Microstructure Characterization and Testing of Plasma Sprayed Thermal Barrier Coating (TBC) for Aerospace Applications

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Abstract-Thermal barrier coatings are used to avoid material damage at high temperature and prolong the working life of materials. The coating layers systematically decreased the operating temperature to a safe working temperature. In the present work stainless steel grade-321 was coated with a standard CoNiCrAlY bond coat and Yttria stabilized Zirconia top coat. The top coat functions as a barrier to heat and decrease the working temperature to 400° C. The bond coat work as a reservoir of producing thermally grown oxide (TGO), which act as a barrier to high temperature corrosion between top coat and bond coat. The barrier property of the TGO limits within few microns. As the thickness of TGO grows the strong barrier layer transform to porous oxide, which allow the passage oxygen and ions through the TGO. An inter layer of Titanium (Ti) or Zirconium (Zr) is introduced between the top and bond coat to see whether these layers can suppress the TGO growth or not. The suppression of TGO to a few microns will improve high temperature corrosion resistance, thermal shock resistance and improve the working life of the material.

Keywords: Thermal barrier coatings (TBC), Top coat Yttria stabilized Zirconia, Thermally grown oxide (TGO), Inter layer of Titanium (Ti) and Zirconium (Zr)

I. INTRODUCTION

Thermal barrier coatings (TBCs) are used to avoid material damage of different components , such as gas turbine and aero engine parts, operating at elevated temperature. Typical examples are turbine blades, combustor cans, ducting and nozzle guide vanes. Thermal barrier coatings allow higher operating temperatures while limiting the thermal exposure of structural components, extending part life by reducing oxidation and thermal fatigue.

The structure of thermal barrier coatings typically consist of four layers the metal substrate, bond coat of CoNiCrAlY, thermally grown oxide, and topcoat of yttria-stabilized zirconia (YSZ). The ceramic topcoat has very low conductivity. While in the present work we introduce an interlayer of titanium or zirconium between bond coat and top coat in order to increase the oxidation resistance of thermal barrier coating by making difficult diffusion of oxygen towards substrate. Thermal shock test and hot corrosion tests are performed to check the effect of these interlayer on the working life of coating.

Failure of TBCs is normally occurred due to mechanical rumpling of bond coat during thermal cyclic exposure, accelerated oxidation, hot corrosion and molten deposit degradation during operating conditions.

II. EXPERIMENTAL SETUP

Spherical substrate of 321 stainless steel is used for thermal barrier coating. The diameter of the substrate is 25mm whereas thickness of sample is 5mm. 321 stainless steel is used for high temperature service because of its good mechanical and creep resistant properties.

Fe	Balance
C	0.08
Cr	17-19
Ni	9-12
Mn	2
Si	0.75
Ti	0.70
P	0.045
S	0.030

Table (A) showing Chemical composition of substrate material

First of all grit blasting of the substrates is done by alumina particles for 2 minutes on the flat surfaces to be coated with bond coat and top coat. Hitting angle is 90 degree. Due to grit blasting the substrate become free of dirt particles and ready for deposition of coating.
The bond coat is deposited by air plasma spraying using spherical powdered particles of CoNiCrAlY having size in range of 45-75 micrometer**.** The gun used for deposition of bond coat is sulzer gun. The bond coat has a thickness of 200 µm (approx.).

The metallic layer deposition for TGO suppression is done using sputtering technique. During this technique atoms are ejected from target material due to bombardment of highly energetic particles. The target material used in this case is Titanium or Zirconium. The layer formed during Sputtering is very thin and is approximately found to be 4-6 µm.

The top coat is deposited by air plasma spraying using spherical powdered particles of Yttria-Stabilized Zirconia having size in the range of 45-75 micrometer. The gun used for deposition of top coat is sulzer gun. The thickness of top coat is 500 µm (approx.).

The Formation of plasma includes the use of different gases including Hydrogen, Nitrogen, and Argon etc. In this work two gases have been used. Argon is used as primary gas whereas hydrogen is used as secondary gas. Argon gas is used as Primary gas because it can be easily ionized also it is inert gas and do not form compounds even if interacts with other elements. The use of hydrogen is due to the fact that it is anti-oxidant gas and is useful for increasing the energy levels of Plasma.

Parameters	Bond Coat	Top Coat
Current (Ampere)	600	600
Voltage (Volts)	70	70
Primary gas (Ar) SLPM	55	32
Secondary gas (H2) SLPM	08	10
Standoff Distance (mm)	100	100
Feed rate g/min	150	150

Table (B) showing Constant spraying parameters for bond coat and top coat

Plasma spraying technique is used for deposition of coating because due to this technique we can achieve high deposition rate, we can control composition of coating material and have coatings with higher mechanical strengths and good durability. Environment during coating deposition is normal room condition i.e. atmospheric condition. In air plasma spraying method the powdered material is melted in molten and semi molten form by using arc. This arc is produced keeping in contact the water cooled cathode and nozzle shaped anode together. The molten material is then deposited on the substrate. This process is affected by oxygen content present in the environment as oxygen react with the coated material and form some oxides and these grown oxides reside within the coatings.
As the top coat and bond coat are deposited in the molten and semi molten form on the substrate so the deposition temperature increases. For better adherence the material is cooled after depositing on the substrate. The cooling process is done by using the air jets, these air jets blow air with some pressure on the deposited material and due to which the temperature of coated material decreases. After performing these steps the samples are ready to use.

