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Application of plasma-sprayed coatings in heat absorption by radiated walls

The values of emissivity coefficients are given for the materials of metal and ceramic coatings. Analytical calculations have been made for the effect of the heating medium (flame) – uncoated wall and then heating medium (flame) – coated wall mutual emissivity coefficients on the values of the exchanged heat flux. Based on the measurement results for the main coating properties, coatings were selected which were the most suitable for spraying the walls of furnaces and heat exchangers, and determined the intensification of heat exchange. These coatings were used to spray the walls of a laboratory waste-heat boiler, and then measurements were taken for the values of the fluxes of heat absorbed by the cooling water flowing in the boiler tubes covered with different type coatings. The analytical calculations and the laboratory tests have been confirmed by the results of full-scale operation on the elements of metallurgical equipment.

Nomenclature

F_s – area wall
T_g – gas temperature / the heating medium
T_s – wall temperature / wall with coatings
T_n – air temperature
$R_p = 1/k_p$ – heat resistance
Q – heat flux
α_k – heat coefficient penetrate gas / heating medium-wall
α_w – heat coefficient penetrate wall-gas / heating medium
σ_c – constant radiation
ε_w – mutual emissivity coefficient

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ε_{pow} – emissivity of Coatings
ε_{s} – wall emissivity coefficient,
ε_{g} – heating Medium Emissivity
ε_{met} – metal Wall Emissivity
λ_{w} – thermal conductivity coating
λ_{pod} – thermal conductivity in-coating
λ_{s} – thermal conductivity wall
$\varepsilon_{w.b.pow}$ – mutual emissivity coefficient of heating medium – uncoated metal wall
ε_{wg-pow} – mutual emissivity of the heating medium – coated wall system

1 Introduction

Furnaces, boilers, recuperators and other large-sized thermal equipment are operated at increased or high temperatures. The effectiveness of their operation is determined by radiant heat exchange dependant, among other things, on the values of emissivity and thermal conductivity coefficients. Such properties can be varied within a broad range of changes through creating on the radiated walls coatings with desirable surface roughness and structure porosity, i.e. the parameters which are directly dependant on the coating type, the grain-size of the materials, and the fraction of material grain-size classes in the coating materials used, as well as on the parameters of the plasma spraying process.

As regards the intended thermal tasks that are to be fulfiled by coatings sprayed on the radiated wall surfaces of furnaces, heat exchangers, and other thermal equipment, the coatings can be classified into the following two basic groups:

A coatings that absorb thermal radiation and conduct heat towards the substrate,

B coatings that emit thermal radiation from the coating surface.

The A group coatings should be characterized by large open porosity, i.e. developed surface that produces a high ability of absorbing heat, and by a large value of thermal conductivity coefficient, λ. They are sprayed, for example, on the radiated wall surfaces of recuperators, or boilers, with the aim of increasing the ability to absorb heat from the radiating flame, gas, or combustion gas, and transfer it to the heated media (such as air, water, steam, etc.).

The basic features of the B group coatings are: absorption of radiation on the coating surface and the emission of heat towards the heated charge, with the essential condition being met at the same time that the heat “accumulated” on the coating surface should not penetrate inside the coating, but only increase the surface temperature instead. Thus, these coatings should also be characterized by high insulating power and be sufficiently thick. They are sprayed on the walls and roofs of furnaces, and particularly those periodically operating, and also on the walls of flues installed after the heating furnaces, with recuperators incorporated in those flues.

The A and B group coatings that intensify the absorption of heat from the flame and from the stream of (combustion) gas leaving the working spaces of furnaces, and heat exchangers, give as a consequence a decrease in the temperature of the combustion gas exhausted to the chimney (heat recovery).

2 Absorptivity of constructional materials and coatings

The exchanged heat flux depends on the value of mutual emissivity coefficient which is a function of the emissivity coefficients of heating and heated media. The industry commonly uses numerous methods of rendering high emissivity to heating media, such as flame carburization [1–3]. Less known and less commonly used are the methods of imparting high ability of thermal radiation absorption and emission to the walls and roofs of furnaces and flues, and to the walls of heat exchangers [4–6].

Variation of the values of heat absorption and emission coefficients for materials commonly used for the making of furnaces and (metal and ceramic) thermal equipment and coatings are shown in Fig. 1. It results from Fig. 1 that the absorptivity of polished metals (e.g. the tight wall of a waste-heat boiler) approximately linearly grows with increasing temperature, while nonmetals exhibit the reverse trend [1]. It also follows that the emissivity coefficient of ceramic and (coarse) cermet coatings has a high and constant value. The depth of radiant energy penetration into the surface is determined by the electric properties of the material. High electric-conductivity materials are penetrated by radiation to a small depth, the major part of the radiation being reflected.

