

WEAR RESISTANCE IMPROVEMENT OF THERMAL PLANT FAN MILL IMPACT PLATES BASED ON NUMERICAL FLOW SIMULATION

POBOLJŠANJE OTPORNOSTI NA HABANJE UDARNIH PLOČA VENTILACIONOG MLINA U TERMOELEKTRANI PRIMENOM NUMERIČKE SIMULACIJE STRUJANJA

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Adresa autora / Author's address:

¹) VTI (Military Technical Institute), Belgrade, Serbia
email: mkozic@open.telekom.rs

²) Central Institute for Conservation, Belgrade, Serbia

³) Institute Goša, Belgrade, Serbia

⁴) ICTM – Inst. of Chemistry, Technology & Metallurgy, Belgrade, Serbia

⁵) University of Belgrade, Innovation Centre of the Faculty of Mech. Engng., Belgrade, Serbia

Keywords

- thermal power plant
- wear
- fan mill
- multiphase flow
- CFD

Abstract

Numerical simulation of 3D multiphase flow is performed to determine the velocity field in the fan mill. The mixture model of the Euler-Euler approach is used. Recirculating gas is a primary phase that carries granular phases including the coal powder and sand. The latter causes heavy wear of mill impact plates. The optimal form of hardfacing geometry and technology has an impact both on velocity magnitude and direction of flow in such a way as to reduce plate wear. This paper presents results of surface modification (based on numerical simulation), implemented on impact plates of the fan mill in the Kostolac B power plant in Serbia. Fishbone hardfacing is made in order to increase the lifetime of impact plates and extend the period between overhauls of fan mills. The experimental tests of fishbone surfacing plates, in exploitation conditions, show that the applied modification, hardfacing technologies and coating materials, give expected results. The application of this hardfacing in the form of a fishbone is simpler, faster and more economical compared to complete overlaying and honeycomb impact plate surfacing. The relative weight loss of base plate after an 1440-hour period of exploitation is 8%, while the weight losses for the hardfaced plate is below 7%.

INTRODUCTION

An increasingly attention to the efficiency of thermal power plants is paid in today's world. Many experimental and numerical studies have been conducted for increased efficiency of boilers, ducts, fan mills and other subsystems of thermal power plants.

An efficient and stable combustion of pulverized coal particles depends on the physical and chemical properties of coal, the diameter of coal particles and other operating

Ključne reči

- termoelektrane
- habanje
- ventilacioni mlin
- multifazno strujanje
- CFD

Izvod

Numeričke simulacije 3D višefaznog fluida su vršene s ciljem da se odredi brzinsko polje u ventilacionom mlinu. U numeričkim simulacijama je korišćen model mešavine u Euler-Euler pristupu. Recirkulacioni gas je primarna faza koja nosi granularne faze ugljenog praha i peska. Pesak je izazvao veliko habanje udarnih ploča. Optimalne forme geometrije i tehnologije navarivanja imaju uticaj na brzinu i pravac strujanja smeše i na stepen habanja udarnih ploča. Ovaj rad predstavlja rezultate površinske modifikacije, primenjene na udarnim pločama ventilacionog mlina u termoelektrani Kostolac B, Srbija. Ploče su navarene u obliku riblje kosti, s ciljem da se produži radni vek ploča i period između remonta mlinova. Eksperimentalna ispitivanja ploča sa navarenom površinom u obliku riblje kosti u realnim eksploatacionim uslovima su pokazali da predložena modifikacija (tehnologija i materijali navarivanja) daju dobre rezultate. Pokazalo se da je navarivanje u obliku riblje kosti jednostavnije, brže i ekonomičnije u odnosu na navarivanje u obliku saće. Relativni gubici u težini osnovnih, nenavarenih ploča nakon 1440 časova eksploatacije su 8%, dok su gubici navarenih ploča ispod 7%.

conditions like temperature, pressure and parameters of fluid-dynamic state of the gas mixture, /1-8/. In Kostolac B power plant in Serbia the coal is pulverized in the fan mills. The system includes eight fan mills of EVT N 270.45 type, with a nominal capacity of 76 t/h of coal. The description of structural and technical characteristics of the fan mill are described in /1-3/. Pulverization of coal into fine particles is made to increase the specific surface area, to optimize the rate of heat and mass transfer between the coal particles and carrier gas phase, /1, 3-7/.

Fan mills are complex systems. Multiphase flow of recirculation gases composed of coal powder, sand and other materials has direct impact on wear of its vital parts, /2, 3, 9-11/. Power plant equipment is exposed to severe erosion and corrosion problems resulting in substantial losses, decreasing of fan efficiency, time period between two repairs and life span. The consequences are reduction in production capacity and energy efficiency, /2/.

The more detailed study of the flow field is important for optimisation of the mill operation and wear reduction of its components, /9-11/. There are different methods of experimental and numerical investigations of the flow, but numerical simulation is the most economical, fastest, and a very reliable method of analysing complex multiphase flow and its optimisation, /12-15/. The velocity amplitude and distribution of sand particles are the main cause of grinding wheel element wear. Numerical and experimental analysis of results presented in /10/ indicate that pulverizing fan failures are mainly caused by inappropriate structural design and harsh operating conditions. The paper /11/ carried out root cause analysis of crack failures occurred in pulverizing wheels of fan mills, applied in 600 MW steam turbine units of a power plant. The numerical results obtained using numerical flow simulation in a real system serve as a useful tool in optimising the geometry of the mill-duct system. Multiphase flow visualization can be used for prediction of the regions with strong wear conditions, /15-19/.

