SAMARIUM ZIRCONATE AS A FUNCTIONAL GRADE THERMAL BARRIER ON A NICKEL BASED SUPPER ALLOY (INCONEL)

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Abstract- The rare earth zirconates are adopted as a thermal barrier coating (TBCs) on the metallic surfaces which are operated at an elevated temperature to provide a heat management to prolong heat loads. Materials like Yttria-stabilised zirconia (YSZ) and Samarium Zirconate (SZO) provide the least thermal conductivity amongst rare earth zirconates and its pyrochore architecture is stable upto 2200°C but its response towards thermal cycling is very less known. Here, the bond coated nickel based super alloy (Inconel) is encrusted with a combination of two rare earth metals ie. Yttria-stabilized zirconia (YSZ) and Samarium Zirconate (SZO) by using plasma spray process. The ceramic deposited has a fluorite architecture which gets transformed to pyrochlore phase when thermal cycling is provided between 100 to 1600°C. Here the deposition is done with different combinations to provide various thermal cycling outputs. The compositional variations of YSZ and SZO have been hypothesized to provide different thermal load characteristics on the super alloy. In this research surface morphology, roughness, thermal cyclic fatigue, porosity, corrosion behaviour, surface profilometry and electro-chemical properties have been explored and the hypothesis critically evaluated.

I. INTRODUCTION

Hot surfaces like transition ducts, combustor cans, turbine blades and piston rings are protected with thermal barrier coatings (TBCs). Here, the TBCs have a three-layer structure consist of samarium zirconate (SZO) top coat (TC), 8 wt % yttria-stabilized zirconia (YSZ) middle coat (CC) and NiCrAlY type bond coat (BC). During operation, thermal grown alumina oxide (TGO), is formed as a reaction product at the middle coat and bond coat. TBC's deterioration and performance during high temperature exposure is strongly dependent on the deposition techniques, material constituents, and the service conditions. Degradation of TBC is considered to be a complex interplay between various factors such as: oxidation of the bond coat, thermal mismatch between the coating and the substrate, sintering of the ceramic coat. Understanding the collegial effect of the complex interplay factors is imperative if the functional coatings are propelled to their superlative limit. Associating the top coat with different rare earth zirconates generally provides high performance, and less deterioration criterion for TBCs. Different crack grown paths of different TBC system depends on the interface roughness.

The cohesion of different interference layers of thermal barrier depends upon the pairing material process used to join them. In between the bond coat and metallic substrate; a stable adherence is observed, but due to metal-ceramic bonding difficulty;

a weak interfacial adherence could be observed. A strong chemical bonding can be achieved by surface energies between metal and ceramic, or by metal and ceramic orientation relationship across their crystal lattices. Failure of the coating could occur by cracking top coat surface. Within the vicinity of the interface, high stress can be generated because of lattice dissenter and thermal dissimilarity between bond coat and TBC. Lattice dissimilarity between layer interface and difference in CTE is reduced by using functionally graded coating (multi-layered coating).

II. MATERIALS AND PROPERTIES

Three different TBC systems, representing functionally gradients TBC, are analysed through this model. The top coat is differentiated in the model to provide different results. TBC system 1 consists of Inconel 718 substrate, an NiCrAlY bond coat, ceramic 8 wt % yttria-stabilized zirconia (YSZ) and a functionally graded ceramic top coat of Samarium Zirconate (SZO) 25% and partially stabilized YSZ 75%. TBC system 2 consists of Inconel 718 substrate, an NiCrAlY bond coat, ceramic 8 wt % yttria-stabilized zirconia (YSZ) and a functionally graded ceramic top coat of Samarium Zirconate (SZO) 50% and partially stabilized YSZ 50%. TBC system 3 consists of Inconel 718 substrate, an NiCrAlY bond coat, ceramic 8 wt % yttria-stabilized zirconia (YSZ) and a functionally graded ceramic top coat of Samarium Zirconate (SZO) 75% and partially stabilized YSZ 25%. The material properties are prescribed in table 1.