Dielectric materials, whose electric conductivity is small, are deeply penetrated by radiant energy, and its main part will be absorbed. Pure nonmetallic surfaces have a low value of absorptivity coefficient. Surface roughness, impurities, and formed corrosion products increase the value of absorptivity, and thick oxide layers can cause a substantial increase in ε so that its value will be similar to that of dielectrics (i.e. more than 0.7).

On account of the complexity of absorption and emission, and the flow of heat through the coatings, and because of these processes being dependent on large number of parameters, there are no equations that would permit the calculation

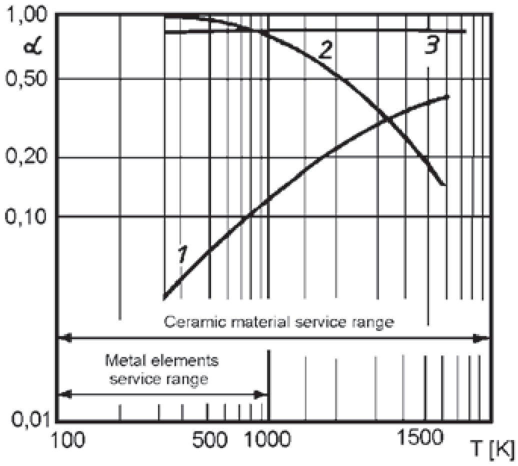


Figure 1. Variation of surface absorptivity and emissivity depending on the temperature of bodies for different materials [1,7–9]. 1 – metal; 2 – nonmetal; 3 – coating (coarse-ceramic or cermet).

of ε and λ values as a function of, for example, coating type, spraying parameters, which would make it possible to design a coating type with predetermined properties.

Because of the above considerations, a need arose to develop methods and apparatus for the examination of the emissivity and thermal conductivity of multilayer coatings, testing the thermal parameters of the coatings, and selecting the coatings to be sprayed on the walls of furnaces, heat exchangers, and other equipment, while assuring their optimal efficiency, and then conducting studies that would confirm the assumptions. The results of the examination of coating properties are reported in work [2,3,5,9,10].

3 Effect of mutual emissivity coefficient on the amount of heat absorbed

The basis for the considerations within the subject specified in the above title is the formula that defines the flux of heat exchanged between the heating medium and the wall surface of furnaces or thermal equipment with a coating applied:

$$F_s \alpha_k \left(T_g - T_s\right) + F_s \sigma_c \varepsilon_w \left(T_g^4 - T_s^4\right) = F_s k_p \left(T_s - T_n\right) \ . \tag{1}$$

In Eq. (1), heat resistance across the wall is describe by the relationship (1a):

$$\frac{1}{k_p} = R_p = \frac{x_w}{\lambda_w} + \frac{x_{pod}}{\lambda_{pod}} + \frac{x_s}{\lambda_s} + \frac{1}{\alpha_w} \; . \tag{1a}$$

By introducing the expression (1b) that defines mutual absorptivity, ε_w, and assuming that the combustion gas is a grey gas, we obtain:

$$\frac{1}{\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_s} - 1} = \varepsilon_w \tag{1b}$$

and then, by taking (1a) and substituting it in Eq. (1), the following equation is obtained:

$$F_s \alpha_k \left(T_g - T_s\right) + F_s \sigma_c \frac{1}{\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_s} - 1} \left(T_g^4 - T_s^4\right) = F_s \frac{\left(T_s - T_n\right)}{\frac{x_w}{\lambda_w} + \frac{x_{pod}}{\lambda_{pod}} + \frac{x_s}{\lambda_s} + \frac{1}{\alpha_w}} \; . \tag{2}$$

It results from the above formulas that the rational utilization of heat from heating media (such as flames or combustion gases) is determined by high temperature of the heating media, high emissivity of the heating media and walls (of furnaces and equipment) taking part in the heat exchange, and high thermal conductivity or insulating power of the walls participating in the heat exchange. To evaluate the influence of the value of wall emissivity coefficient, ε_s, on the variation of the value of mutual emissivity coefficient, ε_s, calculations according to relationship (1b) were made, while taking the constant value of $\varepsilon_g = 0.40$. The value of coefficient ε_s was taken in the range from 0.20 for brightened metals, through 0.55–0.65 for refractory materials, up to 0.95 for coatings made from high-melting metal oxides in black colour.

