Sea water corrosion behavior of plasma sprayed abradable coatings

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Abstract. Aluminum based abradable coating is used for sealing purpose in compressor casing of aero engines to withstand up to a service temperature of 450°C. Al-BN3SiO12 composite coating is deposited using thermal plasma spray technique. Coating thickness measured and porosity of the coating is evaluated. Coating morphology is observed and EDS analysis is done with SEM (Jeol make). The effect of time on the sea water corrosion behavior of the coating is evaluated. It is observed that, there is a sharp increase in weight gain of the coating up to six weeks of immersion. This behavior is attributed to the adsorption/deposition of other elements/reactions taking place during interaction with sea water.

1. Introduction

Abradable aluminum base composite coating is used for clearance control and sealing in compressor of aero engines, thereby improving engine efficiency [1]. This abradable aluminum coating is used as top coat with a bond coat being nickel-aluminide etc. [2]. Abradable aluminum coating is used in the area of cold end components like compressor casings, rings of gas generator, and internal rings etc. To deposit such coatings, flame or plasma spraying is considered as the most effective method. Since 1960, atmospheric plasma spraying (APS) is widely used in many fields of engineering applications. One of the main advantages of plasma spraying process is that, the substrate is heated very little during the coating deposition. During plasma spray process the plasma thermal energy melts the coating/feed material (usually in the form of powder/wire). Molten material is propelled by the carrier gas on a cleaned and prepared specimen surface, where it bonds to the surface predominantly by mechanical bonding. Coating characteristics are very much dependent on substratesurface and critical plasma spraying parameter (CPSP) [3-6].

Parameters those are important in choosing the abrasive for surface roughening are type, size, shape, purity and hardness of blasting powder. Specific CPSP is used for this aluminum based abradable coating for clearance control [7]. These parameters also affect the corrosion behavior of plasma spray ceramic coatings [8]. This coating is intended for operation, when the operating temperature is below 450°C in the rotor sealing of gas turbine engine at general climatic condition. But however study has not been reported for this abradable aluminum coating related to corrosion testing in saline climatic condition. The main aim of the work is to study the sea water corrosion behavior of this abradable aluminum-based composite coating.

2. Experimental Procedure

Before carrying out Nickel plating of Aluminum powder, it was prepared by sheaving the powder with mesh size between 1-60. Granularity structure of the powder was maintained. Nickel chloride (30kg) was added to 50 liters of solution made with (Boric acid + NaCl + Oxalic acid + HF).

All the chemicals were dissolved in distilled water at 70- 80 °C. Then sprinkling of already prepared aluminum powder was done at a temperature of 22 – 25 °C within 5 to 10 minutes at a rate of 96 gm /litr. Then excess solution was taken out and flushed with drinking water for 6 – 8 times.
the powder was taken in a stainless steel tray and heated at 180-200 °C. The powder should have granular size between 16-56 mesh.

Aluminium powder is sieved through mesh size 016. Aluminium powder 74-76 % and BoronNitride 24-26% were mixed with 40-60 rpm in a ball mill for 10-12 hrs. The dry mixture is mixed with liquid glass 140 -160 cc for 1 kg of dry mixture for 30-40 minutes. The blend is dried at 140-160 °C for 8-10 hrs and sieved through vibro-sieve no 315.

2.1 Substrate Preparation
Nickel based Nimonic(70% Ni, 23%Cr) plate was selected as substrate for coating. The surface of the substrate prepared for coating was made free from moisture, oil, and other contaminates. The time gap between surface preparation and spraying process was less than 2 hours to avoid disintegration of coating. Substrate surface was roughened using Al₂O₃ powder of grit size 60.

2.2 Spray Deposition
Coating was made on the surface with a sub layer of nickel-aluminide, of 50 micron thickness by plasmaspray technique using a specific critical plasma spraying parameters (CPSP). The plasmaspray parameters used for spraying are listed in table 1. After coating the samples were heat treated at 450°C for 30 minutes.

| Sl. No. | Parameter          | Value          |
|--------|--------------------|----------------|
| 1      | Nozzle Dia         | 6 mm           |
| 2      | Primary Plasma Gas | Argon (45 lpm) |
| 3      | Secondary Plasma  | Argon (7 lpm)  |
| 4      | Current            | 570 Amp        |
| 5      | Powder carrier gas | Argon (3 lpm)  |
| 6      | Powder feed rate   | 90 % on machine scale |
| 7      | Spray distance     | 120 mm         |

2.3 Specimen preparation for corrosion test
Ten specimens of thickness 3 - 4 mm and weight (ranging between 5-9 grams) were cut from prepared coatings by wirecut EDM. The abradable aluminum composite coatings were subjected to corrosion test, dipping in sea water for different time periods. Sea water was collected from Bay of Bengal; the composition of sea water is shown in table 2.

