree of mixing (%)	Hardness, HV5
Xuper AbraTec 5006	2	5.2	11	644-701
ULTIM112	2	3.7	44	825-966
390 NDO	2	7.0	11	927-946
7888T	2	1.6	33	644-677

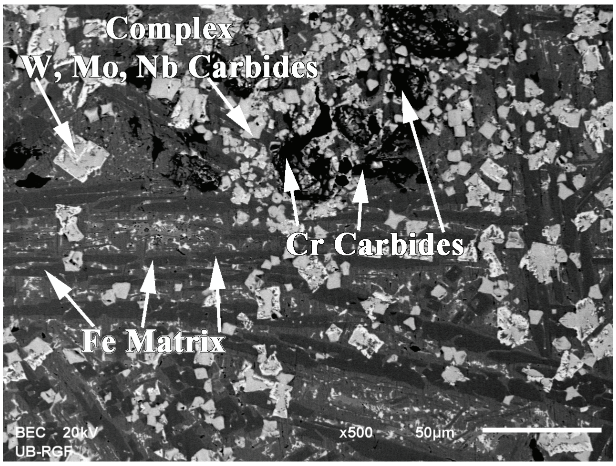
The low degree of mixing (11%) is achieved in hardfaced samples with 5006 (MMA) and 390NDO (SMAW) filler material. Maximum hardness is achieved in samples hardfaced with alloy 390NDO (SMAW) and ULTIM112 (MMA). Besides this, the variation in hardness can be explained by the distribution of different phases along the depth of the hardfacing deposit, as is evident from typical near-surface structures (Fig. 2).



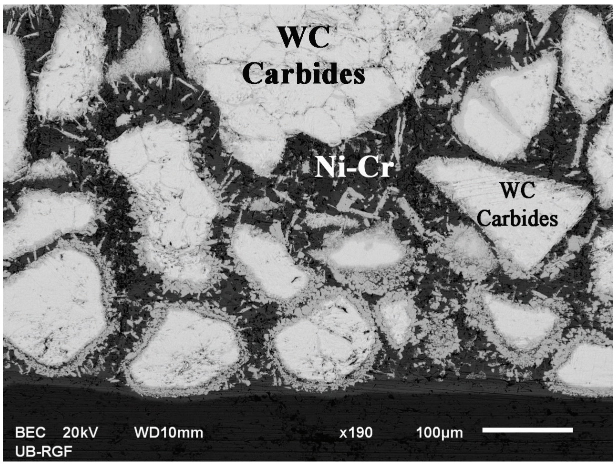
a)



b)



c)



d)

Figure 2. Structures of samples, a) 5006/2, b) ULTIM112/2, c) 390 NDO/2, and d) 7888T/2, with hardfaced coatings (back-scattering electron images).

SEM micrographs with EDS of different phases of hardfaced coatings samples Xuper AbraTec 5006 and 7888T are shown in Figs. 3 and 4. The EDS data, given in Table 3, indicate on different matrix compositions and the presence of carbides in hardfacings.

During solidification the filler material 5006 achieves near-eutectic structure with a dominant presence of blade-like primary Cr-carbides (Fig. 6a and Table 3). In the hardfaced sample with filler material ULTIM 112 there is presence of polygonal WC carbides in the Fe-matrix, Fig. 2b.

The chemical composition and the morphology (Fig. 2b and Table 3) suggests the presence of phases with fine WC carbide and primary austenite with eutectic carbides, /10-12/. Recent studies have shown that an increase of retained austenite in the martensite-carbide structure increases the resistance to wear, regardless of the same decrease in hardness, /2, 3, 5, 10-12/.

