

## Effects of Plastic Deformation on Oxidation Behavior of APS bond coat

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### Abstract

In this study, oxidation behavior of CoNiCrAlY coatings; produced by atmospheric plasma spray (APS) process and APS process followed by shot peening and cold gas dynamic spray (CGDS) process; is investigated. Oxidation tests are conducted isothermally at 1100 °C for 8, 24, 50 and 100 hours periods. Coatings produced by APS process have high porosity and oxide content. In last years, it has been possible to produce coatings with high density, low porosity and oxide content with CGDS process. In CGDS process, unlike thermal spray coatings produced by APS technique, low temperature and plastic deformation is dominant. For this reason, this process makes high quality coating production possible. By applying shot peening process on MCrAlY coatings produced by APS technique, a plastic deformation starting from the surface and compressive stresses have been introduced on this samples. In this study; coatings produced by APS process and APS process followed by shot peening and CGDS process, are compared. This way, effects of plastic deformation on high temperature oxidation behavior on coatings are investigated and evaluated. Characterization studies consist of XRD, SEM, EDX and image analysis and micro hardness tests.

**Key Words:** Plastic deformation, Shot peening, Oxidation, APS, Cold Gas Dynamic Spray

### 1. Introduction

Thermal barrier coatings (TBCs) are used to improve efficiency in gas turbines by increasing the working temperatures or to prolong the life of hot section components. A conventional TBC consists of a ceramic top coat (TC) for insulation, a bond coat (BC) to increase adhesion and provide protection against oxidation, and a thermally grown oxide (TGO) which is a thin oxide layer between BC and TC. The oxide types and thickness of TGO layer has an important role in TBC life [1-3]. It is stated in various studies that the desired TGO is a continuous alumina ( $\alpha$ ) layer [1,4-5]. In many studies the formation, stability and growth rate of the desired TGO is shown to be related to composition and structure of the BC which could change by the coating processes. [6-8]. The TGO structure and growth on BCs produced by APS and CGDS processes have been shown to differ in other studies [6,9]. In both studies the formation and growth of TGO is related to diffusion and chemical dispersion of elements and especially Al in the bond coat. In APS process very high temperatures are reached and process induced oxidation and related preferential oxidation of Al (due to its high affinity) and thus non-uniform distribution and decrease of Al content in as-sprayed bond coats are stated in other studies [6,10]. In CGDS process, since the deposition relies on plastic deformation of the solid powders rather than melting the powder, the feedstock composition is expected to be better protected [6]. In this study, the oxidation properties of an APS BC, a CGDS BC and an APS BC with shot peening modification with no ceramic coating have been examined by focusing on composition, structure and growth rate of the TGO formed on these BCs. The primary concern is kept on the effects of presence or lack of plastic deformation induced by shot peening which would act on diffusion and compositional distribution in BCs. The isothermal oxidation study is conducted in a high temperature furnace at 1100 °C for 8,24,50 and 100 hours. The TGO layer is examined by XRD, SEM and EDS analysis.

## 2. Experimental

### 2.1 Material and methods

Stainless steel disc shaped samples with a diameter of 25.4 mm and thicknesses of 3 mm, were used as substrate. CoNiCrAlY (Sulzer-Metco USA, Amdry 9951, 5-37  $\mu\text{m}$ ) powder was used as the feedstock for the deposition of the bond coat. The thickness of the bond coat was measured as 100  $\mu\text{m}$ . The used spraying system was a GTV F6 APS system. After grit blasting, average surface roughness values were obtained through measurements that are carried out at different points on each specimen ranging between 5 and 10 points in accordance with the standard of DIN EN ISO 3274 norm on surface roughness measurement values of substrate, bond and top coating. Micro-hardness measurement of coatings has been carried out with Future Tech FM-700 brand test device. Measurements have been carried out under 100 g weight for 15 seconds with Vickers indenter tip. The oxidation behavior of coatings were investigated by Protherm high temperature furnace. Spraying parameters is shown in the Table 1.

**Table 1.** APS spray parameters for bond coat powder deposition

APS CoNiCrAlY Bond Coatings			
Arc Current		Electrical power	Argon flow rate
600 A		40 kW	65 slpm
Hydrogen flow rate	Powder feed rate	Stand-off distance	
14 slpm	30 g/min	140 mm	

## 3. Results and Discussions

### 3.1 Microstructure of the As-Deposited TBC

Bond coatings microstructure of SEM that are produced with APS and CGDS method is shown in Figure 1 (a-b). The as-sprayed bond coating samples showed a typical APS microstructure, with crack network and porosity in the bond and top coat. 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.