The calculations of the values of heating medium – uncoated metal wall mutual emissivity coefficient ($\varepsilon_{w.b.pow}$) were made, and then the mutual emissivity of the heating medium – coated wall system ($\varepsilon_{w.z.pow}$) was calculated taking the value of $\varepsilon_{pow} = 0.90$, followed by determining the value of the ratio $\frac{\varepsilon_{w.z.pow}}{\varepsilon_{w.b.pow}}$.

For the tight metal boiler wall or for recuperator segment tubes (generally – for the membrane heat exchanger), $\varepsilon_{s.met} = 0.30$ and $\varepsilon_g = 0.40$ were assumed. The value of uncoated wall mutual emissivity coefficient ($\varepsilon_{w.b.pow}$) as calculated from formula (1b) is:

$$\varepsilon_{w.b.pow} = \frac{1}{\frac{1}{0.40} + \frac{1}{0.30} - 1} = 0.207 \; . \tag{3}$$

For the same metal exchanger surface, but with the sprayed coating with the emissivity coefficient value of $\varepsilon_{pow} = 0.90$, the value of mutual emissivity coefficient (as calculated from Eq. (1b) is:

$$\varepsilon_{w.b.pow} = \frac{1}{\frac{1}{0.40} + \frac{1}{0.90} - 1} = 0.383 \ . \tag{4}$$

The value of the flame-coated wall mutual emissivity coefficient to flame-uncoated wall mutual emissivity coefficient ratio is:

$$\frac{\varepsilon_{w.z.pow}}{\varepsilon_{w.b.pow}} \cong 1.851 \ . \tag{5}$$

The obtained result means an 85% increase in the amount of heat absorbed by the metal exchanger surface with the sprayed coating of the assumed value of $\varepsilon_{s.pow} = 0.90$.

Below, for the specified values of emissivity coefficients, i.e. for:

- metals within $\varepsilon_{s.met}$ change range from 0.20 through 0.30 up to 0.40;
- refractory materials within $\varepsilon_{s.cer}$ change range from 0.55 to 0.65; and
- coatings within ε_{pow} change range from 0.70 to 0.95,

the value of the ratio was calculated as the mutual emissivity coefficients of the coatings divided by:

- mutual emissivity of the metal walls – Tab. 1 – $\frac{\varepsilon_{w.gaz-pow}}{\varepsilon_{w.gaz-met}}$
- mutual emissivity of the ceramic walls – Tab. 2 – $\frac{\varepsilon_{w.gaz-pow}}{\varepsilon_{w.gaz-cer}}$.

The above results show how great is the effect of the coating on increasing the absorption of heat by the radiated wall surfaces both of metal – Tab. 1, and of ceramic materials – Tab. 2. The results shown in Tab. 1 and 2 are depicted in Fig. 2.

The obtained calculation results have significant importance for the indirect heating of furnace and heat exchanger walls, and for the heating of recuperator tubes, particularly their wall-side (rear) circuits, by heat absorbed and emitted through ceramic flue walls. The wall-side tube circuits are reheated by heat absorbed and emitted by the ceramic walls with two-layer coatings applied having high emissivity and low thermal conductivity. It results from Tab. 1 that, for example, for the tight metal wall of a waste-heat boiler (of tube-fin-tube type) with the assumed value of $\varepsilon_{s1} = \varepsilon_{s.met} = 0.30$, after covering this wall with the

Table 1. The value of the ratio of coating mutual emissivity coefficients to the mutual emissivities of the metal walls.

Heating Medium Emissivity	ε_g	0.40														
Metal Wall Emissivity	$\varepsilon_{s.met}$	0.20					0.30					0.40				
Calculated mutual emissivity of the heating medium – metal wall system	ε_{wg-met}	0.154					0.207					0.250				
Emissivity of Coatings	ε_{pow}	0.75	0.80	0.85	0.90	0.95	0.75	0.80	0.85	0.90	0.95	0.75	0.80	0.85	0.90	0.95
Calculated mutual emissivity of the heating medium – coated wall system	ε_{wg-pow}	0.353	0.364	0.374	0.383	0.392	0.353	0,364	0.374	0.383	0.392	0.353	0.364	0.374	0.383	0.392
Ratio of Mutual Emissivity Coefficients	$\frac{\varepsilon_{wg-pow}}{\varepsilon_{wg-met}}$	2.292	2.364	2.429	2.489	2.546	1.704*	1.758**	1.806	1.851	1.893	1.412	1.456	1.496	1.532	1.568

Table 2. he value of the ratio of coating mutual emissivity coefficients to the mutual emissivities of the ceramic walls.

