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Oxidation Behavior of NiCr/YSZ Thermal Barrier Coatings (TBCs)

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Abstract: Nichrome (NiCr) coatings are widely used to provide resistance against oxidation and corrosion in many machine components. TBCs must include bond coatings that are resistant to oxidation resulting fromhigh-temperature operating conditions. In the present study, NiCr powders were sprayed on nickel-based superalloy Inconel 718 substrates using atmospheric plasma spray (APS) technique. Bond-coated substrates were coated with yittria stabilized zirconia (YSZ). As such, the TBC samples were kept at 1000°C for 8 h, 24 h and 50 h in high temperature furnace and their isothermal oxidation behavior was investigated. Microstructure and phase change properties of TBCs before and after isothermal oxidation were then studied and analyzed.

Keywords: Thermal barrier coatings (TBCs); Oxidation; NiCr; Yittria stabilized zirconia (YSZ).

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1 Introduction

High temperature materials like Ni-based superalloys can be oxidized if exposed to prolonged operations in high temperatures. Oxidation in such instances can lead to failures and serious consequences. Various metallic components complete their lifetime early. To protect metallic parts in high temperature applications, thermal barrier coatings (TBCs) are the preferred choice for use as protective coatings, as they are good thermal insulators. Bond coats are deposited on a substrate to obtain better adhesion and to decrease thermal expansion mismatch with a top coat. TBCs also provide oxidation and corrosion resistance. Generally, NiCr, NiAl, NiPt or MCrAlY are used as bond coat materials. Top layer consists of a ceramic material that has low thermal conductivity and high temperature resistance [1-6]. In the production of a bond coat, thermal spray techniques such as atmospheric plasma spray (APS) or high velocity oxygen fuel (HVOF) are often utilized, as they offer low cost and direct applicability. In an APS technique, powders can be sprayed on a substrate as molten or semi-molten materials. All materials can be deposited using this plasma technique. APS coatings have laminar structure, porosity and oxide containing microstructures [7-9]. NiCr and NiCr-based coatings are used to provide resistance against corrosion, oxidation or erosion [10,11]. They were widely adopted in exhaust nozzle of rockets as bond coat material. YSZ is the preferred top coat material in TBC systems [12-14]. YSZ has high coefficient of thermal expansion, high fracture toughness and low thermal conductivity compared to other ceramic materials, and it can be used in temperatures up to 1200°C [15,16].

In this study, Inconel 718 was used as substrate, NiCr was sprayed as a bond coat and YSZ was deposited as a top coat. Ni-based superalloys are typically subjected to 800-1100°C operating conditions thus produced TBCs were exposed to 1000°C in furnace at varying times. Oxidation behavior of TBCs with respect to time was evaluated.

