Structural and mechanical properties of different hard welded coatings for impact plate for ventilation mill

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Abstract

Ventilation mill for grinding coal is one of the main steam power plants in the system that makes a significant influence on the level of energy efficiency with its work. Working parts of the device during exploitation are dominantly exposed to intensive abrasive and erosive wear and also to impact loading at elevated temperatures, which can lead to damage and fracture of homogeneous materials, thus shortening their working life. The consequences are the reduction in mill production capacity and its ventilatory effects compared to the projected value, as well as frequent delays due to parts replacements, that significantly affects the productivity, economy and energy-efficiency of the system.

In order to determine the optimal technology for revitalization of the damaged impact plates the experimental model-hardfacing was engaged and different technologies and additional materials were used. Three technologies arc-hardfacing were applied (MMA, SMAW and gas welding - G) and eight additional materials with different chemical composition and properties (Fe-Cr-C-Si, Fe-Cr-C-Si-Ti, Fe-C-W-Co-Ni-Si, Fe-Cr-W-B-Nb-Mo-C, W-Fe-C and WC-Ni-Cr-Si-B). The aim of this paper is to make the selection of optimum welding procedures and additional materials and hardfacing technology definition based on the results of structural and mechanical properties of samples of experimental model hardfacing. Cutting the samples for mechanical and structural tests is performed with water jet cutting using hardfaced test plan. Investigation of its macrostructure has been done, diagrams of distributions of hardness have been made, zone of the surface layer and HAZ-a, and the degree of mixing for all hardfaced samples have been defined. In addition, microstructural analyses were obtained with optical (OM) and scanning electron microscopy (SEM). The choice of additional materials and hardfacing procedures which were applied in the hard facing impact plates ventilation mill has been made based on the results of this research paper.

Introduction

Hardfacing is a surface treatment method to improve the surface properties of metal, in which a welding metal that has excellent resistance to wear and oxidation is homogeneously deposited onto the surface of a substrate [1]-[4]. Many examples of hardfacing materials tend to be alloys containing hard carbides [5].

In practice, the repair welding is applied for the revitalization of homogeneous and welded components in order to protect them and extend their life. The damaged metal must be replaced with new undamaged, so that the work life for all components satisfy safety requirements to the next full control. Each revitalization of hardfacing is a unique process, so in practice there are no standard procedures for defining and applying the most optimal technology of reparation by hardfacing or the assessment of remaining life of repaired components. A special problem is a complex procedure of checking the quality of hardfaced sample. Process optimization of working of the plant, in this case the ventilation mill is achieved by the necessary correlation between the technological process and condition of working parts.

Deviation from the required working parameters can widely be a result of damaged working parts, as evidenced by the size of interval of the ventilation effect of the mill. Revitalization of these components by welding, or hardfacing is increasingly being applied to power plants. As the importance of revitalization of welding in the maintenance of power plants becomes bigger and bigger, beside the procedures, the new additional materials are being engaged that provide longer lifetime of parts exposed to wear with its structural - mechanical properties. The final goal of modern technologies for revitalization is that the life of a component, or appropriate material from which it is made, is at least equal to or longer than predicted, or that is really possible to define periods of regular control.

In the case of ventilation mill there is predominantly abrasive wear and erosion at elevated temperatures [6]. In many applications, where excellent wear resistance and sufficient impact resistance are required, hardfacing alloys modified with the composite particles may be advantageous, as the presence of composite powders in the microstructure of hardfacing alloys may improve their wear resistance without greatly sacrificing toughness [5]. Experimental research indicates a linear dependence of abrasive wear resistance and mechanical properties of materials. Specifically, based on the mechanical properties, especially hardness, the behavior of metals in the conditions of wearing can be predicted. The depth of penetration of the abrasive particles with high hardness is inversely proportional to the hardness of the surface layers. However, hardness is not the only characteristic that affects the wear resistance and wear in general. Parameters, which also affect the hardness wear resistance, are the structure, shape, size and distribution of microconstituents in the welded layer. Microstructural components in proportion to its hardness, the relative share and the distribution, affect the level of resistance to wear. Based on previous research, it can be concluded for the intensity of abrasive wearing affect the following factors: the nature and characteristics of the abrasive, aggressive working environment, the operating speed and load, and material properties of working parts, or their contact surfaces [2]-[4]. In addition, the intensity of abrasive wearing increases with increasing the temperature above the critical value. Based on above mentioned parameters, we select the additional materials for the revitalization of parts by hardfacing.

