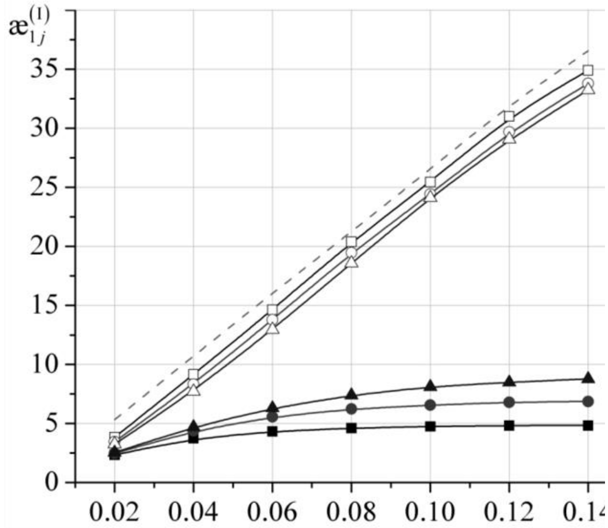

Рис. 2. Зависимости вибродиагностического параметра от параметра повреждения для поврежденной (светлые точки) и неповрежденной (темные) подсистем при субгармоническом резонансе для коэффициента упругой связи γ, равном 0.01 (■,□), 0.015 (●,○), 0.02 (▲,Δ). Штриховая линия – поврежденная подсистема в изолированном состоянии

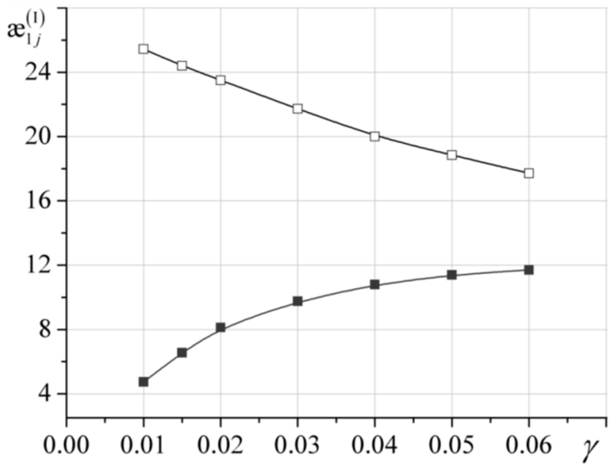

Рис. 3. Зависимость вибродиагностического параметра $æ_{1j}^{(I)}$ от коэффициента упругой связи γ для поврежденной (□) и неповрежденной (■) подсистем при субгармоническом резонансе для $\alpha = 0.1$

Следует также отметить, что при рассматриваемом режиме колебаний имеет место возбуждение антифазной формы подсистем дискретной модели регулярной системы. Однако ввиду малости амплитуд, соответствующих указанной форме колебаний, они не являются значимыми.

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DIAGNOSTICS OF DEGRADATION OF SURFACES TREATED BY THERMAL SPRAYING

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Abstract: The paper deals with possibilities of utilization HVOF coatings in thermal cyclic loading and wear conditions. There were evaluated three types of coatings based on WC-Co, WC-Co-Cr and Cr_3C_2-25NiCr. The quality of coatings was evaluated in terms of their adhesion during the cyclic thermal loading (pull-off test), microhardness and wear resistance (pin-on-disc test). Structure of coatings was studied using optical and electron microscopy. The coating Cr_3C_2-25NiCr

showed the highest resistance to thermal cycles and wear resistance at 900°C and can be recommended for renovation components stressed by high and cyclic temperatures and wear.

