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MICROSTRUCTURE AND OXIDATION RESISTANCE OF LASER REMELTED PLASMA SPRAYED NICRALY COATING

The article presents results of research relating to the impact of laser treatment done to the surface of plasma sprayed coatings NiCrAlY. Analysis consisted microstructure and oxidation resistance of coatings subjected to two different laser melting surfaces. The test were performed at a temperature 1000°C the samples were removed from the furnace after 25, 300, 500, 750 and 1000 hours. The investigations range included analysis of top surface of coatings by XRD characterization oxides formed types and microscopic investigations of coatings morphology

Keywords: NiCrAlY coatings, laser remelted, oxidation resistance

1. Introduction

High efficiency is one of the most important requirements to be met by modern gas turbines. Increasing the operating temperature of critical engine components made of nickel superalloys, it is possible to scale providing significant progress. This limitation stems from the barrier, which is a drop in nickel superalloys creep resistance at high operating temperature [1]. This problem can be solved by applying the alloy matrix such high-melting metals: Nb or Mo but their applications up reduce low resistance to corrosion. The second option is to applications up protective coverings whose purpose is to increase the sustainability of exploitation and optimum use of the materials used. An effective solution is to use thermal barrier coating. The material of substrate elements made of superalloys based on nickel or cobalt.

The role of thermal barriers coating bond-coat is MCrAlY type or aluminized coating that protects against base oxidation and corrosion in an environment containing the sulfur compounds. Additionally have a low tendency to form brittle transitions and high resistance to diffusion of alloying layer and the substrate [2-4]. MCrAlY type coating is used in order to ensure the heat resistance of components made not only with nickel alloys but also the alloys matrix phase of Ti-Al [5].

The time-life of thermal barrier coatings (TBC) is related to many different factors. Most research presents that the main processes degradation of TBC coatings take in the TGO (*thermally grown oxide*) zone in bond-coat [1,6]. The literature describes two mechanisms which influence the process of destruction. In the case of flat surfaces of bond-coat there are buckling mechanism involving on bending of the oxide layer are TGO. This is the cause of deformation and generating of tensile stress on edges of oxide zone. This is characteristic mechanism of the thin and dense oxide layer of low adhesion to the substrate.

The second mechanism is wedging, which occurs with thicker and more defected layers of oxides but also characterized by high adhesion to substrate [7].

Bond-coat obtained by APS method (*atmospheric plasma spraying*) characteristic in high roughness of surface. During cooling process of APS coat the compressive stress in the depression of bond-coat profile of roughness. The tensile stresses are observed in the case of peak of profile of roughness. This kind of stress generated the microcracks in the peak of bond-coat and in consequence starts of delamination process of TBC system. The value of the stress generated is dependent on the thickness of the TGO zone, TGO zone adhesion to the bond-coat, as well as the radius of profile curvature [8,9]. TBC coatings often kinetics of crack propagation in the ceramic layer is lower than the nucleation of cracks and consequently delamination of the coating are on the top TGO roughness profile. It is lead to typical for this process morphology of TGO zone. Oxides present on this zone are thick and cracked. This area is characterized by the column structure and an increase in direction of the substrate [9-11].

2. Experiment description

Material used for testing was a nickel based superalloy Inconel 625 with additional NiCrAlY (Ni22Cr10AlY) coating. The coating was obtained by plasma spraying in air. In additional, laser-melted surface in order to obtain a raster structure. Obtained an area with dense and rare remelting. The treatment is conducted

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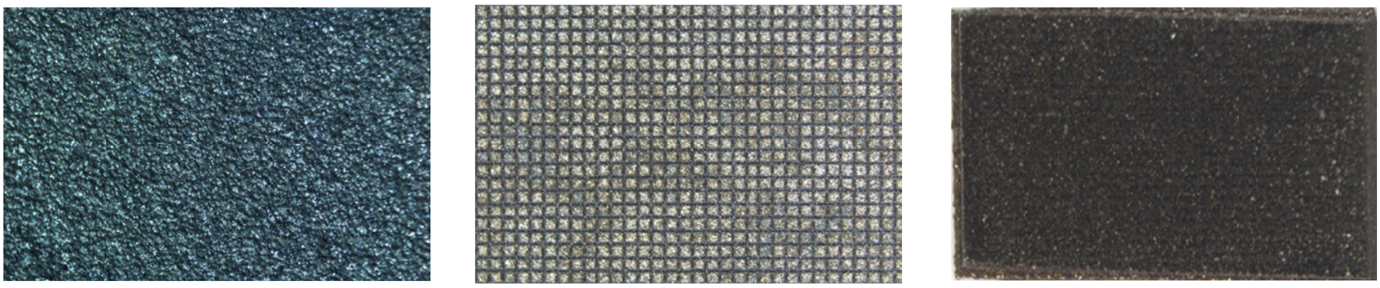
to reduce the surface roughness of the coating relative to that obtained after the plasma spraying. Two types of surface conditions enabled the observation of differences in the mechanism of oxidation. To characterize the surface state used non-contact optical profilograph. Characterization of observed phenomena's was described by XRD (diffractometr JEOL JDX-7s) phases analysis of oxidation products on top-surface of coatings and SEM (Hitachi 3400N microscopy).

3. Results

Melting the coating performed using pulsed fiber laser company IPG. The average power of the laser beam was 100 W. The frequency of pulses was 50 Hz. The diameter of the machined surface on the sample was 0,05 mm. The scan speed of the sample was 50 mm/sec. The laser melting is made of two different densities. In the first case, the grid dimension (ie. Mesh) was 0,5 mm in the second case was 0,1 mm. Figure 1 shows the surface condition after spraying using APS and the condition of the surface after rare and dense laser remelting. In the pictures taken using SEM is seen development of surface area for the sample after spraying and the characteristic grid is the result of melting the coating surface. At the edges of the grid can be observed rise readings melted coating.

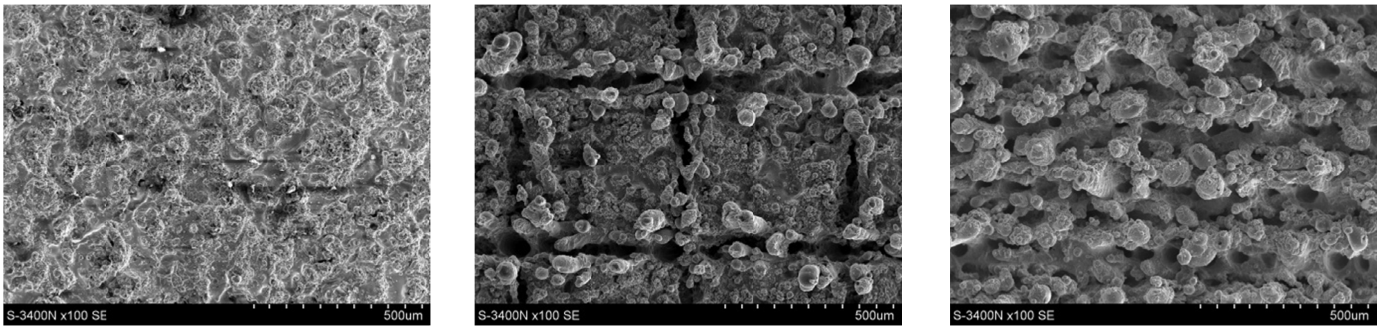
Figure 2 presents the 3D surface image obtained with a non contact optical profilometer. Areas in red show the incidence of vertices. For sample after spraying visible is a large area of occurrence of blue color which indicates that these areas are so-called blind for profilometer. This is due to the very large difference in height between the tops and bottom of the profile. In the case of a sample with a dense laser remelting a large area is visible in red indicating presence of large amounts of vertices. What about the related occurrence as a uniform surface. Table 1 shows the characteristic parameters for each sample topography. The value of the parameter specifies R_a arithmetic mean deviation of the roughness profile assumes the greatest value for the surface after spraying. This value is 8,89 μm. The lowest value