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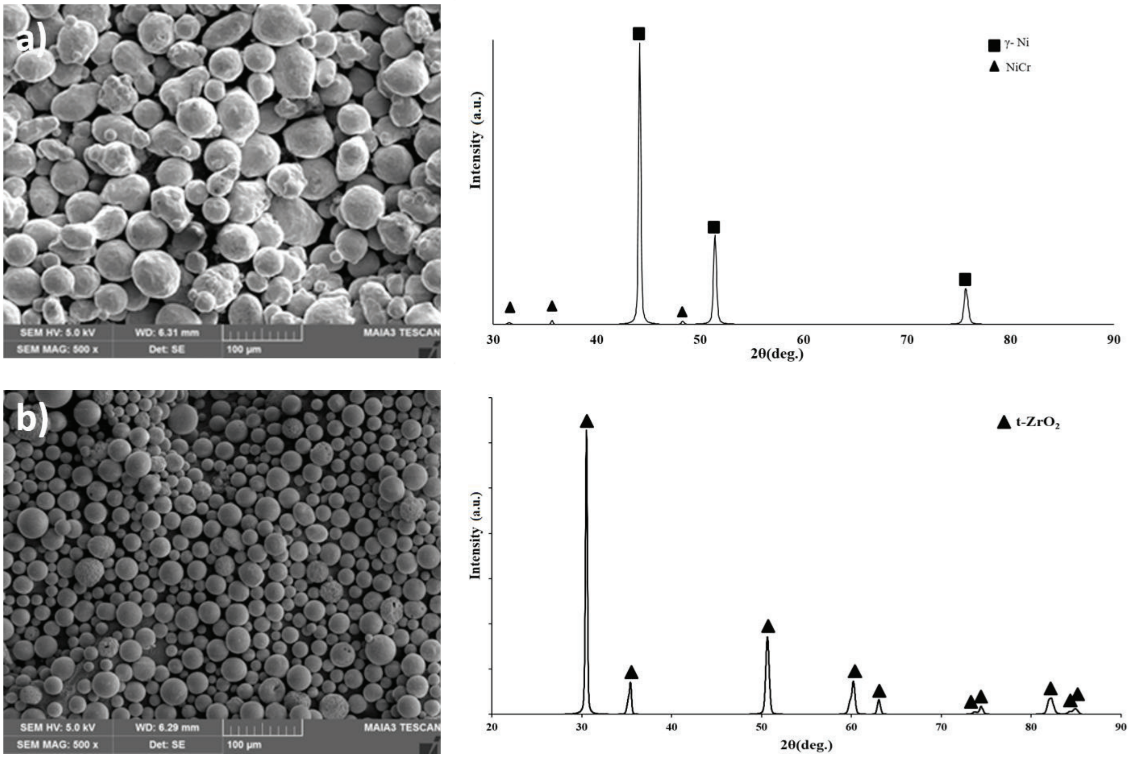

Figure 1: a) NiCr powders and XRD analysis, b) YSZ powders and XRD analysis.

2 Experimental Procedure

2.1 TBC Sample Production and Preparation

Inconel 718 with 25.4 mm diameter and 5 mm thickness was used as a substrate. Its chemical composition mainly consisted of Ni, Fe, Cr, Nb and Mo. Substrates were sandblasted before the bond coat production. NiCr (80/20) powders (firm: GTV, 80.20.1 code, particle: -53 +20 µm,) were sprayed on Inconel 718 using APS technique. In Figure 1, images of a) NiCr and b) YSZ powders are given with their XRD analyses, respectively. NiCr powders have a spherical shape and consist of γ-Ni and NiCr phases. Similarly, YSZ powders have spherical shape, yet they consist of only t-ZrO$_2$.

After depositing the bond coat, YSZ (ZrO$_2$+8%Y$_2$O$_3$) powders (firm: Sulzer Metco 204F, particle: −45 + 15 µm) were sprayed on NiCr bond-coated substrates. Spray parameters of bond and top coat are given in Table 1. According to Table 1, there are small differences between deposition parameters due to plasma atmosphere such as used gas flow rates (standard lit per minute (slpm)), spray distance (mm) or arc current (A).

Table 1: Spraying parameters of NiCr and YSZ.

Coating	Arc current	H$_2$ flow rate	Ar flow rate	Powder feedstock rate	Spray distance
NiCr	500 A	15 slpm	80 slpm	25 g/min.	80 mm
YSZ	630 A	20 slpm	90 slpm	25 g/min.	90 mm

2.2 Oxidation Tests and Characterization

Image J software program was used to calculate average porosity and oxide content as percentage, information obtained from 5 different cross-sectional SEM images at 1kx magnification. In lab atmosphere, oxidation tests were performed at 1000°C for 8 h, 24 h and 50 h, using PLF 130/12 Protherm high-temperature furnace. Cross-sections of oxidized TBCs were analyzed using SEM (Tescan, Maia3). XRD (Rigaku, CuKα) analysis of TBCs was performed to determine material phases. Thermally grown oxide (TGO) values were calculated using Image Pro Plus 6 software program by taking average of 10 measurements from interfaces of 10 images at 3kx magnification for each oxidation periods.

Ethical approval: The conducted research is not related to either human or animals use.