Heating Medium Emissivity	ε_g	0.40														
Ceramic Wall Emissivity	$\varepsilon_{s.cer}$	0.55					0.60					0.65				
Calculated mutual emissivity of the heating medium – ceramic wall system	ε_{wg-cer}	0.301					0.316					0.329				
Emissivity of Coatings	ε_{pow}	0.75	0.80	0.85	0.90	0.95	0.75	0.80	0.85	0.90	0.95	0.75	0.80	0.85	0.90	0.95
Calculated mutual emissivity of the heating medium – coated wall system	ε_{wg-pow}	0.353	0.364	0.374	0.383	0.392	0.353	0,364	0.374	0.383	0.392	0.353	0.364	0.374	0.383	0.392
Ratio of Mutual Emissivity Coefficients	$\frac{\varepsilon_{wg-pow}}{\varepsilon_{wg-cer}}$	1.172	1.209	1.243	1.272***	1.302	1.117	1.151	1.184	1.212	1.141	1.073	1.106	1.137	1.164	1.191

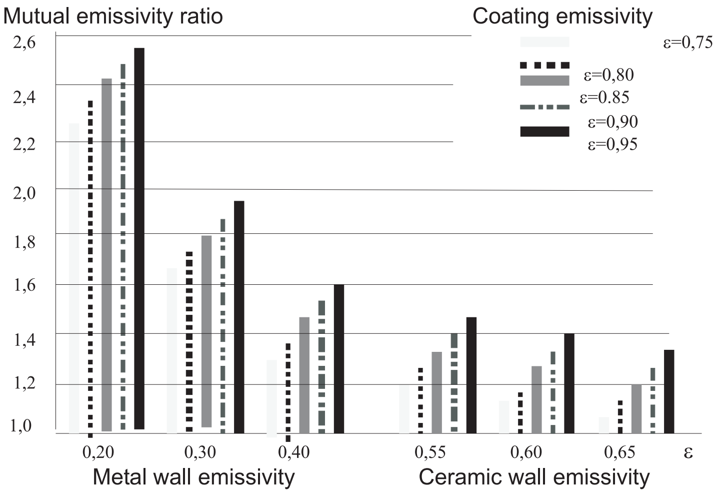


Figure 2. Values of heating medium – coated wall to heating medium – uncoated wall mutual emissivity ratios.

coating of the value of $\varepsilon_{s2} = \varepsilon_{pow} = 0.95$ and calculating the analyzed ratio, the value $\frac{\varepsilon_{w.gaz-pow}}{\varepsilon_{w.gaz-met}} = 1.893$, which means nearly a 90% increase in the amount of heat absorbed by the boiler walls.

4 Selection of coatings for spraying boilers and recuperators

Mutual emissivity coefficient occurring in formula (1b) has a decisive influence on the amount of heat exchanged by radiation. Its effect is the more intensive, the lower is the absorption ability of the radiated wall (before spraying the coating). Hence, in the operation of equipment with metal walls, the presence of coatings with a high value of ε_T substantially increases the flux of exchanged heat.

The attainment of intensive heat exchange in boilers and recuperators is possible due to the presence of coatings with high emissivity and high thermal conductivity on their walls. The intensification of heat exchange and charge heating in the furnace chambers is made possible by the presence of the two-layer coating which is composed of a layer with high heat absorptivity and emissivity and an insulating layer with low thermal conductivity. The produced two-layer coating with such a structure permits the concentration of heat within the emission layer and prevents the heat from flowing to the deeper layers of furnace walls and roofs, thereby reducing the heat losses through the walls to the environment.

The measurement results for the thermal and mechanical properties of cermet coatings made on the basis of aluminium, chromium, and zirconium oxides with the addition of NiAl, and of Cr_3C_2 + NiAl coatings are shown in Tab. 3 and in Fig. 3.