Introduction

In steelmaking, inner parts of basic oxygen furnace (BOF) converter hood are subjected to extreme wear. Material of converter hood is exposed to set of unique factors: cyclic thermal load related to temperature and gas rate variation, dust particles erosion caused by oxides of iron, calcium, magnesium, silicium and other elements occurring in exhaust gas. As a result of mentioned factors thickness of the converter hood is reduced. There are various types of protective coatings used with aim to enlarge hood lifespan. Thermally-sprayed coatings belong to the dynamically developing field of surface engineering [1]. These high-quality functional coatings are applied also in renovations, mainly due to their excellent properties - high wear resistance [2-6], corrosion resistance [7] and resistance against high temperatures. HVOF (High Velocity Oxygen Fuel) is one of the technologies, which formed coatings with very small porosity (<1 %) compared with the basic material and high adhesion strength (> 80 MPa). There are minimal thermal changes of substrate during spraying and also roughness of coating surface is low. The paper presents experimentally obtained results aimed at assessing selected coatings applied by HVOF technology. The coatings were subjected to cyclic thermal stress. The quality of coatings was evaluated by pull-off test and Vickers hardness test, wear resistance was evaluated by pin-on-disc test. Conditions of experimental works were chosen in order simulate operating conditions in BOF.

MATERIALS AND METHODS

Substrates for application the coatings were made of structural carbon steel of grade C15E, 1.1141 (0.12-0.18%C, 0.3-0.6%Mn, 0.15-0.40%Si, P and S max 0.035, Fe balance). Tensile strength of the steel substrate is 740 – 880 MPa, and yield strength ≥ 440 MPa. The test samples were made from round bar Ø50 mm with a height of 15 mm.

Test samples were pre-treated by abrasive grit blasting: air pressure of 0.5 MPa, blasting distance 400 mm, abrasive - white corundum, grain size 1.00 mm, blasting angle 75°.

There were deposited three types of powders by HVOF technology on pretreated samples. On the first group of samples coating of WC-17Co was applied, on the second group of samples coating of WC-Co-Cr deposited and on the third group of samples coating Cr_3C_2-25NiCr was deposited, for chemical composition see Table 1. Materials were supplied as a powder, agglomerated and sintered, produced by Praxair, Inc., USA.

Table 1 Chemical composition of the powders sprayed

Coating	C	Co	Fe	W	Cr	Ni
WC-17Co	5.5	16.2	0.036	78.4	-	-
WC-Co-Cr	5.5	9.9	0.02	80.58	3.9	-
Cr_3C_2-25NiCr	10	-	-	-	68.5	21

For the coating deposition equipment JP-5000, Praxair TA was used; it deposits coatings using system HP/HVOF (High Pressure / High Velocity Oxygen Fuel) with System Powder Feeder 1264. The surface of deposited coatings was not further modified after spraying. Parameters of spraying are listed in Table 2.

Table 2 Parameters of spraying

Particle velocity	Nozzle diameter	Kerosene	Oxygen	Powder feed	Nozzle distance
$m.s^{-1}$	mm	$l.h^{-1}$	$l.min^{-1}$	$g.min^{-1}$	mm
600 ÷ 1000	25.4 mm	22.7	800	75	380

Thickness of the coating was determined by magnetic thickness gauge. Microhardness of evaluated coatings was measured by Vickers hardness pyramid according to STN ISO 4516, load 980.7 mN (HV0.1), dwell time 15 s. Samples were subjected to cyclic thermal load in electric chamber furnace according to the following thermal regime: heating of the samples in electric chamber furnace at 900 °C, dwell in the furnace for 20 minutes, free cooling of samples on still air to ambient temperature.

Samples were subjected to 10 thermal cycles, and after the 3rd, 5th, 8th and 10th thermal cycle samples were collected to evaluate the adhesion of coatings. Adhesive wear of coatings was evaluated by pin-on-disc test: normal load 5 N, linear speed 100 $mm.s^{-1}$, atmosphere: air, stop condition 300 m, static partner WC ball with diameter 6 mm, track radius 5,01 mm, temperature 900°C. Wear of coatings was measured on 3D confocal microscope (Sensofar PLUNEOX Accuron). From the measured wear tracks the worn material volume V_{disc} and specific wear rate W was calculated according to ISO 20808.

