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Nano-Microstructural Characterization of Inconel-718 with Thermal- Barrier Coatings after thermal shock tests

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Abstract*: The immovability and permanence of thermal barrier coatings is very significant parameter for turbo machinery used at high atmospheric temperature such as turbine, compressor used in power generation and space industry. In this paper nano-structured ceramic pinnacle coating of 8YSZ (8wt%$Y_2O_3ZrO_2$) and NiCoCrAlY atomic bond is deposit on Ni based super alloy INCONEL718 by air plasma spray (APS). Thermal shock test of INCONEL718 has been performed as a function of temperature at 1100°C. This thermal shock testing is performed with 45 min heating and 15 min cooling in water and air separately. Delamination is observed due to thermal fatigue damage on 8YSZ coating. Damage of work piece is originated at the corner due to thermal fatigue and is sustained upto 20 cycles, 8 cycles for air and water cooling respectively. Nano-Microstructure characterization was done by high resolution scanning electron microscopy-energy dispersive x-ray (HRSEM-EDX). Result from HRSEM-EDX is co-related to nano and Micro structural development of thermal barrier coatings. After conducting of water and air cooling, lots of non-regular shaped nano size agglomerated clusters were observed in the 8YSZ coating. These non-regular structured leads to the formation of weak in the bond which cause delamination of coatings.

Index Terms*: Delamination, Nano-sized APS coating, Thermal barrier coating, Thermal shock

I. INTRODUCTION

The rare earth (RE) constituent has been practically successfully used in various fields, for example, metallurgy and concoction designing [l]. A territory of current intrigue is the modification of RE on surface designing. Past investigations demonstrated the constructive outcomes of RE in laser cladding and fire showering [2-4]. As per the literature available, it is observed that very less work on the application of RE, particularly its oxide, for example, Yz03, in the plasma transferred arc (PTA) process is quoted. PTA is an alluring preparing strategy that method produces a surface layer with numerous points of interest; for example, enhanced wear, consumption and warmth opposition of material surface. Particularly, the extensive span of RE constituent makes it conceivable to create metallurgical holding between the covering and the substrate substance with less weakening and bending [5-6].

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The thermal barrier coatings more often than not comprises of a solid artistic, for example, zirconia for supporting high temperature angles. Substantial temperature contrasts as the security coat is an intermetallic composite that gives oxidation at high temperatures and helps in addition of the thermal barrier coating to the substrate [7-8]. Notwithstanding the truth that, thermal barrier coatings have a Tendency to delaminating, breaking, is based on cyclic temperature, heat stacking situations and metallic substrate, that's result of the anxieties created in working [9-11]. The attributes of thermal barrier coatings is severely prompted by numerous warm extension houses having by thermal barrier coating frame works containing metallic substrates, protection coat and first-rate coat, warm inclination of pinnacle coat. It enhances the working temperature up to1500^0 C, which permits a required cooling air mass lower [12]. The presentation of the functionally grades materials (FGM) idea to a covering configuration is gone for accomplishing upgrades of unwavering quality and life span. In the mean time, functionally graded material ideas have activated around the world look into exercises and are connected to metals, earthenware production and natural composites to produce enhanced segments with unrivaled physical properties. Coatings were stored by various procedures including physical vapor deposition (PVD), chemical vapor deposition (CVD), plasma splashing, circular segment showering, plasma laser deposition (PLD), and sol–gel strategies, just as develop welding. Jet engines of rockets want to continue amazingly excessive thermal loadings for the reason that gasoline temperature comes to as much as 3500 ^{0}k. In the instance of H_2O_2 fly cars, the dividers of the combustion chamber are cooled via fluid hydrogen coursing through directs inside the divider. To perform an adequate cooling, the internal piece of the cone divider incorporates of a copper-primarily based alloy, even though the external part accommodates of nickel. The life of the jet engine is confined by way of plastic distortion of the copper amalgam at higher temperatures. To decrease the maximum temperature in the amalgam, appropriate warm obstruction coatings are currently created. In contrast to standard thermal barrier coatings the warmth modern via the thermal barrier coating is extraordinarily massive. For instance, inside the event of factors to return age of Arianne rockets, it comes up to 1.6 GW/m^2. As a con- succession, the thermal barrier coating thickness for rocket circulates automobiles wishes to be appreciably littler than for ordinary mills. A primary ductile stacking emerges amid cooling of the jet.