A small number of numerical studies have been conducted for numerical simulation of the multiphase flow in fan mill and duct all the way to the burners. The paper /17/ gives the results of multiphase flow simulation inside the fan mill in Kostolac B power plant in Serbia. The multiphase flow simulations of dilute gas-solid are performed in order to obtain the sand velocity vectors for different surface geometry of mill impact plates and for selecting the optimal redesign of impact plates. One way of mill optimisation and revitalization of its parts is the application of new hardfacing technologies. A new method of impact plate hardfacing is proposed. It is a surface treatment method, selected to improve surface properties of the material in which a welding metal, with excellent resistance to wear and oxidation, is deposited onto the surface of the original plates. Impact plate hardfacing is initially performed in the form of 'honeycomb', using two processes and four types of filler material. Functional tests have confirmed results of numerical simulations related to sand particle trajectories both on the surface of the original plates and on honeycomb surfacing ones.

Results of fishbone hardfacing of impact plates are presented here. The application of this modification is simpler and cheaper than the honeycomb modification, reducing the number of possible repairs and gives significant economic effects.

NUMERICAL MODEL

There were two possible approaches in solving any multiphase problem: the Euler-Lagrange approach and the Euler-Euler approach in the commercial ANSYS FLUENT

software package. In the Euler-Lagrange approach, the fluid phase is treated as a continuum, whereas the dispersed phases are solved by tracking a large number of particles through the calculated flow field. Although the granular secondary phases occupied a low volume fraction in our case, this approach is not convenient because the velocity vectors relative to rotating impact plates are solved, whereas the injections had to be defined in the stationary absolute frame. That is why the Euler-Euler approach is chosen.

The appropriate model depends on particulate loading, defined as the mass density ratio of the dispersed phase to that of the carrier phase. The particulate loading has the most important influence on the degree of interaction between phases. According to the average distance between individual particles of the dispersed phases in the considered multiphase flow, the particles can be treated as isolated, i.e. the particulate loading is very low. It means that the carrier fluid influences the solid particles by turbulence and drag, but the particles have no influence on the carrier. In such a case, the discrete phase Euler-Lagrange, mixture and Eulerian model are applicable. However, the mixture model is recommended because it is as good as full Eulerian models in cases where the coupling between phases is strong, or when the interphase laws are unknown. Also, the Eulerian model is the most expensive because a large number of nonlinear highly coupled transport equations have to be solved.

In the mixture model, different phases are considered as inter-penetrating continua with volume fractions as continuous functions of time and space. The sum of volume fractions for all phases in each computational cell is equal to one. It is the simplified multiphase model that can be also used in modelling flows where the phases move at different velocities using the concept of slip velocities. In this model the continuity, momentum and energy equations for the mixture, the volume fraction equations for each secondary phase and algebraic expressions for slip velocities between phases are solved.

For the pressure-velocity coupling, an extension of the SIMPLE algorithm to multiphase flow is used, i.e. the Phase Coupled SIMPLE one. The velocities are solved coupled by phases. The block algebraic multi-grid scheme is applied in solving a vector equation in terms of the velocity components of all phases simultaneously. A pressure correction equation is based on total volume continuity. Velocity components and pressure are corrected in such a way to satisfy the continuity constraint.

NUMERICAL FLOW SIMULATION INPUT DATA

First, the geometrical model of the mill including the grinding wheel with impact plates is prepared. Then, for the base plates - an unstructured tetrahedral grid is generated with 1 491 254 volume elements and 3 113 974 surface elements, whereas for the modified ones the corresponding number of elements are 2 457 831 and 5 164 609. Figure 1 shows the geometrical model of the fan mill and cross section through the volume mesh for fishbone-like impact plates.

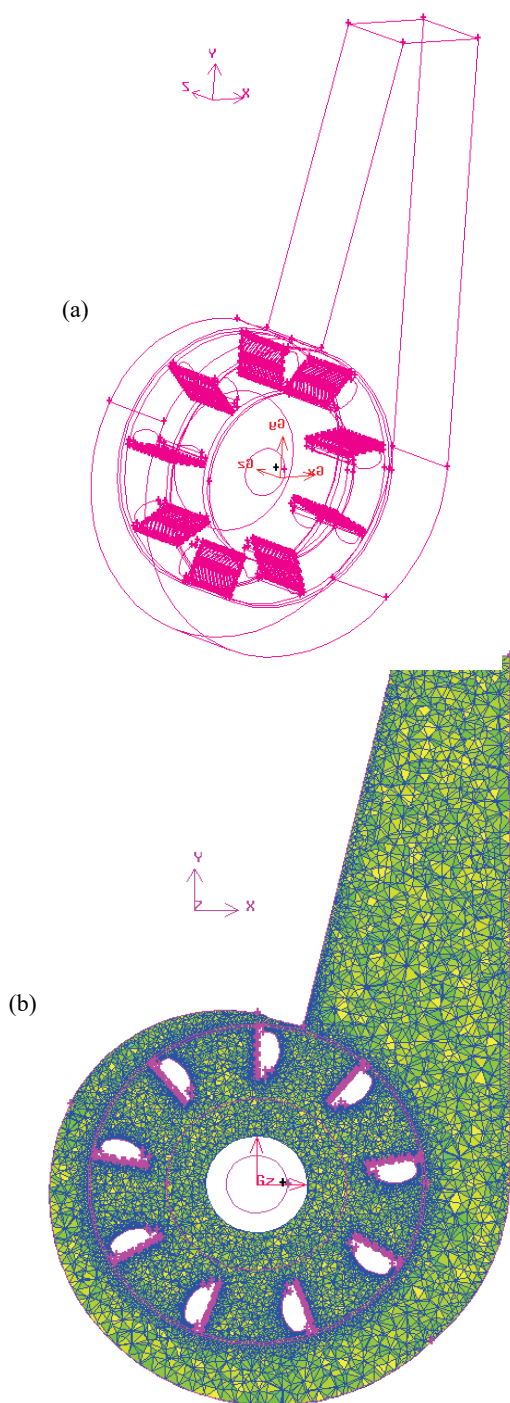


Figure 1. (a) Geometrical model of fan mill; (b) cross section through volume mesh in numerical domain.