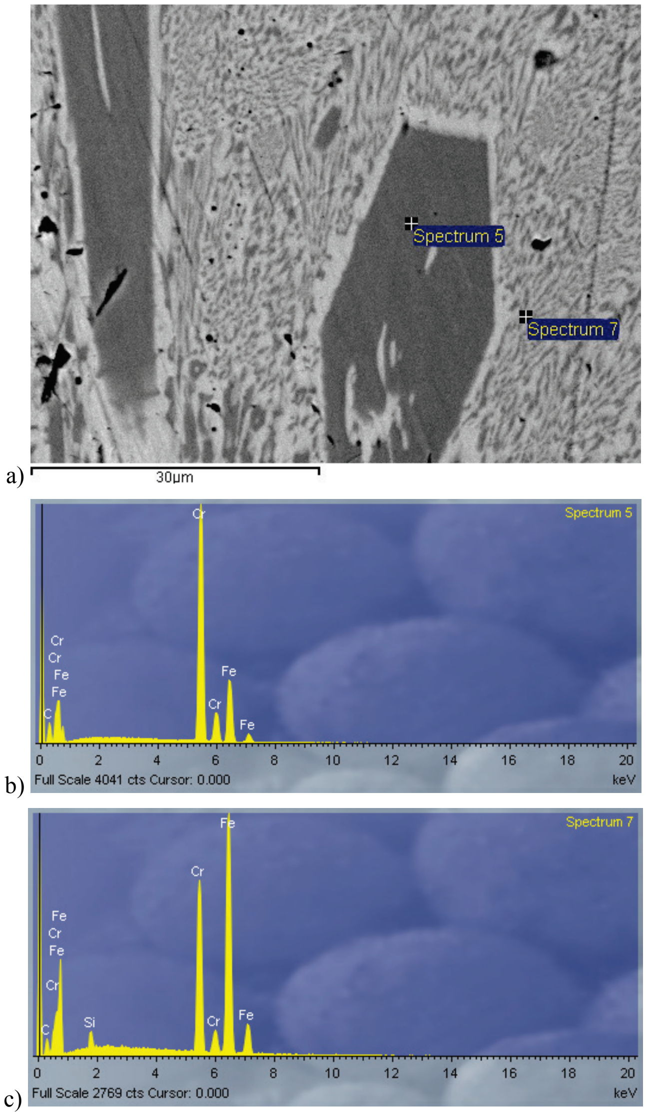


Figure 3. a) SEM micrograph and EDS of hardfaced sample Xuper AbraTec 5006, b) EDS of primary Cr-carbides, c) EDS of matrix FeCrC.

The microstructure of the W-rich deposit is composed of proeutectic MC-type carbides surrounded by eutectic structure containing M_6C-type (fishbone-type) carbides and some martensite, /6/. Deposit contains a high density of tungsten carbide (WC) in a ferrous-based matrix (M) with increased hardness.

The sample hardfaced with material 390N NDO (Fig. 6c and Table 3) shows a homogeneous distribution of carbides and a complex carbide polygonal and spherical shape, /7, 10-12/. As the complex carbide fraction increases, hardness and wear resistance improve, /2, 3/.

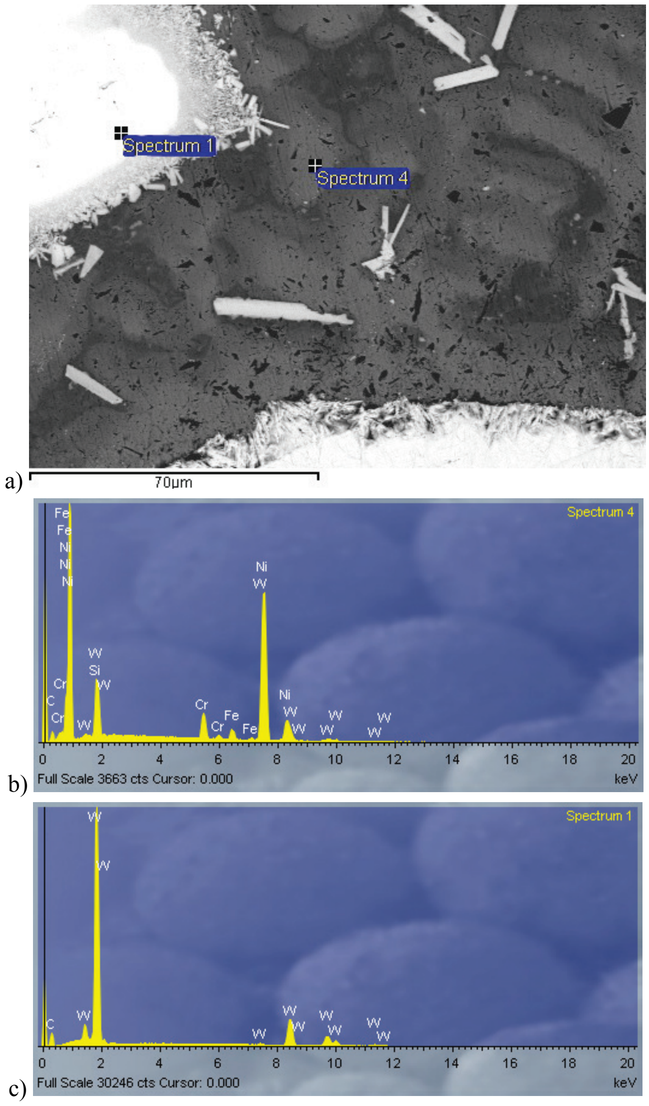


Figure 4. a) SEM micrograph and EDS of hardfaced sample 7888T, b) EDS of matrix NiCrBFe, c) EDS of WC carbides.