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A remember- capable enhancement of the solidness of thermal barrier coatings was normal to end result from: (a) a variety of the anisotropic compelling crack sturdiness; and (b) a control of the protecting pleasant by way of the phase sizes within the thermal barrier coating. The significant instrument for expanding the successful break strength is the prep- proportion of an evaluated lamella structure with frail interfaces so as to maintain a strategic distance from Via-thickness breaking by way of deflection of the damage into the interfaces among the lamellae [13– 15].

II. Experimental Details

A. Materials and procedures

The substrate decided for the experiment is nickel-based super alloy, INCONEL718 of size of 25 mm×25 mm× 3 mm. The composition of INCONEL718 is given in Table1. Substrates have been grit blasted through alumina debris size of 25µm to eliminate floor impurities. Ultimately, bond coat with a 150 µm thickness of NiCoCrAlY deposited at the floor of substrate through Air Plasma Spray (APS) method. In the long run, nano sized yttria stabilized zirconia (YSZ) pinnacle coat with thickness of 250 µm were sprayed onto the bond coat via APS machine. Coatings had been completed at Sai floor Coatings and era, Patencheru (Hyderabad) India.

Table1: Chemical composition of INCONEL718

Elemental	Ni	Cr	Si	Ti	Mn	Other
Composition (%)	50.20	18.00	0.19	0.90	0.17	Balance

Table2: Spraying technique parameter of bond

Current	Voltage (V)	Primary gas, (1/minute.)	Secondary gas, (1/minute.)	Powder feed rate (gm/minute.)	mist space(mm)	Power(kW)
559.8	66.8	42.9	9.6	19.98	101.96	37.6

Table3: Spraying technique parameter of yttria stabilized zirconia

Current	Voltage (V)	Primary gas, (1/minute.)	Secondary gas, (1/minute.)	Powder feed rate (gm/minute.)	mist space(mm)	Power(kW)
599.8	70.89	43.95	12.89	19.98	101.96	42.7

Coating thickness of various layers of thermal barrier coating has become measured with the aid of the usage of virtual Vernier Calipers and Screw gauges. Initially thickness of substrate has become measured at ten locations, and then thicknesses have become measured after bond coat and pinnacle coat. The common coating thickness of pinnacle coat modified as 250 µm. Thickness of bond coat and pinnacle coat became additionally measured from pass-phase picture of HRSEM-EDX. Perfect parameters for bond coat are chosen which showed in Table 2. Best parameters for quality coat are given in Table 3. Figure1 demonstrates the pinnacle coat, bond coat and substrate of thermal barrier coating framework.

B. Thermal cycling testing

The test piece of size 25 mm×25 mm× 3 mm had been used for thermal cycling fatigue test (TFT). TFT involved 45 minute heating at 1100°C and afterwards cooling 15 minute in water and air separately. TFT test is performed 8 cycles and 16 cycles in water and air respectively. After 16 cycle of TFT delamination is observed in thermal barrier coating structures near the boundary between bond coat and pinnacle coat, which can be easily seen by bare eyes.