Three phase flow is calculated where recirculating gas is the primary phase, whereas the lignite powder and sand are secondary phases. The coal powder and sand are modelled as mono-dispersive granular phases with particle diameters equal to $150\ \mu\text{m}$ and $300\ \mu\text{m}$, respectively. Particles weight and drag are accounted for. Restitution coefficient equal to 0.9 is chosen for collisions between granular phase particles.

The standard no-slip boundary condition is applied at all walls including the mill impeller that rotates with 490 rpm. Its rotation is modelled using multiple reference frames

(MRF) option that is essentially quasi-steady. The adiabatic thermal boundary condition is applied at all walls. At the mill exit, an outflow boundary condition is applied satisfying overall mass flow rate. The velocity defined at the mill inlet satisfies the volume flow rate of recirculation gases, obtained by experimental measurements, [17].

The mixture $k-\varepsilon$ turbulence model is used that is the extension of the single-phase $k-\varepsilon$ model, applicable in cases when phases separate.

RESULTS OF NUMERICAL SIMULATION FOR ORIGINAL AND FISHBONE PLATES

Since the multiphase flow is calculated in a rather complex geometry including mill impeller and housing, results of numerical simulations are obtained under some limitations described in detail in [17]. The calculations are done using the second-order scheme. Obtained results are shown in the form of relative velocity vectors on the impact surface of the original and modified plates.

Magnitude and direction of the sand velocity vectors along the impact surface of the plates have predominant influence on plate wear. On the basis of the velocity magnitude the plate placed at 30° after the most upright position, and one at 60° after the lowest position are chosen for checking. In Fig. 2a and 2b, relative velocity vectors are shown for these two plates. The maximal velocity magnitude of sand particles is about 96 m/s, causing strong damage on the plate impact surface. It can be seen that directions of the sand relative velocity vectors obtained by numerical simulation and the noticed damages on impact surfaces of the original impact plates agree very well.

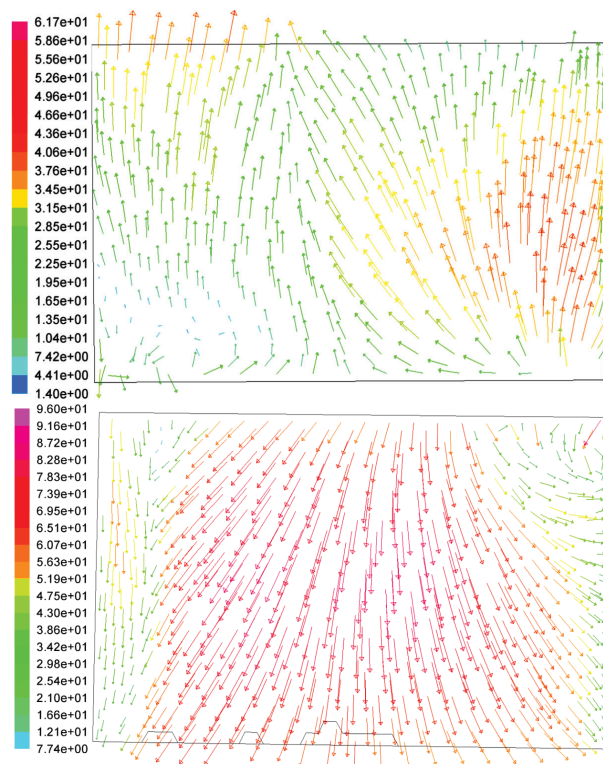


Figure 2. Relative velocity vectors on front surface of base impact plate at: (a) 30° after the most upright position; (b) 60° after the lowest position.

The application of the new modification, proposed here is simpler and cheaper than the honeycomb modification. The results of fishbone hardfacing of impact plates are presented. Geometry of the fan mill with modified plates and plate surface mesh are shown in Fig. 3.

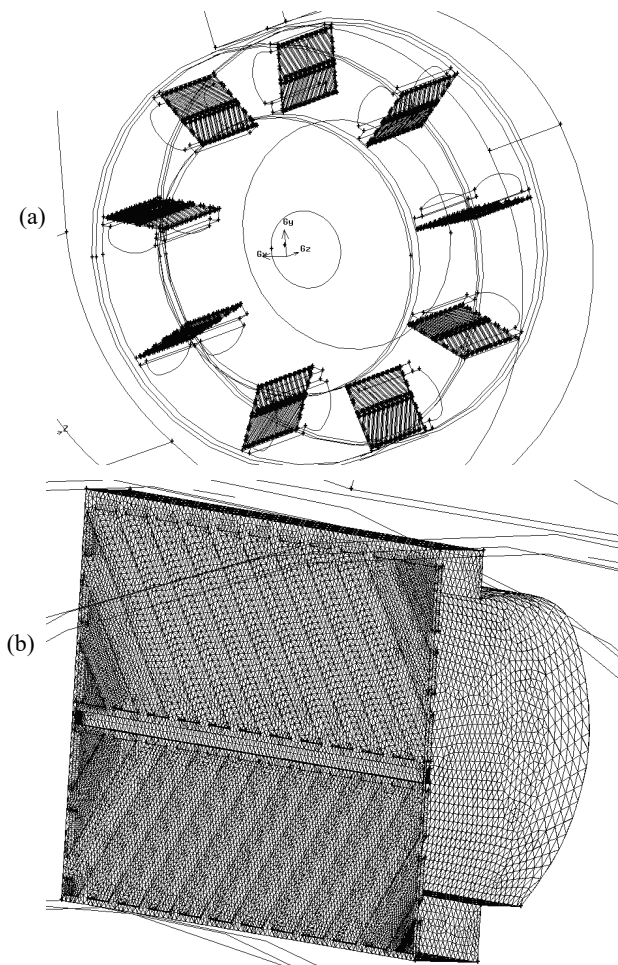


Figure 3. Geometrical model of: (a) fan mill with modified plates; (b) surface mesh of modified impact plate.