The initial state of the surface 10×

The state of the surface of a rare remelting 10×

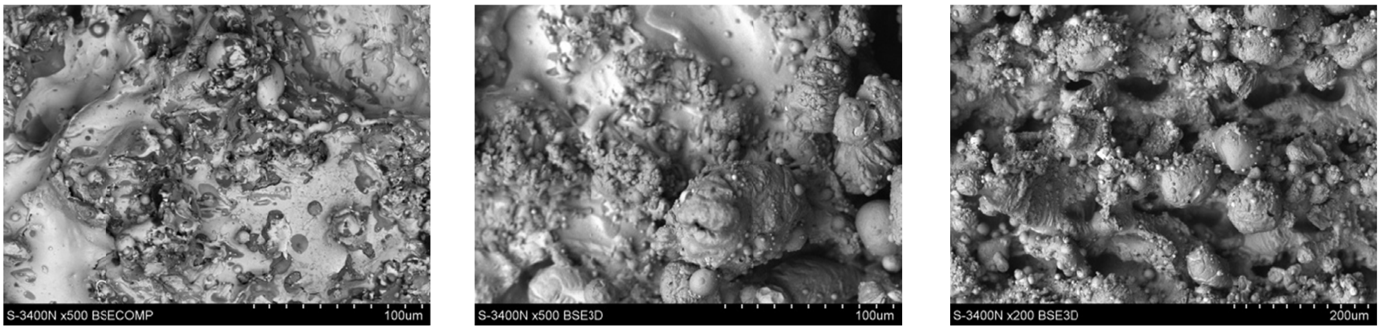
The state of the surface of dense remelting 10×



The initial state of the surface 100×

The state of the surface of a rare remelting 100×

The state of the surface of dense remelting 100×

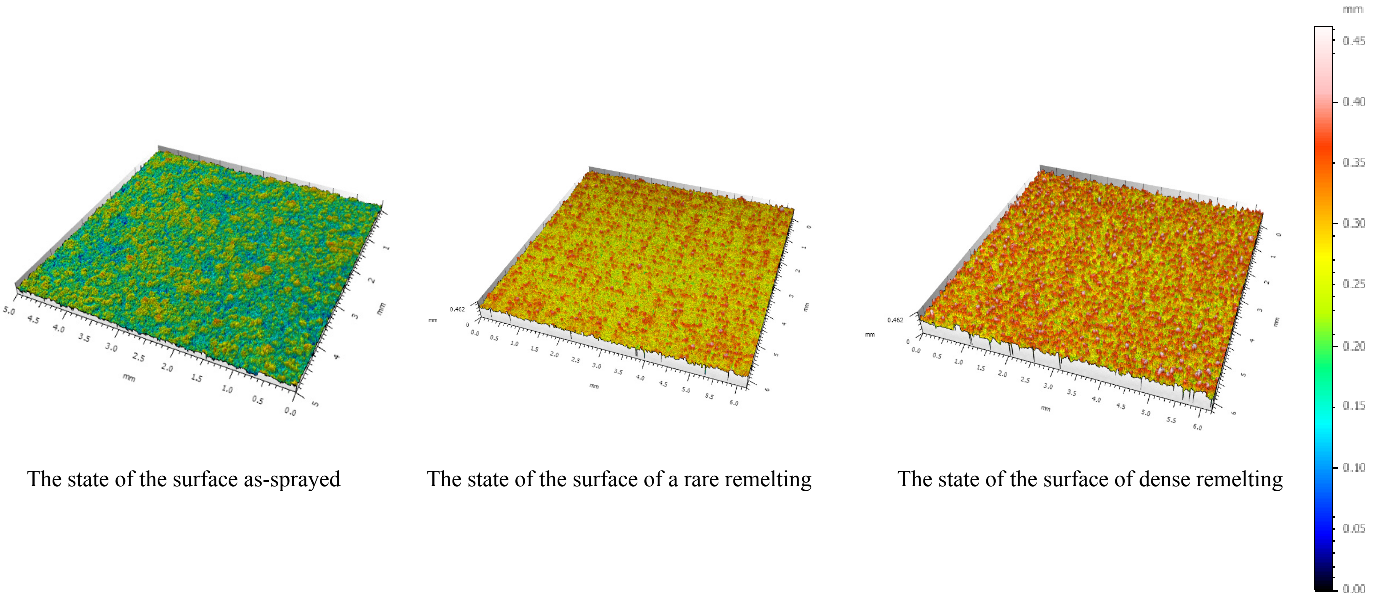


The initial state of the surface 500×

The state of the surface of a rare remelting 500×

The state of the surface of dense remelting 500×

Fig. 1. The surface condition of the sample after spraying and after laser treatment



The state of the surface as-sprayed

The state of the surface of a rare remelting

The state of the surface of dense remelting

Fig. 2. 3D surface topography

of R_a has a surface with a dense laser remelting. This value is 2,32 μm. However, to ensure good adhesion of the ceramic coating, between the layers should be characterized by a parameter R_a value above 2,64 μm. Consequently, the best solution appears to be the surface of a rare remelting. The value of R_a for this surface is 2,88 μm.

TABLE 1

Characteristic parameters of topography

Parameter [μm]	Surface as-sprayed	Rare remelting	Dense remelting
R_z	43,8	11,6	8,94
R_a	8,89	2,88	2,32
R_q	11	5,65	4,78

After determining the differences in surface topography test was performed. Involving the oxidation of samples rare and dense laser remelting. The tests were performed in the furnace in air. The samples were heated in the furnace (5°C/min) up to a temperature of 1000°C. Samples were removed from the furnace after 25, 300, 500, 750 and 1000 hours.

