

# Oxidation Behavior of Thermal Barrier Coatings With Cold Gas Dynamic Sprayed CoNiCrAlY Bond Coats

A. C. Karaoglanli<sup>a,\*</sup>, A. Turk<sup>b</sup>, İ. Ozdemir<sup>a</sup>, F. Ustel<sup>b</sup>

<sup>a</sup>Department of Metallurgical and Materials Engineering, Bartın University, 74100, Bartın, Turkey  
<sup>b</sup>Department of Metallurgical and Materials Engineering, Sakarya University, 54187, Sakarya, Turkey

## Abstract:

The paper presents the results of investigation into the oxidation resistance and thermally grown oxide (TGO) of thermal barrier coatings (TBC). TGO occurred during in service affect the lifetime of the component by introducing several kinds of degradation mechanisms such as decreasing bonding strength, initiation of stress concentration and thermal stresses which lead to crack initiation and propagation associated with delamination or spallation failure. Therefore, TGO plays important role on TBC durability. In this study, TBCs that consist of a typical bond layer / top layer system (CoNiCrAlY bond layers and YSZ top layers) are deposited on Inconel 718 superalloy substrates. The metallic bond coatings are applied via Cold Gas Dynamic Spraying (CGDS); the ceramic top coatings via Atmospheric Plasma Spraying (APS). Investigations are done concerning the oxidation behavior of this TBC system at 1100 °C in normal atmosphere for 8h, 24h, 50 h and 100 hours. The oxidation behaviour and microstructural properties during the oxidation test were evaluated and compared, and TGO growth behavior was also investigated under high temperature oxidation. The microstructural features and oxidation behaviours were characterized by scanning electron microscopy and energy dispersive X-ray spectroscopy. Phase stability of TBCs were evaluated by means of X-ray diffraction method.

**Keywords:** Thermal barrier coatings; Oxidation; Thermally grown oxide; Cold Gas Dynamic Spraying

## 1. Introduction

Due to their insulating property, thermal barrier coatings (TBC) are used in protection of hot section components against high temperature working environment in gas turbine engines. A TBC used in gas turbines typically consists of a superalloy substrate, a metallic bond coat with oxidation resistance (BC), a ceramic top coat (TC) and a thermally grown oxide (TGO) layer that forms between TC and BC by oxidation of BC due to high temperature and oxidizing environment [1-2]. It is widely stated that TGO structure and thickness have important role in failure of TBC system [1,3-4]. There is a general acceptance that the desired TGO is alfa alumina since this type of oxide has the lowest growth rate, higher top coat adhesion etc. [1,5-6]. In many studies relation between TGO formation and BC composition and microstructure is explained by applying the BC with different processes (such as APS, HVOF etc.) and exposing the coating to isothermal oxidation [7-9]. APS has a very high process temperature and melts the powder prior to deposition. As a result the produced BC is high in process induced oxides and Al content in some regions of such BCs is suggested to be low due to preferential oxidation of Al during process. [8,10]. Hence the alumina formation is deteriorated due to lack of Al at the interface. In HVOF sprays since the process temperatures are relatively low compared to APS, the powders to be deposited are usually semi-molten and undergo a plastic deformation during deposition. Thus, resulting BC is lower in oxide content and is denser. As a result, the BC is higher in Al content and TGO is higher in alumina compared to TGO forming on APS BCs [10-11]. Recent developments in CGDS, has made production of the superalloys employed in TBC possible with that process. The main advantage in this spray type is that almost no process induced oxide is involved and the resulting composition of the BC can be very close to feedstock powder [2,8]. Due to that property of CGDS process, the TGO of the BC is expected to be superior to those forming on other spray process BCs. To examine the oxidation behavior, CoNiCrAlY bond layers are deposited on an Inconel 718 substrate. After BC deposition with CGDS, YSZ top layer is deposited by APS. The resulting TBC is isothermally oxidized at 1100 °C in normal atmosphere for 8 h, 24 h, 50 h and 100 h periods. The compositional and microstructural properties of TGO and BC are evaluated via use of scanning electron microscopy (SEM) and X-ray diffraction.

## 2. Experimental

### 2.1 Material and methods

Inconel 718 nickel based superalloy disc shaped samples with a diameter of 25.4 mm and thicknesses of 5 mm, were used as substrate. CoNiCrAlY (Sulzer-Metco USA, Amdry 9951, 5-37 µm) and ZrO<sub>2</sub>/Y<sub>2</sub>O<sub>3</sub> (GTV Germany, -45+20 µm) powders were used as the feedstocks for the deposition of the bond and top coats. The thickness of the bond and ceramic top coats were measured as 100 µm and 300 µm, respectively. The used spraying systems were a Plasma Giken CGDS system and a GTV F6 APS system.