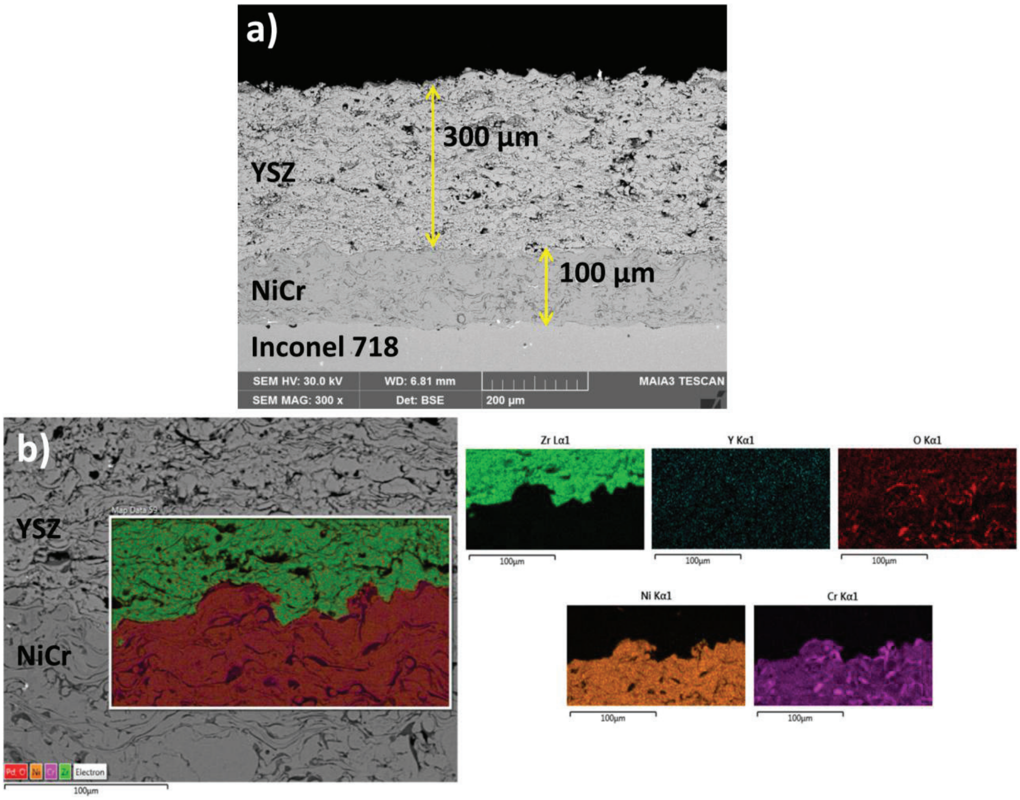

Figure 2: As-deposited TBC SEM and elemental mapping microstructures.

3 Results and Discussion

SEM and elemental mapping microstructures of as-sprayed TBC are shown in Figure 2. Bond coats have porosity and show presence of oxides. Top coat has porosity the same as the bond coat, which is caused by the characteristic properties of APS technique. Average oxide and porosity content of as-sprayed 100 µm-NiCr coating were 5.91% and 1,59%, respectively while as-sprayed 300 µm-YSZ coating had 5.58% porosity according to Image analysis. Elemental distribution shows that there are locally oxidized regions consisting of mainly Cr_2O_3 phases.

YSZ has an ionic conductivity due to the its crystal structure. At high temperature, oxygen diffuses from top coat to bond coat with affecting both, YSZ structure and existing porosities [16,17]. Cr is more reactive compared to Ni according to Ellingham diagrams [18]. For this reason, Cr first reacts with oxygen forming protective Cr_2O_3 layer at the interface during this oxidation reaction. Cr_2O_3 layer acts as an oxygen barrier and that is why TGO layer mainly consists of Cr_2O_3 phase considering all oxidation periods [19,20].

In Figure 3, SEM microstructures of oxidized TBCs at 1000°C for 8 h, 24 h and 50 h are shown. TGO layer thickness increased with the increase of oxidation time. CrO_3 phase can be volatilized at the temperature higher than 1000°C [19-21]. However, volatilization of CrO_3 was not detected with use of YSZ, as it provided thermal barrier and caused temperature drop.

At the end of oxidation periods, spallation was not observed, as evident from Figure 4. Top coat shows little densification, whereas bond coat layer shows localized oxidation. Based on elemental distributions, there was no evidence of presence of other oxides, such as NiO or $NiCr_2O_4$ which are undesired phases due to higher growth rate [22]. This shows that NiCr is a suitable bond coat material for TBCs at 1000°C applications.

