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# Metallurgical Analysis of Rainbow Rotor Coatings: Analysis of Fleet Blades

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## ABSTRACT

In a continuing effort to increase component lifespan and decrease overhaul cost, the US Navy has completed a 2nd phase of the Rainbow Rotor project. This project, initiated in the early 1990's, consists of three LM2500 main propulsion engine, high pressure turbines (HPT) built up with refurbished blade pairs protected by various coatings. This turbine was operated for over 7,000 hours on a Cruiser-class ship where it was subjected to a typical operating profile. Six coatings were examined ranging from differing chemical compositions to application processes. The coating compositions were of four types, CoCrAlHf, PtAl, Physical Vapor Deposition (PVD) Zirconia thermal barrier coating (TBC) with a PtAl bond coat and a silicon aluminide type coating. The BC-22 (CoCrAlHf) overlay coatings were applied by either a plasma spray process or an electroplating process. The PtAl coatings, supplied by two vendors, and the TBC were applied by standard commercial processes. The goal behind this study is to find a coating that has the best balance between cost and performance. With the already realized cost savings in using refurbished components to overhaul the gas turbine engine, the emphasis is now placed on delaying the deterioration of the reprocessed blade pairs. The following discussion covers all aspects of this completed phase.

## INTRODUCTION

It is understood that the hot section of the General Electric (GE) LM2500 gas turbine engine is susceptible to type-1 and type-2 corrosion degradation due to the extreme environment the components are subjected to. The life span of the engine is limited by the failure of any major component. During the earlier times of the US Navy gas turbine program, any time a gas generator was removed from service the high pressure turbine blades were replaced with new blade pairs because these blades were thought to be the life limiting components of the LM2500. This action was mainly due to lack of experience with gas turbine degradation in the marine environment (Driscoll, et al. 1996). In order to expand the life expectancy of the high pressure turbine rotor, the blades (composition - Rene 80; cast air cooled) are now coated with various coatings to withstand the temperatures that sometimes exceed 1088 K (1500 ºF) leaving the combustor.

In the mid-1990's, the US Navy established that there is a significant amount of money that can be saved if high pressure turbine blades used in overhauled GE LM2500 gas turbine engines, are refurbished as opposed to purchasing new blades. When the blades are refurbished, they are stripped of any original coating left on the blade surface, the tips built up by welding so they are within specified limits, and the airfoil is recoated before being placed back into service. Platinum aluminide (PtAl) was a coating originally suggested by a blade refurbishment company since it was a standard used on industrial LM2500 engines. This coating has been selected as the standard coating when refurbishing the blades after the first Rainbow Rotor analysis. (Driscoll et al. 2002). Essentially this set of HPT blades represents the second data point for this ongoing analysis between refurbishment cost and coating performance. This particular rotor differs in several aspects from the first rotor tested in the Australian Navy ship HMAS DARWIN (FFG-44), a frigate of the US Navy FFG-7 class. One difference is the type and number of coatings used on the blades. The rotor used on the HMAS DARWIN had two types of coatings on refurbished blades and one coating that is used on new blades. This second rotor used all refurbished blades with various coatings and differing application processes. Details of the various coatings tested on this rotor are given by Nagaraj et al. 1995 and Driscoll et al. 1996. Another difference between these two data points is the platform on which they were tested. The first rotor was removed from an engine used aboard the Oliver Hazard Perry Class Frigate (FFG-7) which was rated at 20,500 horsepower while the second rotor was removed from an engine used on Ticonderoga class cruiser (CG-47) which are rated at 21,500 horsepower. However, this difference in operating environment should not be enough to discount the comparison between these two data points since the time that each ship spends at full power is very minimal. Since Cruisers have better filtration systems than Frigates as well as a higher intake above the waterline, therefore, you would expect to see slightly more corrosion on the Australian rainbow rotor than on the cruiser parts. Another difference between these two rotors is the accumulated hours that each high pressure turbine experienced. The Australian rotor was removed from service after accumulating over 11,000 hours while the latest rotor, removed from USS BUNKER HILL, CG-52, only had a little over 7,000 hours.

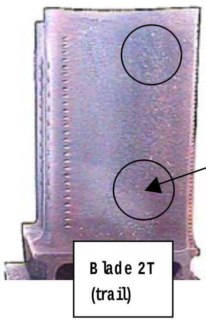
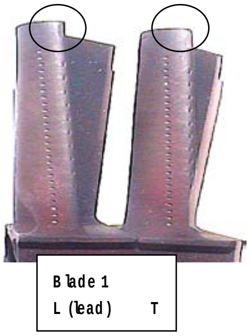
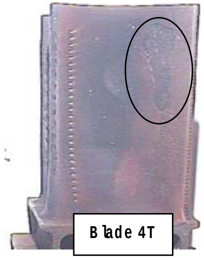
This last difference was perhaps the largest influence on the course of action while moving through this analysis. The engine from the USS BUNKER HILL was removed from the ship due to problems not related to the high pressure turbine. With respect to the HPT components, this removal was premature in regards to the expected life span. For this reason, it was proposed that after a visual inspection, suitable blades would be reinstalled into an overhauled HPT in order to accumulate more operating hours on the coatings being tested. The criteria used during this inspection is shown in Table 1 with the results of that inspection shown in Table 2 for the first stage blades (all second stage blades fell under the "None" classification). Table 3 shows the latest distribution of the blades for metallurgical evaluation after the visual inspection. Approximately 43% of the first stage blade pairs were reinstalled and 94% of the second stage blades were reinstalled.

