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Study the chemical stability effect of thermal barrier coating by thermal Testing and FEA

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Abstract

This paper is on coatings (TBCs) made of temperature resistant, ceramic coatings provide thermal insulation on metallic components as gas turbine parts, aero-engine parts, IC engine parts. The high hardness, wear resistance and good chemical stability are very desirable in cutting tool applications in jute fiber sandwich structures. The durable life of parts increases on which the coating is employed, to characterize the coatings experimentally and find intermediate temperatures and residual stresses based on the experimental results of conductive heat transfer in TBCs. In experimental method of Atmospheric Plasma Spraying, top coat material ZrO28Y2O3 was selected, metallic bond coat NiCrAlY was selected. Ti6Al-4V was selected as substrate material 4 mm Ti 6 drill. These substrates were coated for maximum coating thickness of 700µm. Coating specimens were characterized for surface roughness using mitutoya surf test profilometer, Porosity, microstructure using SEM, composition elements in the coating by EDX. SEM of plasma sprayed TBCs revealed porosity level between 12.2 to 20 percent.

Keywords: Air Plasma spraying, Substrate Cutting and Polishing, Surface roughness, SEM, Nano-indentation, EDX, Burner Rig testing.

Introduction

Creep test were conducted on all three coating types in the as-sprayed condition at stresses from 40-80 MPa and temperatures of 1000° – 1200°C. The linear thermal expansion of YSZ/Mullite composite specimens was 6.4 x 10-6/°C. While the creep behavior of YSZ/mullite composite specimens was between that of pure YSZ and pure mullite specimens for all combinations of temperature and stress tested, the creep response of the composite was more similar to that of pure mullite for all cases tested [1]. Conventional thermal barrier coatings (TBCs) were deposited by air plasma spraying (APS). The thermal shock behaviors of the nanostructured and conventional TBCs were investigated by quenching the coating samples in cold water from 1 150, 1200 and 1250°C [2]. The microstructure and durability of a thermal barrier coating (TBC) produced by the thermal spray method have been characterized. Upon exposure, the bond coat chemistry and microstructure change by inter-diffusion with the substrate and upon thickening of the thermally grown oxide (TGO) [3]. The quality of TBCs was improved by using the spray-dried powders for high temperature TBCs (> 1523 K) [4]. The selection of top coat &bond coat materials, Weight of powder required, Preparation of substrate for coating i.e.,EDM wire cutting of Titanium, EDM parameters, Atmospheric Plasma Spray procedure, plasma spray parameters etc., Here in this project we selected Ti-6Al-4V (titanium super alloy) as substrate material. For bond coat& top coat SULZER METCO MAKE Powder is selected. The name of the coating is top coat and bond coat particle size is Zr028 y203 (meto 204NS (SAP#10005777) and Ni17.5 Cr5.5 Al2.5, Co0.5 Y203 Metco 461NS (SAP # 1000601)

2. **Experimental of Atmospheric Plasma Spraying:**

APS coating process selected to coat the bond coat and top coat materials on Ti 6 substrate.

Selected SULZER METCO made 8wt%YSZ ceramic top coat & NiCrAl metallic bond coat both in the form of powder.EDM wire cutting machine used to cut Ti 6 substrates to the required sizes hence calculated powder requirement for bond coat &top coat taking in to consideration of deposition efficiency as instructed by coating manufacturer. Specimens coated using APS technology to the required top and bond coat thickness. APS carried out at SPRAYMET COATINGS, Characterization of coatings done by using nano indentation curves &SEM Designed & fabricated BURNER RIG testing equipment for conductive heat transfer experiment conducted fabricated Burner Rig Test equipment, temperature of top coat &substrate found by using Laser infra red thermometer. Using the above temperature as input we found intermediate temperature & hence found residual stresses. Further, specimens subjected to isothermal temperature exposure for long time say 6 to 8 hours & tested for TGO layer thickness. Cutting of Ti6 plates to the required dimensions: Here we selected titanium alloy as substrate material for TBCs. Here we cut titanium plates in to required dimension of 50 mmx30 mm. Since Titanium is a very hard material we used EDM wire cutting to cut the titanium plates.EDM Wire Cutting: EDM wire cutting machine used to cut the titanium plates to the required dimensions. Following are the wire cutting parameters used to cut titanium specimens. Areas of to be coated components calculated, volume of coating calculated by using coating thickness. Calculated weight of powder requirement by knowing density of coating powder. It is found that it is only theoretical weight requirement of powder .We come to know coating deposition efficiency with

the coating manufacturer is between 30 % to35%.Actually we have used double the theoretical requirement of powder to account for powder losses.

