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Abstract. Atmospheric plasma spraying (APS) consists in injecting a powder feedstock material in a plasma jet to melt and accelerate the injected particles and spray them onto a substrate. However, this mechanism of coating formation induces the presence of pores and micro-cracks. In order to eliminate those defects, laser remleting may be used to improve the properties and performances of plasma sprayed coatings. In the present paper, the Ni-Cr-Re coatings fabricated by plasma spraying on stainless steel substrate were remelted by CO_2 laser, and the effects of laser remelting were studied. The structure and chemical composition of plasma sprayed and laser remelted coatings were analyzed using scanning electron microscopy (SEM) and energy disperse spectroscopy (EDS). The results show that the laser remelted coating becomes much denser and, moreover, the chemical composition of the coatings becomes homogeneous.

Keywords: coatings, rhenium, thermal spraying, laser remelting, microstructure

1. Introduction

Rhenium has found application in industry as a refractory metal due to its unique properties. It is characterized by very high tensile and creep rupture strength over a wide temperature range and has the third-highest melting point and second-highest boiling point of any stable element [1, 2]. This element is also often used as an alloying additive. The addition of rhenium in nickel- or cobalt-based superalloys increases their creep strength [3]. Therefore it is also used for manufacturing of coatings [4] or reinforced composites [5]. To obtain coatings with the desired chemical composition the plasma spraying process can be used. This technology enables the production of layers with desired thickness even on elements with complex shape. However, a significant disadvantage of plasma sprayed layers is the lack of uniformity and compactness within their structure, caused by the presence of pores and cracks. The porosity of these layers can be reduced in the process of laser beam [6-10] or electron beam remelting.

This paper presents the effects of laser remelting processes of thermal sprayed coatings in relation to rhenium content and process parameters.

2. Experimental procedure

The materials used in this procedure were Ni20%Cr, Ni20%Cr + 10%Re, Ni20%Cr + 20%Re, Ni20%Cr + 30%Re alloys. The procedure consisted of 3 stages. The first stage was the production of powders at the Łukasiewicz - Institute of Non-Ferrous Metals. Powders were produced from commercial NiCr powders through their modification with rhenium. The modification technique consisted of a thermo-chemical treatment for producing metallic rhenium from NH_4ReO_4 (ammonium perrhenate) directly on the surface of modified powders.

During the second stage, manufactured powders with different rhenium content were plasma sprayed on an austenitic stainless steel (AISI 316Ti) substrate. The surface of the substrate was prepared by abrasive blasting using corundum abrasive. The plasma spraying parameters: current 530 A, arc voltage 690 V, shielding gas flow rate (Ar) 54 l/min, plasma gas flow rate (H_2) 9 l/min, transport gas flow rate (Ar): 5 l/min, spraying distance 140 mm, travelling speed 400 mm/s.

The last stage was laser remelting that was carried out using a laser CO_2 generator (Trumpf Lasercell 1005). 9 samples were made for each rhenium content with different process parameters (the parameters changed were the power and beam travelling speed). Argon gas (ISO 14175-I1-Ar) was used to prevent oxidation during the process. The gas flow rate was 12 l/min, the working distance of the laser head was 100 mm. Other process parameters are given in Table 1.

Table 1. Laser beam remelting parameters

Variant no	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Laser beam power, W	3000	3500	3800	3000	3500	3800	2000	1500	2000
Laser beam travelling speed, mm/min	300	300	300	500	500	500	300	500	500

The microstructures of the etched samples were investigated by light microscopy (LM; Zeiss Axio Imager) and scanning electron microscopy (SEM; FEI Nova NanoSEM 450) with energy dispersive spectroscopy (EDS). The coatings thickness were measured by light microscopical examination of the cross-sections. The thickness error was about 1 µm samples. The SEM observations and EDS line analysis were carried out with an acceleration voltage of 15 kV, at working distance of 5 mm.