RESULTS AND DISCUSSION

Thickness and hardness of the coatings as sprayed are listed in Table 3.

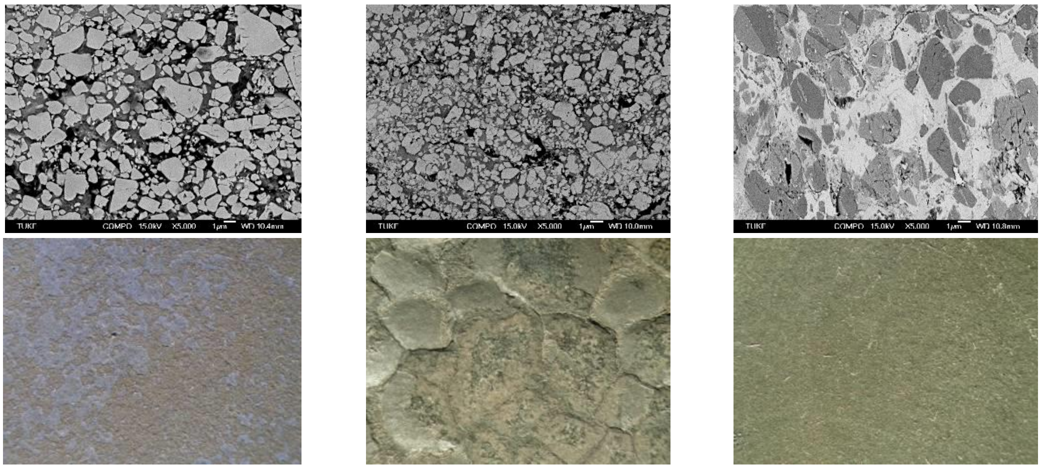
Table 3 Thickness and hardness of the coatings

coating	Thickness / µm	Hardness HV 0.1
WC-17Co	234	1010
WC-Co-Cr	356	1447
Cr_3C_2-NiCr	393	975

Fig. 1 shows cross-sections and appearance of surface the coatings after thermal cycles. Despite its high hardness, coating WC-Co-Cr after 3 thermal cycles showed thermal cracking, Surface of coating WC-17Co during the thermal cyclic loading was covered with a layer of blue oxides with a strong chalking. Coating Cr_3C_2-NiCr after thermal cycles retained its appearance and tactile qualities.