Table 3. EDS chemical composition of the phases in Xuper AbraTec 5006, ULTIM112, 390 NDO,7888T (mas. %).

Samples	Phas.	C	Fe	Ni	Cr	Nb	Mo	W
Fe- Cr-C- Si (5006)	M	6.56	64.29	/	26.97	/	/	/
	MC	11.87	26.40	/	61.46	/	/	/
Fe-C-W-Co-Ni-Si (ULTIM112)	M	7.67	79.69	0.50				5.75
	MC	10.39	5.22	/				83.93
Fe-Cr-W-B-Nb-Mo-C (390NDO)	M	3.47	83.81	/	8.73	/	1.07	1.45
	MC	4.35	22.88	0.25	18.25	7.55	16.26	30.55
WC-Ni-Cr-Si-B (7888T)	M	6.39	47.36	33.56	2.29			6.62/
	MC	9.28	/	/	/	/	/	90.72

M-matrix, MC-carbides (M-MC forming elements: Cr, Mo, Nb, W, B

Samples hardfaced with 7888T indicate a homogeneous distribution of larger carbides of polygonal and spherical shape (Fig. 6d). EDS data shown in Table 3 indicate that hardfaced layer is a phase with high content of W, Cr, Ni, Nb, Fe and C. Present carbides are the primary, special carbides type WC which are embedded in the Ni-Cr based matrix, /3, 12, 22/. As the special carbide fraction increases, the hardness and wear resistance improve, /2, 3/.

TRIBOLOGICAL TESTING

Tribological analysis of these coatings is just another to be done to completely understand the behaviour of hardfaced coatings. Tribological tests are carried out on the pin-on-disc tribometer according to the standard test method for pin abrasion testing (ASTM G 132) in ambient air at room temperature (≈ 25°C). Testing was performed under normal load of 5 N, i.e. under specific normal load-pressure of 0.25 MPa (taking into account the contact area of approximately 20 mm^2). Sliding distance of 30 m was constant, with an average sliding velocity of 0.2 m/s. The testing parameters were chosen such as to match approximately the exploiting conditions and to provide reasonable amount of wear, i.e. at least 1 mg loss. In order to achieve a higher confidence level in evaluating test results for each material, at least five runs were performed and the results are averaged. Before and after testing, pins were degreased and cleaned with benzene. Mass loss was used to calculate the wear intensity for each material. The value of friction force was monitored during the test and through data acquisition system stored in the PC, enabling the calculation of friction coefficient. The results of the wear tests are presented in Fig. 5. Hardfaced coatings obtained the expected deviations due to the inhomogeneity of these materials.

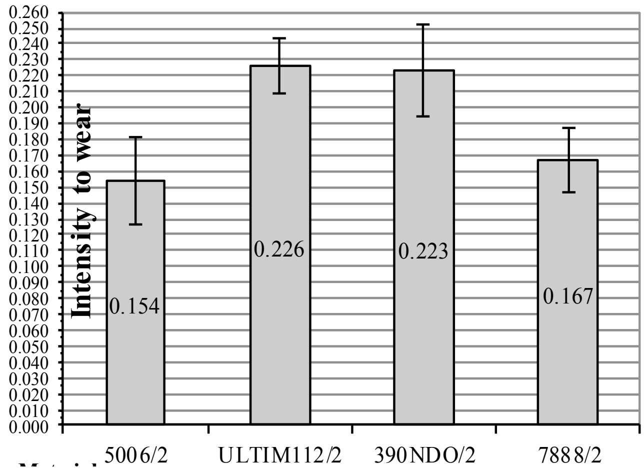


Figure 5. Ranking of tested materials on the basis of resistance to abrasive wear.

