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Institute of Metallurgy and Ore Beneficiation, Satbayev University, Almaty, Kazakhstan
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Maulet Meruyert
Sarsen Amanzholov East Kazakhstan University,
Ust-Kamenogorsk, Kazakhstan
E-mail: maulet_meruert@mail.ru
ORCID ID 0000-0003-1570-0301

Wojciech Wieleba
Wroclaw University of Science and Technology,
Wroclaw, Poland
E-mail: wojciech.wieleba@pwr.edu.pl.
ORCID ID 0000-0002-5461-9568

Impact of aluminum content upon the microstructure of Ni-Cr-Al gradient coatings

Abstract: Studied the aluminium concentration in the composite powder NiCr-Al influences the structure of NiCr-Al gradient coatings. Gradient coatings based on NiCr-Al were obtained by detonation spraying, with a phased reduction in the barrel filling volume with acetylene-oxygen gas mixture from 50% to 25%. The coatings' microstructure was analyzed across different aluminum concentrations: 15%, 20%, and 30%. By adjusting the aluminum concentration in the powder mix, we achieved coatings with a gradient formation. The findings indicated that the phase composition of the gradient coating is significantly influenced by the Al mass percentage. The findings suggest a powder composition of 80%NiCr and 20%Al to produce NiCr-Al coatings with a good gradient structure.

Keywords: Ni-Cr-Al coating, gradient coating, detonation spraying, microstructure, XRD.

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Introduction

Power plant components are currently exposed to high temperatures, leading to corrosion, oxidation, hot corrosion, and other detrimental effects. As a solution, protective coatings that offer heat resistance are applied to the superalloy surfaces. Among these, coatings in the MCrAlX system (where M represents Ni, Co, or NiCo; X signifies Y, Ce, Si, Ta) are most prevalent (Darolia, 2013). This popularity stems from the coating's attributes: M and Cr offer wear and heat resistance, while Al combats oxidation by forming Al_2O_3 on the surface. Elements like Y enhance the coating's adhesion. Nevertheless, coatings from this system have room for enhancement. An excessive presence of Al and Cr elements can lead to coating cracks. Conversely, a minimal Al presence can result in an inadequate Al_2O_3 film, compromising oxidation resistance. Hence, ongoing research aims to augment the performance attributes and prolong the lifespan of the MCrAlX coatings.

In recent times, efforts to enhance the corrosion resistance of MCrAlY coatings have centered on refining MCrAlX coatings with reactive elements through laser processing and by creating multilayered and gradient coatings. The introduction of reactive elements or their oxides can bolster the high-temperature corrosion and oxidation resistance of MCrAlX coatings. Yet, there are divergent views regarding the impact of integrating reactive element oxides on the oxidation properties of MCrAlY coatings (Shuting et al., 2017). As a result, the spotlight has shifted towards multilayer and gradient coatings using MCrAlY as a foundation. The structure and chemical composition of such multilayer/functional gradient materials undergo progressive changes to enhance various attributes like mechanical, thermal, and physical properties (Bolelli et al., 2012; Naebe et al., 2016; Song et al., 2011). Recent innovations in functionally graded coatings have proven effective for operations under high temperatures and challenging thermal scenarios (Naebe et al., 2016; Lee et al., 1996; Movchan & Yakovchuk, 2012).

In an earlier research (Rakhadilov et al., 2021), we introduced a technique to produce a gradient coating of NiCr-Al using detonation spraying. A unique aspect of this method involves achieving the desired gradient structure by adjusting the barrel's gas fill volume during the coating procedure, thereby controlling the NiCr-Al composite powder distribution from the base material to the coating's outer surface. Essentially, this means establishing a majority of heat-resistant and wear-resistant particles, primarily Ni and Cr, on the substrate surface, with Al concentrations gradually increasing from the substrate towards the outer coating, culminating in a high Al presence on the exterior. This facilitates the formation of a substantial Al_2O_3 layer on the surface of the coating.

The primary objective of the present study is to examine how the mass ratio of Al composite powder NiCr-Al influences the structure and characteristics of NiCr-Al gradient coatings.