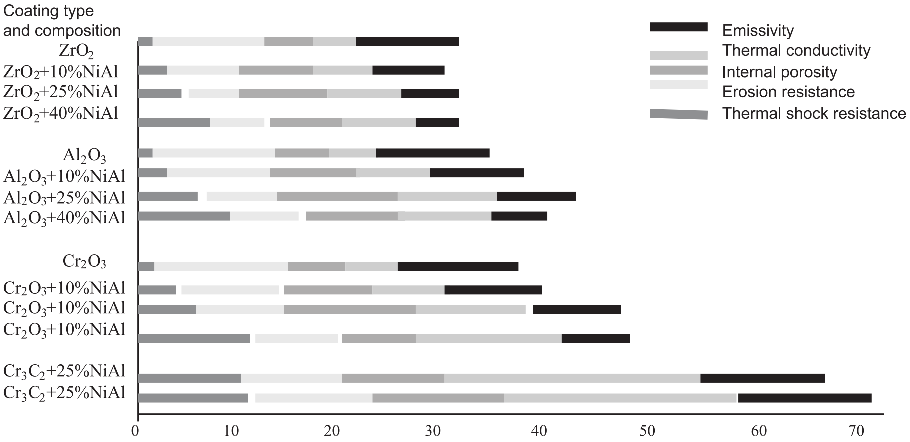


Figure 3. Score (conventional) evaluation of the suitability of coatings for spraying the walls of boilers and recuperators.

In Tab. 3, the protective properties are summarized in columns 3–5, and the evaluation of the suitability of cermet coatings for spraying on the walls of heat exchangers, furnaces, and ducts is shown in columns 9–11. It results from the presented data that the greatest suitability spraying heat exchangers was revealed by the Cr_3C_2-based cermet coatings. According to the adopted evaluation (conventional) scale, they obtained approx. 70 scores. The coatings made from the mixtures of chromium oxide with nickel aluminide came second with over 50 scores. The third position was occupied by the coatings from the mixtures of aluminium oxide with nickel aluminide. The coatings made from the mixtures of ZrO_2 with NiAl proved to be unsuitable for spraying boilers, recuperators, etc.

The above mentioned coatings were used to spray the radiated walls of heat exchangers, and then the measurements of their effect on the heat flux values were taken.

Table 3. The score evaluation of the suitability of coatings for furnaces and thermal equaipment

No.	Coating Type	Protective Properties [6]				Thermal Properties			Suitability for Spraying		
		Thermal shock resistance	Erosion resistance	Internal porosity	Total scores	Heat radiation absorption ability {ε}	Thermal conductivity {λ} W m^{-1} K^{-1}	Thermal insulating power 20 - λ W m^{-1} K^{-1}	Membrane heat exchangers	Ceramic walls	
										absorption properties	insulating properties
1	2	3	4	5	6	7	8	9	10	11	12
		Number of temperature change cycles	Scores for 1 g coating loss time	Scores for gas pressure equalization time	**3+4+5**	1 score for each 0.01 above 0.7	actual value of λ		**6+7+8** for p>40 is good	**6+7** outer layer	**6+8** inner layer
1	Al_2O_3	0	10	6.8	17	16 (0.86)	3	17	36	**30**	**14**
2	Al_2O_3+10%NiAl	2	10	6.0	18	13	9	11	40	**22**	2
3	Al_2O_3+25%NiAl	6	10	6.5	23	9	13	7	**45**	19	-
4	Al_2O_3+40%NiAl	9	5	5.4	19	6	16	4	**41**	9	-
5	Cr_2O_3	0	8	6.3	14	22 (0.92)	5	15	**41**	**31**	**10**
6	Cr_2O_3+10%NiAl	4	8	6.0	18	16	9	11	**43**	**25**	-
7	Cr_2O_3+25%NiAl	4	7	5.7	17	12	19	-	**48**	10	-
8	Cr_2O_3+40%NiAl	8	6	5.0	19	9	21	-	**49**	7	-
9	ZrO_2	0	1	11.5	13	15 (0.85)	1	19	29	17	**18**
10	ZrO_2+10%NiAl	1	2	10.0	13	10	4	16	27	19	**12**
11	ZrO_2+25%NiAl	5	3	8.0	16	5	7	13	28	14	6
12	ZrO_2+40%NiAl	7	4	7.2	18	2	9	11	29	11	2
13	Cr_3C_2+25%NiAl	11	12	4.5	28	13 (0.93)	29	-	**70**	12	-
14	Cr_3C_2+40%NiAl	12	11	4.0	27	10	32	-	**69**	5	-

NOTES: 1- in columns 3,4 and 5, the appropriate mechanical properties of coatings as tested in work **[2]** are shown, expressed in a score scale with 0-12 statistical weights taken into account; 0 – the worst property, 12 – the best property

2 – column 7 includes dimensionless absorption ability, e.g. from the actual value of emission coefficient 0.7 was subtracted, and the result was multiplied by 100: $(0.92 - 0.7)\ 100 = 0.22 \cdot 100 = 22$.

3 – column 10 contains the sum of scores from columns 6+7+8; coatings with the best properties for membrane exchanger applications are put in bold.