The coefficient of friction (given in Table 4) is a mean stationary value (of the period when its value has stabilized after 20 to 25 m). The obtained values are expected for pure abrasive wear and they generally follow the wear intensity values. Samples with a higher coefficient of friction had a higher intensity of wear.

Table 4. Stationary friction coefficient with corresponding deviations.

Material/ coating	5006/2	7888T/2	390NDO/2	ULTIM112/2
Coefficient of friction	0.378	0.420	0.430	0.386
Deviation of friction coeff. %	3.4	4.2	5.5	4.4

Tribological tests carried out on the tribometer which belong to the sixth category of tribological tests. The results are primarily aimed at comparing different materials in relation to only abrasion resistance and the preliminary selection of the best one. Based on Fig. 7, it is observed that samples with filler materials 5006 and 7888T showed higher resistance to abrasive wear compared to other samples.

The best abrasion resistance was obtained in microstructures composed of eutectic matrix and primary M_7C_3 or MC carbides sample 5006. Good abrasion resistance achieved in filler material 7888T contains large WC carbides in Ni-Cr matrix, /6, 8, 23/. The coating of sample (5006) of Cr-rich deposits has an eutectic matrix with proeutectic M_7C_3-type chromium carbides, which were identified by EDS-SEM due to their large size. Samples coated with ULTIM112 and 390NDO show less abrasion resistance. Those materials are Fe-base matrix with inserted W, Cr, Mo, Nb complex carbides. These two materials have higher hardness values, /31, 32/. Another important factor in abrasion resistance is the carbide orientation. Carbides in the coating deposits show carbides elongated in direction normal to the interface between the hardface and the substrate. The M_6C tungsten carbides (fishbone-type) also contributed to prevent the cutting effect of abrasive particles in the W-rich deposit. Tungsten carbides in W-rich deposits had different response as a function of their shape and size: M_6C carbides absorbed high amounts of plastic deformation, while MC carbides were broken by the abrasive particles, /20, 21, 22/.

FUNCTIONAL TESTING

Suction plates are one of the vital parts that are exposed to the most intensive wear and therefore were chosen to be modified. Results, obtained by numerical simulation show that suction plates are subjected to intensive erosive wear at elevated temperatures up to 235°C, /21, 22/, which can lead to damages and reduction of mill capacity.

In the process of choosing the hardfacing technology, previous knowledge of the shape and dimensions of the workpiece is important, as well as chemical composition and structural - mechanical properties of materials, hardfacing method and characteristics of the filler material. The process of hardfacing is used as appropriate because of mobility of equipment, the rate of application of materials, wide range of filler materials, etc. Compared to welding, the hardfacing procedure is carried out under conditions which allow obtaining the least possible penetration, and a lower degree of dilution in order to possibly preserve the properties of weld metals, which are, in general, considerably different from the base material, as far as possible, /12, 23/. Numerical simulation has analysed the rate of mixture of gases with particles of coil, sands, other mineral material and their acting pressure on suction plates.

On the basis of the model testing, experimental results of surfacing with the selection of optimal hardfacing technologies and (coating) materials is carried out, and definition of technology specifications for surfacing of suction plates. With the application of new technologies for hardfacing with different filler materials on prepared surfaces of mill suction plates, improvements in wear resistance can be expected. Based on the numerical flow simulation around the suction plates, model testing of a wide group of filler material wear resistance is presented. The new innovative hardfacing technology is applied for the mill suction plates. Thirty five of the modified plates (hardfaced suction plates) are installed in the ventilation mill and are functionally tested. Three filler materials, (5006, ULTIM 112 and 390 NDO) and two hardfacing procedures (manual metal arc welding and shielded metal arc welding) are selected for the redesign of suction plates.

Suction plates are made of low alloy cast steel GS 36Mn5 according to DIN 17204, /27/. Model experiments are performed with S355J2G3 (EN 10025-2) steel and also it is necessary to be perform weldability analysis of alloy cast steel. The analytic evaluation of weldability and the prediction of the effects of thermal cycles of hardfacing on the microstructure and properties of the low alloy cast steel GS 36Mn5 are done, /21/.

Results suggest that cast steel GS 36Mn5 is conditionally weldable by using conventional welding processes, but with appropriate precautions. During welding it is needed to take care of preheating temperature, heating rate, cooling and interpass temperature, and also the thermal cycle of welding. Results of analytical evaluation by using the software of the Japanese Institute of Welding (*Weld simulator*, /20-22/) show the following: it is possible to eliminate the possibility of cold cracking with higher preheating temperature than that obtained by calculation, /21/.

