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EFFECTS OF THERMOPHYSICAL AND MECHANICAL PROPERTIES OF THE SUBSTRATE ON THE NORMAL ADHESION OF Ni-Cr-Fe COATINGS DEPOSITED BY THERMAL SPRAY

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ABSTRACT

Thermal spray process is used to obtain high quality coatings that improve corrosion resistance, mechanical and tribological properties, in various technical applications: auto parts, turbine elements, in the naval industry. It aims at the increase service life of components, greater reliability and a higher degree of safety. A major contribution to achieving these goals is due to the good adhesion of the coating to the substrate. Generally, spray distance, design speed powders, powders nature, source temperature (flame, arc, plasma) are the most analyzed parameters in the thermal spray process. But, substrate roughness can strongly influence the performance of the coatings. The aim of this paper is to present the effect of substrate roughnes on the normal component of the adhesion of Ni-Cr-Fe coatings.

KEYWORDS: thermal spray, roughness, adhesion

1. Introduction

American Society for Testing and Materials (ASTM) defines adhesion as "the state in which two surfaces hold together because connection interfacial forces which may be of Van der Waals, interlocking forces, or a combination of these (ASTM D907-70)" [1].

Coating adherence to the substrate is considered as the most important property monitored in thermal spray deposition process.

A low level of adherence leads in time to delamination and corrosion at the interface coating/substrate, undesirable phenomena will progress continuously [2].

Literature states that the factors influencing adhesion layers deposited by thermal spray process are highly correlated with:

-the nature of the materials used for spraying, grain size, preparation method;

-spraying process mainly (oxy-fuel spraying, plasma spraying, arc spraying), and parameters (the distance the spray deposition temperature, the design speed of the particulates);

-thermophysical properties of the substrate (conductivity and thermal diffusivity) and the appearance of the surface (roughness and method used for cleaning and surface profiling) [3].

In Figure 1 is shown schematically how to achieve deposition using thermal spray process [4].

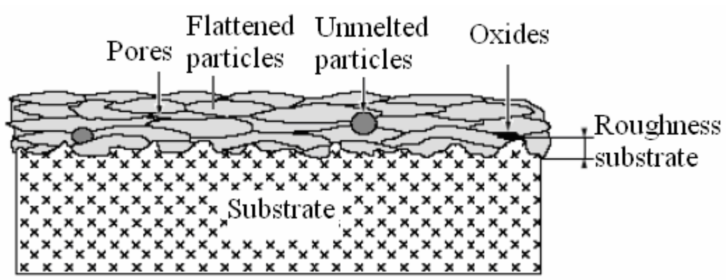


Fig. 1. *Principle of coating formation during thermal spraying*

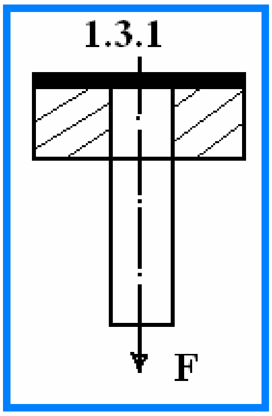
Layer deposited on a rough substrate comprises the largest proportion of flattened particles and pores, but can include unmelted particles and oxides. The appearance of oxides and unmelted particles is due to the variation of the spraying parameters such as the melting temperature of the powder, the design speed or the spray distance.

Adhesion of the coating to the substrate is achieved through several mechanisms, but the mechanical interlock due to the rough surface of the substrate support is most important. A too high content of oxide inclusions and / or unmelted particles leads to decreasing the level of deposit adhesion to the substrate, in the literature stating that just melted and unoxidized particles can adhere to the rough surface of the substrate.

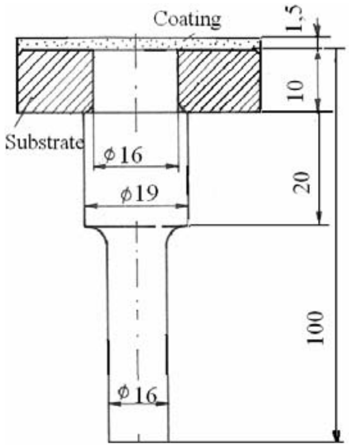
This paper aims at presenting the effect of substrate roughness on the normal adhesion strength of Ni-Cr-Fe coatings deposited by thermal spray.

2. Materials and experimental procedures

For testing tensile adhesion there is a wide variety of standardized methods: ASTM D 4541, ASTM C633, EN 582, ISO 14916 [5]. In this paper we used the non-standard method shown schematically in Figure 2a [6]. Samples of steel S355JR were made according to the dimensions shown in Figure 2b.



a



b

***Fig. 2. a**- Testing method; **b**- Sample dimensions*

The surfaces of the samples (Figure 3) were processed in order to make deposits as follows:

-Sample 1 was processed by turning coarse followed by sandblasting; surface roughness 12.5μm;

-Sample 2 was processed by turning normal followed by sandblasting; surface roughness 6.3μm;

-Sample 3 was processed by turning fine followed by sandblasting; surface roughness 3.2μm;

-Sample 4 was processed by polishing with diamond disc; surface roughness 1.6μm;

-Sample 5 was processed by grinding; surface roughness 0.8μm.

***Fig. 3.** Test samples with different roughness*

The coatings were deposited by employing an oxy-acetylene thermal spray system type Castodyn DS 8000 onto S355JR steel substrate samples. The spraying operation is carried out in two stages: first, a bond coat, followed by the anti-wear coating (figure 3a). The selected powders used in our research are the comercial powders Ultrabond 51000 as bond layer and LubroTec 19985, a Ni-Cr-Fe alloy producing anti-wear deposits (figure 3b). The use of Ultrabond 51000 powder as a bond layer brings about an exothermic reaction so that a solid state metallurgical bonding is obtained, thus making it possible to deposit bonding layers on ferrous metals, coppers and on aluminium alloys.

a *b*

Fig. 4. a *- Anti-wear coatings;* ***b*** *- The selected powders*

It also has good mechanical characteristics and very good resistance to elevated temperatures.

