LASER SURFACE MODIFICATION OF Ni-Cr-Re ALLOY PLASMA SPRAYING COATING

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Introduction

Rhenium is a refractory metal that has gained significant recognition as a high performance engineering material because it exhibits an outstanding combination of properties. Compared to the other refractory metals, Re has superior tensile strength and creep rupture strength over a wide temperature range (up to approximately 2000°C). For example, between room temperature and 1200°C, its strength is approximately double that of tungsten. In addition, the rupture strength of rhenium is greater than that of tungsten at temperatures approaching 2800°C. At 2500°C its strength is comparable to the strength of carbon composites. Unlike other refractory metals (W, Mo, Ta) it exhibits good ductility at room temperature. These properties make rhenium an attractive candidate for numerous applications, especially in high-temperature structural and energy systems applications. Currently, additions of rhenium are commonly used in Ni- or Co-based super-alloys for the purpose of improving the creep strength, reinforced composite or manufacturing of coatings. On the other hand, plasma spraying process is able to produce coatings with any chemical composition that are necessary for different industrial applications, spray on complex shapes as well as on elements with small thickness. The plasma spraying also allows for produce layers of a precisely defined thickness, contrary to the flame spraying process or weld cladding. The plasma spraying method is increasingly used for the production of coating on elements used in the aerospace and military industries. The main difficulty, however, is the fact that the spraying process does not allow for a uniform and compact coating within its entire volume. The plasma sprayed layers are usually characterized by porosity. In order to reduce it, the processes of laser beam remelting or electron beam can be used.

Experimental procedure

Ni20%Cr + 20%Re coatings were prepared in three steps. Firstly, the plasma sprayed materials in the form of powder were produced at the Łukasiewicz - Institute of Non-Ferrous Metals from commercial NiCr powders by the modification of them with rhenium (Fig. 1). The technique of powder modification with rhenium has been already elaborated at the Łukasiewicz - Institute of Non-Ferrous Metals. The process is based on an application of thermo-chemical treatment for producing metallic rhenium from a raw material in the form of ammonium perrhenate directly on the surface of modified powders.

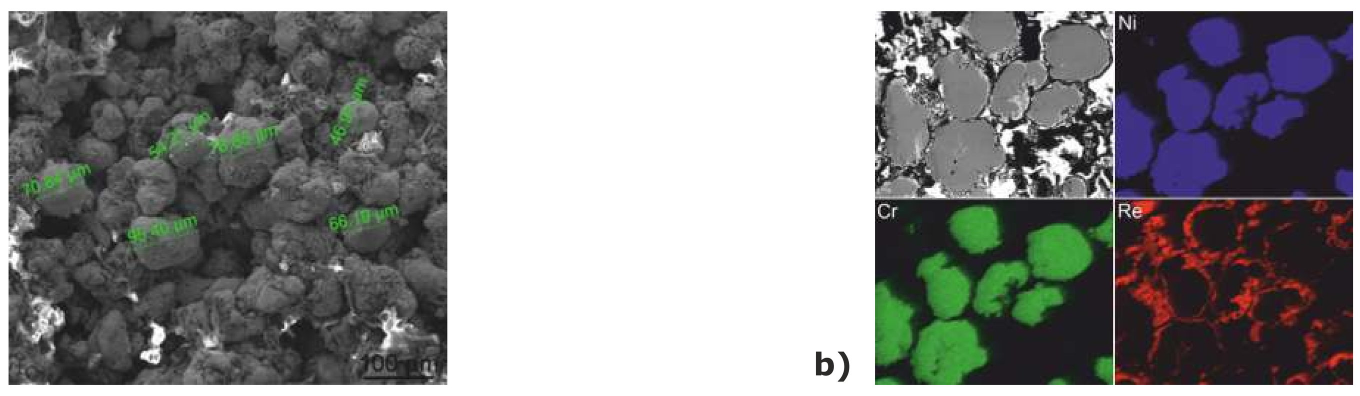

Figure 1. Ni20%Cr + 20%Re powder for plasma spraying,
a) general view, b) EDS analysis – Ni (blue), Cr (green), Re (red)