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Wire Dia.	0.25 mm
Wire Material	Brass
Wire Tension	1300 gms
Wire feed rate	10 m/min
Resistivity	$5x10^4$ Ω cm
Cutting Speed	4.3 mm/min
Water flow	10 liters/min
Water pressure	13 Bar
Water flushing rate	10 liters/min
Working voltage	52 volts
Working current	4.5 Amps

Table: 2.1

Fig 2.1.1 EDM wire cutting machine

EDM wire cutting machine: Calculation of coating powder requirement: Areas of to be coated components calculated, volume of coating calculated by using coating thickness. Take the calculated weight of powder requirement by knowing density of coating powder. It is found that it is only theoretical weight requirement of powder .We come to know coating deposition efficiency with the coating manufacturer is between 30 % to35%.Actually we have used double the theoretical requirement of powder to account for powder losses.

Air Plasma spraying procedure: The coatings were applied to the Titanium substrate strips. The strips were 50mm long by 30 mm wide & had a thickness of 4mm. Substrate strips were silica grit blasted & bond coated to a size of 100μm thick NiCrAlY bond coat. The top coat was then applied Table gives the spraying parameters for the .bond coat & top coat using METCO SULZER M/C. 100 KW power supply.

The Fig 2.1.1 shows the general setup of an air-plasma spraying process, it consists of a gas supply for the ionization process argon is used and a carrier gas is hydrogen. A power system, a control equipment to control the various parameters in the process. A water-chiller which circulates water to keep the plasma gun under working temperatures. All these components are connected to the main component plasma gun, a powder feeder which feeds the plasma gun exit with the required coating powder. The substrate of titanium initially was preheated by the plasma gun without any particles being injected. Then bond coat of approximate thickness of 100 µm is sprayed on it, the ceramic coating of 200µm, 400µm, 500µm on different specimens was coated as the top coat. The bond coat thickness is maintained the same for all the specimens. The powders used for both the top coats were obtained from Sulzer Metco manufactures; the particle size of metallic bond coat was 150 +22µm. That of ceramic top coat was 125 +16µm.

Fig 2.1.1. Examples of twist drillbit coat.

Fig. 2.1.2 shows the actual specimen after coating and the cut off piece is the piece used for other experimentation like SEM and Nanoindentation

1. **Characterisation of APS coatings**

   1. Surface Roughness measurements
   2. Micro structural investigation [Transverse Section].
   3. Preparation Method of samples.
   4. Scanning Electron Microscopy& Analysis of SEM results
   5. Porosity of TBCs

2. **Nanoindentation a measure of mechanical properties:**

surface roughness measurements: After plasma spraying specimens were tested for surface roughness using Mitutoya Surftest profilometer.Checked roughness in different orientation to the specimen surface.The Ra (arithmetic average roughness) found to be 5.5 to 6.5 microns.The roughness was independent of measuring orientation. Rt (peak roughness thickness) found to be 30 to 40 microns.It is found from literature surface roughness of top coat is lesser than the bond coat roughness , bond coat surface roughness is lesser than the substrate roughness .It is found that Ra of Substrate after grit blasting is found to be 10 to 11 microns.Ra of bond coat found between 8 to 9 microns.

Micro Structural Investigation [Transverse Section]:

Under this section we study how the samples are made ready for micro structure analysis using SEM,Nanoindentation to know mechanical properties. Calculate porosity, to interprete SEM&Nano indentation results.

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Preparation Method of samples for SEM&NanoIndentation.

First step is cutting of APS coated samples Transverse cross section by using diamond cutting wheel. Only 10 x10 x4 mm material cut from the samples to study characterization.

After cutting the samples in transverse section by diamond cutting wheel we polish the sample cross section to the desired accuracy as required for SEM & Nano indentation.

Polishing procedure: Sample cross section held in PVC pipe in which acrylic powder with acrylic solution mixed allowed it for cold setting for ten minutes after which sample ready for polishing operation.We used emery paper coarse to fine i.e,220,320,400,500,600,800,1000,1500,2000.After applying emery we polished the surface using diamond paste of grit size 5micron,2micron, 0.5micron for this we use velvet cloth to hold diamond paste.