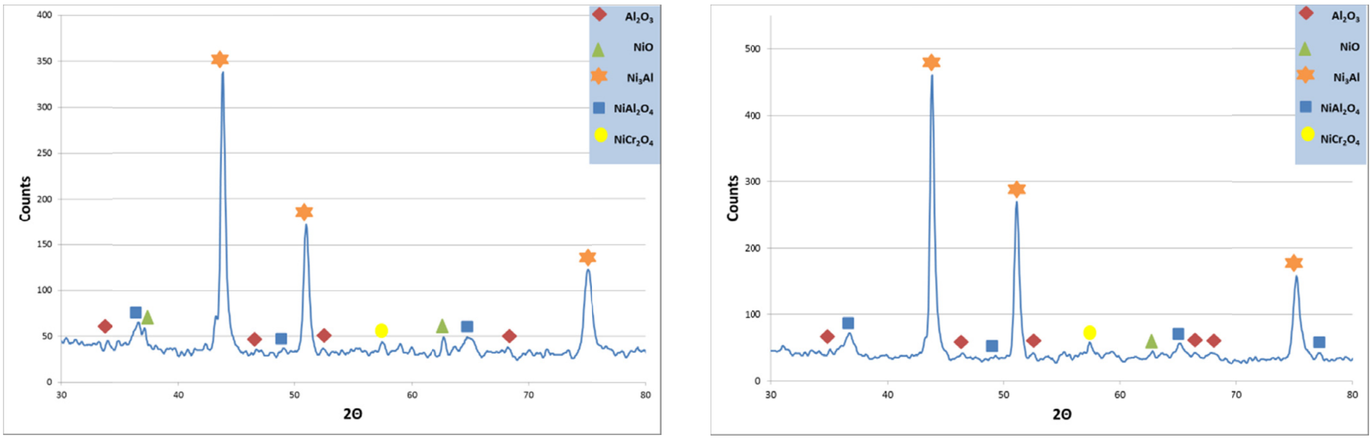
Figure 3 presents an analysis of the chase composition of the samples after 25, 500 and 1000 hours at temperature 1000ºC oxidation obtained using the XRD method. The samples removed from the furnaces after 25 hours, regardless of the test temperature is dominated by strong reflections Ni_3Al phase. In the case of staying the sample at 1000°C can further be noted the presence of oxide phases reflection: $NiAl_2O_4$ and Al_2O_3. After 500 hours of testing at 1000°C appeared reflections of the phases: $NiAl_2O_4$ and $NiCr_2O_4$. In the sample after rare remelting appeared relatively high reflections of $NiAl_2O_4$ phase. In both cases, dominate reflections of Ni_3Al phase. After the next 500 hours of testing in both samples is dominated by strong reflections Ni_3Al phase and weaker reflections: $NiAl_2O_4$, $NiCr_2O_4$ and Al_2O_3 phases. Reflections oxide phases are much stronger in a sample after rare remelting than sample after dense remelting. Phase composition of the samples after remelting does not differ from sample as-sprayed only above 500 hours phenomenon appears amorphousness. The results of phase composition for as-sprayed presenting in (Fig. 4) [13]. Compared to as-sprayed it is visibly generally the intensity of the peaks of each phase. However, there is no difference in their composition.

The analysis of the distribution of elements on the surface of 25, 500 and 1000 hours of oxidation is presented in (Figs. 5-7). Distribution of elements confirms that the compounds identified by the methods XRD. If the surface of samples after laser remelting rare reached after 25 hours shows the great uniformity of nickel (NiO), chromium ($NiCr_2O_4$) and aluminum (Al_2O_3, $NiAl_2O_4$). In the case of a sample with thick remelting notable is the presence of a large amount of area not identified by the detector.

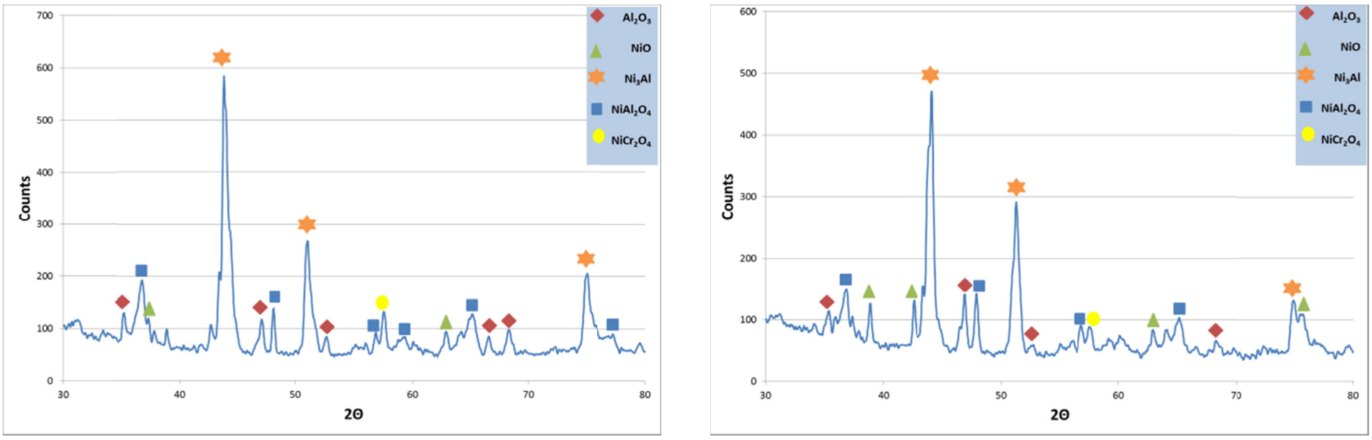
It is associated with a large height difference. In the case of a sample of remelting rare visible can be observed even distribution of the yttrium. After 500 hours is visible appearance of clusters rich of chromium both in a sample of dense and rare remelting. After 1000 hours are shown rich areas in the nickel, chromium and aluminum, which indicates the presence on the surface of a large amount of spinel, type oxides: $NiCr_2O_4$ and $NiAl_2O_4$. The (Fig. 8) shows the distribution of elements in the case of as-sprayed [13]. Noticeable is more uniform distribution of individual elements. However, no apparent differences in the chemical composition of the surface compared to the samples after remelting.

4. Summary

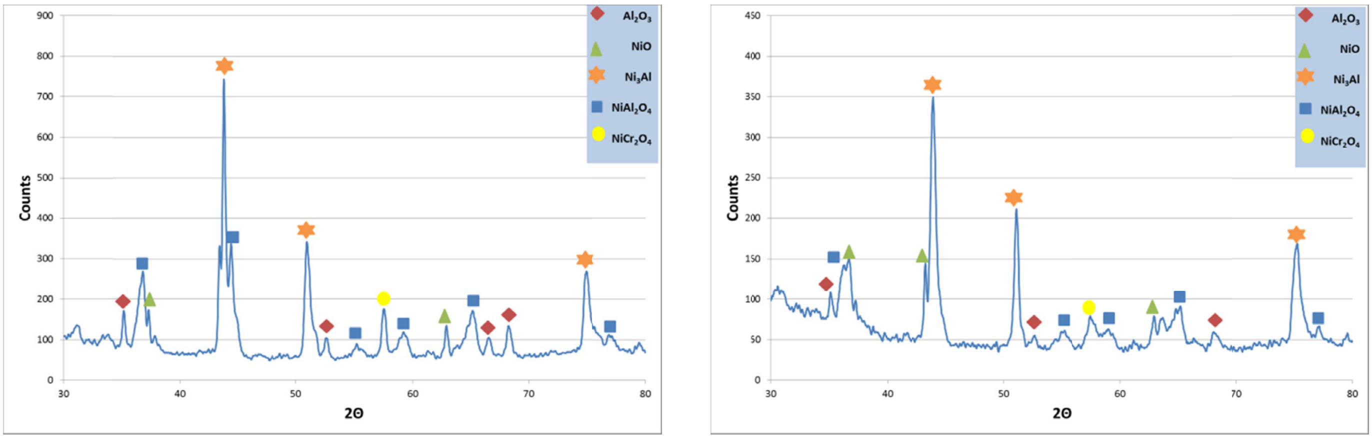
Surface condition affects the way the oxidation. Performing laser melting allows reducing the roughness of the surface, and should ensure good adhesion of the ceramic coating. Reducing



Inconel 625/NiCrAlY rare remelting 1000°C / 25h Inconel 625/NiCrAlY dense remelting 1000°C / 25h



Inconel 625/NiCrAlY rare remelting 1000°C / 500h Inconel 625/NiCrAlY dense remelting 1000°C / 500h



Inconel 625/NiCrAlY rare remelting 1000°C / 1000h Inconel 625/NiCrAlY dense remelting 1000°C / 1000h

Fig. 3. XRD diffraction patterns of coated by rare and dense remelting after 25,500 and 1000 hours at temperature 1000°C

the roughness should ensure reduced stresses from zone TGO on the border of bond-coat. Base on the analysis performed the phase composition and chemical analysis can be seen that in the case of surface remelting rare showing greater tendency to the formation of spinel – type oxides, in particular $NiAl_2O_4$ compared to an area of dense remelting. However, the coating of dense remelting does not meet the technology criterion related parameter R_a and adhesion of the ceramic coating. Rare remelting despite a weaker protection against oxidation than thick laser treatment showed the better performance than the surface as-sprayed [13].