The oxidation behavior of TBC systems were investigated by Protherm high temperature furnace. All spraying parameters are shown in the Table 1.

Table 1. CGDS and Plasma spray parameters for bond and ceramic top coat powder deposition

YSZ Top Coatings		
Arc Current	Electrical power	Argon flow rate
630 A	40 kW	44 slpm
Hydrogen flow rate	Powder feed rate	Stand-off distance
13 slpm	25 g/min	90 mm
CGDS CoNiCrAlY Bond Coatings		
Sprey pressure	Gas temperature	Working gas
3.0 MPa	600 °C	Helium
Gun speed	Stand-off distance	
20 mm/sec	15 mm	

### 3. Results and Discussions

#### 3.1 Microstructure of the As-Deposited TBC

CGDS and its top coatings, cross-sectional microstructure of SEM bond/top coating interface that are produced with APS method is shown in Figure 1.

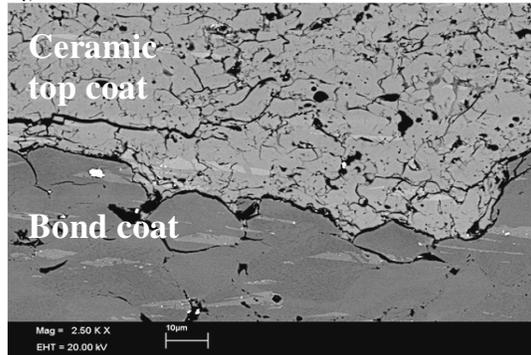


Figure 1. An image of the cross-sectional microstructure of TBC produced with CGDS method

It is seen that bond coating microstructure of TBC produced with CGDS method have gaps and porosity that can be seen with naked eye. The presence of these gaps and porosity on bond coating structure are thought to be caused by insufficient local plastic deformation of the particles that crash each other during accumulation and this situation's causing small gaps between two adjacent particles.

#### 3.2. Oxidation behavior of coatings

CoNiCrAlY bond layer produced with CGDS method consists of bcc structure  $\beta$ -(Co,Ni)Al precipitates and fcc structure  $\gamma$ -matrix (Ni,Co) phases.  $\beta$ - precipitates structure that is rich in Al shows formation depending on oxidation and disappears as a result of decreasing of Al concentration in time. After oxidation tests that are carried out at 1100 °C and different time processes, TGO layer formed on bond and top coating interface as a result of oxygen penetration from top ceramic coating and this formation structure can also vividly be seen in microstructures in Figure 2.

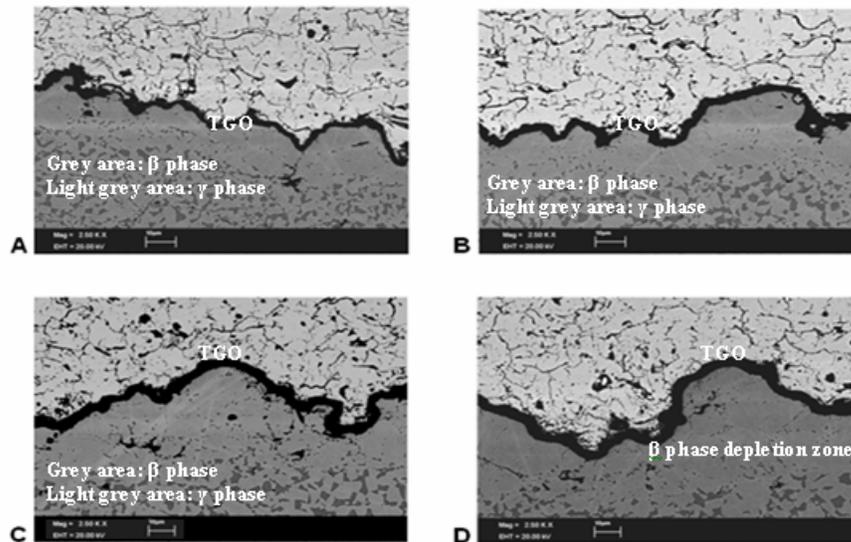


Figure 2. Oxidation SEM cross-sectional microstructures of TBC samples at 1100 °C that have CGDS CoNiCrAlY bond and APS YSZ top coating: (a) 8 hours, (b) 24 hours, (c) 50 hours and (d) 100 hours