In Fig. 4a and 4b relative velocity vectors of the sand are shown for fishbone impact plates at two previously defined positions. Compared with the relative velocity vectors for the original plates, the two facts are obvious. First, the velocity magnitude decreases on the whole impact surface. Secondly, the direction of velocity vectors on some parts of the impact surface changes in such a way to follow the direction of the added fishbone-like material. Both of these facts affect the reduction of wear of the impact surfaces.

FISHBONE HARDFACING IMPACT PLATES AND EXPERIMENT RESULTS IN REAL CONDITIONS

Based on the numerical flow simulation around original and modified impact plates presented above, the new fishbone hardfacing technology is applied for mill impact plates. Impact plate hardness is not only a characteristic that affects the wear resistance and wear in general. Parameters which also effect the wear resistance are the structure, shape, size and distribution of micro-constituents in the hardfaced layer.

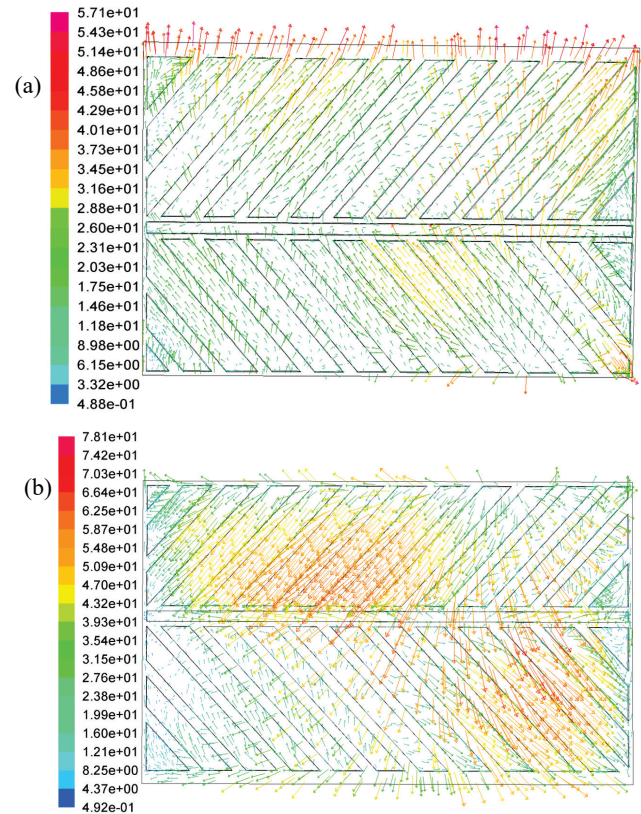


Figure 4. Relative velocity vectors of sand on impact surface of modified plates at: (a) 30° after the most upright position; (b) 60° after the lowest position.

Optimal filler material and technologies that are selected are presented in Table 1. Before applying hardfacing materials on impact plates, the model hardface samples are tested in order to verify the recommendations. Before the testing, model cladding is done, [20-23]. Comparative analyses of model tests show that plates hardfaced with filler materials 5006 and EC 4541 EC have greater resistance to wear compared to the original base plates, but smaller than hardfaced with filler material 4010 EC. Hardfacing of the impact plate is performed in the form of 'fishbone', using two processes and four types of filler material. The height of hardfacing is 5 mm. Here, the results are obtained by applying filler of chemical composition Fe-Cr-C-Si/Ti and the manual metal arc welding (MMA) hardfacing process. Before hardfacing, samples are preheated to $T_p = 160-170^\circ\text{C}$. Upon hardfacing, coatings are air-cooled down to room temperature.

Table 1. Filler material and hardfacing procedures.

Hardfacing electrode	Nominal chemical composition (M*/C and M/Fe wt.% ratio)	Process hardfacing
Xuper AbraTec 5006	Fe- Cr-C- Si (9.0 and 0.5)	MMA
EC 4541 EC	Fe-Cr-C-Si (8.9 and 0.5)	MMA
4010 EC	Fe-Cr-C-Si/Ti 0.18 (7.0 and 0.6)	MMA

*Notice: M - Carbide forming elements (Cr, Mo, Nb, W, B)

Sets of modified plates are installed in the fan mill and functionally tested.

In Fig. 5a and 5b the schemes and appearance of hardfaced plates before the period of exploitation are shown.