Acknowledgements

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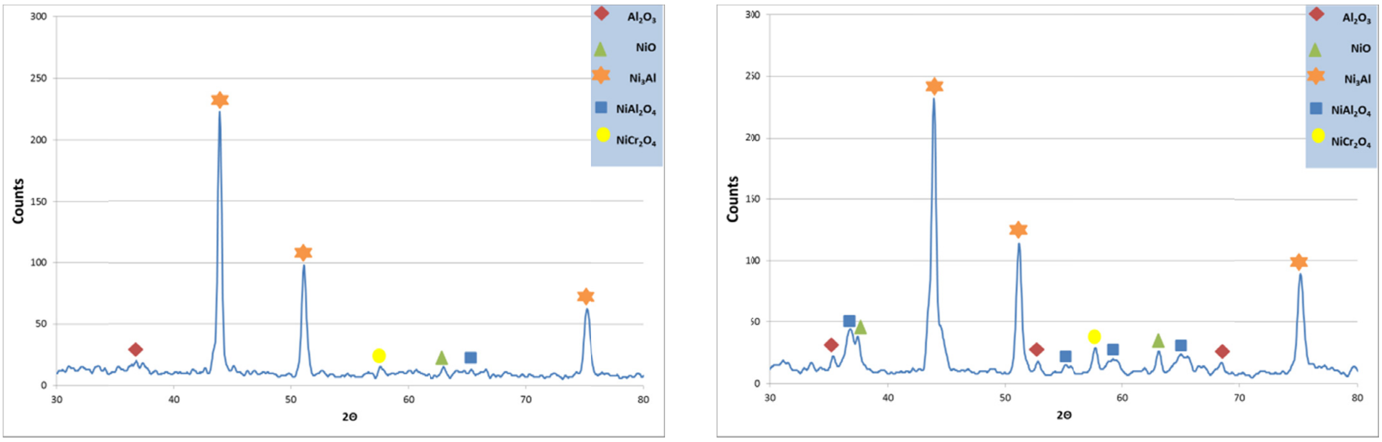
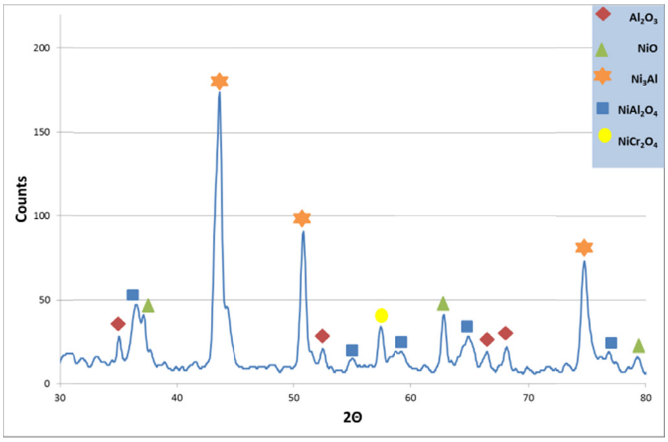


Inconel 625/NiCrAlY as-sprayed 1000ºC / 25h

Inconel 625/NiCrAlY as-sprayde 1000ºC / 500h



Inconel 625/NiCrAlY as-sprayed 1000ºC / 1000h

Fig. 4. XRD diffraction patterns of coated as-sprayed after 25,500 and 1000 hours at temperature 1000°C