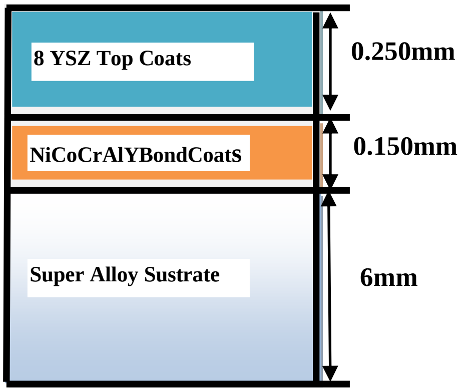


Fig.1.Schematic diagram of thermal barrier coating system

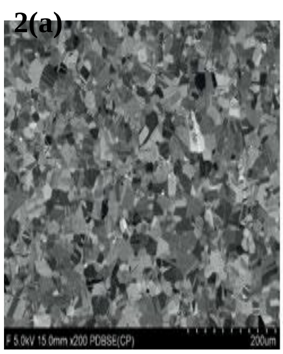


Fig.2a.Surface microstructure of thermal barrier coatings

Fig.2b.Enlarge picture of Nano-microstructure of coatings

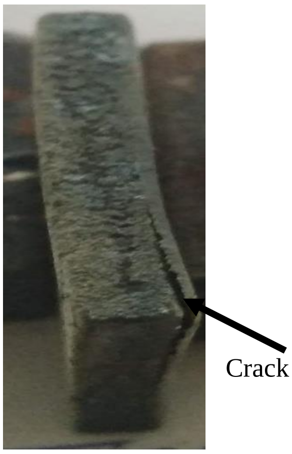
TFT was carried out till failure of the thermal barrier coating. Failure of coating is taken if 20% delamination of the thermal barrier coating observed. The cooling of TFT specimen is done in laboratory temperature after removal from furnace. It is observed that, the pinnacle coat generally delaminated off completely in a few pieces.

III. RESULT AND DISCUSSION

C. Microstructure of thermal barrier coating system

Figure-2a demonstrates the microstructure image of thermal barrier coating surface and Figure-2b demonstrates the enlarge picture of thermal barrier coating frame works before TFT. Figure 3a shows the cross sectional image of crack induced delamination after TFT using water cooling. This delamination occurred after 6 cycles of TFT with water medium which leads to breaking of coating after 8 cycles as shown in Figure 3b. TFT is performed at 1100ºC in Muffle furnace. It tends to be seen from Figure-3b. It is observed that delamination is originated from corner. This delamination is due to the thermal fatigue created in due to quenching of test piece in water. Bulging is observed after 8 cycle of TFT in pinnacle coating surface. Figure4 shows the image of thermal barrier coating of air cooling processes) shows the delamination of coatings after 16 cycles of thermal loading of 1100°C.

Fig.3a After 6 cycles



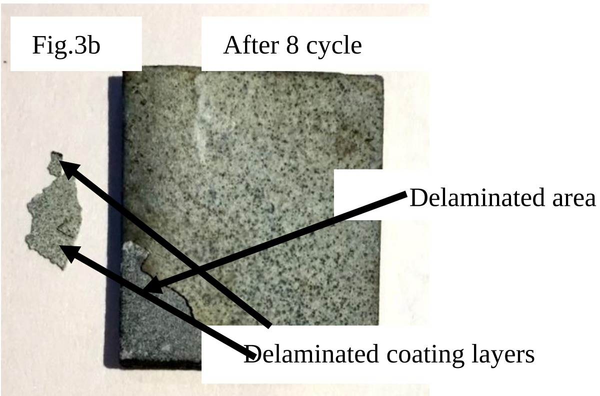


Fig.3 Images of thermal barrier coatings viewing water cooling (a) crack prompted delaminated, (b) fail thermal barrier coating material after 20% delamination

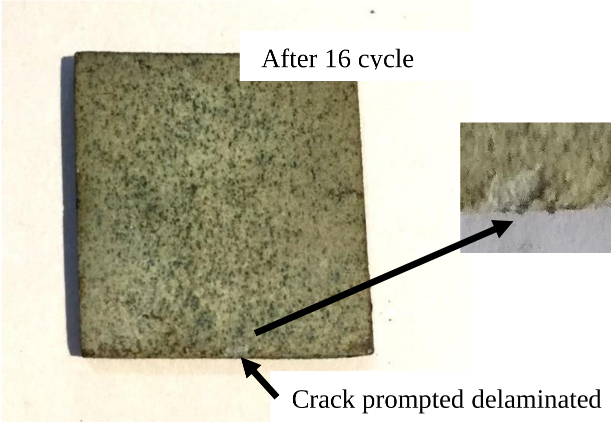
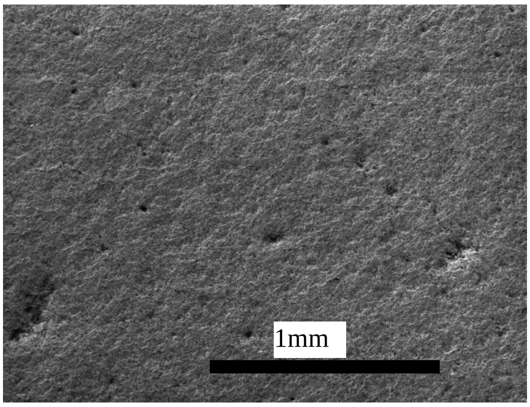
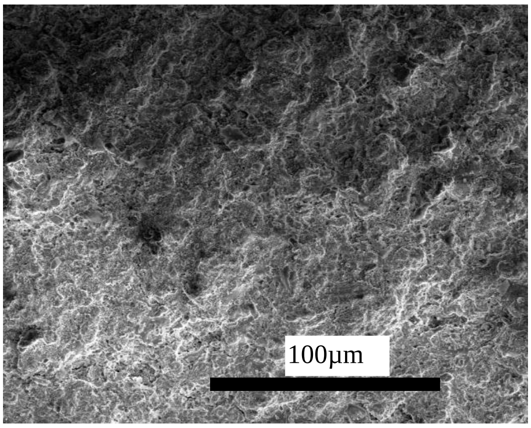