Figure 5 shows XRD and TGO growth behavior of TBCs. According to XRD results, phase transformation on the top coat did not occur at the end of the oxidation and the top coat only consisted of tetragonal ZrO_2 (t-ZrO_2). Semi-tetragonal ZrO_2 phase is durable at temperatures up to 1173°C, therefore, phase transformation has not occurred [23]. With increased time, TGO layer thickness increased and, with the highest increase observed in initial oxidation stage. Interestingly, TGO thickness exhibits similar growth but lower growth rate compared to CoNiCrAlY TBCs in literature [22,24] for isothermal oxidation tests at 1000°C.

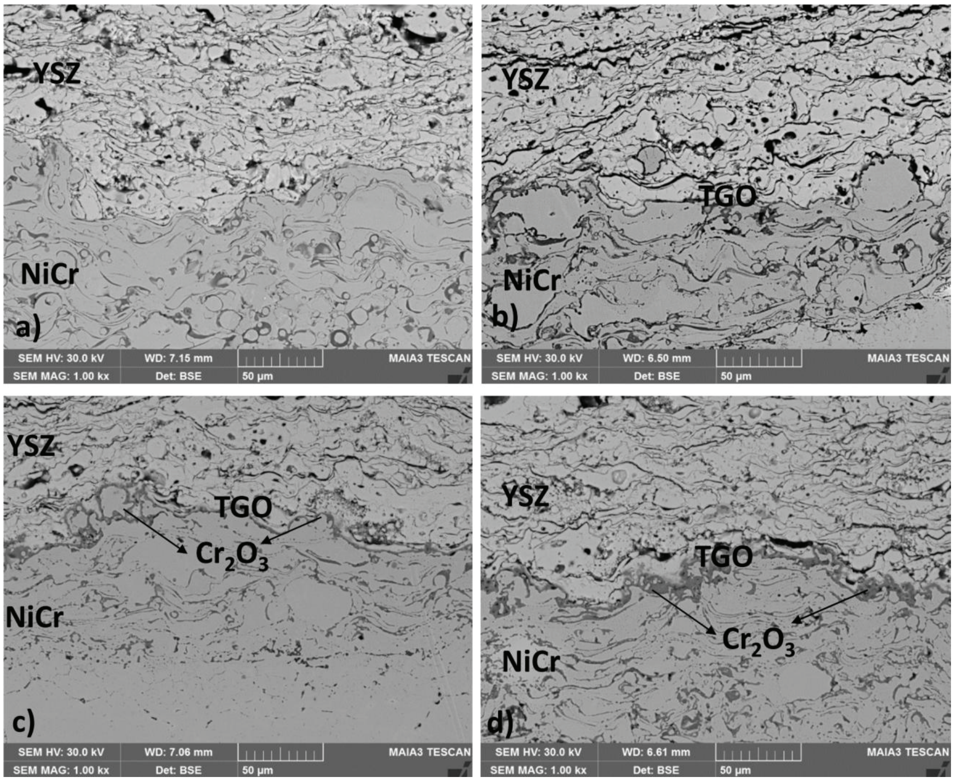

Figure 3: SEM microstructures after a) as-sprayed, b) 8 h, c) 24 h and d) 50 h oxidation tests at 1000°C.