The thickness of formed TGO structure shows an increase depending on time.  $\text{Al}_2\text{O}_3$  layer formed at interface as a result of the increase of oxygen and aluminum concentration at ceramic top coating and bond coating interface. Generally, at first stages of oxidation,  $\text{Al}_2\text{O}_3$  form does not undergo a structural change and have a more decisive structure, however, mixed oxide structures (light grey colored) are seen to form on  $\text{Al}_2\text{O}_3$  form depending on the increasing time. CoNiCrAlY bond layer consists of  $\beta$ -(Co,Ni)Al precipitates and  $\gamma$ -(Ni,Co) matrix micro-structure.  $\beta$ - precipitates structure that is rich in Al shows formation depending on oxidation and disappears as a result of the decreasing of Al concentration depending on time. At 1100 °C after 50 hours oxidation, it is seen that  $\beta$ - precipitates decreases starting at TGO level and forms at depletion zone. Micro-structures with some cracks and non-continuous gaps are also seen on top ceramic coating structure. Different discontinuities, porosity and crack-like formations are present at interface zones of coatings. As it can vividly be seen in the micro-structure and elemental distribution in Figure 3. TGO oxide structure that form between bond and top coating have Al and O elements and formation of mixed oxide structures on the interface are seen, as well. Besides Al and O elements density is high in TGO zone, mixed oxides are seen at light grey areas outside the  $\text{Al}_2\text{O}_3$  oxide layer.

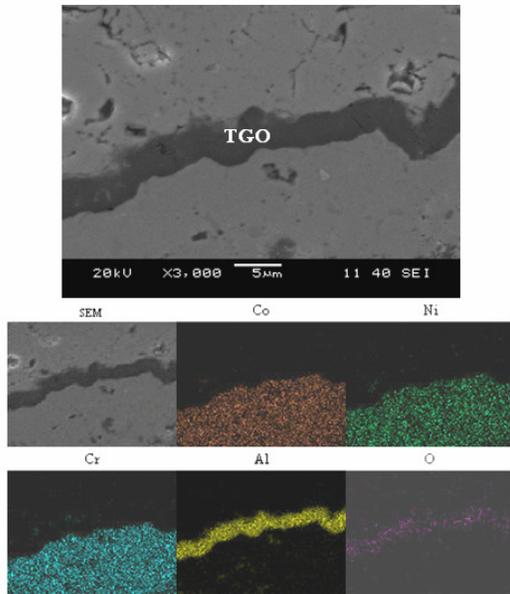


Figure 3. SEM image and EDS elemental mapping showing the surface oxide morphology of TBCs with CGDS bond coating following 100 h of oxidation at 1100 °C

### 3.3. XRD analysis

XRD analysis results of bond coating, produced with CGDS method at 1100 °C and 100 hours and XRD analysis results of TBCs, that have bond coating produced with CGDS method, at 1100 °C temperature and 8, 24, 50 and 100 hours are shown in Figure 4 and Figure 5.