For functional testing two procedures of welding:MMA and SMAW with three filler materials of different chemical composition are selected. During the testing of hardfaced samples a low degree of mixing is achieved, but it is necessary to further decrease mixing and to maintain hardfaced material characteristics. For achieving a reduced degree of mixing hardface and base materials on the whole group of thirty-five suction plates, a puffer layer with austenitic electrode 18/8/6 (EN 1600) is used. Puffer layer carried out with FCAW (flux core wire) process by wire thickness 1 mm and parameters 150-170 A, 21-25 V and wire feeding speed of 18-19 cm/min, gas velocity is 10 l/min.

A set of hardfacing of first eleven suction plates is carried out with filler material 5006 (Castolin Eutectic) by MMA. Hard coating is done with wire thickness 3.2 mm in two layers with parameters I = 130 A, U = 28 V with preheat temperature 170°C and interpass temperature 170°C. The second set of twelve suction plates is carried out with the MMA process and 390NDO (Castolin Eutectic) filler materials. Hard coating is done with wire thickness 4 mm in two layers with parameters I = 170 A, U = 36 V, preheat temperature 200°C and interpass temperature 150-170°C. The third set of twelve suction plates is carried out with ULTIM112 (Castolin Eutectic) filler materials by SMAW (shield metal arc welding). Hard coating is performed with wire thickness 1.6 mm in two layers with parameters I = 160 A, wire feed speed 15 cm/min, gas flow 14 l/min, preheat temperature 200°C and interpass temperature 175-260°C.

Hard coatings are placed on two longitudinal, previously ground and cleaned front surfaces of suction plates. A scheme of hardfaced plate is presented in Fig 6. and appearance of the suction pates after hardfacing is shown in Fig. 7.

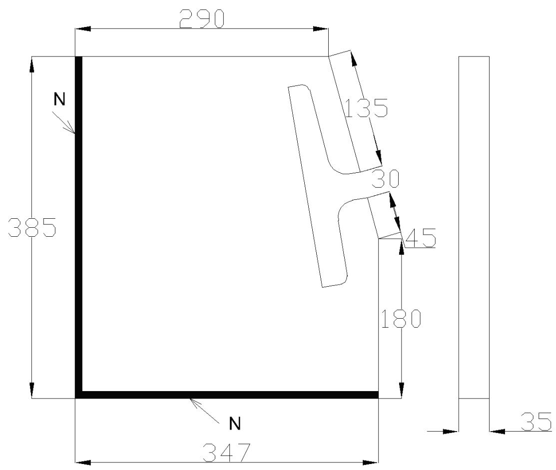


Figure. 6. Scheme of hardfacing suction plates.

Figure 7. Hardfaced suction plates.

The average height of the hardfaced layer is ≈ 5 mm. Coatings are done at the middle of suction plate faces, because it is very important that hardfaced layers do not exceed from the plate surface and reduce the gap when they are packed in the ventilation mill. Figure 8 shows mounted hardfaced suction plates in the ventilation mill. The whole set of thirty-five hardfaced suction plates (positions shown by arrows) are installed in one ventilation mill and functionally tested at same conditions and same rules.

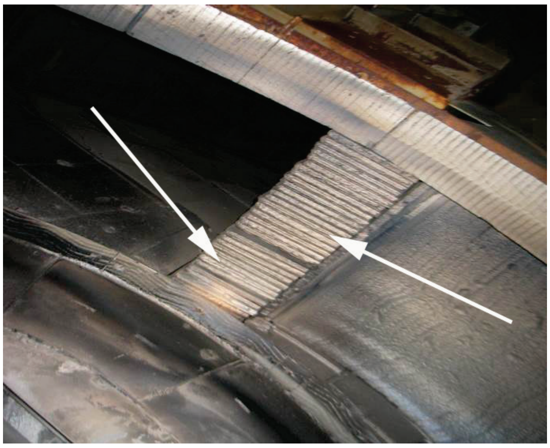


Figure 8. Mounted hardfaced suction plates in ventilation mill ready for testing in real conditions.