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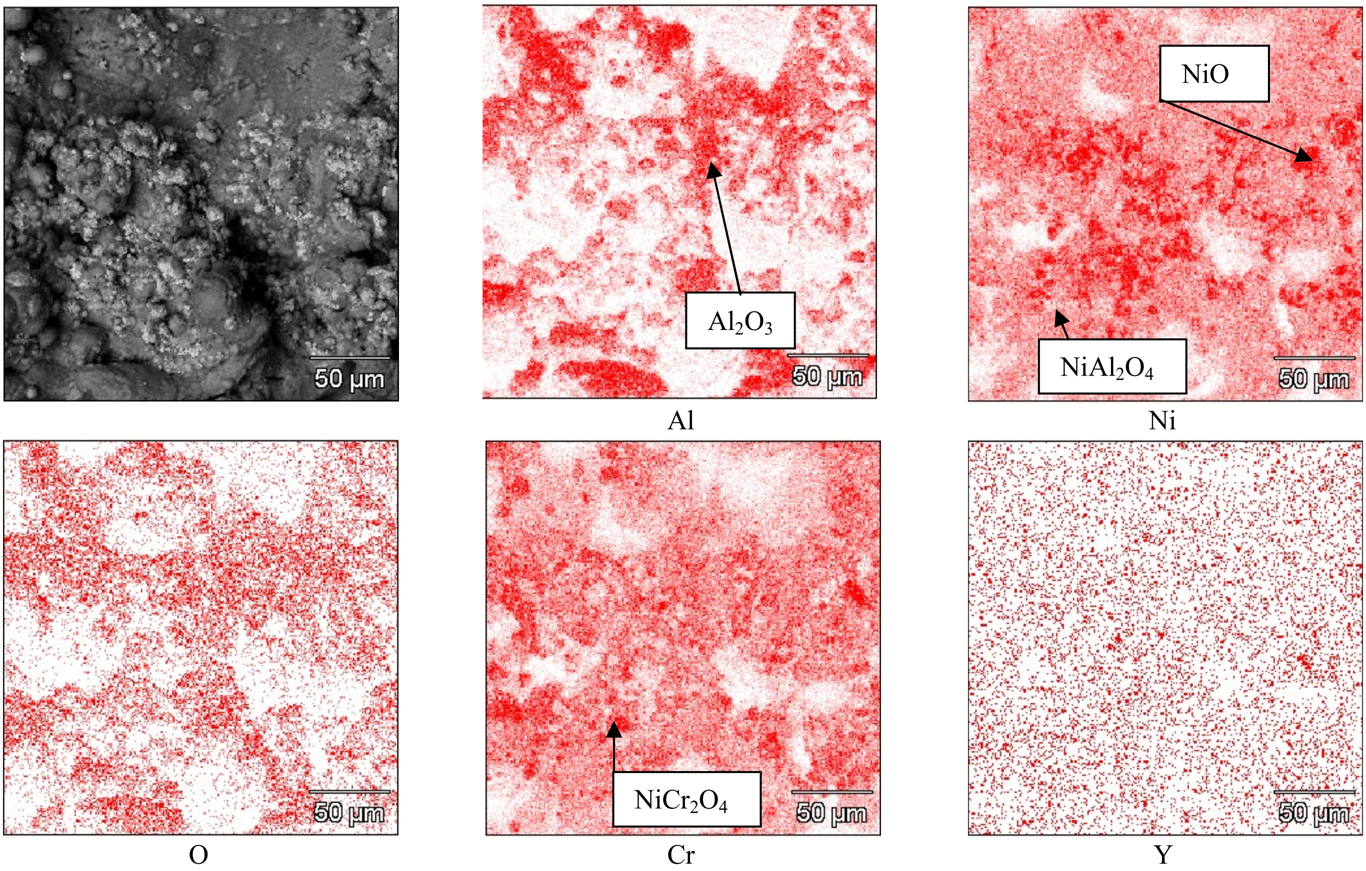
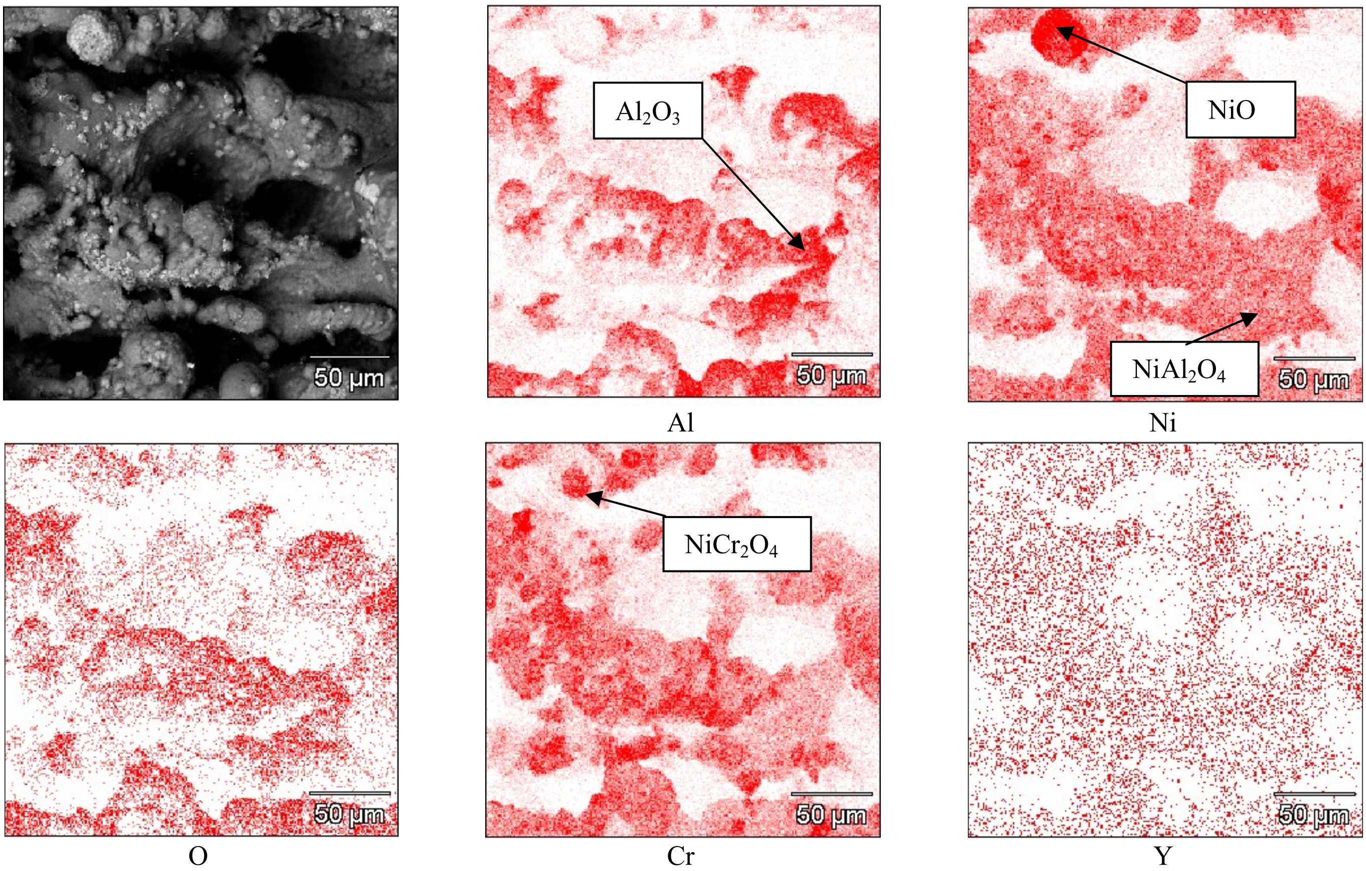
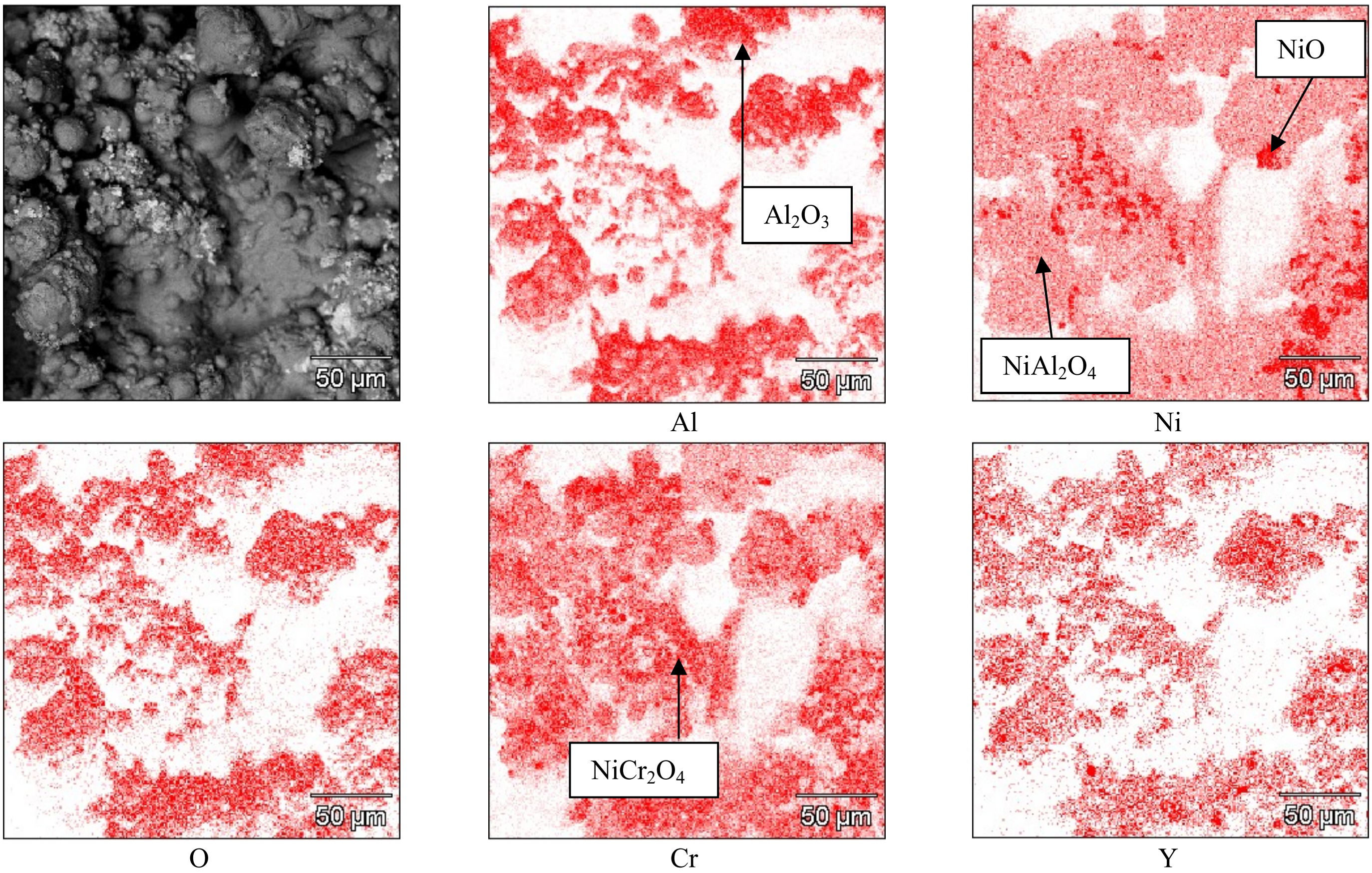