Secondly, manufactured alloy powders were sprayed on a ferritic stainless-steel (316Ti) substrate by an atmospheric plasma-spraying facility (AP-50 Plasma Spray System). The plasma spraying parameters: current 530 A, arc voltage 690 V, shielding gas flow rate (Ar) 54 l/min, plasma gas flow rate (H2) 9 l/mi, transport gas flow rate (Ar): 5 l/min, spray distance 140 mm, travelling speed 0.4 m/s. Before plasma spraying the surface of the substrate was decreasing and oxide layers was removing. Abrasive blasting using corundum abrasive F36 (500-600 μm grain size) and F40 (425-500 μm grain size) were applied. After plasma spraying, a coating ~380 μm in thickness was achieved. The average roughness of the APS surface was 19.42 μm. Finally, laser remelting was carried out on the coating using a laser CO_2 generator (Trumpf Lasercell 1005). The travelling speed was 0.5 m/min at a fixed laser head to work distance (100 mm), and laser power was applied: 3.5 kW. High-purity argon gas (ISO 14175-I1-Ar) at flow rate 12 l/min was used to prevent oxidation during laser processing. The general view of sprayed surface and after laser remelting in Fig. 2 were presented. The resultant plasma sprayed and laser remelting coated samples (cross-section) were cut, polished and etched chemically (NH4F+HNO3). The microstructures of the etched samples were investigated by scanning electron microscopy (SEM; FEI Nova NanoSEM 450) with energy dispersive spectroscopy (EDS). The microhardness of samples was measured by a TUKON 2500 digital microhardness tester with a load of 300 gr for 10s. Microhardness measurements were performed on the substrate, bond layer and coating.

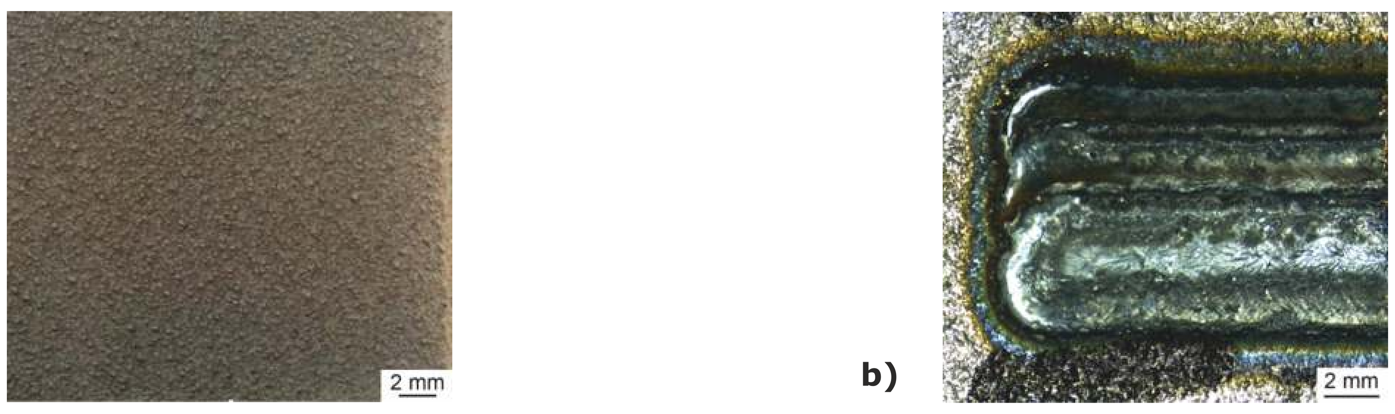

Figure 2. General view of sprayed surface, a) after spraying, b) after laser remelting

Results and discussion

The cross-section SEM images of plasma-sprayed and laser remelted Ni20%Cr + 20%Re coatings are shown in Fig. 3. From the top to the down, there are the bond layer and ceramic coating in turn. The plasma sprayed coating has a typical plasma sprayed lamellar-like structure and contains a lot of pores and cracks (Fig. 3a). Laser remelting can effectively reduce the pores and microcracks of the plasma sprayed coating, and the coating became much denser. In addition, the lamellar defects of the plasma sprayed coating were erased, and fine equiaxed grains with homogenous distribution were obtained (Fig. 3b). So the compactness of the plasma sprayed coating was improved significantly using laser remelting.