| Type of ion | Element | Concentration (Mg/ltr) | % by wt. |
|-------------|---------|------------------------|---------|
| Cation      | Na⁺¹   | 10500                  | 30.42   |
|             | Mg²⁺   | 1350                   | 3.91    |
|             | Ca²⁺   | 400                    | 1.16    |
|             | K⁺¹    | 380                    | 1.10    |
|             | Sr²⁺   | 8                      | 0.02    |
| Anion       | Cl⁻¹   | 19000                  | 55.04   |
|             | SO₄²⁻  | 2655                   | 7.04    |
|             | CO₃²⁻  | 140                    | 0.41    |
|             | Br⁻¹   | 65                     | 0.19    |
|             | BO₃⁻³  | 20                     | 0.06    |
|             | SiO₃²⁻ | 8                      | 0.02    |
|             | F⁻¹    | 1                      | 0.003   |
3. Results and discussion

3.1 Hardness test
The heat-treated coated sample surfaces were polished using emery paper for hardness measurement. The coatings were checked for any defect using 7X magnifying glass. Blow holes, cracks, separation and unfused particles were not found. Hardness was measured (with Brinell hardness tester) on five areas of the sample after making the surface smooth. Ball indenter of diameter 5mm was used at a force of 62.5 kg/cm², having indentation dia of 3.15 to 2.4mm. Ten readings were taken and the hardness of the specimens was in the range of 7 – 13 HB.

3.2 Corrosion Test
Specimens were weighed in a balance of least count 0.01 gm. Prior to corrosion test the samples were washed with distilled water and dried at 110 – 120 °C for 1 hr. The specimens were put in the sea water at different interval of time and kept under observation. After 10 weeks of observation samples were taken out and again dried at 110 – 120 °C for 1 hr. Again weight of specimens were taken and listed at Table 3 and shown in Figure 1.

| Sl. No. | Time in days | Initial weight | Final weight | Change in weight | Percent weight gain |
|--------|--------------|----------------|--------------|------------------|--------------------|
| 1      | 86           | 6.28           | 6.86         | 0.58             | 9.24               |
| 2      | 79           | 5.02           | 5.38         | 0.36             | 7.17               |
| 3      | 65           | 8.1            | 8.88         | 0.78             | 9.63               |
| 4      | 58           | 8.26           | 8.99         | 0.73             | 8.84               |
| 5      | 44           | 6.97           | 7.62         | 0.65             | 9.33               |
| 6      | 36           | 6.47           | 6.7          | 0.23             | 3.55               |
| 7      | 28           | 6.7            | 6.98         | 0.28             | 4.18               |
| 8      | 19           | 6.34           | 6.61         | 0.27             | 4.26               |

Figure 1. Time dependence of wt. change in sea water corrosion.

From the figure, it is evident that, the rate of increase in wt. is very rapid up to six weeks and then takes a linear trend.
3.3 Microstructural observations

SEM and EDS analysis is done with the raw and corroded samples, shown in figure 2 and figure 3 for these samples, respectively.

![Figure 2. SEM and EDS spectrum of the surface of the coating.](image1)

![Figure 3. SEM and EDS spectrum of the surface of the untreated specimen.](image2)

From the above figures, it can be seen that, very good quality coatings could be made with using the above said plasma operating parameters. It is well known that, plasma spraying parameters plays an important role on deposition and the microstructure and the surface morphology is more important for optimization of plasma spray parameters for developing the best quality coatings [9-11]. Hence the selection of plasma spray parameters (in our case) is suitable to develop dense coatings. In case of the corroded specimen, fig.2, deposition of small particles and dimples are developed on the coating/surface. From the EDS composition analysis, table – 4 and 5, it can be seen that there is major increase in amount of Ca, Cl and a little increase in Mg also. This implies that, some kind/type of ionic change/reactions is taking place on the samples and investigations in this regard are on the way.

| Element | Weight% | Atomic% |
|---------|---------|---------|
| C K     | 11.40   | 17.71   |
| O K     | 49.04   | 57.20   |
| Na K    | 12.35   | 10.03   |
| Al K    | 17.30   | 11.97   |
| Si K    | 1.16    | 0.77    |
| Ca K    | 0.27    | 0.13    |
| Cu K    | 1.61    | 0.47    |
| Zn K    | 2.19    | 0.63    |
| Br L    | 4.67    | 1.09    |

Totals 100.00
Table 5. EDS elemental analysis of the coating surface after dipped in sea water for 10 weeks.

| Element | Weight% | Atomic% |
|---------|---------|---------|
| O K     | 51.43   | 70.76   |
| Na K    | 3.92    | 3.75    |
| Mg K    | 1.06    | 0.96    |
| Cl K    | 8.06    | 5.00    |
| Ca K    | 35.54   | 19.52   |
| **Totals** | **100.00** |        |

4. Conclusions

Aluminum based composite coating is deposited through plasma spraying bears the hardness of 7-13HB. With sea water treatment, weight gain of the samples is observed. The rate of increase in wt. is very rapid up to six weeks and then takes a linear trend. There a change in surface morphology of the coating after corroded in sea water. Deposition of Ca and Cl is observed on the surface of the sea water treatment.

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