MATERIAL	**E (GPa)**	**α (10^{-6}/k)**
SZO ($Sm_2Zr_2O_7$)	231	10.4
YSZ (ZrO_2, 8 YSZ)	80	8.6
NiCrAlY	170	12.5
Inconel 718	204	14.4

Table 1: Young's modulus and coefficient of thermal expansion of SZO ceramic, YSZ ceramic, bond coat and substrate material.

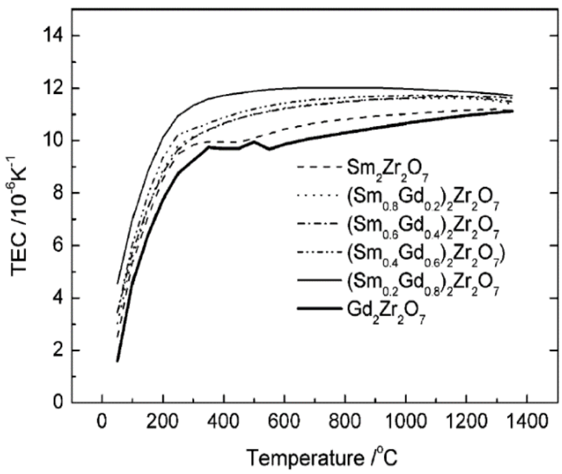

Fig. 1: Thermal expansion coefficient of SZO at different temperatures

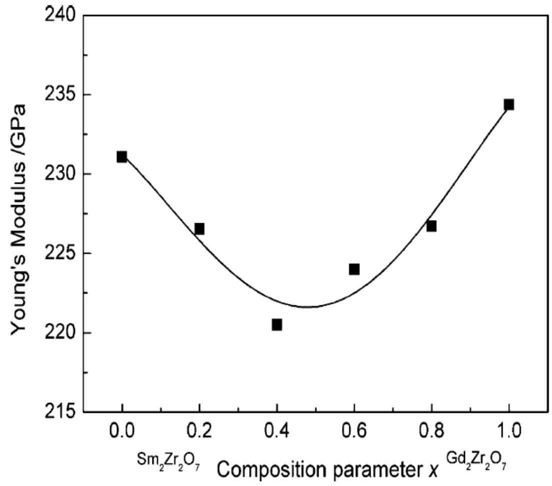

Fig. 2: Young's modulus of SZO specimens measured at room temperature

III. COATING PROCEDURE

Here, TBC system consist of an alloy bond coat (100µm) and a middle ceramic bond coat (300µm) and a ceramic top coat (300µm). A commercially available NiCrAlY powder, sintered 8 wt % Yttrium Stabilised Zirconia and Samarium Zirconate were utilized to prepare the required TBC. The YSZ powder illustrates a sintered shell with 20-85 nm grain size inside it. Supersonic atmospheric plasma spraying (SAPS) system was used to deposit all the three coats (AUM Technologies, Bangalore, Karnataka, India).

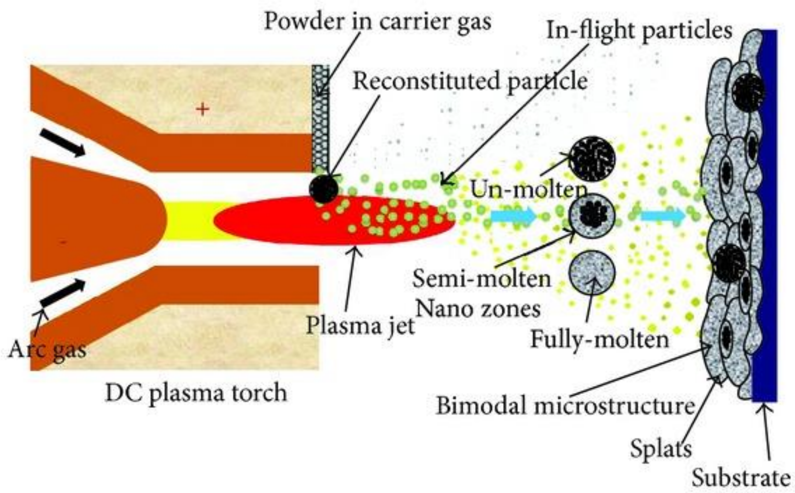

Fig. 3: Schematic diagram of Supersonic atmospheric plasma spraying (SAPS) system