3. Results and discussion

The cross-section images of the coatings are shown in Figure 1. Figure 1a shows photos of plasma sprayed coatings: Ni-Cr and NiCr + Re. Those are characterized by high porosity and contain a lot of cracks and have typical plasma sprayed lamellar structure. In turn, Figure 1b illustrates the cross-section of coatings after laser remelting (for given remelting parameters: speed 300 m/min and laser beam power 3800 W). As shown in Figure 1b laser remelting effectively reduces the presence of pores and microcracks resulting in much denser coating. After laser remelting the lamellar structure of the plasma sprayed coating was replaced by fine homogenous microstructure.

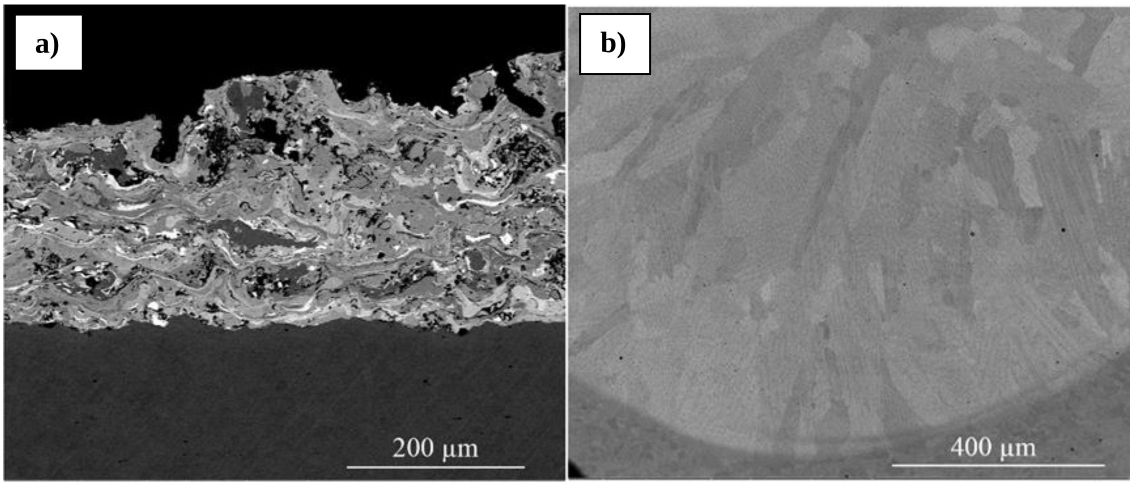

Figure 1. The cross-section images of coatings with different rhenium content: a) plasma-sprayed; b) laser remelted .

Based on SEM observation, lower adhesion Ni-Cr coating to the substrate than NiCr+Re coatings is visible. The detailed quantity analysis of the adhesion phenomena base on scratch tests will be carried. On the other hand, in the coatings with the highest rhenium content, the largest clusters of pores (5.6 %) were observed. After the laser remelting process, the coatings were characterized by good adhesion to the substrate and the absence of porosity (0.2%) and material discontinuities. For variant 8 (the lowest laser power), the Ni-Cr and Ni-Cr-20% Re coatings are discontinuous. Lack of continuity was also observed for the Ni-Cr-10% Re coating from variant 6 (highest power and speed). In the Ni-Cr-30% Re coatings remelted at a speed of 300 mm/min (for all laser power values) cracks were visible. Cracks were also seen in the variant 9 Ni-Cr-20% Re coating.