TESTS IN REAL EXPLOITATION CONDITIONS

The set of all thirty-five suction plates are installed in one ventilation mill and functionally tested in similar conditions and by the same rules. After 1440 h of exploitation in the same conditions, the plates are disassembled and their masses are measured. Typical appearance of suction welded plate after exploitation (Fig. 9) shows significant wear resistance of hardfaced layers. During exploitation there was no change in dimensions of plates. The comparative overview of hardness and relative weight loss in % for hardfaced and original non-modified suction plates of cast steel G-36Mn5 and hardfaced suction plates after exploitation are given in Table 6.

Figure 9. Suction plates after exploitation frontal area

Table 6. Hardfacing (coating) materials and procedures.

Filler material	Composition of filler material	Coating hardness, HRC	Weight loss (%)
Base metal G-36Mn5	Fe-C-Mn	38	3.9
5006	Fe- Cr-C- Si	≈ 59	3.0
ULTIM112	Fe-C-W- Co-Ni-Si	≈ 66	2.2
390NDO	Fe-Cr-W-B-Nb-Mo-C	≈ 69	1.8

Comparative quantitative and visual analyses have indicated that suction plates hardfaced with filler materials 5006 have 3.0% of weight loss but filler materials 390NDO have 1.8% of weight loss and greater resistance to wear, compared to the original suction plates with 3.9% weight loss. Filler material ULTIM112 is in the middle with 2.2% weight loss. Functional tests have pointed to the possibility of reducing the suction plate wear with modified working surface compared to the existing ones. The application of this approach can reduce the number of possible repairs and extend the period between them, resulting in significant economic effects.

CONCLUSION

On the basis of the experimental tests of model testing, the selection of critical area, optimal hardfacing technologies and filler materials for suction plate revitalization are carried out.

Hardface carbides are noticed in the microstructure with different shape, size and composition, depending on the chemical composition of filler material. In white irons with high content of Cr carbides in dominate rod-like form, and in alloys with W, Nb, B, Mo, etc. there are also complexes of polygonal and spherical shaped carbides. Hardface hardness increases with a greater presence of complex carbides of polygonal and spherical shapes. Coatings with lower hardness showed lower abrasive wear resistance, but the dependence (hardness vs. wear rate) is nonlinear.

Based on model testing, the hardfacing is performed on suction plates with one group of filler materials. After the hardfacing, suction plates have been installed in ventilation mill in order to test them in real conditions of exploitation. Whole set of 35 suction plates done by three filler materials are put into one ventilation mill for testing under in the same conditions. After 1440 h of operation, comparative, quantitative and visual analyses indicated that hardfacing of suction plates goes from 3.0% of weight loss with filler materials 5006 to 1.8% of weight loss with 390NDO, and higher resistance to wear compared to original plates with 3.9% of weight loss. Functional tests have pointed to the possibility of reducing wear in suction plates with a hardfaced working surface compared to the existing ones. Because the plates have lost a small amount of mass from the original, it is possible to continue further operation in the ventilation mill.

The application of this approach can reduce the number of possible repairs and extends the period between them, and gives significant economic effects. Experimental functional tests of revitalized mill wearing parts in real exploiting conditions show that the proposed modification, hardfacing technologies and filler materials give good results. Research results are applied in the Kostolac B thermal power plant and can be used for other parts in these and in similar facilities.

ACKNOWLEDGEMENT

This paper is the result of research within the project TR 34028, financially supported by the Ministry of Education, Science and Technological Development of Serbia, Messer Tehnogas, and PD TE – KO Kostolac.

REFERENCES

1. Metals Handbook, 9th Ed., Volume 18, Friction, Lubrication and Wear, ASM, Metals Park, Ohio, ISBN978-1-61503-163-4, pp.320-380, 1993.
2. Perković, B., A. Mazurkijevič, V. Tarasek, Lj. Stević, *Reconstruction and realization of the projected modernization of power block B2 in the TE Kostolac*, Termotehnika 1, pp.57-81, 2004.
3. Kazemipour, M., H. Shokrollahi, Sh. Sharafi, *The influence of the matrix microstructure on abrasive wear resistance of heat-treated Fe–32Cr–4.5C hardfacing alloy*, Tribol Lett Vol.39, pp.181-192, 2010.
4. Prokolab, M., S. Budimir, M. Kočić, *Structural and mechanical properties of different hard welded coatings for impact plate for ventilation mill*, Welding and Material Testing 3, pp.7-11 (ISSN 1453-0392), 2011.
5. European Product Catalogue, Wear and Fusion Technology, Castolin Eutectic International Co, Vienna.
6. Holleck, H., *Material selection for hard coatings,* J Vac. Sci. Technol. A, 4(6): 2661-2669, 1986.
7. Buchely, M.F., J.C. Gutierrez, L.M. Le´on, A. Toro, *The effect of microstructure on abrasive wear of hardfacing alloys*, Wear 259: 52-61, 2005.
8. Šolar, M., Bregant M., *Filler materials and application for repair welding*, Welding and Welded Structures, 51(2): 71-77, 2006.

