Analysis of Thermal Barrier Coating’s Behaviors on Alloys – A Review

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Abstract: Thermal barrier coatings (TBC) are made from alloys such as super alloys, titanium alloys and advanced steel materials. These alloys are widely used to make parts of aircraft, and these parts are used for in corrosive environments and high temperature operations. TBCs are therefore miserably needed to improve fatigue life, creep strength and corrosion resistance of these alloys. Thermal barrier coating consists of a bond coat and a top coat. The behaviour of the coating, such as oxidation resistance, hardness, microstructure and thermal oxide formation, depends on the coating technique and the bond and top coating materials. Therefore, an attempt has been made in this paper to review recent research on the Thermal Barrier Coating Behavior. Most researchers used NiCoCrAlY as a bond coat and YSZ as a top coat. HVOF and plasma spray techniques were found to be effective than other techniques such as Electron beam physical vapor deposition in this review.

1.Introduction

TBC materials are applied to the surface of the turbine to withstand the very high temperature gas effect. Many TBC techniques are available, such as physical vapor deposition electron (PVDE), plasma spray type (PST), high-speed oxygen fuel (HVOF), electro spray vapor deposition (ESVD) etc., TBC has layers such as metallic bond coat, thermal oxide and ceramic coat [1]. The TBC is required to withstand thermo-mechanically loaded working conditions. TBC should also withstand heat stress induced by heating and cooling and the coating should stabilize its phase and structure under the load on the coating. TBC consists of layers such as substrate, bond coat, TGO and top coat. YSZ, Mullite, Alumina, Ceria, rare earth zirconates and Meta glass composites are all used as top coat. TBC can be produced on the substrate of materials using Electron Beam Physical Vapor Deposition (EBPVD), Air Plasma Spray (APS), High-Speed Oxygen Fuel (HVOF), Electrostatic Spray Assisted
Vapor Deposition (ESAVD) and Direct Vapor Deposition. TBC is widely used to coat aircraft materials, steam engines and heat exchangers. It is understood that the importance of the TBC and the application of techniques are identified. An attempt is therefore made to review the performance of various TBC materials and to apply oxidation resistance techniques, coat life, formation phases and structural change.

2. Effect of TBCs on Mechanical Properties

Hitesh Vasudev et al. [2] carried out an analysis of the effects of TBC coated cast iron. Alloy 718 and NiCrAly were used as a source of coating. Micro hardness, high temperature oxidation resistance and erosion resistance have been reported to have been improved by TBC iron coating compared to the uncoated iron. The HVOF method was used to coat Inconel 718 and the rate of oxidation of the coated alloy was reported. Nickel chromium was used as a source of coating. Uniform thermally grown oxide (TGO) was observed after a test of up to 1000°C, but cracks in the coating layer and non-uniform TGO were observed after an oxidation test of 1000°C and 50 hours. The SEM images of the substrate after the oxidation test at 1100°C for a time period of 8 hours, 24 hours and 50 hours are shown in Figure 1 [3].

Inconel 600 alloy coated by Ravi Shankar et al. [4] using Ni-50 % Cr and Alumina. The HVOF method was used to coat the surface of the substrate and Alumina was coated on the top using a plasma spray technique. They investigated the thermal life cycle of the coated Inconel alloy and reported an improvement in the thermal cycle performance at 650 °C for 100 cycles, as well as an improvement in the adhesion bond strength. Zhe Lu et al. [5] made TBC on the nickel alloy substrate using the EBPVD technique and the bond coat was produced using the APS and HVOF techniques. The thermal cycle life, thermal fatigue and thermal shock tests were analyzed. The hardness rate was increased on the top coat after thermal fatigue test at 1429 cycles and the adhesive strength decreased when the HVOF bond coat was implemented.

![Figure1. (a-b) SEM Images of the structure after the test at a) 1100C for 8hours, b) 1100 for 24 hours c) 1100C for 50 hours](image-url)
Omid Khanali et al. [6] discussed the effect of the composite coating on Inconel 718. Materials such as YSZ-Nano size and aluminum oxide have been used as composite coatings. They noted that the sintering temperature influences the size of the YSZ particles and that the best nano-composite coating of YSZ and Al was obtained by sintering at 1250 °C for four hours. Two samples of Inconel 738 coated TBCs were made with respect to coating materials such as NiCrAly/YSZ and NiCrAly/CSZ and their coating performance was investigated for hardness test and hot corrosion test. The method of plasma spraying was used for coating. Al2O3 was used as a top coat for both samples. The resistance of hot corrosion to NiCrAly/CSZ and nanostructured Al2O3/CSZ coating was improved when compared to YSZ [7].