In recent years, in the area of resistance to abrasion and erosion, the technologies of surfacing have been developed or are developing, which use more complex materials alloyed with Cr, Mo, Nb, W, V, Ti, B, Co and other elements [1]-[5]. The nano technology is used in making any additional materials. Full chemical composition in not known for the certain number of additional materials in aim to protect them from the competition.

In addition, unlike the traditional technologies, in the implementation of some additional materials the heat treatment is not used before and after model hardfaced samples. Besides the price of model hardfaced samples, this certainly affects the ability to perform model hardfaced samples, which is often limited by performing heat treatment before and after model hardfaced samples. Practical advantages are reflected in the higher operational and easier performance process with less volume of testing during revitalization by hardfacing. However, before applying these materials in the exploitation conditions, it is necessary to test model hardfaced samples in order to test the recommendations.

One group of additional layers of materials for hardfacing resistant to abrasion are alloys based on Fe and Ni, which contain the following elements: C% 0.2-7.5; Cr% 5-40; No ≤ 4% or without Ni, Mn% ≤ 4 or without Mn ; Mo% ≤ 9 or without Mo, W% ≤ 9 or without W, V% ≤ 10 or without V, Nb ≤ 10% or without Nb and others. The second group of additional materials are so called hard metals, composites with a matrix based on Fe and Ni and WC particles of different shape and size [2]- [5].

The main goal of this research is, beside the known hardfacing alloys from the system of Fe-Cr-C, the conquest of the application of new additional complex materials alloyed with Cr, Mo, Nb, W, V, Ti, B, Co and other elements. Defining technical requirements and procedures for revitalization and expanding the knowledge in the the field of repair hardfacing work pieces ventilation mills. By applying these technologies it would reduce the number of possible emergency repairs and it would prolong the period to complete the necessary repair facilities, which would achieve significant economic effects and also increase the energy efficiency of thermal power plants.

Experimental part

The additional materials used in this study were Fe-Cr-C-Si, Fe-Cr-C-Si-Ti, Fe-C-W-Co-Ni-Si, Fe-Cr-W-B-Nb-Mo-C, W-Fe-C and WC-Ni-Cr-Si-B manufactured by Castolin Eutectic Co., Ltd, Vienna. The table 1 presents the hardfacing procedures, signs and nominal chemical composition of additional materials, which are used in hard facing test samples. Hardfacing was carried out on samples which were hot-rolled steel sheet S355J2G3. 200 x 250 x 15 mm, in one, two and three coats.

Table 1: Additional materials and hardfacing procedures

Hardfacing electrode	Nominal chemical compositions	Process hardfacing
5006	Fe- Cr-C- Si	MMA
4541 EC	Fe-Cr-C-Si	MMA
6710	Fe-Cr-C-Si/Ti 0.2	MMA
4010 EC	Fe-Cr-C-Si/Ti 0.18	MMA
Ultim 112	Fe-C-W-Co-Ni-Si	MMA
DO*48	W- Fe-C	SMAW
390N DO	Fe-Cr-W-B-Nb-Mo-C	SMAW
7888 T	WC-Ni-Cr-Si-B, matrix with WC	G

Hardfacing was carried out under the following conditions (Table 2) depending on the procedure and the type of additional material. In Fig.1 the appearance of welded samples is shown.

Table 2. Condition of hardfacing

MMA	d electrode (mm)	3.2; 4; 5
	I (A)	100 – 180
	U (V)	16 – 55
	v (cm/min)	10 - 12
	En (kJ/mm)	1.2 – 4.8
	Tp (^{0}C)	160 - 170
SMAW	d wire (mm)	1.6
	I (A)	110 – 170
	U (V)	19 – 30
	v (cm/min)	10 - 41
	En (kJ/mm)	0.3 – 2.4
	Tp (^{0}C)	160 - 170
	Vgas (l/min)	12 – 16
G	d wire(mm)	1.6
	Vgas (l/min)	1.5 – 1.7
	Tp (^{0}C)	160 - 170

Before testing the model, hardfaced samples are preheated at Tp = 160-170 ^{0}C and cooled in ambient air.