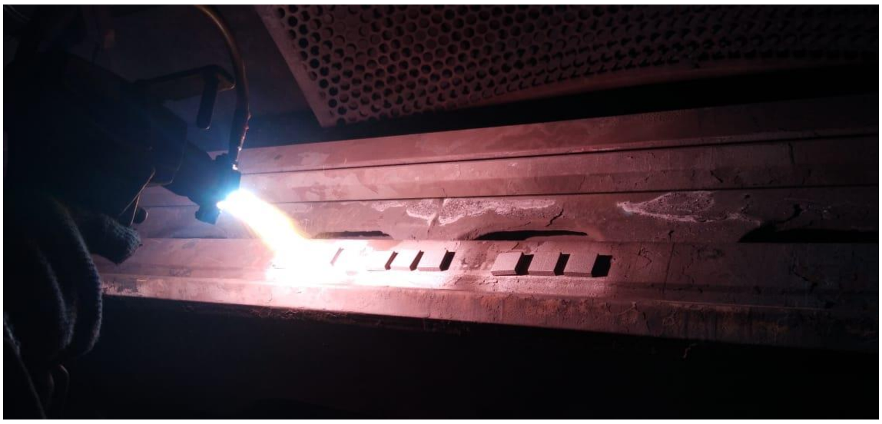

Fig. 4: Plasma spray coating event

The supersonic atmospheric plasma spraying system uses a DC electric arc to produce a beam of high temperature ionised plasma gas. This beam acts as a heated spraying source. The powdered coating material is carried via inert gas stream into plasma jet. Here, the powdered material gets heated and propelled out towards the substrate metal.

Material with high melting points can be deployed over the substrate via this method since the system works on high temperature (15000˚C) and high thermal energy of the plasma jet.

The spraying gun consists of copper anode and tungsten cathode. This gun is water cooled. To produce a plasma beam, a working gas (argon or hydrogen) is passed through a strong electric gap between anode and cathode. This releases energy with instantly heats the gas at high temperature (approx. 14,000K). This leads to rapid expansion which allows high jet flow through the nozzle. The speed of the jet could exceed up to 800 m/s. The finely powdered coating material (within the range 25-100mm) is then injected into the plasma jet. Due to high temperature molten droplets of coating material are formed which are propelled towards the substrate due to high velocity plasma beam.