9. Wang, V, F. Hanb, X. Liu, S. Qua, Z. Zoua, *Microstructure and wear properties of the Fe–Ti–V–Mo–C hardfacing alloy*, Wear 265: 583-589, 2007.
10. Kirchganer, M., E. Badisch, F. Franek, *Behavior of iron-based hardfacing alloys under abrasion and impact*, Wear, 265: 772-779, 2008.
11. Zhou, Y., Z. Huang, F. Zhang, S. Jing, Z. Chen, Y. Ma, G. Li, H. Ren, *Experimental study of WC–Co cemented carbide air impact rotary drill teeth based on failure analysis*, Engng. Fail. Analysis, 36: 186-198, 2013.
12. Hou, L., Y. Wei, Y. Li, B. Liu, H. Du, C. Guo, *Erosion process analysis of die-casting inserts for magnesium alloy components*, Engng. Fail. Analysis, 33: 457-464, 2013.
13. Correa, E.O., Alcantara, N.G., Tecco, D.G., Kumar, R.V., *Development of an iron-based hardfacing material reinforced with Fe-(TiW)C composite powder,* Metall. and Mater. Trans., 38 A(5): 937-945, 2007.
14. Seong-Hun, C., Chang, K.K., Kvangjun, E., Sunghak, L., Jae-Young, J., Sangho, A., *Correlation of microstructure with the wear resistance and fracture toughness of hardfacing alloys reinforced with complex carbides,* Metall. and Mater. Trans., 31 A(12): 3041-3052, 2000.
15. Santanu, Kr.R., Prasanta, N., Mani, S.M., *Development of chromium-rich hardfacing welded deposit using in-situ carbo-thermic reduction,* J of Mater. Sci. Lett., 11: 1469-1470, 1992.
16. He, B., L. Zhu, J. Wang, S. Liu, B. Liu, Y. Cui, L. Wang, G. Wei, *Computational fluid dynamics based retrofits to reheater panel overheating of no.3 boiler of Dagang power plant*, Comp. & Fluids, 36: 435-444, 2007.
17. Thermo investigation and analysis of boiler plant blocks B1 and B2 in Kostolac TE, PD Ltd. Production–technical sector, (internal study in Serbian), 2014.
18. Katavić, B., B. Jegdić, M. Prokolab, M. Prvulović, S. Budimir, Z. Milutinović, *Optimal parameters estimation by the analytical methods for the welding of the GS-36Mn5 steel*, Congress - Welding 2012 & NDT 2012, Proc. of abstracts, ISBN 987-86-82585-10-7, pp.51-51, 2012.
19. www.it.jwes.or.jp/weld_simulator
20. Katavić, B., Jegdić, B., Odanović, Z., Hut, N., Mladenović, M., Jaković, D., Ristivojević, M., *Prediction of optimal parameters of repair welding steel 13CrMo4-5 by analytical methods*, Welding & Welded Struc. (*Zavarivanje i zavarene konstrukcije*), 55(3): 91-96, 2010.
21. Vencl, A., B. Gligorijević, B. Katavić, B. Nedić, D. Džunić, *Abrasive wear resistance of the iron and WC based hardfaced coatings evaluated with Scratch Test method*, Trib. in Industry, 35(2): 123-127, 2013.
22. Gligorijević, B.R., A. Vencl, B.T. Katavić, *Characterization and comparison of carbides morphologies in the near-surface region of single- and double-layer iron-based hardfaced coatings*, Sci. Bull. of the 'Politehnica' Univ. of Timisoara, Romania, Trans. on Mech., ISSN 1224-6077, 57(71): 15-21, 2012.
23. Wang, Q., Z.H. Chen, Z.X. Ding, *Performance of abrasive wear of WC-12Co coatings sprayed by HVOF*, Trib. Intern., 42: 1046-1051, 2009.