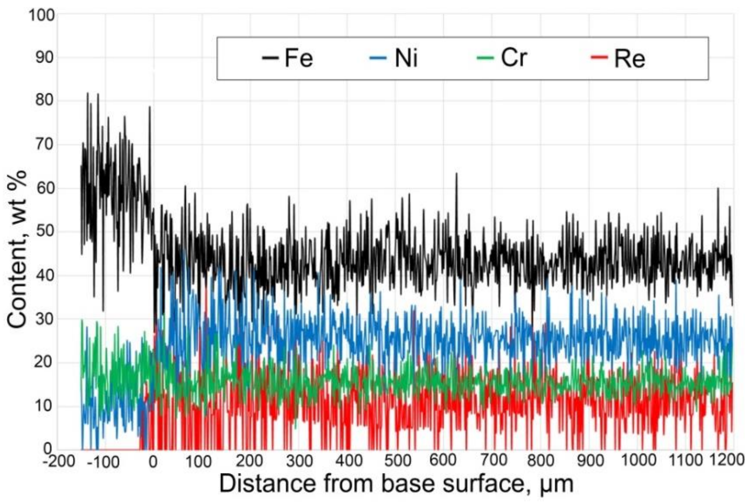

Figure 2 EDS line scan results of the plasma-sprayed Ni20%Cr + 20%Re coating after laser remelting

The micro-area chemical composition of the coatings before and after the laser remelting was analyzed using EDS. It was found that the distribution of elements before remelting is not uniform. The analysis revealed that the ratio of Ni, Cr and Re in different areas is not the same.

The result of EDS line scan of laser-remelted coating is shown in Figure 2. After laser remelting the lamellar structure becomes homogeneous in composition. The Fe (black line) content changes from about 70% in the base material surface region to about 48% in the remelted region. The content of Cr (green line) in base material is in the range up to 25% and decreases to approx. 15% (average value) in the remelted zone. Inversely, the Ni (blue line) content in the remelted region is much higher (about 26%) than that in the surface region (about 10%). Only the remelted region contains approx. 10% rhenium (green line).

All of the samples were measured before and after the process of laser beam remelting.

Table 2. Average thickness of plasma sprayed coatings

Coating material	Average thickness, µm
Ni-Cr	287 ± 21
Ni-Cr-10%Re	280 ± 20
Ni-Cr-20%Re	164 ± 21
Ni-Cr-30%Re	255 ± 30

The thickness of the plasma sprayed coatings is summarized in Table 2. The Ni-Cr coating with 20% rhenium content was characterized by the smallest thickness. This is caused by higher density of powder with Re and higher kinetic energy. For all used alloys the thickness of the coatings after laser remelting is shown in the graphs below (Figure 3).

The laser energy density (laser energy per area unit) is proportional to laser power while it is inverse to scanning velocity and beam size. Laser energy density increases as the laser scanning speed declines. From the Fig.3 it is clearly visible that increase of the laser power caused increase the layer thickness (distance between top of surface and max. penetration depth in substrate). Therefore, the layer thickness can be even twice higher after remelting. If the travelling speed increases, the penetration depth becomes lower and thus, total layer thickness decreases. However, it should be noted that when the laser scanning speed drops to some extent, the coatings will become more homogenous and compact, and this results in the relatively high thermal conductivity of the laser-treated coatings. After the laser