Research methods and Materials

Heat-resistant steel, 12Kh1MF, was selected as the base material. The steel's chemical makeup includes 0.15% C; 0.37% Si; 0.7% Mn; 0.3% P; 1.2% Cr; 0.35% Mo; 0.3% V; and 0.2% Cu. For coating application, the steel was shaped into discs with a 50mm diameter and 3 mm thickness and then polished using SiC grinding paper from P100 to P1000. Before the coating process, the sample surface underwent sandblasting. NiCr and Al powders (with 99.99% purity) were combined in varying proportions (Table 1). This mixture was then processed in a PULVERISETTE 23 planetary ball mill at a frequency of 30 Hz for 2 hours to produce composite powders.

The coating was produced using the CCDS 2000 detonation system [9]. An oxygen-acetylene blend with a ratio of O_2/C_2H_2 = 1.856 served as the explosive gas, while nitrogen functioned as the carrier gas. To achieve gradient coatings, the barrel's gas fill volume was progressively reduced from 50% to 25%. A detailed methodology for creating a gradient coating is elaborated upon in the earlier study (Rakhadilov et al., 2021; Buitkenov et al., 2020). The specific parameters used for the coating process can be found in Table 1.

Table 1. Technological parameters for obtaining NiCr–Al gradient coatings

Powder, wt %	O_2/C_2H_2	Barrel Filling Volume,%	Spray Distance, mm	Number of Shots
NiCr70Al30	1,856	50-25	250	40
NiCr80Al20	1,856	50-25	250	40
NiCr85Al15	1,856	50-25	250	40

We determined the phase composition of the sprayed coatings via the X-ray diffraction technique (XRD) using an X'PertPRO diffractometer with Cu-Kα radiation (λ = 2.2897 Å) at a voltage of 40 kV and a current of 30 mA. The diffractograms were decoded using the HighScore program with measurements were performed in the range of 2Θ equal to 200–900 with 0.02 step size and 0.5 s/step counting time. We photographed the surface of the coatings at 5× optical magnification using a metallographic microscope (Altami MET 5S model).

Results and discussion

Using the CCDS2000 detonation unit, gradient NiCr-Al coatings with different aluminium mass ratios were successfully produced. The coatings produced ranged in thickness from 70-116µm (figure 1). The thickest coating, measuring 116µm, was achieved with an Al mass ratio of 15%. In contrast, the thinnest coating, at 70µm, resulted from an Al mass ratio of 30%. It's likely that during detonation spraying, a significant portion of a softer element in the powder mix, Al in this instance, melts and adheres to the material's surface. Particles of comparatively harder elements embed themselves into the malleable matrix.

X-ray diffraction phase analysis of the gradient NiCr-Al coatings, with varying aluminium mass percentages (15%, 20%, 30%), is depicted in Figure 2. The data suggests that alterations in the Al mass percentage result in phase transitions within the gradient NiCr-Al coatings. With Al mass percentages of 15% and 20%, the coatings primarily consisted of $CrNi_3$ and Al phases. However, when Al mass percentage reached 30%, a new γ-Al_2O_3 phase emerged.

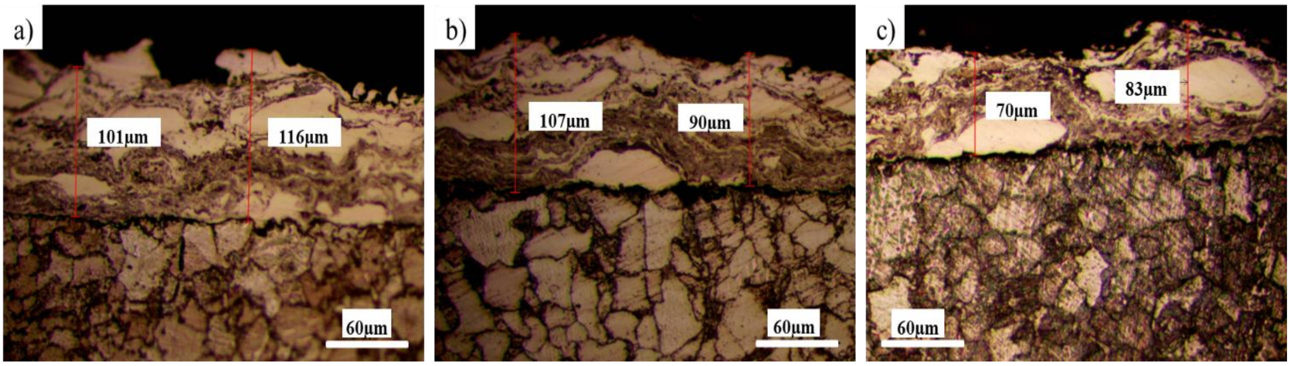

Figure 1. Microstructure and thickness of NiCr-Al gradient coatings at different Al mass ratios:
a) NiCr85Al15, b) NiCr80Al20, c) NiCr70Al30