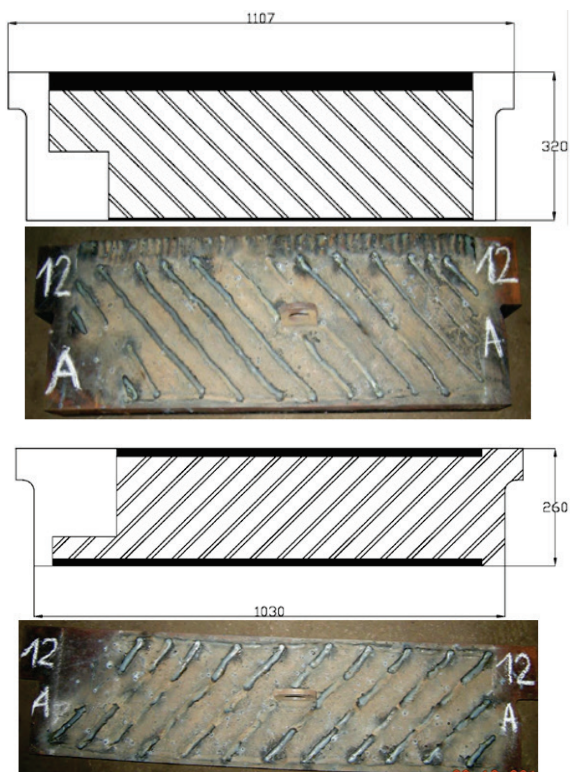


Figure 5. Schemes and hardfaced: (a) front (inner); and (b) back (outside) surface of a set of mill impact plate before exploitation.

The estimated lifetime (lifecycle) of impact plates in the fan mill is a very important parameter. It can be calculated with:

$$\tau = k_r \ln \frac{D_1^{0.45}}{0.24},$$

where: D is radius of mill fan (m); k_r is abrasive coefficient of impact plate.

Experimental data obtained from thermal plant Kostolac B, [2], for the time τ (h) between two replacements of base impact plates makes it possible to calculate coefficient k_r . The average value of k_r , based on 10 measurements is:

$$k_{rs} = 743.37,$$

$$\text{and } \tau_{sr} = k_r \ln \frac{D_1^{0.45}}{0.24} = 743.37 \ln \frac{3.6^{0.45}}{0.24} = 1489.4 \text{ h}.$$

If it is assumed that the lifecycle of mill impact plates is distributed in accordance with normal (Gaussian) distribution, then the standard deviation (confidence interval) can be determined on the basis of the following expression:

$$\sigma = \sqrt{\frac{1}{10} \sum_{i=1}^{10} (\tau_i - \tau_{sr})^2} = 240.81 \text{ h}.$$

The estimated lifecycle of mill ventilation impact plates at Kostolac B, with a probability of 68.2%, is:

$$\tau = \tau_{sr} \pm \sigma = 1490 \pm 241 \text{ h}.$$

On the base of these calculations, the exploitation time is chosen. After 1440 h, the plates are dismantled and their masses are measured. Schematic models of hardfaced plates are presented in Fig. 6. Hardfacing of plates is done on the lateral side by transversal (Fig. 5a for inner plate), and longitudinal (Fig. 5b for outside plate) layers. Hardfacing

on front surfaces for both plates is done by sloped, equidistant layers of fillers.

For the purpose of carrying out a comparative analysis, fishbone hardfacing plates are tested experimentally in the same manner as the honeycomb hardfacing ones.

Figures 6a and 6b show the edge and the central part of the unmodified inner plate, and 6c and 6d show the same for the outside one after an exploitation period of 1440 h.

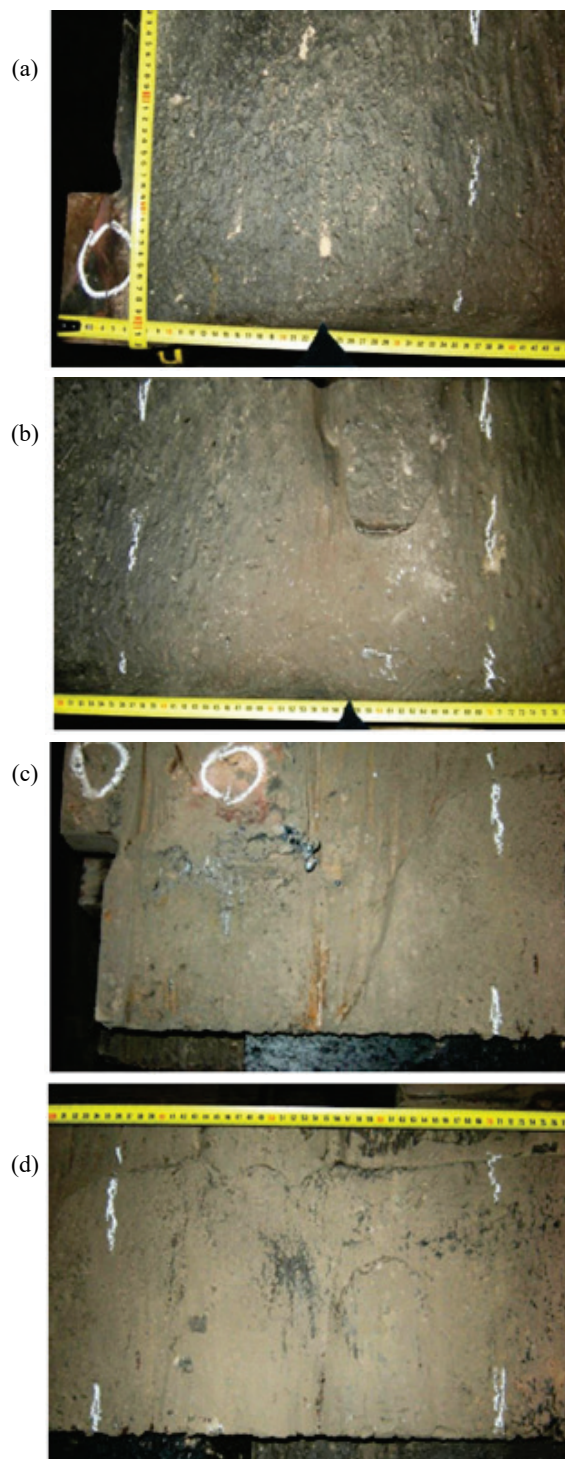


Figure 6. Appearance of base plate (O) after period of exploitation: (a) edge and (b) central area of inner plate, (c) and (d) the same for outside plate.