**TABLE 1 –INSPECTION CRITERIA**

| **Classification** | **Description** |
|---|---|
| None | No obvious damage |
| Minor | Surface roughening only, no coating loss, no oxides |
| Moderate 1 (M1) | Small localized areas of light coating loss – some brownish oxides visible |
| Moderate 2 (M2) | Light coating loss similar to M1 but in narrow bands generally confined to surface between the nose holes (less than 3 mm wide) - some brownish oxides visible |
| Heavy 1 (H1) | More extensive coating loss in wider band up to about 3-1/2 mm wide extending beyond edge of nose holes – some loss of base metal – some greenish oxides visible |
| Heavy 2 (H2) | More extensive coating and base metal loss and oxides than H1 in wider band up to 4 mm |

A representative sample of each type of coating was kept from reinstallation and used for a destructive metallurgical evaluation. As shown in Table 3, 4 separate parties analyzed the blades with the results being reviewed by NSWC metallurgist in order to obtain an unbiased outlook on the coating performance.

# TABLE 2- RESULTS OF VISUAL INSPECTION OF FIRST STAGE BLADES

| COATING | TOTAL NUMBER ON ROTOR | Visual Classification | THUMBPRINT AREA A (airfoil top) | THUMBPRINT AREA B (airfoil bottom) | LEADING EDGE Area A (from 1/2" above platform to tip) | LEADING EDGE Area B (from platform to 1/2" above platform) |
|---|---|---|---|---|---|---|
| GE-PtAl | 29 | **M1** | Light roughening only. All airfoils examined.<br><br> | Same as Area A | Slight spalling near tip.<br><br> | No damage |
| Chromalloy-PtAl | 12 | **M1** | Similar to GE PtAl |  | Similar to GE PtAl | No damage |
| GE-PBC22 | 28 | **Minor to None** | Minor damage. 1 of 6 airfoils examined<br><br> | No damage | No damage | No damage |
| GE-BAJBC22 | 14 | **Minor to None** | No damage | No damage | No damage | No damage |
| Sermalloy J | 12 | **Minor to None** | No damage | No damage | No damage | No damage |
| Howmet PtAl + GE TBC | 17 | **M2** | More extensive damage than the other coatings. Majority of airfoils examined<br><br> | No damage | No damage | Spalling<br> |