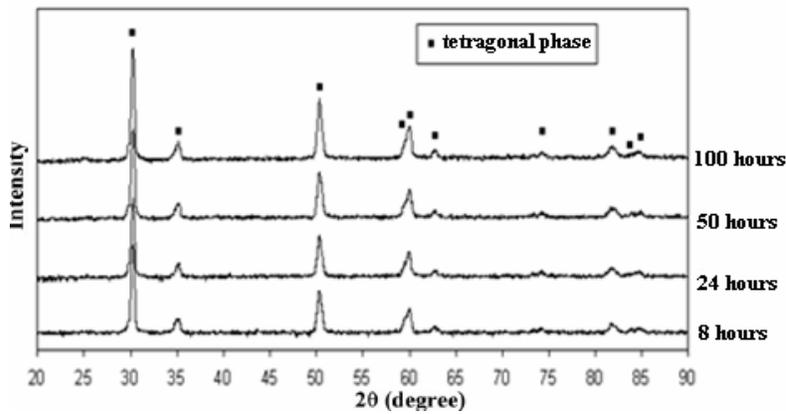


Figure 4. XRD patterns of TBCs after various oxidation times at 1100 °C

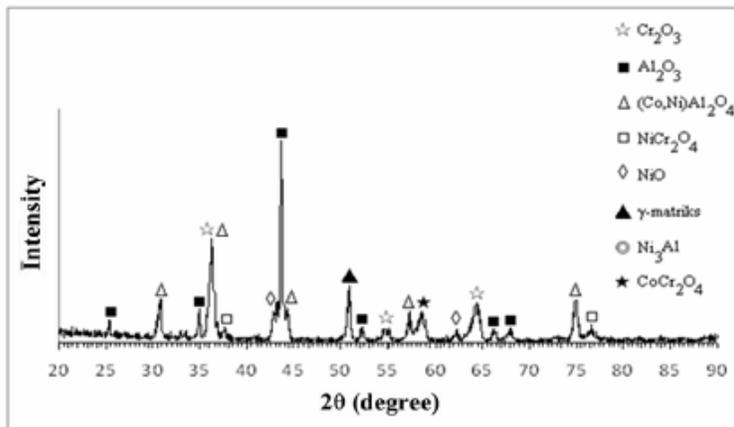


Figure 5. XRD patterns of CGDS CoNiCrAlY coatings following 100 h of oxidation at 1100 °C temperature

When XRD analysis results of bond coatings produced with CGDS method are investigated,  $\text{Al}_2\text{O}_3$  phase is generally seen to be stable position. Mixed oxides as NiO and spinel phase structures are seen to form on bond coating.

### 3.4. TGO growth behavior of TBC

After 8, 24, 50 and 100 hour oxidation processes of TBCs whose bond coating are produced with CGDS method, thickness change of TGO layer in time is shown in Figure 6. At TGO layer thickness counts whose measurement has been done on SEM micro-structure views that are taken at 2500X magnification, measurements are done on 4 micro-structure photos for each specimen and measurements, changing between 10 and 20 in the average, are taken for each micro-structure. Measurements are done on areas where TGO remains its continuity and unity. Measurements are done at a point where TGO layer, which lies parallel to bond/top coating interface, growth direction, namely vertical to bond coating surface.

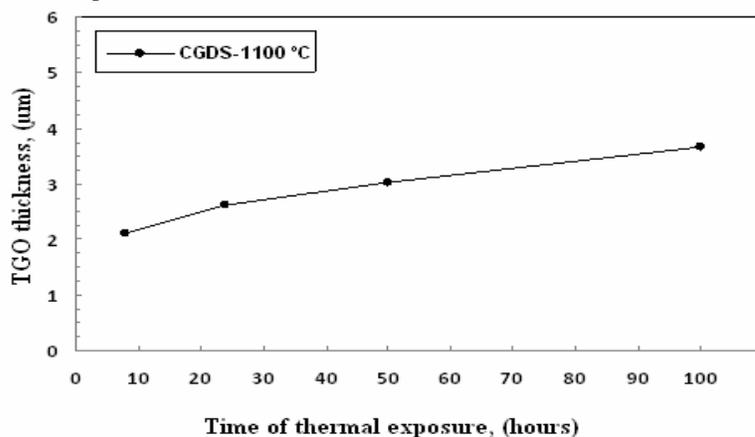


Figure 6. TGO growth in TBC with a CDGS-CoNiCrAlY bond coat at 1100 °C for 8, 24, 50 and 100 hours

It can be seen in Figure 4 that the thickness of TGO structure that forms in TBC system shows increase depending on the increasing time.

## 4. Conclusions

In the present work, oxidation behaviour and micro-structural characterization were studied in TBC system with CGDS bond coats during high temperature oxidation for different times. It is seen that as-sprayed TBC coating structure is generally uniform and in a dense structure, local gaps form in bond coating structure as a result of insufficient local plastic deformation of particles that crash each other during accumulation. It is seen that ceramic top coating structure produced with APS method have high porosity because of process production conditions and crack and many similar imperfect formation structures. At the micro-structure inspections after oxidation, it is seen that CoNiCrAlY bond layer that is produced with CGDS method consists of bcc structure  $\beta$ -(Co,Ni)Al precipitates and fcc structure  $\gamma$ -matrix  $\gamma$ -(Ni,Co) matrix phases.  $\beta$ - precipitates, which is rich in Al, structure disappears as a result of the decrease of Al concentration depending on time, by showing formation depending on oxidation. After oxidation tests that are carried out at 1100 °C temperature and different time processes, TGO layer is seen to form on the bond and top coating interface as a result of top ceramic coating's oxygen penetration and TGO thickness increased depending on the increasing oxidation time. In the XRD inspections after coating oxidation; it is seen that other mixed oxide formations besides  $\text{Al}_2\text{O}_3$  phase exist in coating structure. Consequently, that coating structure undergoes change depending on the increasing oxidation, TGO oxide layer forms in BC/TC interface and thickness increases because of increasing oxidation and other mixed oxide layers form in the interface as a result of  $\text{Al}_2\text{O}_3$  structure, which forms TGO, losing its unity are seen as a result of micro-structural inspections and XRD analysis.

## 5. Acknowledgment

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