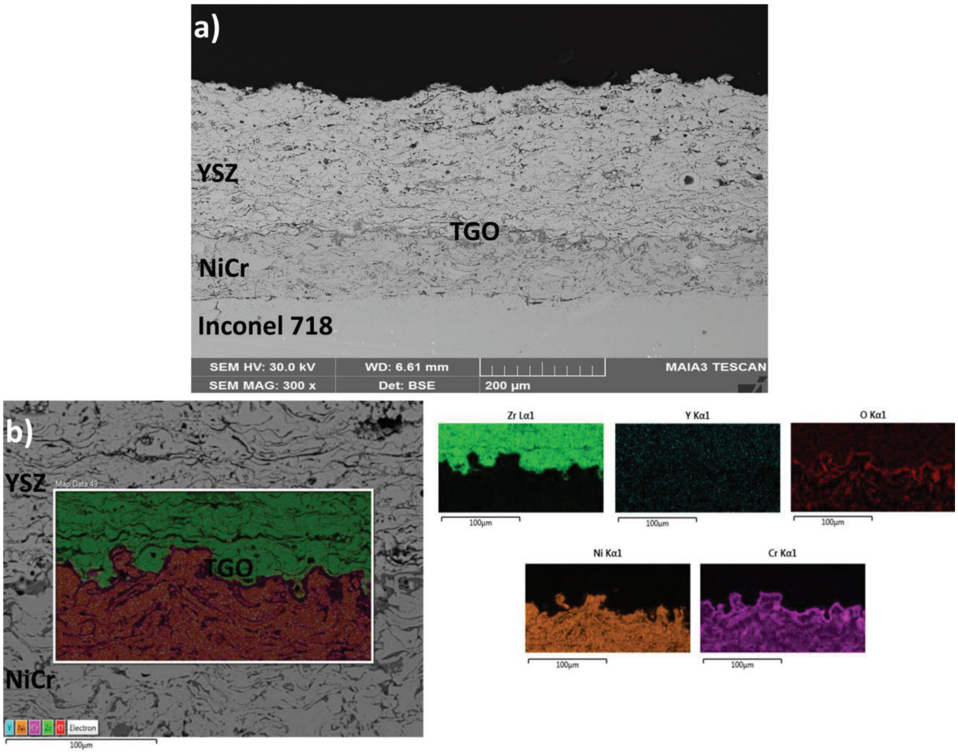

Figure 4: SEM and elemental mapping image of TBC oxidized for 50 h at 1000°C.

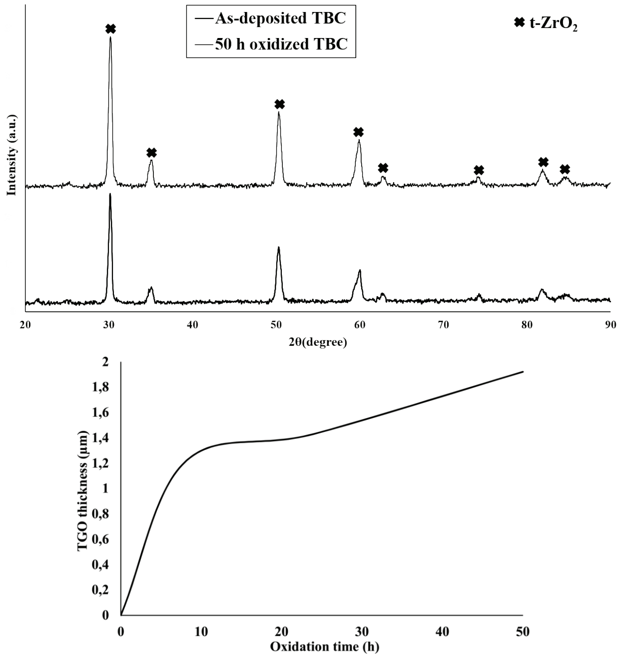

Figure 5: XRD analysis of as-sprayed and 50 h oxidized TBC and, TGO growth behavior with respect to time.

However, internal oxidation rate can be higher in NiCr TBCs. Thus, results can change at higher dwell times.

4 Conclusion

Bond and top coat were successfully deposited on Inconel 718 substrate. TBCs exposed to oxidation experiments and other tested specimens withstood to oxidation periods. TGO layer consisting mainly of Cr_2O_3 layer preserved its uniformity. During the oxidation, YSZ did not experience phase transformation and did not result in crack formations. The thickness of TGO layer increased with an increased time. Normally, 1000°C temperature is not preferred with NiCr coating due to the volatilization of CrO_3 phase. However, with the use of YSZ, a temperature drop has been achieved. As a result, the present study was able to demonstrate that a low cost NiCr bond coating combined with low cost APS technique can be used in 1000°C applications. In future studies, the effects of different production techniques on durability of high temperature NiCr TBCs will be investigated.

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Conflict of interest: Authors state no conflict of interest.

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