A. *Thermal Shock Test:*

In this test the samples are heated at 1000°C for five minutes after that these samples are water quenched in ceramic crucible containing 100ml water. After quenching the temperature of the water is measured to check the temperature difference. These heating cycles continue until the cracks appear on the coatings or spallation of coatings occurs. The furnace used for performing this test is muffle furnace.

B. *Hot corrosion test:*

In this test operating conditions for the samples are high temperature and mixture of salts. The salt mixture consist of 45% of sodium sulphate (Na_2So_4) and 55% of Vanadium penta-oxide (V_2O_5). This mixture of salts are placed in the center of the samples in order to avoid edge corrosion, 0.3 g of mixture is placed in such a way that the salt is 2 mm away from the edges. Then the samples are heated at 1000°C in tube furnace for 4 hours then furnace cooling of samples is done in order to avoid thermal shock. The furnace used for performing this test is tube furnace.

III. Results and Discussions

During thermal shock test spallation of coating is observed in the sample containing zirconium as an interlayer after 33 numbers of cycles while spallation of coating is observed in sample with no interlayer after 37 numbers of cycles and spallation of coating with titanium as an interlayer is observed after 52 numbers of cycles. Due to the addition of titanium as an interlayer between bond coat and top coat the oxidation resistance of coating increased which ultimately results in increased of thermal shock resistance of coating.

During hot corrosion test it is observed that the sample with no interlayer fails after first cycle. After performing first cycle the spallation of coating is observed in sample with no interlayer but the samples with titanium as interlayer and sample with zirconium as an interlayer fails after 2 cycles. The spallation of coating is observed in the sample with titanium as interlayer and zirconium as interlayer after performing test twice. Due to the addition of titanium and zirconium as an interlayer separately between bond coat and top coat the hot corrosion resistance of coating increased. It is observed that zirconium have no significant effect on increasing the working life of coating but titanium significantly increased working life of coating. Zirconium interlayer between bond coat and top coat increased hot corrosion resistance of coating but have no significant effect on thermal shock resistance. But due to the addition of titanium between top coat and bond coat not only thermal shock resistance of coating increased but also hot corrosion resistance of coating increased. Titanium as an interlayer between bond coat and top coat made difficult diffusion of oxygen towards substrate at high temperature due to which the oxidation resistance of coating increased which ultimately results in increased of working life of coating at high temperature.

IV. CONCLUSION

One obvious observation is that surface damage increases with increase in temperature. The main reason behind this behavior is the formation of oxides. This formation of oxides increases with increase in temperature due to higher diffusion of oxygen. These oxides grow and form an extra layer called thermally grown oxides (TGO). The cracking and spallation in thermal barrier coatings directly depends on the amount of oxides and thickness of TGO. As the oxide grows it develops stresses at the interface of bond coat and top coat and this stresses propagate into the top coat due to presence of porosity resulting in cracks initiation.

While after performing the thermal shock and hot corrosion test we can easily conclude that sample having titanium as a metallic layer has shown better resistance to penetration of oxygen into the substrate and suppress the TGO growth and due to this the working life of thermal barrier coatings enhanced. As compared to this, sample having zirconium (Zr) as a metallic layer and standard sample having no inter layer showed less resistance to oxygen penetration and the coatings started to spall off.

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VI. REFERENCES

[1] D.R.Clarke, S.R.Phillpot "Thermal Barrier Coating Materials ", materialstoday, vol.8(2005), Issue6, pp.22-29.

[2] R.A. Miller "Thermal Barrier Coatings for Aircraft Engines History and Directions" Journal of Thermal Spray Technology, vol.6(1997), Issue1, pp.35-42.

[3] R.L. Jones "Some Aspects of the Hot Corrosion of Thermal Barrier Coatings", Journal of Thermal Spray Technology, vol.6(1997), Issue1, pp.77-84.

[4] J.W. Byeon, B. Jayaraj , S. Vishweswaraiah , S. Rhee, V.H. Desai, Y.H. Sohn, Non-destructive evaluation of degradation in multi-layered thermal barrier coatings by electrochemical impedance spectroscopy, Materials Science and Engineering, 2005, A 407, p213–225.

[5] M. Leoni, R.L. Jones, P. Scardi, Phase stability of scandia–yttria-stabilized zirconia TBCs, Surface and Coatings Technology, 1998, p107–113

[6] Jan Ilavsky, Judith K. Stalick, Phase composition and its changes during annealing of plasma-sprayed YSZ, Surface and Coatings Technology, 2000, 127, p120-129.

[7] Md Shawkat Ali, Shenhua Song, Ping Xiao, Evaluation of degradation of thermal barrier coatings using impedance spectroscopy, Journal of the European Ceramic Society, 2002, 22, p101–107.

[8] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

[9] I.S. Jacobs and C.P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G.T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350.