Figure 7 depicts photographs of base- and modified impact plate surfaces after exploitation under the same conditions.

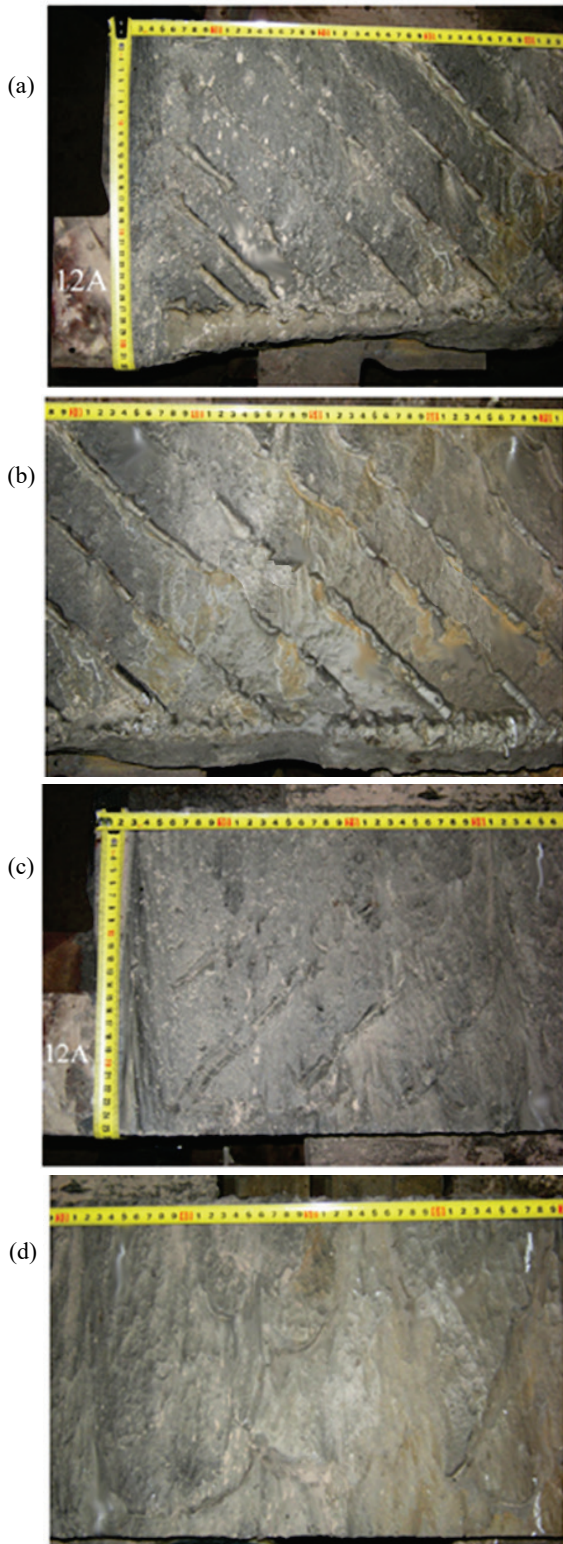


Figure 7. Appearance of modified plate /12/ after period of exploitation: (a) edge and (b) central area of inner plate, (c) and (d) the same for the outside modified plate.

The compilation of numerical simulation results and impact plates with wear surface damages after real exploita-

tion of fan mill for base plates and for some zone of the modified plate is presented in Fig. 8.

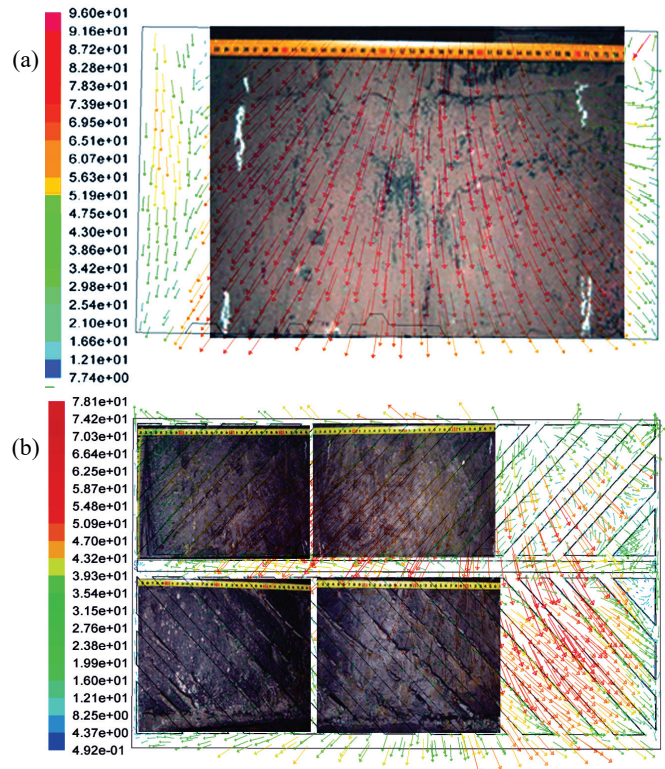


Figure 8. Compilation of numerical simulation results and impact plates with wear surface damage: (a) base plate, (b) some zone of modified plate.