Fig.4 Image of crack prompted delaminate in thermal barrier coating (air cooling)

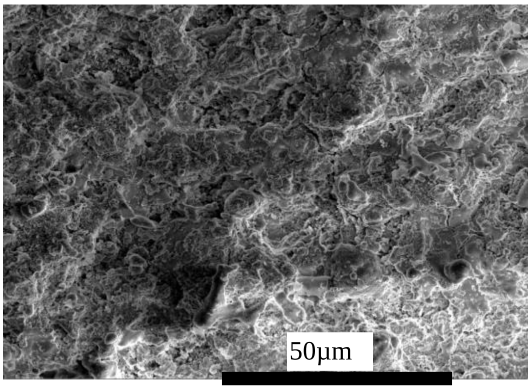
(5a)



(5b)



(5c)



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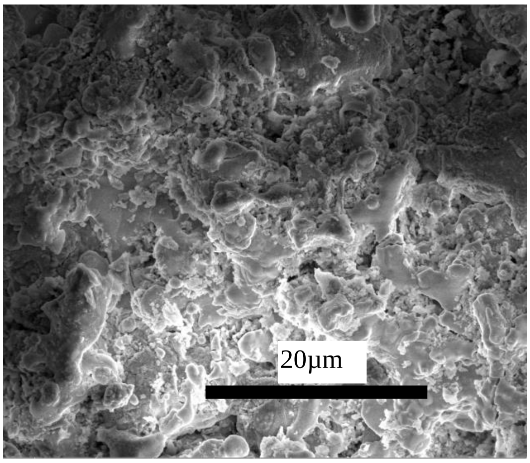
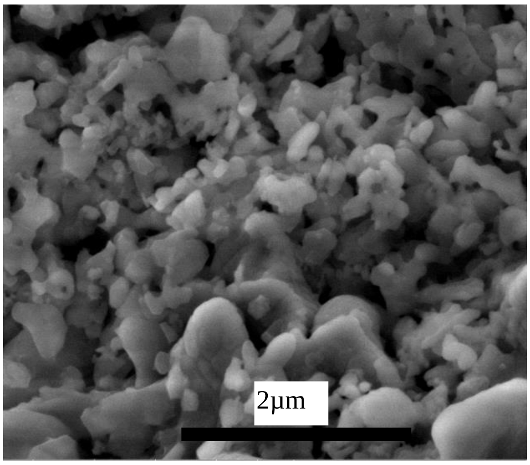
(5d)



(5e)



(5f)