4 – column 11 contains the sum of score values from columns 6+7; coatings with the best properties for absorption layer applications are put in bold.

5 – column 12 contains the sum of scores from columns 6+8; coatings with the best properties for insulation layer applications are put in bold.

5 The testing stand and the measurement methods

A schematic of the stand on which tests were carried out on the effect of the coatings sprayed on the radiated tight walls of a boiler on the amount of heat absorbed by water flowing in the system of tubes is shown in Fig. 4.

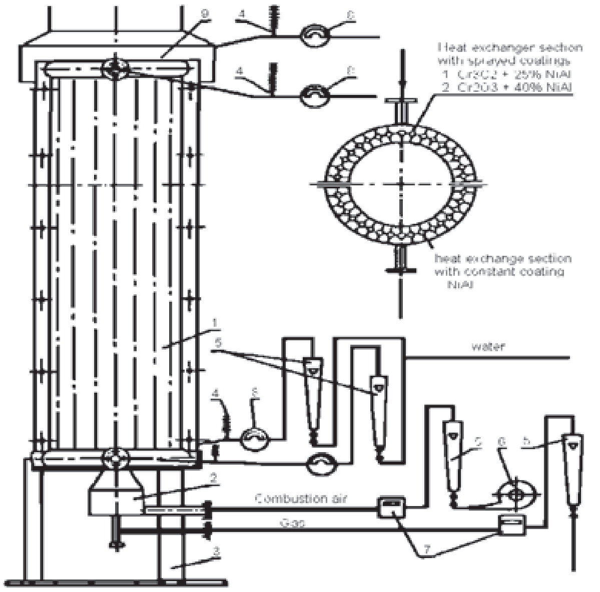


Figure 4. A schematic of the installation of a model heat exchanger used for testing the effect of the coating types on the heat exchange in the waste-heat boiler. 1 – model waste-heat boiler; 2 – burner; 3 – stand; 4 – thermocouple - recorder; 5 – rotameter; 6 – fan; 7 – gas meter; 8 – water meter; 9 – hood with a combustion-gas exhaust and a thermocouple for the measurement of combustion-gas temperature.

The model boiler was composed of two 600 mm-diameter and 2300 mm-high semi-cylinders built in a tube-fin-tube arrangement (38-diam. x 4 tubes, and 20 x 4 fins). Using a diffusion burner, natural gas was burnt producing a luminous flame up to the 3/4 of the boiler's height. Measurements of the heat-exchange characterizing parameters were started after the thermal balance had been reached. The tests were performed in two stages, each of the stages including three measurement series. The measurement results are depicted graphically in Fig. 5 and summarized in Tab. 4. On the Stage II, section 1 (NiAl) and section 3 were used, the latter being sprayed with the Cr_2O_3 + 40%NiAl coating.

On Stage I, two sections with coatings sprayed on their surfaces were used: section 1 – NiAl (reference state of measurements); and section 2 – Cr_3C_2 + 25% NiAl.

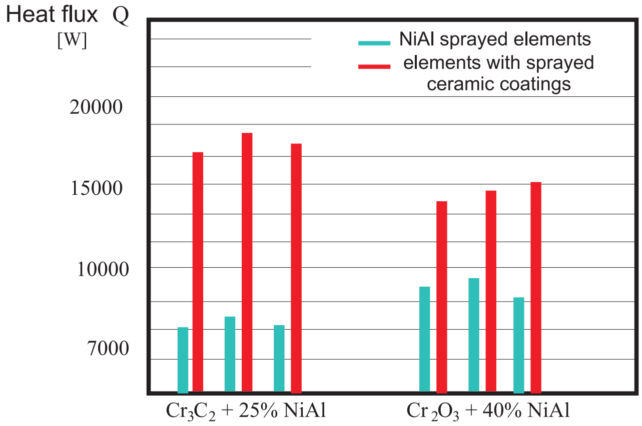


Figure 5. Effectiveness of the effect of cermet coatings on the flux of heat absorbed by the boiler.

Table 4. Parameters of water streams flowing through the boiler sections.