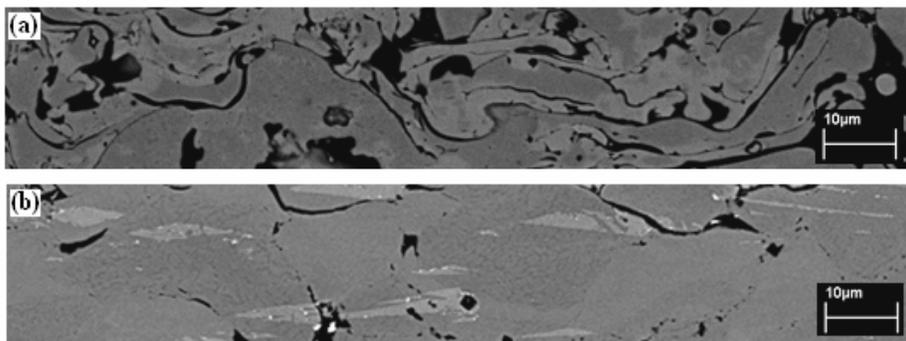


Figure 1. An image of the bond coating microstructure produced with APS method

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. After 8, 24, 50 and 100 hour oxidation processes of shot peened and normal coating samples whose bond coating are produced with APS method, thickness change of TGO layer in time are shown in Figure 3.

The microhardness values of coating is shown in Table 2.

Table 2. Microhardness average values of TBCs

Coating abbreviation	Microhardness (Hv)
APS-CoNiCrAlY	340± 25

### 3.3. XRD analysis

XRD analysis results of APS bond coating and after oxidation at 1100 °C and 100 hours are shown in Figure 4 and Figure 5.

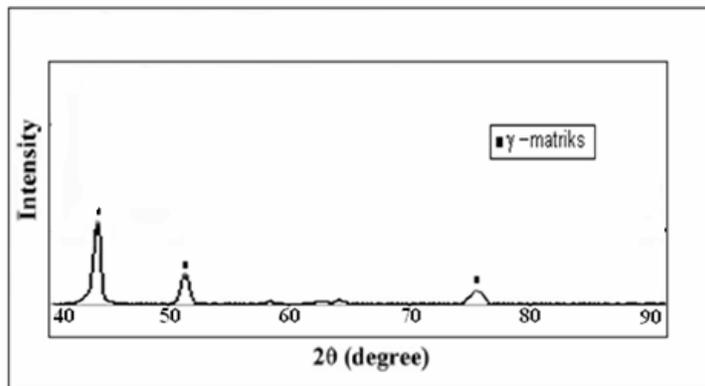


Figure 4. XRD patterns of APS CoNiCrAlY bond coatings

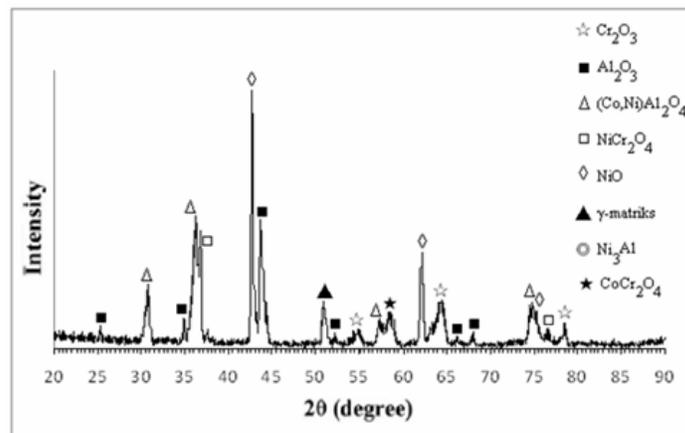


Figure 5. XRD patterns of APS CoNiCrAlY coatings following 100 h of oxidation at 1100 °C temperature

When XRD analysis results of bond coatings produced with APS method are investigated,  $\text{Al}_2\text{O}_3$  phase and mixed oxides as NiO and spinel phase structures are seen to form on bond coating.

#### 4. Conclusions

In the present work, oxidation behaviour and micro-structural characterization were studied in bond coating and shot peened bond coating samples during high temperature oxidation for different times. After oxidation tests that are carried out at 1100 °C temperature and different time processes, TGO layer is seen to form on the bond coating surface as a result of 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. During oxidation of coatings the TGO layer was formed along the interface of the BC surface layer. The thickness of TGO in traditional bond coating is higher in comparison with shot peened coating after oxidation at 1100 °C for different oxidation times. According to TGO growth in both coating system, the TGO thickening became steady state in shot peened coating and on the other hand the TGO thickness in normal bond coating system was still in increase. Consequently, that coating structure undergoes change depending on the increasing oxidation, TGO oxide layer forms in BC surface 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.

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