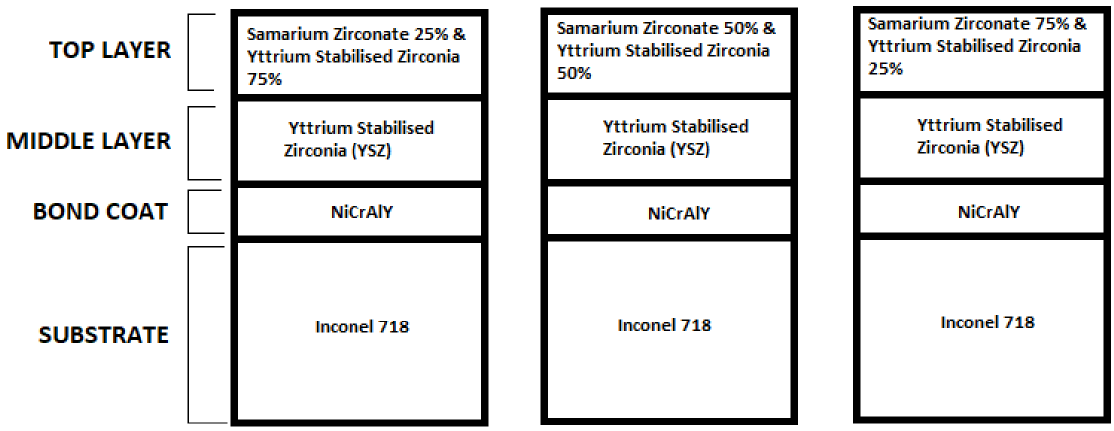

Fig. 5: TBC system sample 1, 2 and 3

IV. RESULTS AND DISCUSSIONS

4.1 THERMAL CYCLING ANALYSIS

The thermal cycling property of the Thermal Barrier Coating was evaluated by a Muffle Furnace apparatus (SRM Institute of Science & Technology, Chennai, Tamil Nadu, India). The specimen with different composition as described above were heated via heating coils inside the furnace. The sample surface was heated to the 600 ± 20°C for 1 hr. After heating the specimen was kept at room temperature to cool down for ½ hour. The test was deployed when the spallation area reached approx. 10% and the number of thermal shock cycles during the process are defined as thermal cycling life of coating. Difference in temperature between coated and uncoated sides of the sample provides thermal insulation temperature of the coating. The phase analysis of failed coatings was conducted by X-Ray Diffraction (XRD; SRM Institute of Science &Technology, Chennai, Tamil Nadu, India) using Cu Kα radiation.

4.2 SALT SPRAY CORROSION ANALYSIS

TEST PAPAMETERS:

Chamber Temperature: 34.5 – 35.5˚C
pH Value: 6.65 – 6.85
Volume of Salt Solution Collected: 1.00 – 1.50 ml/hr
Concentration of Solution: 4.80 – 5.30% of NaCl
Air Pressure: 14 – 18 Psi
Components Loading in the Chamber Position: 30 Degree Angle