Stage series	Coating type	Burner feeding parameters		Flowing water warameters				Heat flux warried with water	
				temperature		Temperature	Mass		
		Gas	Air	Inlet	Outlet	Increase	Flux		
		m^3h^{-1}	m^3h^{-1}	°C	°C	°C	$g\ s^{-1}$	W	%
1	2	3	4	5	6	7	8	9	10
I.1	NiAl	2	18	11.1	24.9	13.8	164	9460	100
	Cr_3C_2+25%NiAl			11.1	30.9	19.8	210	17380	184
I.2	NiAl	2	18	11.1	26.0	14.2	160	9496	100
	Cr_3C_2+25%NiAl			11.1	32.6	20.8	216	18779	198
I.3	NiAl	2	18	11.1	25.5	14.5	182	11031	100
	Cr_3C_2+25%NiAl			11.1	30.5	19.5	226	18421	167
II.4	NiAl	2	18	11.1	25.0	13.9	176	10226	100
	Cr_3C_2+40%NiAl			11.1	30.3	19.1	189	15089	148
II.5	NiAl	2	18	11.1	26.1	14.7	170	10445	100
	Cr_3C_2+40%NiAl			11.1	29.8	184	193	14844	132
II.6	NiAl	2	18	11.1	25.1	14.1	189	11140	100
	Cr_3C_2+40%NiAl			11.1	30.4	19.4	180	16637	149

6 Analysis of the test results

In the first stage of the measurements carried out, the most favourable results were obtained from the second measurement series. The temperature of water flowing to the both sections, i.e. to section 1 with the NiAl coating and to section 2 with the Cr_2O_3 + 25% NiAl coating was 11.8 ˚C, whereas the water temperature at the outlet of the section system was: from section 1–26.0 °C, and from section 2–32.6 °C. The water temperature increase was, respectively: in section 1–14.2 °C, and in section 2–20.8 °C. With the water flow values as per Tab. 4, column 8, row 2, the fluxes of heat carried away with the heated water reached the following values:

- from section 1 sprayed with the NiAl coating – 9496 W (100%),
- from section 2 sprayed with the Cr_2O_3 + 25% NiAl coating – 18779 W (198%),

which is roughly twice as high as the values obtained from section 1 sprayed with NiAl coating.

This doubling of the amount of heat carried with water, obtained as the result of spraying section 2 with the carbide coating (with the high value of Q_α/Q_ε and the high value of λ_{pow}) clearly confirms the suitability of this kind of coating for intensifying the processes of heat absorption from heating media.

The absorption by water of almost doubled amount of heat from the flame and from the flowing combustion gas indicates high efficiency of heat utilization in the working space of the exchanger sprayed with absorptive-conductive coatings.

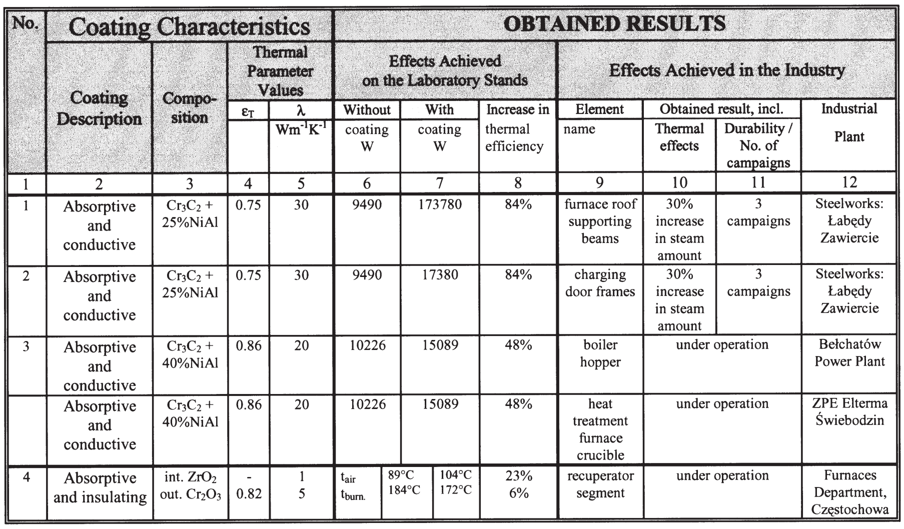
The 66.7% to 97.7% increase in the value of heat absorbed by water flowing in the system of tubes covered with the Cr_2O_3 + 25% NiAl coating causes the lowering of the combustion gas temperature, which leads to a decrease in the combustion gas volume and, in industrial installations, causes an increase in the dust concentration in the combustion gas volume and increases the amount of dusts precipitating in the dust collector through which the combustion gas flows.

The results obtained from the second stage of tests, which was carried out by combining section 1 (NiAl) with section 3 (Cr_2O_3 + 40% NiAl), proved to be less interesting from those obtained from the first stage. The greatest values of heat fluxes carried away with water were attained in the 6-th measurement series (II.6). The obtained values of the heat fluxes carried away by water from the section of the exchanger covered with the Cr_2O_3 + 40% NiAl coating were by approx. 50% higher than the values of heat fluxes carried away with water flowing out of section 1.