Fig.1: Hardfaced sample with two layers (4541EC)

Microstructual Analysis and Hardness Test

The microstructures of the hardfacing alloys were analyzed, and their hardness were evaluated. Cutting the samples to analyse the structure and hardness was carried out by the water jet on the plane perpendicular to the surface of hardface. Structural tests were carried out on polished samples etched with a solution of 3pct Nital (macrostructure) and 60 cm^3 HCl + 20 cm^3 HNO_3 + 40 cm^3 glycerin (microstructure) with standard optical microscopy (OM) and scanning electron microscopy (SEM) with EDS. Also, the measurements of hardness in the cross section of hardfaced samples was made(Vickers HV5). Based on the results the diagrams of hardness distribution have been made and the zone of hardface, HAZ and base material, as well as the degree of mixing for all hardfaced samples has been defined.

Results and discussion

Figures 2a and 3a show the measurements of the macrostructure of samples hardfaced with two layers, with additional material 4541EC, and the three-layers DO 390N, and the Fig. 2b and 3b show the measurements of the distribution of hardness in the zone of hardface, the transition zone and the base metal.

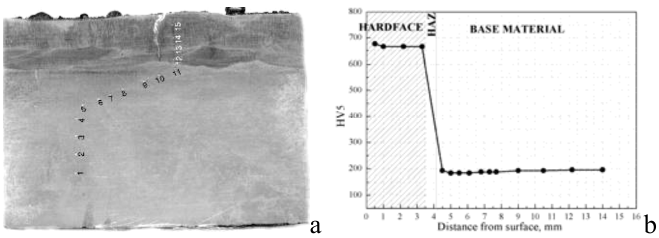


Fig 2: a) macrostructure and b) distribution of hardness in cross section of the sample hardfaced with MMA in two layers with additional material 4541 EC

The numbers of layers, the average thickness of hardface, the degree of mixing and hardness of hardface were given in table 3, depending on the type of addititon material and process of hardfacing.

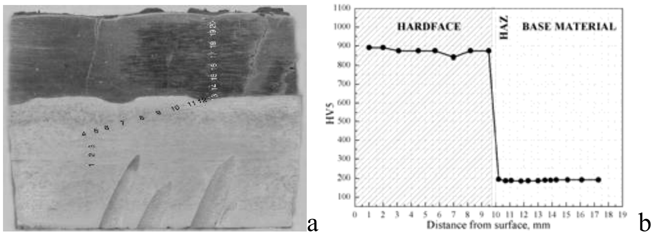


Fig 3: a) macrostructure and b) distribution of hardness in cross section of the sample hardfaced with SMAW in three layers with additional material 390N DO.

Table 3: Characteristics of hardface

Addition material	Number of layers	thickness mm	Degree of mixing, %	Hardness, HV5
5006	1	3.1	28	487-781
	2	5.2	11	644-701
4541 EC	1	2.5	27	739-739
	2	3.5	26	666-677
6710	2	7.2	21	841-874
	3	9.8	19	677-739
4010 EC	2	6.8	22	781-810
	3	8.4	13.5	701-874
Ultim 112	1	2.7	62	1027-1120
	2	3.7	44	825-966
DO*48	2	3.5	23	739-781
	3	7.1	12	766-781
390N DO	2	7.0	11	927-946
	3	9.7	5	841-891
7888 T	1	1.6	33	644–677

The low degree mixing of 11% is achieved in a double layer hardfaced samples with alloys 5006 (MMA) and 390NDO (SMAW). Surfacing patterns in three layers hardfaced samples SMAW process with alloys 390N DO and DO 48 get the lowest degree of mixing of 5 and 12%. In all welded samples is an obvious decrease the hardness layer with increasing thickness layer and number of layers. Decrease in hardness is the result of slower cooling of layer. The maximum of hardness is achieving by welded with alloy Ultima 112 (MMA) and390N DO (SMAW). Beside that, the variation in harddness can be explained by the distribution of the different phases along the depth of the hardfacing deposit, as was evident from microstructural investigation (Fig.4-6).