A slight difference is noticed in mass loss between the honeycomb- and fishbone hardfacing plates during impact plate experiment in the fan mill. The numerical data, for unmodified and modified sets (numbers: 0, 6 /17/ and 12a) of tested plates, the hardness and relative weight loss in %, are given in Table 2. It is clear that the wear of fishbone and honeycomb hardfaced plates is smaller than the wear of base plates (base plate weight is 375 kg).

Experimental tests of revitalised mill wear parts in real exploitation conditions show that the proposed fishbone modification, surfacing technologies and coating materials give results very similar to the results for honeycomb hardfacing (Table 2), /17/. The base plate, steel S235JRG2, is marked as 0, honeycomb hardfacing is marked as 6, and 12a is the set of fishbone-like plates. Q_1 is the weight of one set of plates before exploitation; Q_2 is the weight of plate set after experimental exploitation; Q_3 is the absolute weight loss of plates; R is total absolute weight loss in percent; R_1 is the percentage of base weight (375 kg) loss ($R_1 = (\Delta Q - Q_f)/Q_1$). The period after which the impact plates have been replaced, service life, is $\Delta T = 1440$ h. The absolute 'loss' weight of impact plates ΔQ ($\Delta Q = Q_1 - Q_2$) is measured (Table 2). Based on these data, it is possible to calculate the average speed of weight loss V_Q ($V_Q = \Delta Q/\Delta T$) during the mill operation in (kg/h) (Table 2). Analysis of the data shows that the highest average loss of weight have the base plates, and the lowest fishbone hardfacing ones.

Table 2. Experimental results.

Plate number	Q ₁ (kg)	Q _f (kg)	HB	HR _c	Q ₂ (kg)	ΔQ (kg)	V _Q (10 ⁻³ kg/h)	R (%)	R ₁ (%)	Q ₃ (kg)	ΔT _{8%} (h)
0, /23/	375	0	140		345	30	20,83	8.00	8.00	30	1440
6, /23/	382	7	560	54	353	29	20,14	7.39	5.9	37	1830
12A	380	5	560	54	353	27	18,75	7.11	5.9	35	1860

The estimated service life of impact plates, the expected period of impact plate repair and replacement, can be calculated. If the criterion 8% weight loss of base plate and 100% hardfacing layer weight loss is adopted for replacement of plates, the replacement period is calculated by: $\Delta T_{8\%} = Q_3/V_Q$, where $Q_3 = Q_f + 30$ and is given in Table 2. The results show that fishbone hardfacing plates have maximal service life about 29.2% longer than base plates. The honeycomb hardfacing plates have 27% longer service life than base plates, and about 2% shorter than fishbone hardfacing ones.

CONCLUSION

Numerical simulations of multiphase flow in the fan mill of Kostolac B power plant are performed in order to define locations mostly exposed to wear due to granular phase motion. The mixture model and Eulerian model of the Euler-Euler approach are used for numerical simulations. Two methods give similar results for mixture flow and relatively small differences for granular phase flow characteristics.

Fishbone hardfacing technology is chosen and applied for sets of impact plates. Functional tests of these plates are performed together with tests of base plates and honeycomb hardfacing ones. Numerical results of relative velocity vectors in the vicinity of mill walls, for all types of plates, correspond to damages due to wear on impact plate surfaces in real exploiting conditions.

Quantitative analyses have indicated that fishbone hardfaced plates have greater resistance to wear compared to the original plates and to the honeycomb hardfaced ones. Total absolute weight loss R is 7.11% and 5.9% of a base weight. Wear is more pronounced on the outside plates than at the inner ones. Functional tests have confirmed that the best technology for hardfacing of impact plates in the fan mill is the fishbone hardfacing. Estimated service life for fishbone hardfaced plates is almost 30% longer than the same for base plates.

In particular, functional tests have pointed to possibilities of numerical simulation in defining reconstruction and revitalisation of mill parts exposed to wear, and numerical prediction of the hardfacing technology for impact plates and wear reduction.