The use of cermet coatings made from the mixtures of oxides with NiAl proved to be positively less advantageous that the use of coatings made from the mixtures of the carbide with NiAl.

The results obtained in the laboratory were confirmed in the full-scale operation of the supporting beams of furnace roofs and charging door frames. By spraying the radiated surfaces of these constructional elements of metallurgical furnaces, a few dozen percent increase in the steam amount an parameters (such as pressure) was obtained – Tab. 5, rows 1 and 2.

Table 5. Comparison of laboratory and industrial results of the effect of coatings.



No.	Coating Characteristics				OBTAINED RESULTS						
	Coating Description	Composition	Thermal Parameter Values		Effects Achieved on the Laboratory Stands			Effects Achieved in the Industry			
			ε_T	λ	Without coating W	With coating W	Increase in thermal efficiency	Element name	Obtained result, incl.		Industrial Plant
				$Wm^{-1}K^{-1}$					Thermal effects	Durability / No. of campaigns	
1	2	3	4	5	6	7	8	9	10	11	12
1	Absorptive and conductive	Cr_3C_2 + 25%NiAl	0.75	30	9490	173780	84%	furnace roof supporting beams	30% increase in steam amount	3 campaigns	Steelworks: Łabędy Zawiercie
2	Absorptive and conductive	Cr_3C_2 + 25%NiAl	0.75	30	9490	17380	84%	charging door frames	30% increase in steam amount	3 campaigns	Steelworks: Łabędy Zawiercie
3	Absorptive and conductive	Cr_3C_2 + 40%NiAl	0.86	20	10226	15089	48%	boiler hopper	under operation		Bełchatów Power Plant
	Absorptive and conductive	Cr_3C_2 + 40%NiAl	0.86	20	10226	15089	48%	heat treatment furnace crucible	under operation		ZPE Elterma Świebodzin
4	Absorptive and insulating	int. ZrO_2 out. Cr_2O_3	- 0.82	1 5	t_{air} 89°C $t_{burn.}$ 184°C	104°C 172°C	23% 6%	recuperator segment	under operation		Furnaces Department, Częstochowa

7 Findings and conclusions

1. The experimental studies have confirmed that both ceramic and cermet coatings with rough surface have great ability of absorbing heat. The emissivity of the coatings decreases with the addition of a metal component to the ceramic material. It has been found at the same time that the emissivity of the metal coatings is above twice as high as the emissivity coefficient value for solid-state metals.

2. The examination of the effect of coatings sprayed on the elements of equipment operated in the laboratory showed that:

  - in the presence of the cermet coatings having high values of emissivity and heat conductance, the doubling of the amount of heat carried away by water flowing in the exchanger was obtained (Fig. 5, Tab. 4);
  - in the presence of the two-layer coating (composed of a low-conductivity inner layer and a high-emissivity outer layer), an increase in the heated air temperature and a decrease in the temperature of combustion gas leaving the model flue with an installed recuperator were obtained.

3. The values of the emissivity and thermal conductivity of the coatings have been found to correlate with relationship (1b) and also with the values of heat fluxes absorbed by the heated media flowing in the model (Tab. 4) and industrial heat exchangers with coating applied on their surfaces (Tab. 5).

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Zastosowanie plazmowo natryskiowanych powłok w wymianie ciepła przez promieniowanie

Streszczenie

Przytoczono wartości współczynników emisyjności materiałów metalowych i ceramicznych oraz powłok. Dokonano analitycznych obliczeń wpływu współczynnika emisyjności wzajemnej: czynnik nagrzewający (płomień) - ściana bez powłok, a następnie czynnik nagrzewający (płomień) ściana z powłoką (czynnik nagrzewany) na wartości strumienia wymienianego ciepła. W oparciu o wyniki pomiarów podstawowych własności powłok wytypowano najbardziej przydatne do natryskiwania ścian pieców i wymienników warunkujące intensyfikację wymiany ciepła. Powłokami tymi natryskano ściany laboratoryjnego kotła odzysknicowego i dokonano pomiarów wartości strumienia ciepła przejmowanego przez wodę chłodzącą – przepływającą w rurach kotła pokrytych różnymi rodzajami powłok. Obliczenia analityczne i badania laboratoryjne potwierdzono wynikami eksploatacji przemysłowej w elementach urządzeń hutniczych.