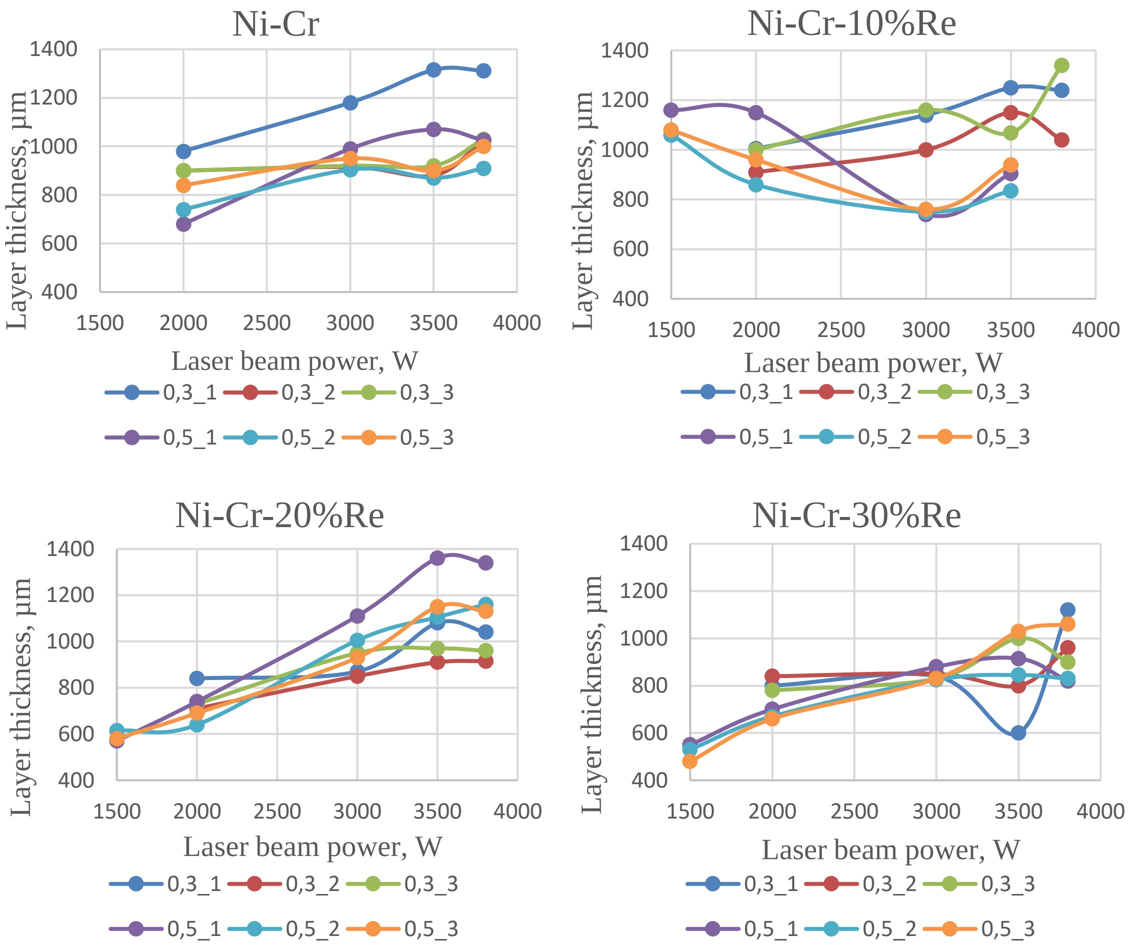

Figure 3. Graphs showing the relationship between the applied process parameters and the thickness of the resulting coatings

beam passes, the heat in the molten regions is conducted quickly to the substrate and external environment. On the other hand, at higher travelling speed the remelted coatings are cooling down faster, solidification process become promptly, thus cracks happen as a consequence of the restriction of the substrate and side coatings. The cracking tendency is more visible. Therefore, it is important and necessary to explore the proper laser parameters to obtain the relatively better performance of laser-remelted coatings.

4. Conclusion

In this paper, the effect of laser remelting on plasma-sprayed coating was studied. Ni-Cr-Re coatings were fabricated by plasma spraying and then remelted by CO_2 laser. The plasma sprayed coatings are characterised by high porosity and presence of cracks. These coatings also show the presence of a lamellar structure, thus, resulting in not-homogeneous chemical composition

Coatings with rhenium addition show better adhesion to the surface than Ni-Cr. Highest rhenium content coatings are characterized by high porosity. After the laser remelting process, the coatings present good adhesion. Laser remelting process also reduces the presence of the pores and microcracks. The structure and chemical composition becomes homogenous and uniform.

The thickness of the coatings usually increases with the power of the laser beam. Too high or too low laser beam power causes discontinuities in the coatings. The travelling speed of the laser beam significantly affects the quality. Layers produced at lower beam travelling speeds become more homogenous and compact. Coatings produced at higher speeds show cracking tendency.

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