Cross-section of coatings

Appearance after 10 thermal cycles



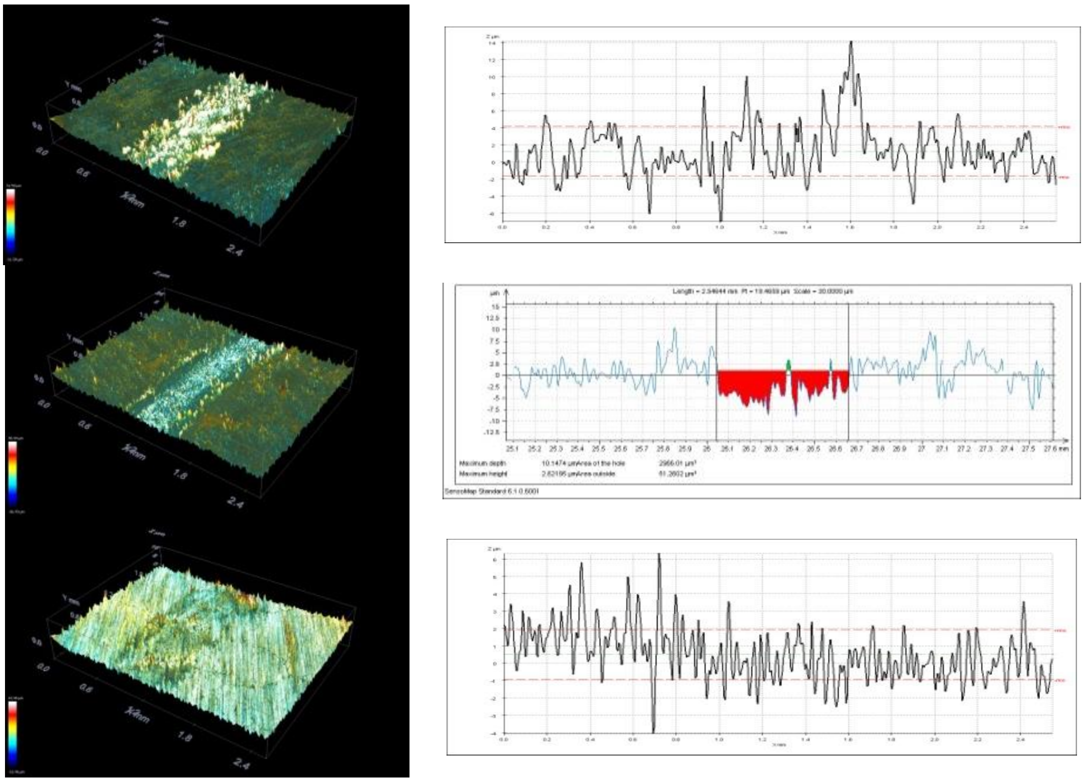
WC-17Co **WC-Co-Cr** **Cr_3C_2-NiCr**

Fig. 1 Cross-sections and appearance of surface the coatings after thermal cycles

Adhesion of coatings could not be determined by pull-off test due to limited cohesion strength of used epoxy resin. Adhesion of all coatings as sprayed and also after thermal load exceeded 30 MPa.

The coefficient of friction for all evaluated coatings gradually increased from the start of the test. This phenomenon was due to increasing the contact area between the coating and the static ball. The friction coefficient value depends on the interior structure of the coatings that consists of large number of hard carbide particles. These particles interact with the material of the static ball during friction. The highest friction coefficient was found for coating Cr_3C_2-NiCr (0.8). Mentioned value was found after 234 m of the test, when the test was stopped because the coefficient of friction increased to unacceptable levels. The reason for stopping was also much faster wear of the ball compared to other coatings. The lowest coefficient of friction coating was recorded in WC-Co-Cr (0.7). Wear of the coatings after pin-on-disc test shows Fig. 2.

From Fig. 2 is clear that the coatings WC-17Co and Cr_3C_2-NiCr are characterized by high wear resistance, value V_{disc} was unmeasurable. For the coating WC-Co-Cr there was detected measurable wear: $V_{disc} = 5.6e10^{-2}$ mm^3, $W = 3.7e10^{-5}$ $mm^3.N^{-1}.m^{-1}$.



WC-17Co

WC-Co-Cr

Cr_3C_2-NiCr

Fig. 2 Coatings wear track and profile of the track after pin-on-disc test realized at 900°C

CONCLUSION

Based on the results of the experiments it can be said that the coating WC-Co-Cr (1447 HV0.1) showed the highest hardness and the coating Cr_3C_2-NiCr (975 HV0.1) showed the lowest. To the environment of BOF with high and fluctuating temperatures coating WC-Co-Cr cannot be applied, because of its cracking after a few thermal cycles and thereby disruption of its barrier protective effect what creates a precondition for high temperature corrosion of the substrate. In high temperature the coating WC-17Co showed strong chalking, which may cause significant losses in weight (and consequently in thickness) of the coating and its low durability. Coating Cr_3C_2-NiCr compared with the previous coatings showed a lower hardness, but during the thermal cyclic loading maintains its integrity and adhesion, any other qualitative changes didn't occur. Adhesive wear resistance of all coatings at 900°C was excellent, only for coating WC-Co-Cr was detected low wear rate $3.7e10^{-5}$ $mm^3.N^{-1}.m^{-1}$.

Based on the experimental results obtained, it is possible to recommend for renovation components stressed by extremely high and cyclic temperatures and wear coating Cr_3C_2-25NiCr.

Acknowledgement

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