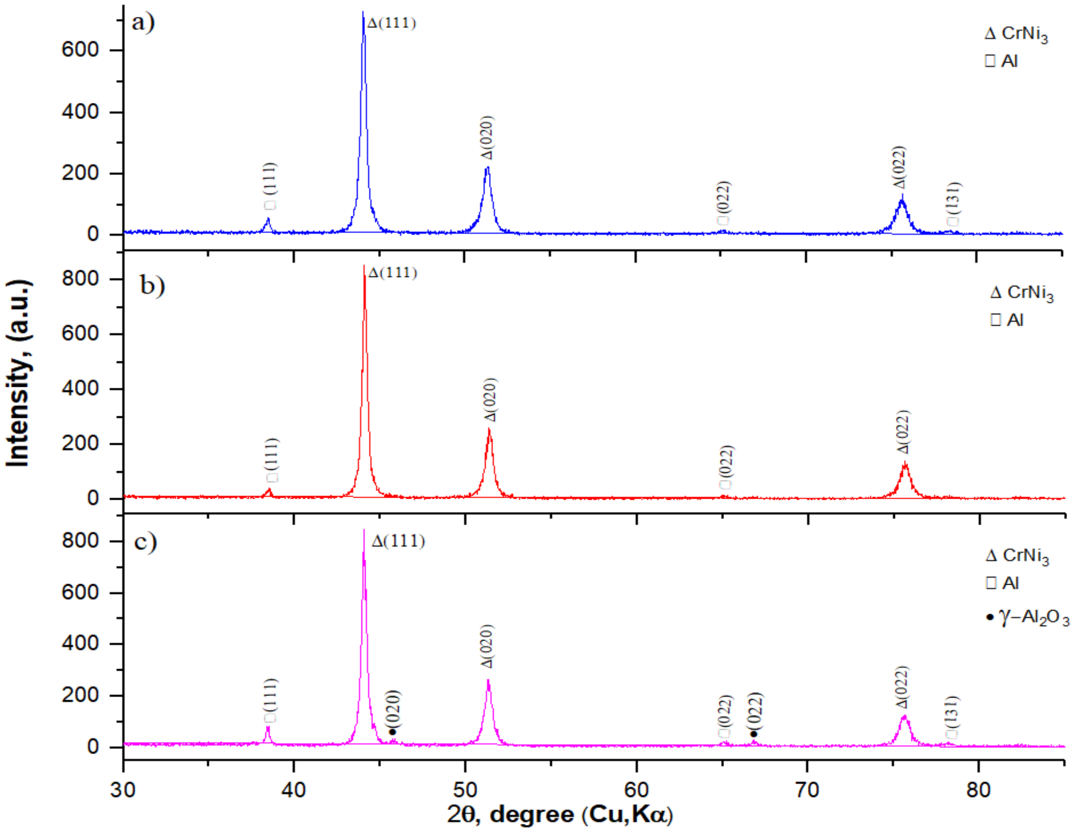

Figure 2. X-ray phase structure analysis of NiCr-Al gradient coatings at different Al mass ratios:
a) NiCr85Al15, b) NiCr80Al20, c) NiCr70Al30

Conclusions

NiCr-Al coatings with varying aluminum concentrations of 15%, 20%, and 30% were produced using detonation spraying. We explored how the coating's structure formation was influenced by the powder's composition. The detonation spraying technique was adjusted to achieve a gradient structure by altering the barrel's filling volume with an acetylene-oxygen gas mix, decreasing it from 50% to 25% throughout the NiCr-Al coating procedure. Our findings indicated that a composite mix of NiCr – 80% and Al- 20% is ideal for creating gradient-structured coatings with a higher Al concentration in their surface layers. We observed the formation of aluminum oxides γ-Al_2O_3 in coatings with a 30% Al content. The coating's characteristics revealed a correlation between the coating's thickness and the composite powder's composition. Specifically, NiCr70Al30 coatings are thinner compared to NiCr85Al15 and NiCr80Al20 coatings. It's likely that during the detonation spraying, a significant portion of a softer element, in this case, Al, melts and adheres to the material's surface. Particles of the harder elements are embedded into the softer matrix. The microstructural analysis of the NiCr70Al30 coatings' cross-section supports this theory.

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