Eh Hovsepian et al. [8] used the Magnetron sputtering technique for depositing CrN and NbN material on P92 steel. The P92 steel is used to make a steam turbine. The resistance of oxidation to the coated steel has been improved. Hardness and young modulus have been improved in the low Nb coating of the mixture of CrN and NbN, although the creep rate for the coated sample has been reduced. It was concluded that the Magnetron sputtering method did not have a good impact on the coated sample. Khushdeep Goyal et al. [9] used CNT reinforced coating materials Cr3C2–20NiCr and normal coating materials Cr3C2–20NiCr to coat steel substrates SA213-T-22. The HVOF technique has been used to coat the steel. They noted that the porosity, roughness and corrosion resistance decreased when CNT mixed Cr3C2–20NiCr was used as a coating material.

Fatoba et al. [10] used a laser system to coat titanium and cobalt on the Ti-6Al-4V substrate. They studied the impact of the laser system parameters on corrosion resistance and the mechanical properties of the coated alloy. The laser power of 750W, scanning rate of 1.2m/min, was observed as the best solution for alloy coating with 60% titanium and 40% cobalt. The refined structure was seen at a higher rate of scanning speed; however, the structure became coarse at a lower rate of scanning for the same laser power. Tensile strength of this alloy has also been improved if the cobalt content is more than aluminum in the coating mixture. Boissonnet et al. [11] analyzed the performance of coated aeronautical engine parts, such as combustion chambers, deflectors and injectors. HVOF was used for bond coating of Haynes-188 & AM1 with NiCoCrAlY and Inconel 600 with NiCrAlY and YSZ ceramic coating was produced using a plasma method. They concluded that sintering temperature played a role in slowing down the coarse structure, inducing cracking.

Kadir Mert Doleker et al. [12] have deposited Nichrome as a coat bond and YSZ as a top bond on Inconel 718 alloy. The coating was made using a plasma technique and it has been observed that this has been shown to be the best environment up to 1000 °C. Vibha et al. [13] stated that after loading, the TBC must maintain the same microstructure and permanent thermal insulation. They carried out a test of fatigue on the coated Inconel 718. Coating materials such as NiCoCrAlY as bond coat and
8wt % Y2O3ZrO2 as top bond were used to coat the substrate of Inconel 718 and it was concluded that the coated alloy performed well without damage up to less than 16 cycles. Delamination and damage were observed when this alloy was subjected to more than 16 cycles. Elbert Contreras et al. [14] deposited a single layer and several layers of coating on a steel substrate using the Sputtering method. They used (Ti, Al) (N) and TaN as coating material. They concluded that the growth of the columnar was seen in more layers of coating. In the case of more layer coatings, the size of the grain and the surface roughness were reduced. After heat treatment, Pasquale Cavaliere et al. [15] sprayed Inconel 625 powder on Inconel 718. They studied the impact of the cold spray parameters on the structure and mechanical properties of the coated alloy. The best solutions for reducing porosity and increasing adhesion are low gas temperature, high pressure and medium distance between the spray gun and the steel surface. In addition, the repaired parts were deposited and the fatigue test was analyzed with regard to the change in cyclic loadings.

Adam Khan et al. [16] analyzed the impact of coatings such as NiCr – Cr2O3 and (A40 T) in the salt-H2O condition. The plasma spray technique was used for the IN617 coating and the IN617 coated A40 T coating proved to be best for corrosion resistance than the IN617 coated NiCr – Cr2O3 coating. Masayuki Araia et al.[17] performed a finite element analysis to investigate the behavior of the IN738 coated alloy in terms of deformation and crack formation. CoNiCrAly was used as bond coat and 8wt % Y2O3-ZrO2 as top coat. They reported that the crack initiated at the concave place of the top coat and the strain rate was low at crack initiation at high temperature.

Shailesh Dhomne et al. [18] coated the spark ignition engine and stated that the TBC gave a good heat loss insulation. Coating materials such as YSZ, Mullite, Al2O3, Alsi, NiCrAl, Mg-PSZ, Y-PSZ, CaZrO3, MgZrO3 were used. Obrtlik Karel et al. [19] analyzed fatigue life of the coated IN713 and CoNiCrAlY and ZrO2 with stabilized Y2O3 were used as bond coat and top coat respectively. The fatigue life response of the coated alloy was compared to the uncoated alloy. Cracks were mostly initiated at the top and bond coat interfaces, and these cracks are homogeneous. The crack formation is shown in Figure.2.

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Figure 2. (a-b) Crack Initiation a) Growth of the crack from top to bond coat b) Surface of the fracture
Gupta et al. [20] stated that the porosity and delamination of the defective coating had a significant impact on the mechanical properties, oxidation and corrosion resistance. Therefore, the TBCs should be free from defects. They therefore attempted to analyze the performance of the IN71 coated with NiCoCrAlY as bond coat and ZrO2.7% Y2O3 as top coat. Thermal spray gun has been used for coating. They predicted thermal conductivity and the Youngs modulus of top coats. They made analysis of changes in the coat structure, porosity and coat life. It was noted that the optimized coat showed low thermal conductivity and was associated with low porous and crack levels. The lowest current and high spray distance were identified as the best coating structure parameter.