Inconel 625/NiCrAlY rare remelting 1000ºC / 25h

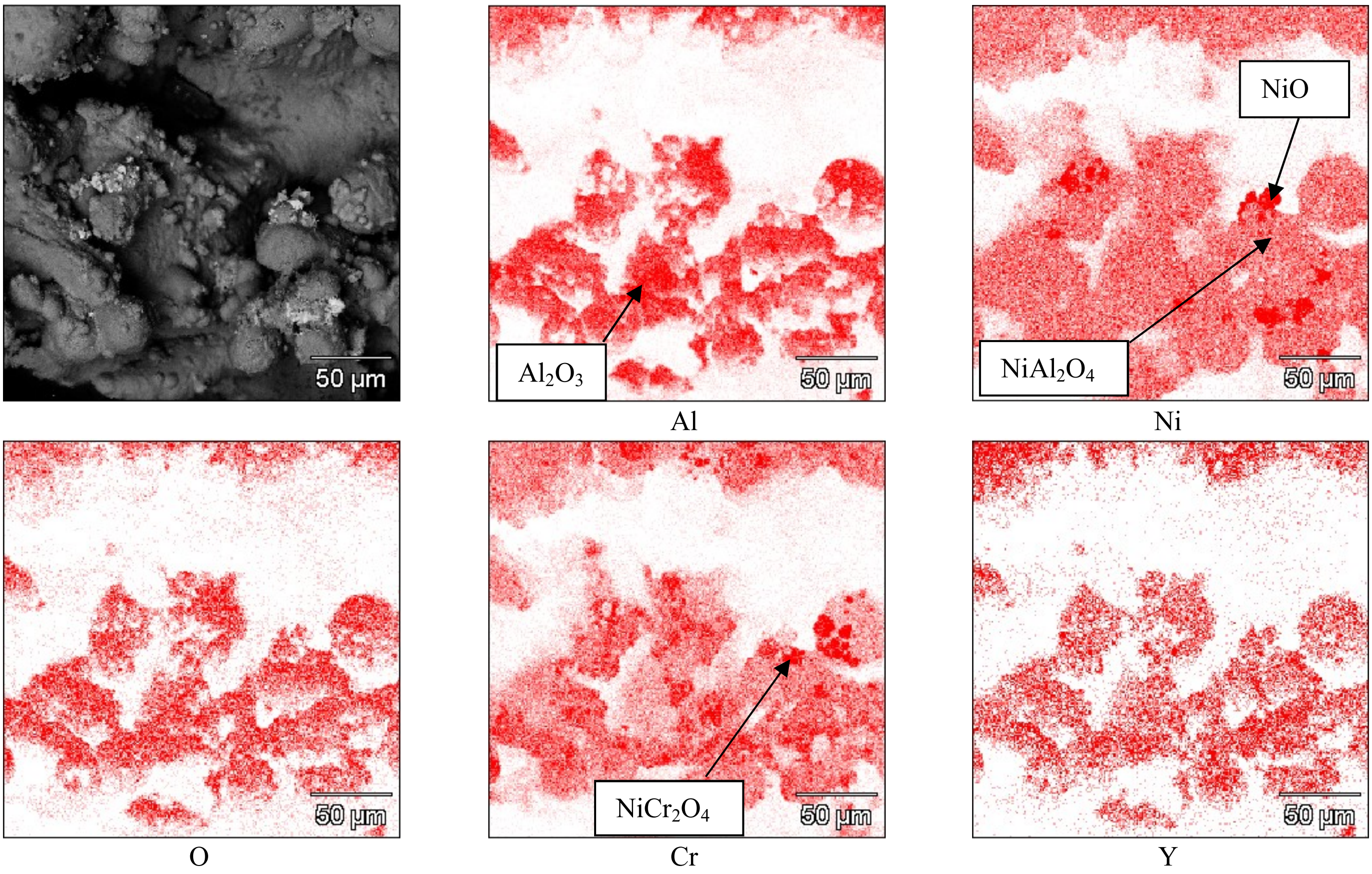


Inconel 625/NiCrAlY dense remelting 1000ºC / 25h

Fig. 5. Mapping of selection elements of rare and dense remelting after 25 hours at temperature 1000°C