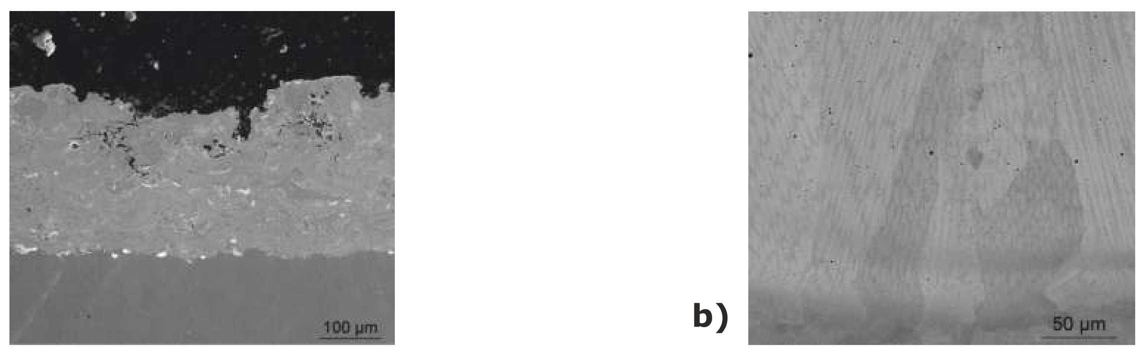

Figure 3. The cross-section SEM images of coatings: (a) plasma-sprayed, (b) laser remelted.

The micro-area chemical composition of the plasma-sprayed coating are analyzed. The high-magnification SEM of cross-section of coating and EDS of different micro-areas are shown in Fig. 4. The analysis of the chemical composition of the Ni-Cr-Re coating, revealed that the ratio of nickel and chromium in different areas is not the same. It was found that the distribution of elements is uneven. There are areas consisting mainly of nickel and chromium (darkest), nickel and chromium with approx. 20% rhenium addition (lighter) and only rhenium (white).

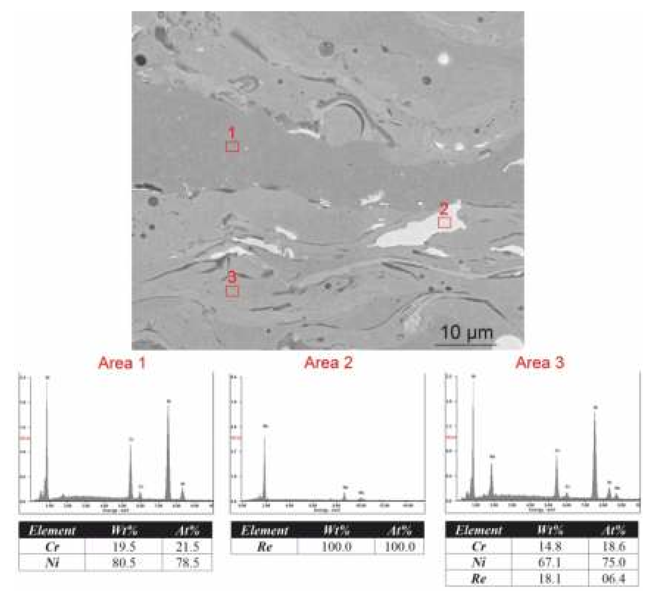

Figure 4. The corresponding EDS result of different micro-areas of the plasma-sprayed coating

Fig. 5 presents the EDS line scan images of plasma-sprayed coatings after laser remelting. The content of Cr (green line) is in the range up 25% in the area of surface and decrease to 14.9 % (average value). The content of Fe (black) in the surface region is higher (up 70%) while lower in the remelted plasma-sprayed coatings region (about 47.9%). Conversely, the content of Ni (blue) in the surface region is much lower (about 10%) while higher in the remelted plasma-sprayed coatings region (about 25.9 %). Finally, the content of Re in the plasma-sprayed coatings after laser remelting amounts about 10 % (red line). After laser melting, the lamellar structure disappears and the laser-remelted coating becomes homogeneous in composition (Fig. 5).