Figures 4, 5, 6 and 7 are an optical micrograph of the hardfaced samples after etching. In 5006 hardface sample a larger number of primary carbide rods sizes from 50 to 250 micrometers is present, than in the samples 4010EC and 390N DO. It has been reporeted that large primary carbides, which are indentified to be $(Cr,Fe)_7C_3$, are formed from the melt of the hardfaced electrodes and exhibit columnar growth with a hexagonal cross section [7]-[9].

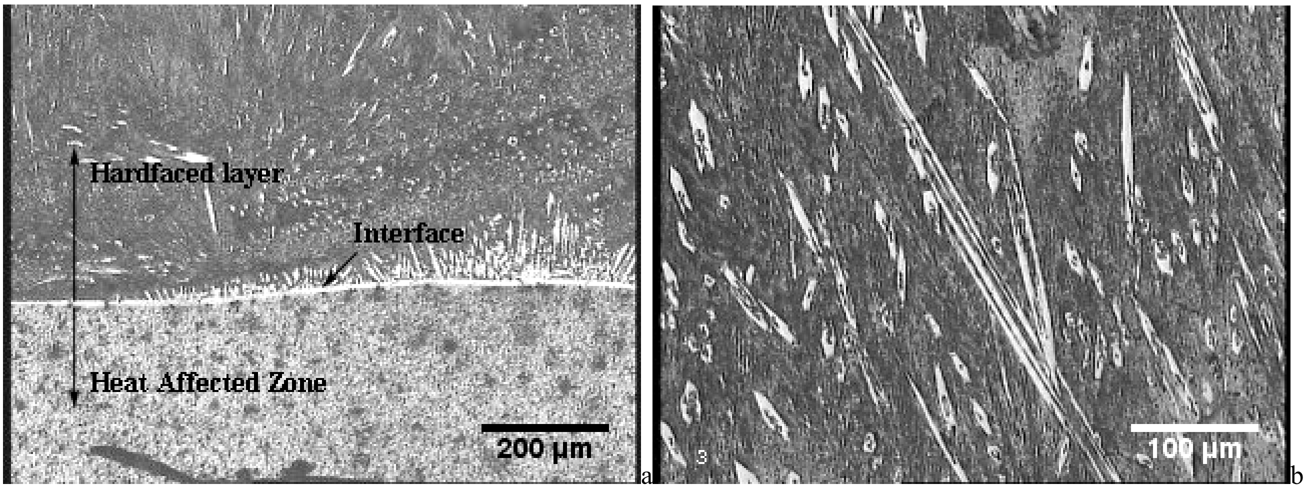


Fig 4: Optical micrograph (OM) of sample hardfaced with two layers of alloy 5006:
a) basic material - hardface, x100, b) surface of layer of hardface, x200