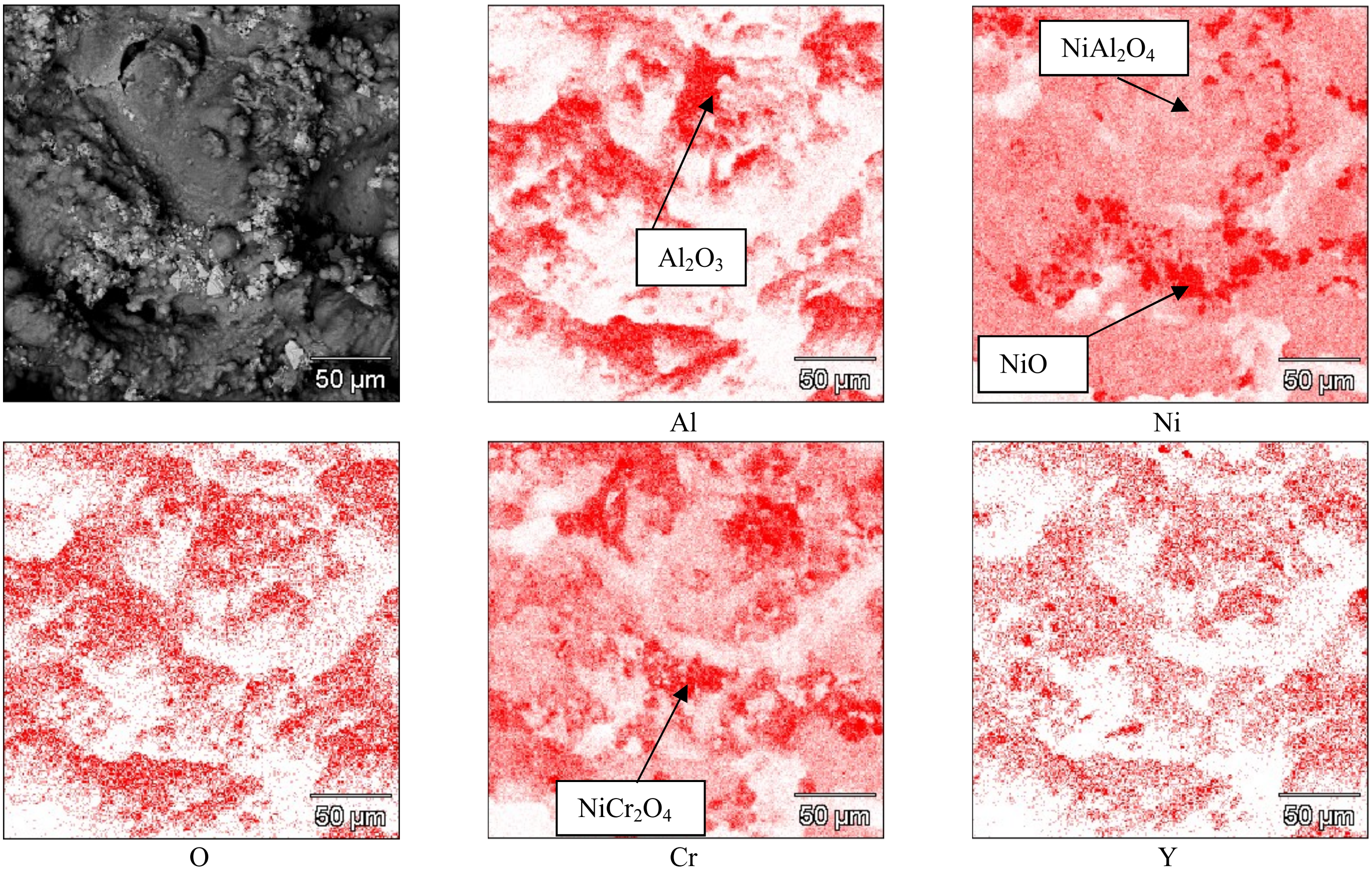


Inconel 625/NiCrAlY rare remelting 1000°C / 500h

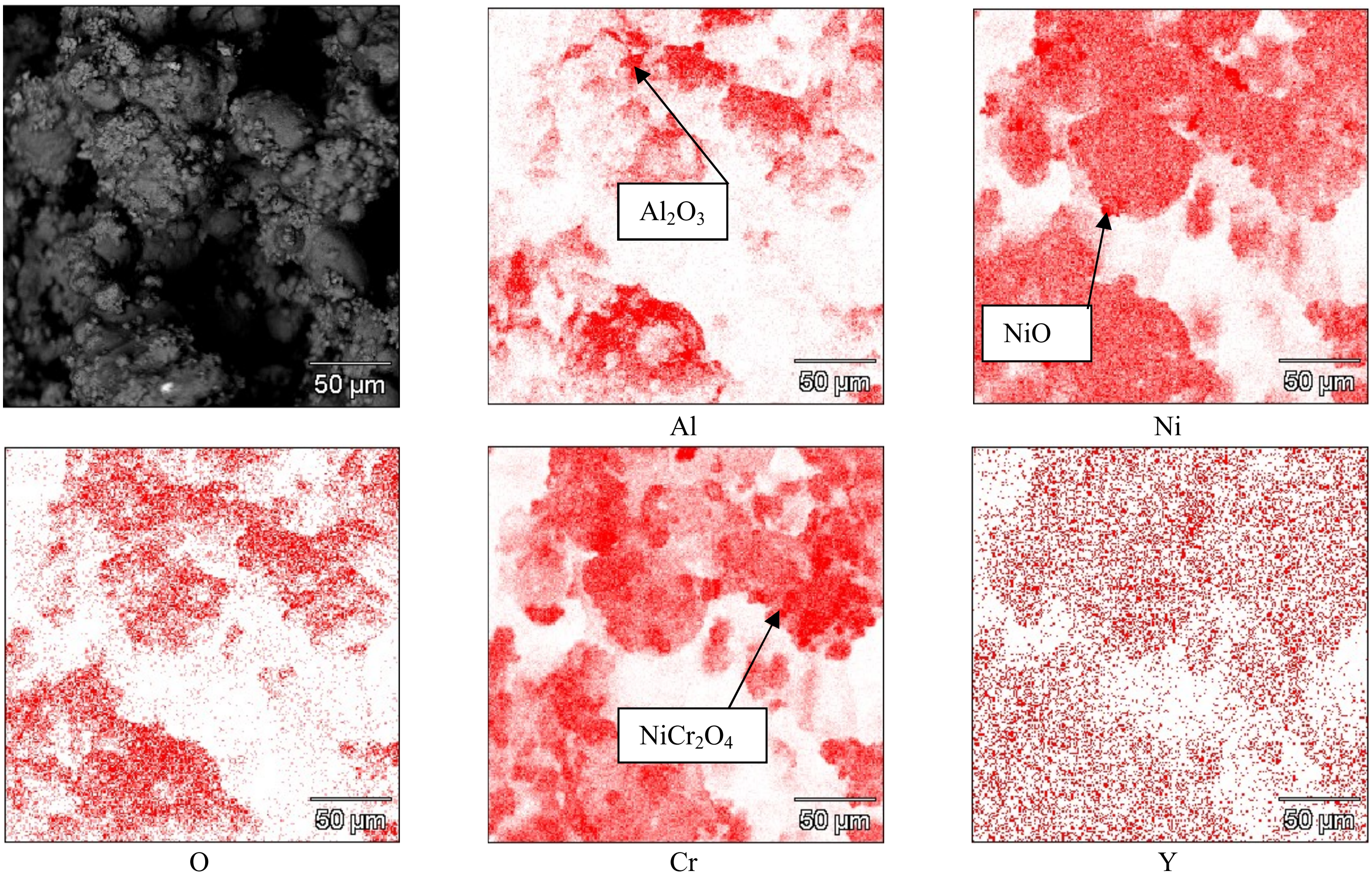


Inconel 625/NiCrAlY dense remelting 1000°C / 500h

Fig. 6. Mapping of selection elements of rare and dense remelting after 500 hours at temperature 1000°C