OBSERVATION: Red Rust formation noticed at 24Hrs

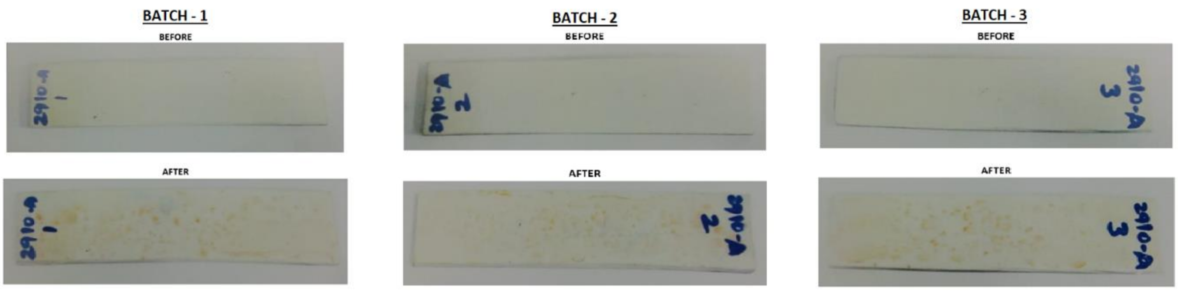

Fig. 6: Salt spray corrosion analysis samples

4.3 MICRO VICKERS HARDNESS ANALYSIS

BATCH-1

LOAD: 100gm

OBSERVATION (HV50gm): 480, 409, 406

BATCH-2

LOAD: 100gm

OBSERVATION (HV50gm): 450, 458, 452

BATCH-3

LOAD: 100gm

OBSERVATION (HV50gm): 429, 458, 446

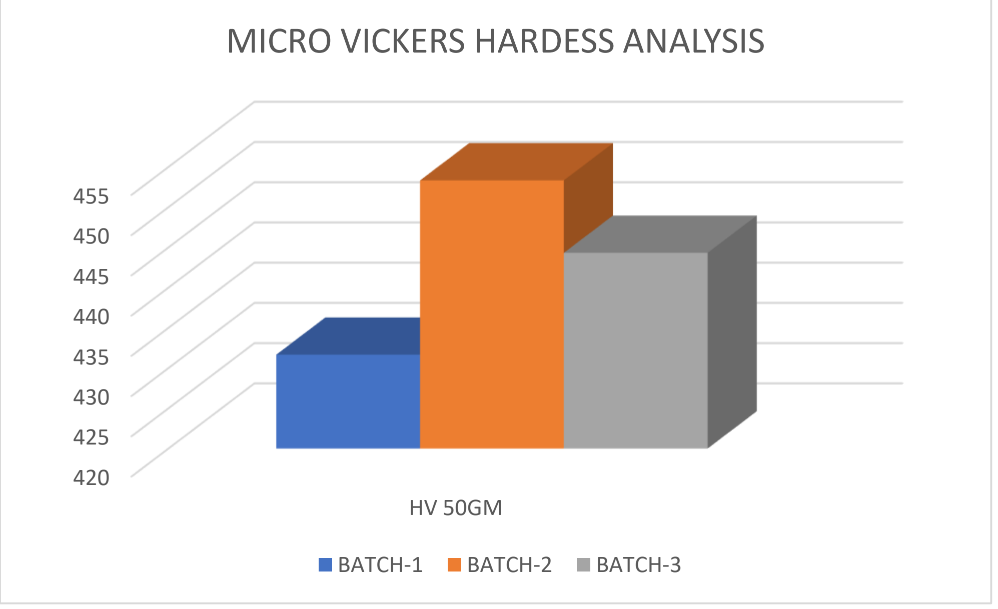

Fig. 7: Comparison of Specimen's Micro Vickers Hardness Test

Batch-2 provides maximum hardness amongst other batches which is more optimum for TBC.

4.4 SURFACE ROUGHNESS ANALYSIS

BATCH-1

OBSERVATION (Ra Values in µm): 6.593, 5.751, 6.014, 4.998

BATCH-2

OBSERVATION (Ra Values in µm): 5.965, 7.012, 6.881, 6.669

BATCH-3

OBSERVATION (Ra Values in µm): 6.860, 6.763, 6.142, 5.971

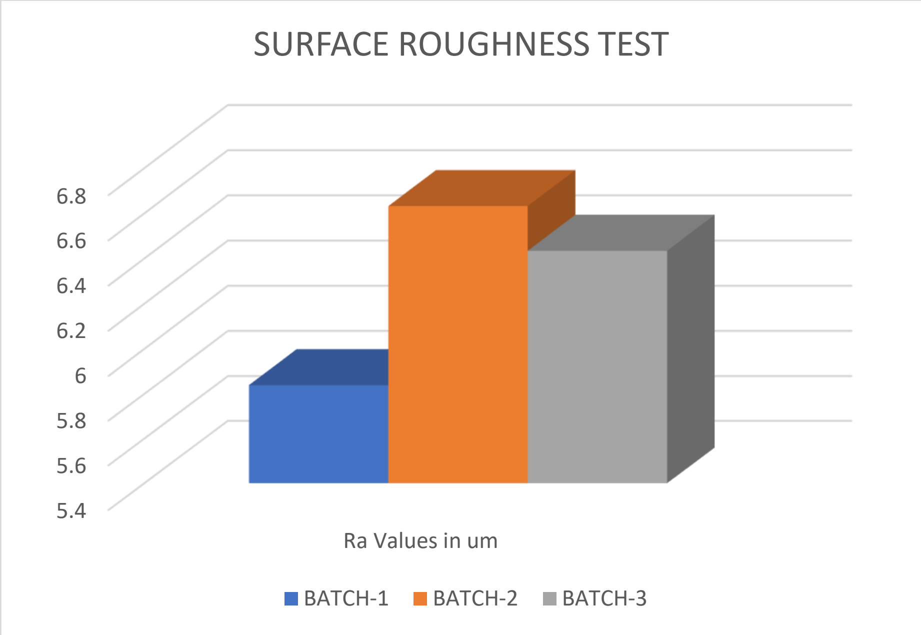

Fig. 8: Comparison of Specimen's Surface Roughness Test

Here, batch-1 has the least roughness amongst other batches which is more optimum for TBC