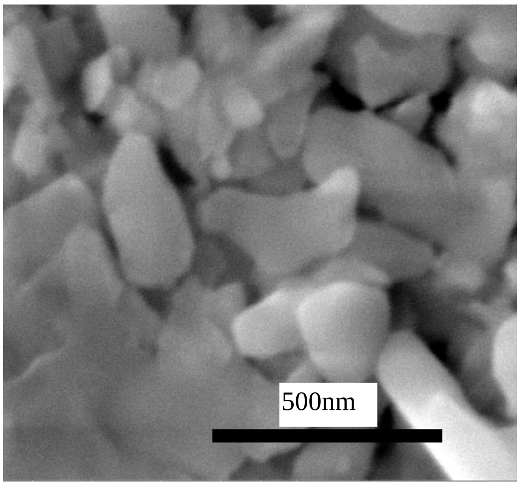
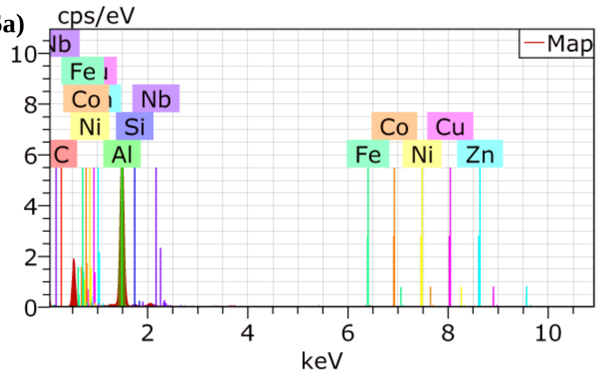


Fig. 5 HRSEM micrographs of 8YSZ coating after braking of material with air cooling test of 16 cycles from 1100°C to air,(a) 1 mm magnified surface, (b) 100 µm magnified surface, (c) 50 µm magnified surface, (d) 20 µm magnified surface, (e) 2 µm magnified surface, (f) 500 nm magnified surface

(6a)



(6b)

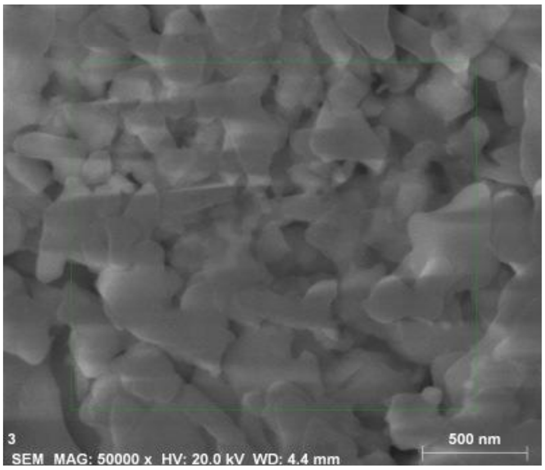
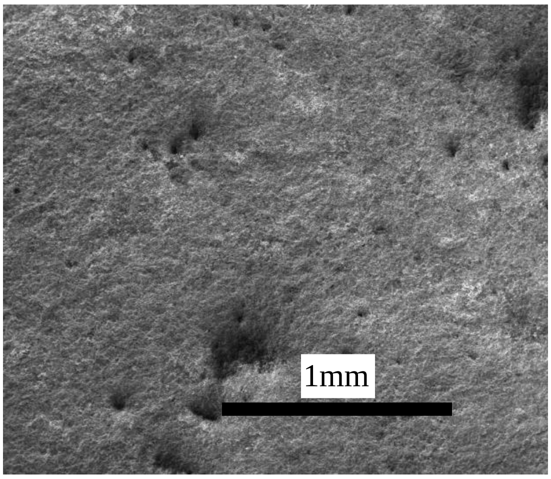


Fig.6 HRSEM-EDX micrographs of 8YSZ coating after air cooling test of 8 cycles from 1100°C to air,(a) composition of thermal barrier coatings with APS (b) very low magnified surface(500 nm)

(7a)