The hardness distribution of the plasma-sprayed coating after laser remelting in Fig. 6 was presented. It was revealed that the hardness of Ni-Cr-Re coating is higher than Ni-Cr after laser processing. Moreover, the hardness in separated points after remelting process becomes lower to compare to coating without remelting. This is caused, probably by high content of Fe (46.9%) in the processing plasma-sprayed coating to compare to plasma-sprayed direct after spraying with Ni20%Cr + 20%Re.

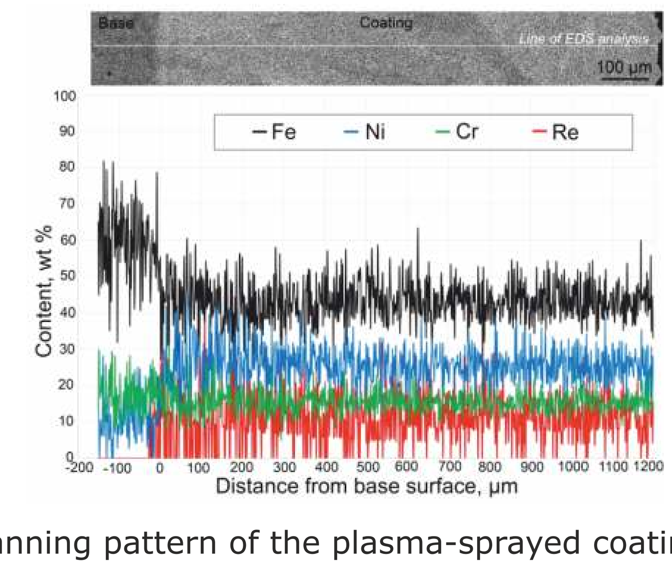

Figure 5. The line scanning pattern of the plasma-sprayed coating after laser remelting

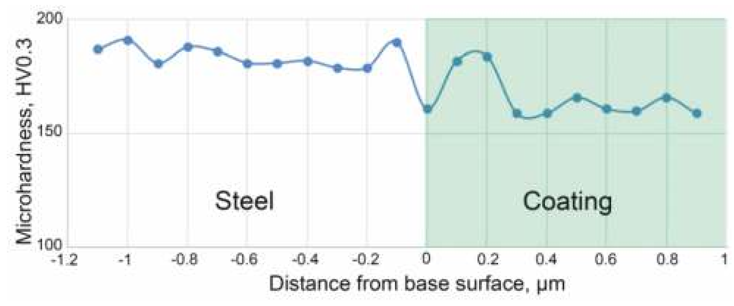

Figure 6. The line scanning pattern of the plasma-sprayed coating after remelting

Conclusion

In this work, Ni20%Cr + 20%Re coating fabricated by plasma spraying was remelted by CO_2 laser, and the effect of laser remelting on microstructure and harndess of coating was studied.

- the plasma sprayed coating shows a lamellar-like structure and has a lot of pores. The microcracks were also detected. Laser remelting can reduce the pores and microcracks and eliminate the lamellar defect. The microstructure of the coating becomes homogenous and compact,
- the scanning speeds of the laser beam in the process of remelting of plasma sprayed layers have a significant impact on quality. More favorable layer properties ensure at less scanning speeds,
- un-remelted coating is characterized by higher hardness in relation to those subjected to the laser treatment process, moreover after laser remelting the chemical composition of the coatings becomes homogeneous.

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