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Scanning Electron Microscopy& Analysis of SEM results:

We use SEM to analyse microstructure , microcracks, porosity, top coat, bond coat,TGO layer thickness.Transeverse section of the polished specimen examined using Scanning Electron Microscopy(SEM) using a QUANTA,FEI

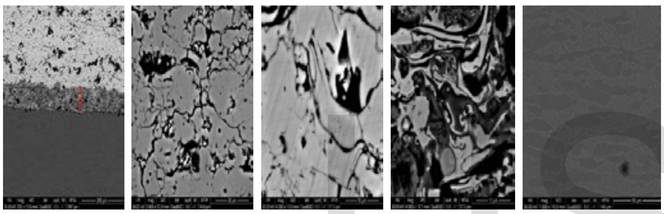

Fig.2.1.3. SEM image of Ti 6 Substrate,EDX of Top coat & Bond coat

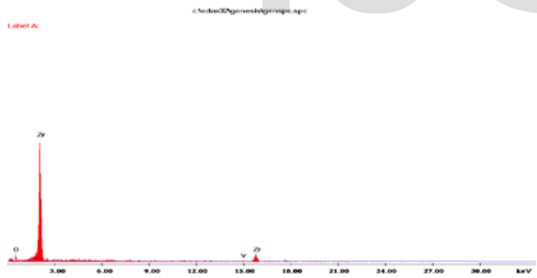

Fig.2.1.1.1

EDX of Top coat ceramic:

Element	Wt%	At%
o	19.34	57.69
y	9.02	4.84
Zr	71.64	37.47
Total	100.00	100.00

Table 2.2 Element contents of top coat ceramic:

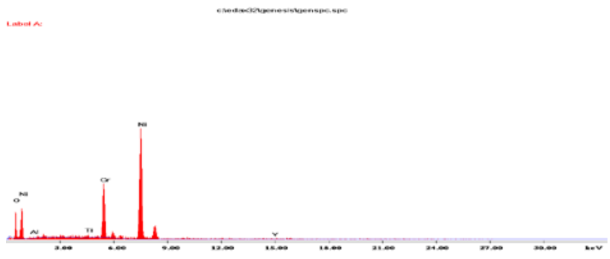

Fig.2.1.1.2.

EDX of Metallic Bond coat:

Element	Wt%	At%
O	17.94	43.48
Al	0.77	1.11
Ti	0.99	0.80
Cr	23.88	17.81
Ni	54.28	35.86
Y	2.15	0.94
Total	100.00	100.00

Table 2.3 Element contents in metallic bond coat:

Fig 2.1.4. Hysteron nanoindentation machine

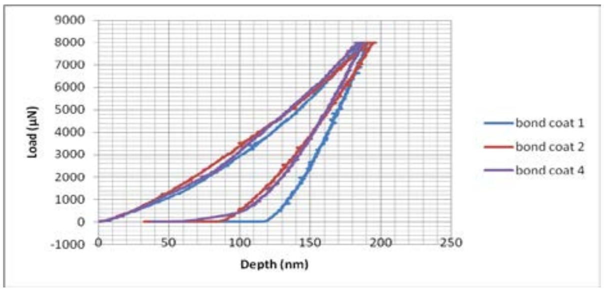

Fig 2.1.1.3.Loading curve for substrate

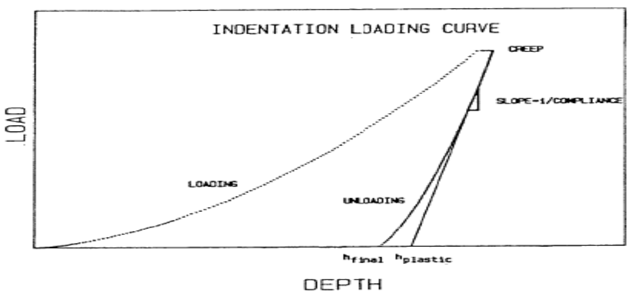

Fig 2.1.1.4. Load v/s Depth nanoindentation curve

Conclusions:

Thermal Barrier Coatings (TBCs) made of a temperature resistant ceramic topcoat and a metallic bond coat. The main purpose of the

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bond coat is to attach the top coat to the substrate and to prevent or delay oxidation of the substrate. Strictly speaking life time of TBCs is limited by the oxidation of the bond coat itself and also the damage or spalltion of TBCs (failure of TBCs) occurs due to thermally induced stresses.

1. From the experiments conducted on this project and FE analysis the following conclusions were drawn. Increasing top coat thickness increases the temperature drop in the top coat in turn more thermal barrier effect.

2. More thermal stresses induced in the bond coat as a result of increased temperature drop which is caused due to increased top coat thickness. In the process of burner rig testing most thick coatings (in our experiment 500µm, 600µm thick) failed by delamination starting from a free edge.

3. Modeling and FEA is a cheap tool for determining intermediate temperatures and residual stresses in the coatings.FEA software indicated increased bond coat thickness reduced thermal stresses.

4. Effect of TGO layer on temperature profile is negligible. But considerable thermal stresses induced in it. Nano indentation /depth sensing indentation is a measure of mechanical properties.

5. SEM images helps us to identify micro cracks, pores, porosity, formation of structure EDX images givablees the exact % of elements existing in the coatings.

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