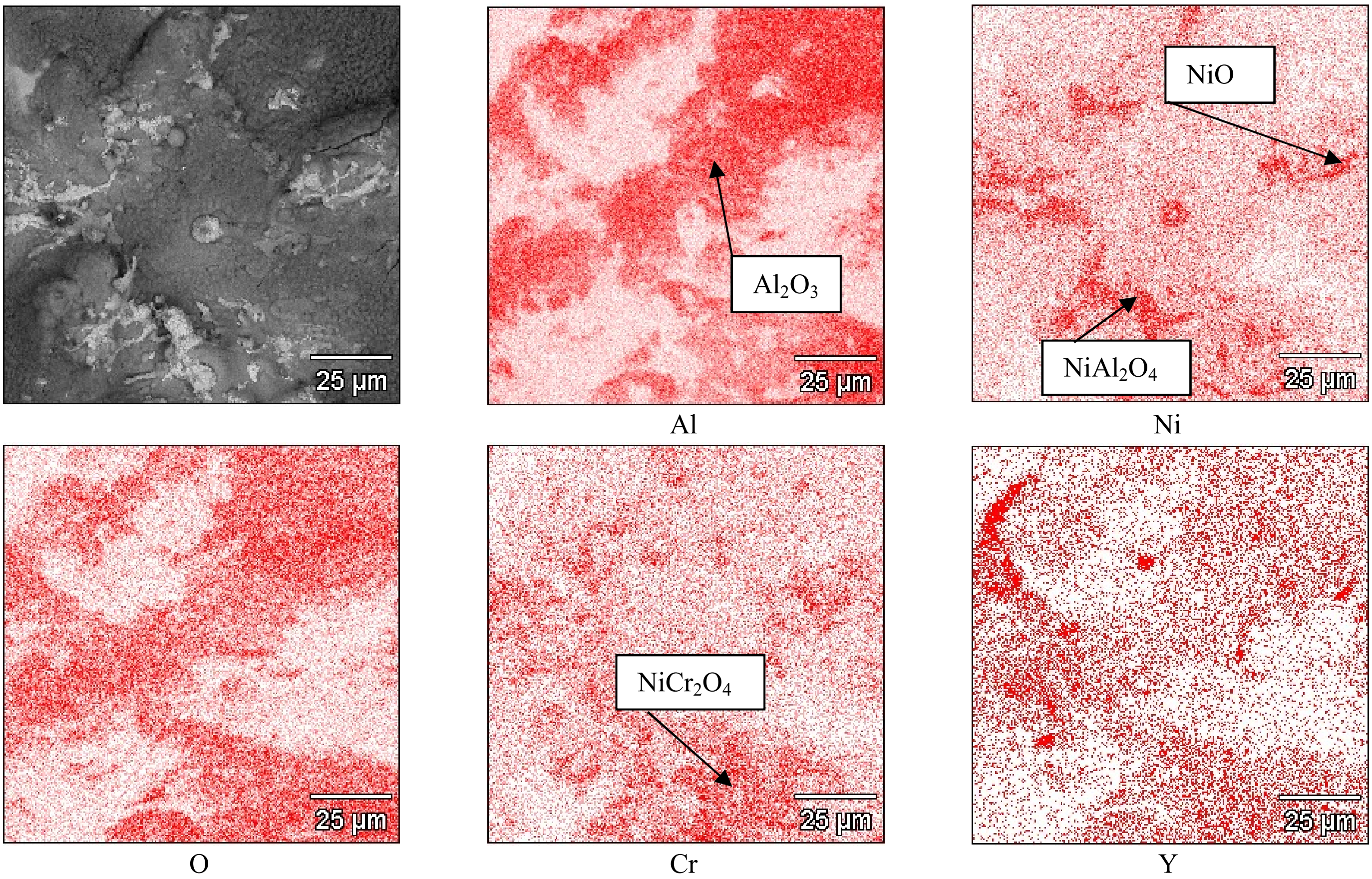


Inconel 625/NiCrAlY rare remelting 1000°C / 1000h



Inconel 625/NiCrAlY dense remelting 1000°C / 1000h

Fig. 7. Mapping of selection elements of rare and dense remelting 1000 hours at temperature 1000°C



Inconel 625/NiCrAlY as-sprayed 1000°C / 25h

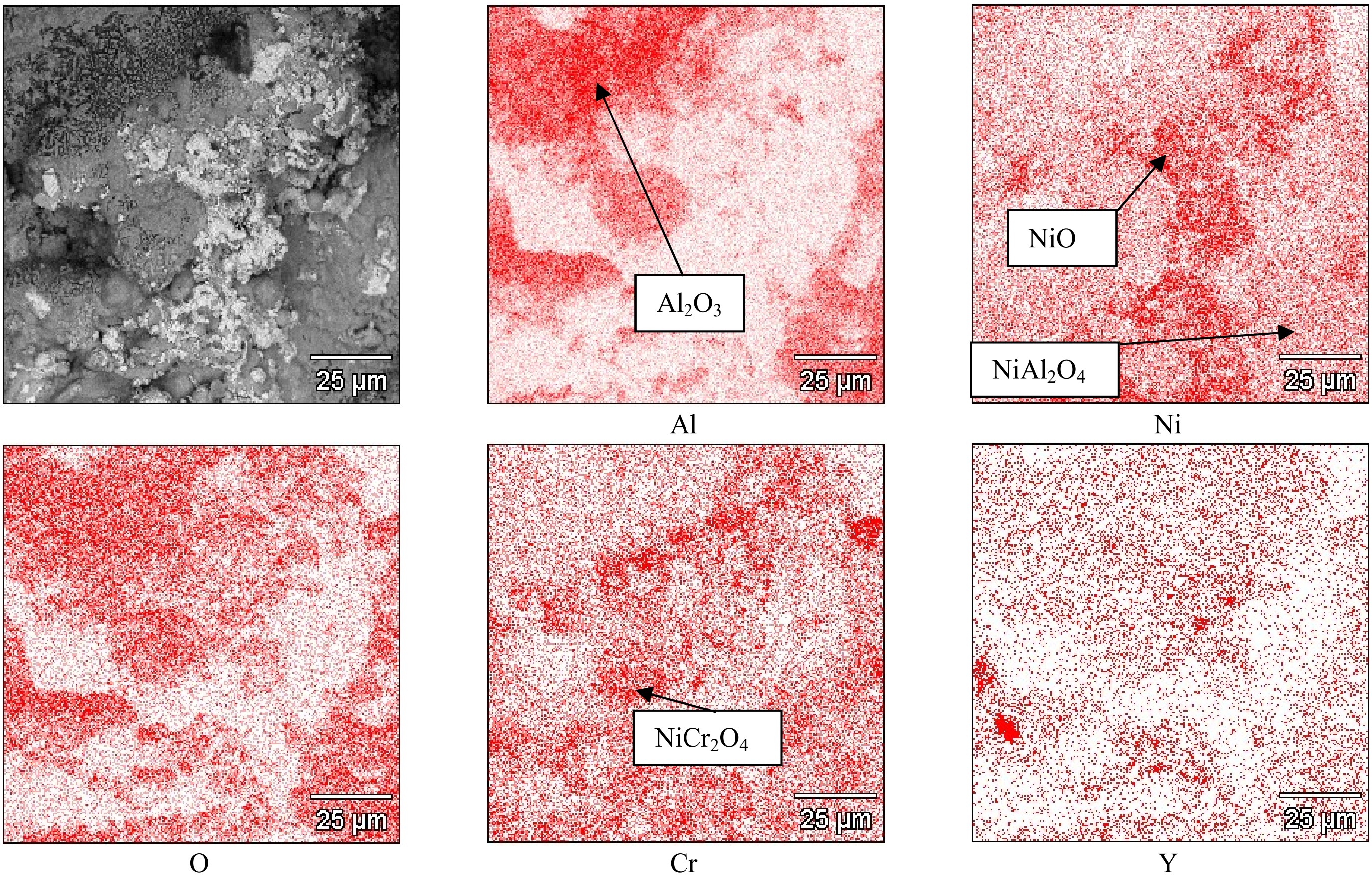


Fig. 8. Mapping of selection elements of as-sprayed coating after 25, 500 and 1000 hours at temperature 1000°C