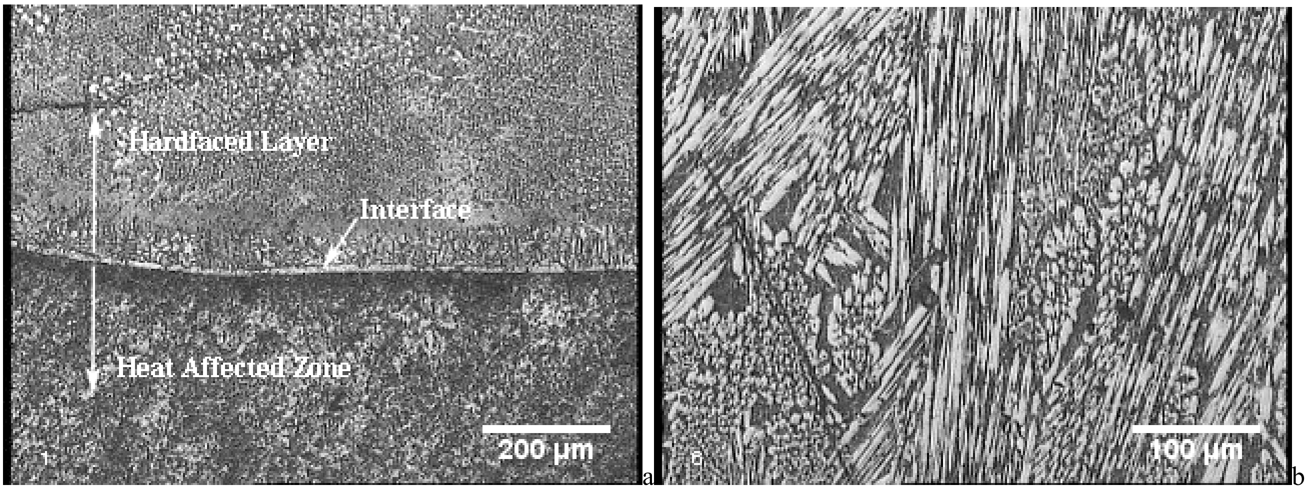


Fig 5: Optical micrograph (OM) of sample hardfaced with three layers of alloy 4010 EC:
a) basic material - hardface, x100, b) surface of layer of hardface, x200

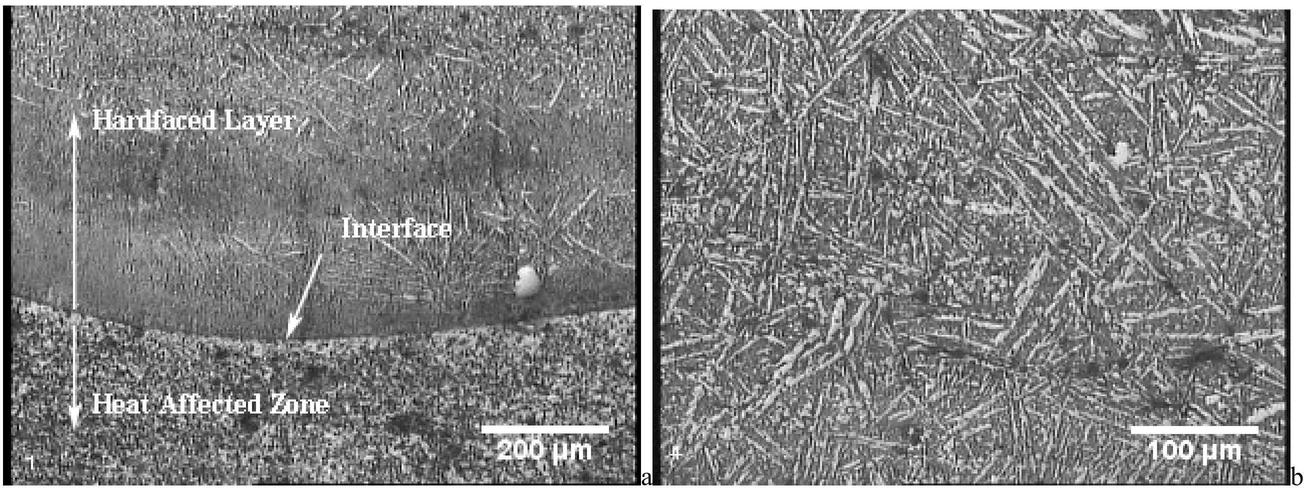
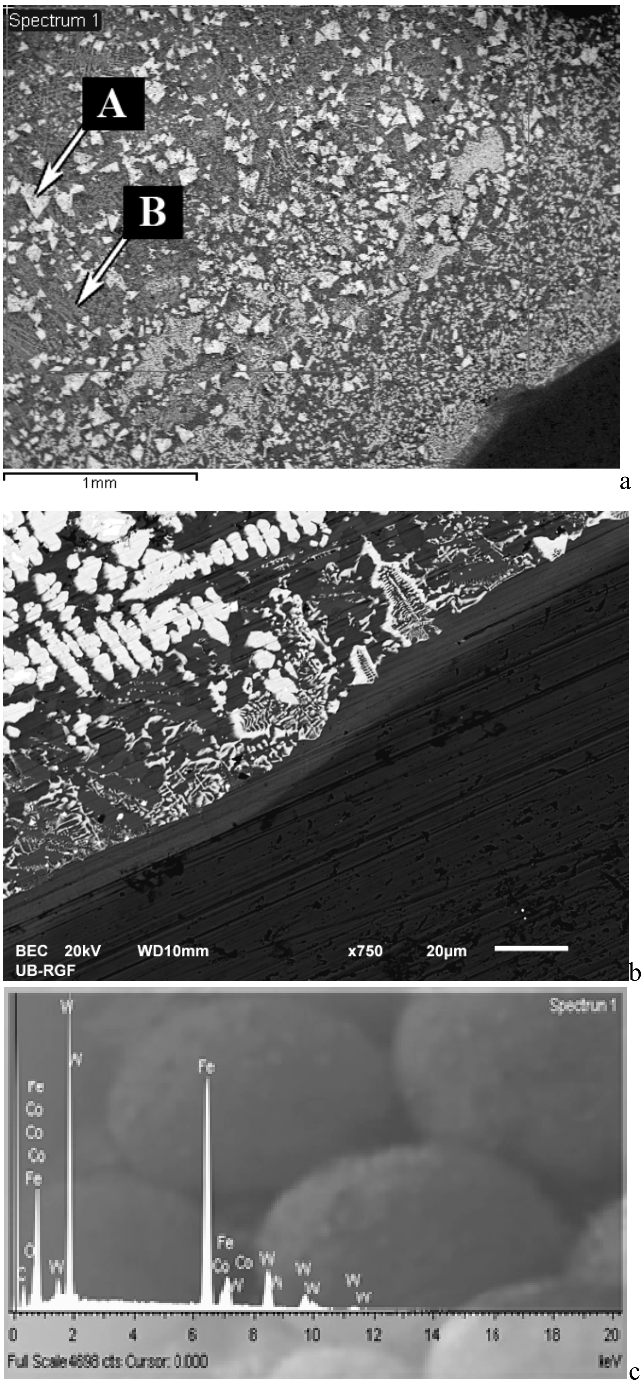