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REFERENCES

1. Gulić, M., et al., Fan Mill Calculations (in Serbian), ZEP, Belgrade, 1982.

- Perković, B., et al., (2004). *TTP Kostolac unit 2 refurbishment and improvement aiming to obtained designed production* (in Serbian), Termotehnika XXX(1):57-81.
- Ristić, S., Kozić, M., Puharić, M., Katavić, B. (2011). *Numerical simulation of multiphase flow in ventilation mill and channel with louvers and centrifugal separator*, Thermal Science, 15(3):677-689. doi:10.2298/TSCI101203018K
- Shah, K.V., Vuthaluru, R., Vuthaluru, H.B. (2009). *CFD based investigations into optimization of coal pulveriser performance: Effect of classifier vane settings*, Fuel Proc. Tech., 90(9):1135-1141. doi:10.1016/j.fuproc.2009.05.009
- Bhambare, K.S., Ma, Z., Lu, P. (2010). *CFD modeling of MPS coal mill with moisture evaporation*, Fuel Proc. Tech., 91(5): 566-571. doi.org/10.1016/j.fuproc.2010.01.002
- Mazur, Z. Campos-Amezcuca, R., Urquiza-Beltrán, G., García-Gutiérrez, A. (2004). *Numerical 3D simulation of the erosion due to solid particle impact in the main stop valve of a steam turbine*, Appl. Thermal Engng., 24(13):1877-1891. doi:10.1016/j.applthermaleng.2004.01.001
- Vuthaluru, R. et al., (2006). *Investigation of wear pattern in a complex coal pulveriser using CFD modelling*, Fuel Processing Techn., 87(8):687-694. doi:10.1016/j.fuproc.2005.10.011
- Belošević, S., Tomanović, I., Beljanski, V., et al., (2015). *Numerical prediction of processes for clean and efficient combustion of pulverized coal in power plants*, Appl. Thermal Engng., 74:102-110. doi:10.1016/j.applthermaleng.2013.11.019
- Ashrafizadeh, H., Ashrafizadeh, F. (2012). *A numerical 3D simulation for prediction of wear caused by solid particle impact*, Wear, 276-277 75-84. doi:10.1016/j.wear.2011.12.003
- Liua, C., Jiang, D., Chu, F., Chen, J. (2014). *Crack cause analysis of pulverizing wheel in fan mill of 600 MW steam turbine unit*, Eng. Failure Anal., 42, 60-73. doi: 10.1016/j.engfailanal.2014.03.015
- Yao, Z., Wang, G., Song, L., et al. (2015). *Failure investigation of the pulverizing fan of ventilation mill*, Eng. Failure Anal., 49:11-19. doi:10.1016/j.engfailanal.2014.12.006
- Bhasker, C. (2002). *Numerical simulation of turbulent flow in complex geometries used in power plants*, Advances in Engng. Software, 33:71-83.
- Costa, V.J., Krioukov, V.G., Maliska, C.R. (2014). *Numerical simulation of pulverized wet coal combustion using detailed chemical kinetics*, J Braz. Soc. Mech. Sci. Eng. 36:661-672.
- Drew, D.A., Lahey, R.T. Jr. (1993). *Analytical modeling of multiphase flow*, MC Roco (ed.) Particulate Two-Phase Flow, Ch.16 509-566, Butterworth-Heinemann, Boston, pp.509-566.
- Kozić, M., Ristić, S., Puharić, M., et al., (2010). *Comparison of numerical and experimental results for multiphase flow in duct system of thermal power plant*, Sci. Tech. Rev. 60(3-4): 39-47.
- Kozić, M., et al. (2011). *Numerical visualization of multiphase flow in fan mill and mixture channel*, IA Znamenskaya (ed.), Proc. The 8th Pacific Symp. on Flow Visual. and Image Proc., Moscow 2011, p.119.
- Kozić, M., Ristić, S., Katavić, B., Puharić, M. (2013). *Redesign of impact plates of ventilation mill based on 3D numerical simulation of multiphase flow around a grinding wheel*, Fuel Proc. Technol. 106:555-568. doi:10.1016/j.fuproc.2012.09.027
- Chen, X., McLaury, B.S., Shirazi, S.A. (2006). *Numerical and experimental investigation of the relative erosion severity*

- between plugged tees and elbows in dilute gas/solid two-phase flow, *Wear*, 261:715-729. doi:10.1016/j.wear.2006.01.022
19. Gnanavelu, A., Kapur, N., Neville, A., et al. (2011). *A numerical investigation of a geometry independent integrated method to predict erosion rates in slurry erosion*, *Wear*, 271(5-6):712-719. doi:10.1016/j.wear.2010.12.040
20. Choo, S-H., Kim, C.K., Euh, K., et al. (2000), Correlation of microstructure with the wear resistance and fracture toughness of hardfacing alloys reinforced with complex carbides, *Metall. & Mater. Trans. A*, 31(12):3041-3052. doi:10.1007/s11661-000-0083-5
21. *Metals Handbook 9th Ed., Vol.6, Welding, Brazing and Soldering*, ASM, Metals Park, Ohio, 1993.
22. Wang, X., Han, F., Liu, X., et al. (2007). *Microstructure and wear properties of the Fe-Ti-V-Mo-C hardfacing alloy*, *Wear*, 265(5-6):583-589. doi:10.1016/j.wear.2007.12.001
23. Alil, A. et al., (2011). *Structural and mechanical properties of different hard welded coatings for impact plate for fan mill*, *Welding and Material Testing*, 20(3):7-11.

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April 12-13, 2018	ESIS TC-1 Meeting Workshop on 'Damage and Damage Tolerance of Welded Structures'	Prague, Czech Republic	Invitation ESIS TC 1 Spring 2018-1.pdf
May 10-11, 2018	ESIS TC-9 Meeting Innov. in Cement and Concrete Techn. Materials, Methods and Applications	Torino, Italy	info TC09-1.pdf
June 4-6, 2018	IGF Workshop Fracture and Structural Integrity: ten years of 'Frattura ed integrità Strutturale'	Cassino, Italy	link
June 17-20, 2018	1 st International Conference on Theoretical, Applied and Experimental Mechanics (ICTAEM 1)	Paphos, Cyprus	https://www.ictaem.org/
July 1-5, 2018	18 th International Conference on Experimental Mechanics (ICEM 2018)	Brussels, Belgium	http://www.icem18.org/
July 2-6, 2018	10 th European Solid Mechanics Conference (ESMC 2018)	Bologna, Italy	http://www.esmc2018.org
July 5-6, 2018	2 nd International Conference on Materials Design and Applications	Porto, Portugal	https://web.fe.up.pt/~mda2018/
July 8-11, 2018	8 th Internat. Conference on Engineering Failure Analysis (ICEFA VIII)	Budapest, Hungary	link
August 25-26, 2018	ESIS Summer School in the scope of ECF22	Belgrade, Serbia	link
August 26-31, 2018	22 nd European Conference of Fracture (ECF22)	Belgrade, Serbia	http://www.ecf22.rs
September 19-21, 2018	CP 2018- 6 th International Conference on 'Crack Paths'	Verona, Italy	http://www.cp2018.unipr.it/
June 24-26, 2019	12 th International Conference on Multiaxial Fatigue and Fracture (ICMFF12)	Bordeaux, France	link
March 30 - April 3, 2020	VAL4, 4 th International Conference on Material and Component Performance under Variable Amplitude Loading	Darmstad, Germany	First Announcement