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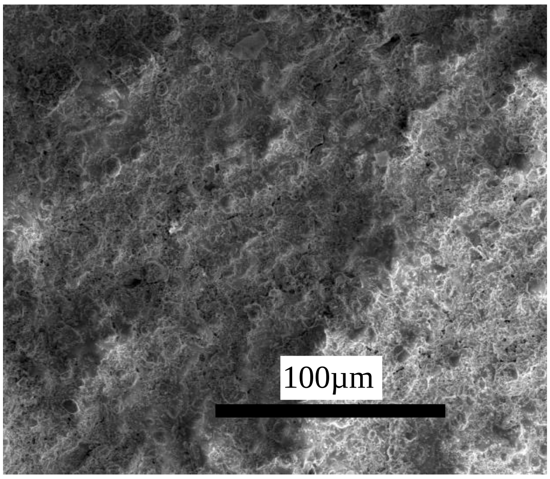
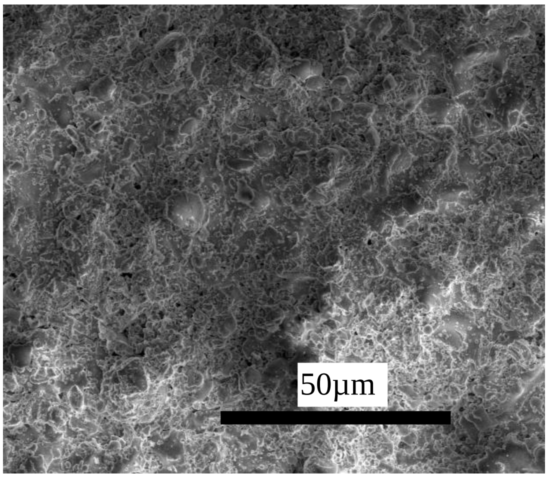
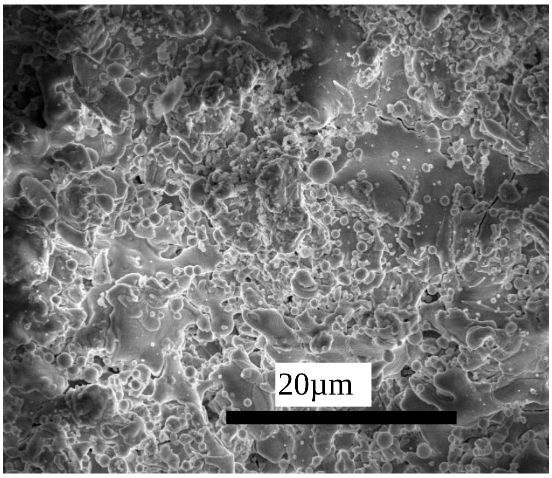
(7b)



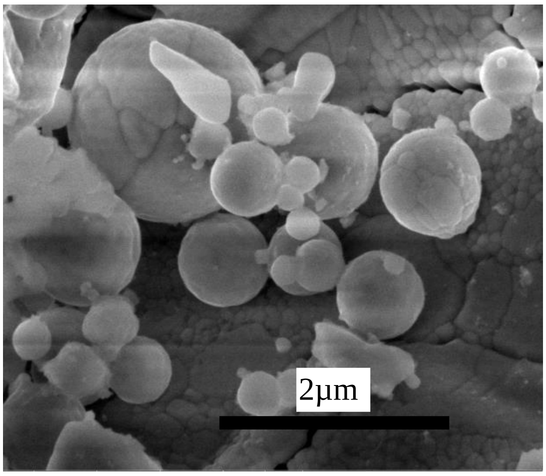
(7c)



(7d)



(7e)



(7f)

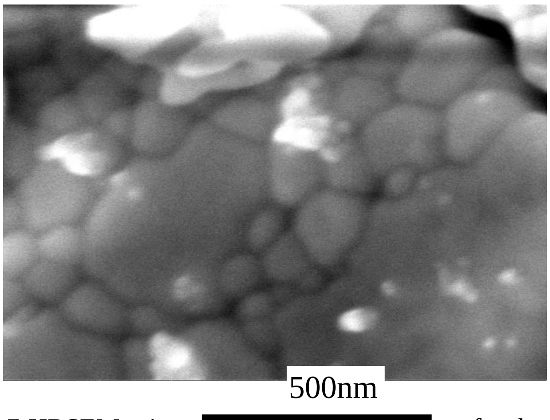
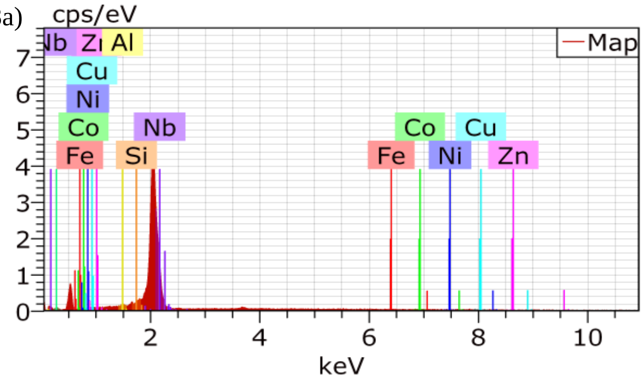