Fig 6: Optical micrograph (OM) of sample hardfaced with three layers of alloy 390N DO:
a) basic material - hardface, x100, b) surface of layer of hardface, x200

Beside that, the samples hardfaced 4010EC and 390N DO show a homogeneous distribution of carbide and complex carbide polygonal and spherical [5], [7]-[9]. As the complex carbide fraction increases, hardness and wear resistance improve [1]-[3]. The microstructures of hardfaced specimens were observed by an scanning electron microscope (SEM) and their chemical compositions were examined by energy-dispersive spectroscopy (EDS). Figure 7 (a) through (c) are SEM micrographs with EDS of the hardfaced layer (a and c) heat-affected zone HAZ (b) of hardfaced electrode Ultima 112.



a b c

Fig. 7: SEM micrograph of a) hardfaced layer, b) heat-affected zone HAZ and EDS of Ultim 112 sample

Table 4: Chemical composition of the phases in alloy Ultim 112, mas %

Phases	C	Si	Fe	Co	Ni	W
HL	9.74	0.48	45.89	3.62	0.42	40.27
WC	13.19	0.00	1.41	0.00	0.00	85.40
M	7.67	0.80	79.69	5.60	0.50	5.75

The EDS date shown in table 4 indicate that hardfaced layer is phase with high content of W, Co and C. Deposit contains a high density of tungsten carbide (WC) in a ferrous based matrix (M) with increased hardness.

The chemical composition and the morphology (fig. 7 and tab. 4) suggest that phase A is fine WC carbide and B is primary austenite with eutectic carbides [7]-[9]. Tubular electrode developed for extra hard coatings (68-72 HRC) on alloy and low-alloy steels [7], [9]. Recent studies have shown that an increase of retained austenite in the martensite - carbide structure increases resistance to wear regardless the same drop in hardness [1]-[3], [7]-[9].

Conclusion

Test of the structure and hardness hardface samples hardfaced by different procedures and additional materials indicated the following:

1. Increase in thickness or number of layers of hardface reduces the degree of mixing and hardness of hardface.

2. In the microstructure of hardface carbides were noticed with different shape, size and composition depending on the chemical composition of additional material. In white irons with high contents of Cr carbides in the dominate form of bars, and in alloys alloyed with Ti, W, Nb, B, Mo, etc. there are also complex of polygonal carbides and spherical sizes.

3. Hardface hardness increases with a greater presence of complex carbides of polygonal and spherical sizes. It can be assumed that in this way the resistance to wear will increase,too.

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