This first deposit should be approximately 0.1mm thick, obtained in a single pass. Next, the Ni-Cr-Fe alloy is deposited, by spraying a layer of LubroTec 19985 onto this bonding layer until it reaches the final dimension required (1.5mm - in our case).

During the coating, the temperature of the part does not exceed 200°C. The powders used had a particle size between ~38 and 150μm, according to the manufacturer’s information.

3. Effect of thermophysical and mechanical properties of the substrate on the normal adhesion strength of Ni-Cr-Fe coatings deposited by thermal spray

To highlight the influence of substrate roughness on the normal component of adherence of coatings, we proceeded to spray tests using the five test samples with different roughness. To deposit layers, samples were successively mounted on a lathe. Spray parameters were adjusted in accordance with Table 1.

Table 1. *Spray parameters*

Parameter	Bond coat	anti-wear coating
Powder	51000	19985
Standard Spray Module	SSM 10	SSM 10
Setting of container mounting	3	4
Flame setting	Neutral	Neutral
Air without extension neck (bar)	0-1	0-1
Spraying distance (mm)	150	160
Pressure: Ox = 4 bar; Ac = 0.7 bar; Air = 2 bar Oxygen flow rate: ~2000 NL/h (flame) Acetylene flow rate: ~1800 NL/h Flame power: ~28 kW		

Fig. 4. *Normal adhesion strength testing*

Testing normal component of adherence for the samples was done on a press Nilles model (Figure 4).

To calculate the normal adhesion strength of coatings of Ni-Cr-Fe deposited by thermal spray we used the following formula [7]:

$$A^{\perp} = (F^{\perp})/A \qquad (1)$$

where:

-$F^{\perp}$ is the maximum force applied perpendicular to the surface coating in order to coating detachment from the substrate,

-A is the surface of interface coating/substrate.

Test results of five samples are presented in Table 2.

Table 2. *Normal adhesion strength of Ni-Cr-Fe coatings*

Test sample	**Roughness**	**Normal adhesion strength**
	[µm]	[Mpa]
1	12.5	10.5
2	6.4	12.2
3	3.2	9.1
4	1.6	7.3
5	0.8	4

Variation of normal adhesion strength depending on substrate roughness was approximated by a 2nd order polynomial expressions using Excel software [8]:

$$A^{\perp} = -0,6071x^2 + 5,6329x - 1,22 \qquad (2)$$

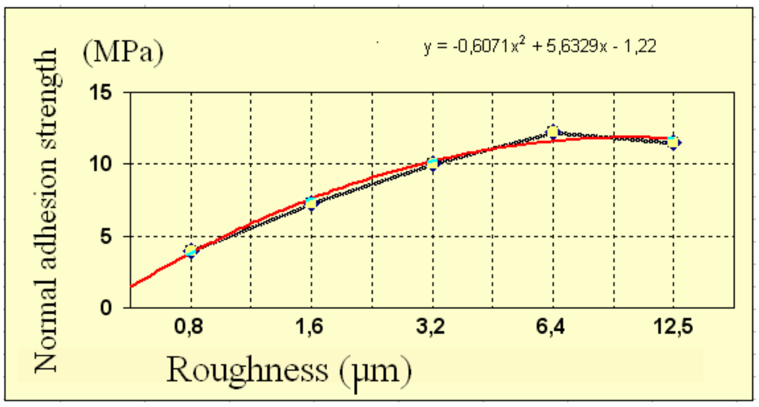


Fig. 5. *Influencet of substrate roughness on the normal adhesion strength of Ni-Cr-Fe coatings*

To highlight the importance of thermophysical properties of the substrate was achieved a deposit on a sample prepared similarly to sample 5 but in the process of achieving thermal spray deposit has omitted the deposition of bond coat Ultrabond 51000. The result of failing to submit the bonding layer (which should be improved conductivity and thermal diffusivity of the substrate) consisted of almost instantly deposited layer delamination. The traces of low thermal diffusivity can be easily observed in Figure 6 (right), showing clearly the existence of the temperature gradient. For comparison was achieved the detachment of coating deposited on sample 5 (Figure 6 left), in order to highlight the lack of distinct thermal zones, which leads to the conclusion that improving conductivity and thermal diffusivity of the substrate by applying bonding layers with excellent thermophysical properties is compulsory.

Fig. 6. *Coatings detached;* ***left*** *- with bonding layer deposition;*
right *- without bonding layer deposition*

4. Conclusion

The results show that normal adhesion strength of Ni-Cr-Fe coatings strongly decreases if the substrate roughness decreases under 3.2µm, while increasing substrate less roughness reduces the coating adhesion. The maximum adherence value was recorded for substrate roughness of 6.3µm. This is probably due to increased exposed surface of the substrate.

Adhesion of coatings is strongly influenced by the thermophysical properties of the substrate and substrate processing quality. Application bonding layer Ultrabond 51000 has improved conductivity and thermal diffusivity of the substrate, and thus has increased adhesion of the coating deposited on the substrate. Good roughness coupled with the absence of oxides and other impurities is a compulsory condition for achieving adhesion.

Detachment of coatings from the substrate after tensile test was achieved uniformly, without damaging the coating or the substrate at the interface coating / substrate.

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