4.5 COATING THICKNESS ANALYSIS

BATCH-1

MAG: 100X

OBSERVATION: 377-404 Microns

BATCH-2

MAG: 100X

OBSERVATION: 205-241 Microns

BATCH-3

MAG: 100X

OBSERVATION: 219-248 Microns

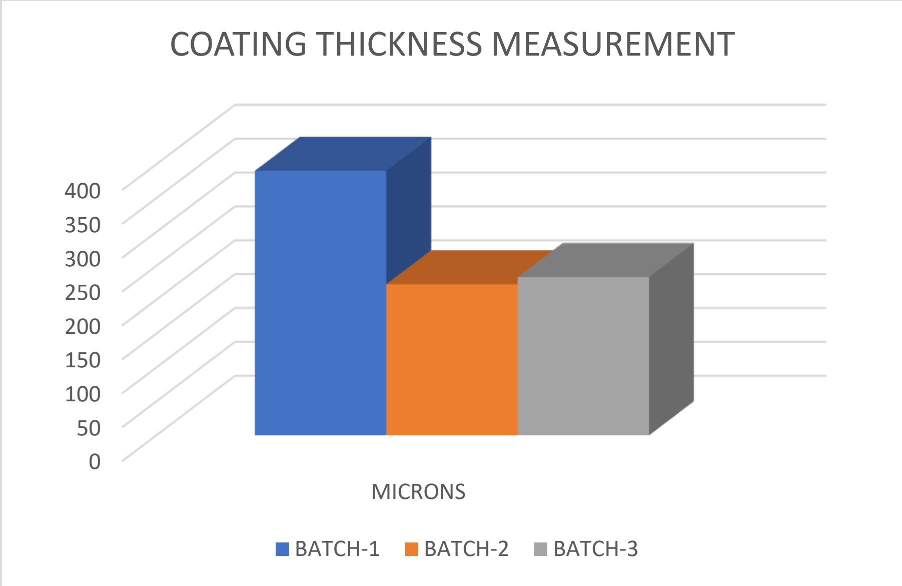

Fig. 9: Comparison of Specimen's Coating Thickness

Here batch-2 has least thickness amongst other batches which is more optimum for TBC.

V. CONCLUSIONS

Both SZO and SZO/YSZ hi-layer have been deposited on the polished NiCrAlY bond-coated Inconel-718 substrate using a plasma spray deposition method and their cycling response has been investigated. Amongst the three batches we found batch-2 more optimum against the other batches since during the test we found batch-2 to provide good strength and optimum thermal barrier with having the least thickness. We also found that:

1. By increasing incorporating voids in the SZO coating, the lifetime of the coating gets increased. The life of the coating gets reduced by chemical interaction of rare earth zirconate and alumina rich TGO which forms SmAlO3. This reaction also reduces the toughness interface.
2. Introduction of 300µm thick YSZ layer between substrate and SZO reduces TGO failure mechanisms and also improves coating life.
3. Intensity of stresses between substrate and top layer are not by number of functional graded layers. The intensity discrete stress is reduced by increasing number of functional graded layers.
4. Stress intensity on the top layer depends on thermal expansion of all the functional graded layers and substrate. The top layer is always in compression with substrate + bond coat + YSZ, the top layer remains in partial tension and compression depending on concentration of YSZ and SZO in top layer. Increasing concentration of SZO in the top layer decreases the tension.
5. TCF life of the predictive modal is estimated to withstand temperatures of 1600˚C or below reasonably good.

VI. REFERENCES

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