Fig.7 HRSEM micrographs of 8YSZ coating after braking of material with water cooling test of 16 cycles from 1100°C to water,(a) 1 mm magnified surface, (b) 100 µm magnified surface, (c) 50 µm magnified surface, (d) 20 µm magnified surface, (e) 2 µm magnified surface, (f) 500 nm magnified surface.

(8a)



(8b)

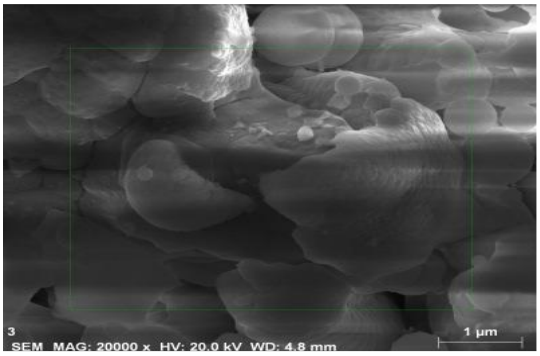


Fig.8 HRSEM-EDX micrographs of 8YSZ coating after water cooling test of 8 cycles from 1100°C to water,(a) composition of thermal barrier coatings with APS (b) very low magnified surface (1 µm)

D. Deposition mechanism of Thermal barrier coating

In this above failure analysis which is based on 8YSZ thermal barrier coating after air cooling and water cooling tests, it is seen that un-evaporated square shaped particle and nano-sized agglomerated cluster situated in the inner 8YSZ coating will increase the failure risk. This risk can be avoided with the help of deposition mechanism of 8YSZ thermal barrier coatings.

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HRSEM micrographs of nano-sized agglomerated 8YSZ coating after braking of material with air cooling tests show in Fig5. The Fig. 5(a-b-c-d-e-f) was 1 mm, 100 µm, 50 µm, 20 µm, 2 µm and 500 nm magnified surface pictures of 8YSZ powders correspondingly. This nano sized agglomerated un-evaporated square shaped particles weakened the bonds between pinnacle coat and bond coat which leads to breakage of thermal barrier coating. Figure 6 shows the HRSEM- EDX micrographs of 8YSZ thermal barrier coating with air cooling tests. The Figure 6 (a-b) represents the composition of thermal barrier coating with respect to kilo electron vs. characters per seconds with the very low magnified surface (500 nm).
HRSEM micrographs of nano-sized agglomerated 8YSZ coating after braking of material with water cooling tests show in Fig7. The Fig. 7(a-b-c-d-e-f) was 1 mm, 100 µm, 50 µm, 20 µm, 2 µm and 500 nm magnified surface pictures of 8YSZ powders respectively. This nano sized agglomerated un- evaporated square shaped particles weakened the bonds between pinnacle coat and bond coat which leads to breakage of thermal barrier coating.. The powders were used to prepare the 8YSZ coating by APS. Figure 8 show the HRSEM-EDX micrographs of 8YSZ thermal barrier coating with water cooling tests. The Figure 8 (a-b) represents the composition of thermal barrier coating with respect to kilo electron vs. characters per seconds with the very low magnified surface (1 µm).

IV. CONCLUSION

In this article authors concluded that the micro-structural components of TFT at 1100°C of thermal barrier coating system on super alloy INCONEL-718. Under thermal cyclic loading studied they developed coating damage. Because of the thermal cyclic loading the coefficient of thermal growth mismatch stresses and additionally larger thermal gradients among pinnacle coat and bond coat interface. The conclusions are-

- From the any corners the thermal barrier coating samples gets delaminated.
- The thermal fatigue damage caused in form of delamination and damage become not confined to the edges of the work piece.
- Macro-void configuration occurs due to delamination in failed samples.
- The repetitive nature of cooling phenomenon is responsible for the acceleration and origination of edge delamination.

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