Kromer et al. [21] coated the AM1 alloy with no bond coat and made only the top coat with YSZ. The coating was made using the Plasma spray method. They analyzed the thermal mechanical fatigue, the creep test and the structure of the coat. Coting was performed with AM1 aging and without AM1 aging to compare the performance of the test. Increased Creep elongation and low yield point were observed during the non-aging AM1 alloy test. Surface treatment was also performed on the coating and there were no identical defects. Joao et al. [22] analyzed the performance of the coated Nimonic C263 alloy and MCrAlY was used as a bond coat and 8 wt. percent YSZ as a top coat. The coating was made using a plasma spray method. Figure 3 (a-c ) shows the microstructure observed at the lowest life, middle life and good life of the coated alloy after the fatigue test. The microstructure captured at the lowest lifespan consists of a minimum of micro surface roughness and a minimum of larger radii peaks. The microstructure captured at mid-life performance consists of a greater number of swelling micro roughnesses. The microstructure captured at higher life performance consists of a surface that is curved and rounded outwards.

Components such as gas and steam turbines are heavily affected by heat, and the surfaces of these components must be coated to resist corrosion and improve performance. The resistance of hot corrosion depends on the type of coating that is either liquid or solid-state. Cr content in super alloys has superior resistance to hot corrosion, but the Cr content would not withstand enough resistance in the Sulfur container situation. Working temperature and the presence of phase at that temperature would also have an impact on the resistance of hot corrosion [23].
Hitesh Vasudev et al. [24] coated gray cast iron using Inconel 718 powder and aluminum oxides as a composite coat by HVOF technique. The impact of the composite coat on hardness and oxidation resistance was found to vary the weight percentage of aluminum (10 %, 20 %, 30 %) with Inconel powder. It was noted that Wt-30% of Al2O3 with Inconel 718 powder improved resistance to oxidation and increased hardness. Furthermore, the presence of phases in the composite coat, namely chromium oxide, titanium oxide, nickel chromium oxide and chromium niobium oxide, has been reported to improve oxidation resistance.

Pasupuleti Kirti Teja et al. [25] used NiCrAly as a bond coat and 8 % YSZ as a top coat on INL718 alloy. The coating was made with a plasma spray. They observed that the sintering temperature had a significant influence on the oxidation resistance, the failure mechanism of the shock test. The failure mechanism was induced by the presence of thermal stress and the TGO layer in the bond and top coat interfaces. Jinku Yu et al. [26] carried out an analysis of the performance of coated copper and nickel-based coating materials used as coating materials. Jet electrode deposition has been used for coating. The best resistance of oxidation at 900 °C in copper coating with nickel and nickel with iron was reported as nickel-iron-tungsten coating material.

Zhang Na et al. [27] investigated the effect of micro arc oxidation and solution gel method on the coating of AZ91D magnesium alloy. It was concluded that the combination of MAC and TiO2 solution gel produced good resistance to oxidation compared to MAC single coating. Nikhil Rajendra Kadam et al. [28] evaluated the indentation on the coated surface using a finite element analysis. They considered INL718 alloy to be a substrate, NiCoCrAly to be a bond coat and 7YSZ to be a top coat. They concluded that the flat shaped indenter exhibited compressive and von-mises stress than the spherical and conical shapes of the indenter.

Dutta et al. [29] coated iron-nickel-chromium alloy 800 by spray technique. Aluminum was used to coat the substrate of this alloy. Analyzes such as the microscopic, hardness test and scratch test of the coated alloy were performed and the Al / rich oxygen, iron / aluminum and aluminum oxides were observed in the intermediate layers of the coating. Kadir Mert Doleker [30] used the HVOLF method to coat the 316L steel substrate. Iron and aluminum powders have been used as coating material and coated steel analysis, such as oxidation testing, XRD and SEM analysis, has been carried out. The laser coat melting showed good performance in resistance to oxidation than the iron & aluminum coat.

3. Conclusions

- Thermal barrier coating effects of substrates such as Inconel alloys, magnesium alloys and steels have been reviewed.
- The effect of various TBC bond and top coat materials was discussed.
Microstructure, micro hardness, fatigue life, creep life, oxidation resistance, crack formation in the coating and coating defects were discussed with respect to the coating of different coating materials.

Resistance to oxidation at different temperatures has been reviewed with respect to different coating materials.

Impact of different coating techniques and methods have been reviewed and HVOF and plasma spray techniques have been found to be effective than other techniques.

The TBC investigation of nickel-based alloys, titanium alloys, various grades of steel, magnesium alloys and other alloys used in the hostile environment is inadequate.

It was found that most researchers used NiCoCrAlY as a bond coat and YSZ as a top coat.

The impact of the various TBCs on porosity, TGO formation, phase changes, alteration of the microscope, fatigue life and creep life was found to be inadequate with respect to coatings by different coating materials and different substrate materials.

4. References

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