# TABLE 3 – DISTRIBUTION OF HPT BLADES REMOVED FROM GGA-219

🟨 Sent To GE

🟦 Sent To JJMA

▨ Blades Reinstalled

🟧 Sent to Sermatech

🟩 Not Analyzed

🟦 Sent to Chromalloy

| **First Stage** | | | | | **Second Stage** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Blade** | **Coating** | **Position** | **Distribute To:** | **Comments** | **Blade** | **Coating** | **Position** | **Distribute To:** | **Comments** |
| C4 | Chromalloy PtAl | 8 | General Electric | | CC5 | Chromalloy PtAl | 12 | | |
| C1 | Chromalloy PtAl | 17 | JJMA | | CC1 | Chromalloy PtAl | 15 | | |
| C2 | Chromalloy PtAl | 24 | General Electric | 1st Distribution | CC4 | Chromalloy PtAl | 19 | | |
| C9 | Chromalloy PtAl | 37 | Chromalloy | | CC3 | Chromalloy PtAl | 27 | | |
| C3 | Chromalloy PtAl | 43 | Chromalloy | | CC2 | Chromalloy PtAl | 42 | | |
| C6 | Chromalloy PtAl | 51 | JJMA | | CC6 | Chromalloy PtAl | 56 | General Electric | 1st Distribution |
| B9 | GE BAJ BC-22 | **5** | | | BB7 | GE BAJ BC-22 | 2 | | |
| B1 | GE BAJ BC-22 | **12** | General Electric | 1st Distribution | BB4 | GE BAJ BC-22 | 5 | | |
| B7 | GE BAJ BC-22 | 19 | | | BB2 | GE BAJ BC-22 | 20 | | |
| B6 | GE BAJ BC-22 | **33** | | | BB6 | GE BAJ BC-22 | 30 | | |
| B2 | GE BAJ BC-22 | 41 | | | BB3 | GE BAJ BC-22 | 35 | | |
| B5 | GE BAJ BC-22 | **45** | | | BB5 | GE BAJ BC-22 | 45 | General Electric | 1st Distribution |
| B3 | GE BAJ BC-22 | 49 | | | BB1 | GE BAJ BC-22 | 48 | | |
| P18 | GE PBC-22 | **6** | | | PP4 | GE PBC-22 | 3 | | |
| P14 | GE PBC-22 | **7** | | Worst Case Example | PP14 | GE PBC-22 | 6 | | |
| P6 | GE PBC-22 | 10 | | | PP9 | GE PBC-22 | 7 | | |
| P4 | GE PBC-22 | **11** | | Worst Case Example | PP1 | GE PBC-22 | 8 | | |
| P10 | GE PBC-22 | 20 | | | PP2 | GE PBC-22 | 14 | | |
| P3 | GE PBC-22 | 22 | | | PP8 | GE PBC-22 | 16 | | |
| P7 | GE PBC-22 | 23 | General Electric | 1st Distribution | PP11 | GE PBC-22 | 18 | General Electric | 1st Distribution |
| P12 | GE PBC-22 | 31 | | | PP10 | GE PBC-22 | 31 | | |
| P2 | GE PBC-22 | 34 | | | PP12 | GE PBC-22 | 33 | | |
| P13 | GE PBC-22 | 35 | | | PP5 | GE PBC-22 | 34 | | |
| P8 | GE PBC-22 | **36** | | Worst Case Example | PP6 | GE PBC-22 | 46 | | |
| P1 | GE PBC-22 | 46 | | | PP7 | GE PBC-22 | 47 | | |
| P5 | GE PBC-22 | 48 | | | PP13 | GE PBC-22 | 49 | | |
| P11 | GE PBC-22 | 50 | | | PP3 | GE PBC-22 | 58 | | |
| A1 | Ge PtAl | 1 | | | AA1 | Ge PtAl | 1 | | |
| A66 | Ge PtAl | 2 | JJMA | | AA11 | Ge PtAl | 9 | | |
| A7 | Ge PtAl | 13 | | | AA17 | Ge PtAl | 13 | | |
| A10 | Ge PtAl | 14 | | | AA16 | Ge PtAl | 22 | | |
| A5 | Ge PtAl | **15** | General Electric | | AA9 | Ge PtAl | 26 | | |
| A8 | Ge PtAl | **18** | General Electric | 1st Distribution | AA6 | Ge PtAl | 28 | | |
| A2 | Ge PtAl | **25** | JJMA | | AA3 | Ge PtAl | 29 | General Electric | 1st Distribution |
| A4 | Ge PtAl | **28** | General Electric | | AA2 | Ge PtAl | 36 | | |
| A12 | Ge PtAl | 29 | JJMA | | AA15 | Ge PtAl | 37 | | |
| A9 | Ge PtAl | 39 | | | AA10 | Ge PtAl | 41 | | |
| A6 | Ge PtAl | 40 | | | AA5 | Ge PtAl | 43 | | |
| A21 | Ge PtAl | 42 | JJMA | | AA4 | Ge PtAl | 50 | | |
| A34 | Ge PtAl | 47 | | | AA14 | Ge PtAl | 52 | | |
| A3 | Ge PtAl | **53** | General Electric | | AA7 | Ge PtAl | 55 | | |
| T1 | GE TBC | 3 | JJMA | | AA8 | Ge PtAl | 57 | | |
| T4 | GE TBC | 4 | JJMA | | TT1 | GE TBC | **10** | | |
| T13 | GE TBC | **9** | General Electric | | TT8 | GE TBC | **11** | | |
| T14 | GE TBC | **30** | | | TT3 | GE TBC | **23** | | No Coating Penetration |
| T3 | GE TBC | 32 | JJMA | | TT2 | GE TBC | **24** | | |
| T9 | GE TBC | 44 | General Electric | 1st Distribution | TT10 | GE TBC | 25 | | |
| T7 | GE TBC | 52 | General Electric | | TT9 | GE TBC | **38** | General Electric | 1st Distribution |
| J1 | Semaloy J | 16 | | | TT4 | GE TBC | 39 | | |
| J7 | Semaloy J | 21 | General Electric | 1st Distribution | TT5 | GE TBC | **40** | | |
| J2 | Semaloy J | 26 | | | TT16 | GE TBC | **53** | | |
| J10 * | Semaloy J | 27 | | | TT6 | GE TBC | 54 | | |
| J4 | Semaloy J | 38 | Sermatech | 1st Distribution | JJ3 ** | Semaloy J | **4** | | |
| J3 | Semaloy J | 54 | | | JJ2 | Semaloy J | **17** | | |
| | | | | | JJ6 | Semaloy J | 21 | Sermatech | 1st Distribution |
| | | | | | JJ1 | Semaloy J | 32 | | |
| | | | | | JJ4 | Semaloy J | 44 | | |
| | | | | | JJ5 | Semaloy J | 51 | General Electric | |

## COATING DESCRIPTION & PERFORMANCE

### PLASMA BC-22 (PBC-22)

This coating, CoCrAlHf, is a production standard coating for new LM2500 blades and is applied by a Low Pressure Plasma Spray Process (LPPS) and is carried out in a vacuum chamber backfilled with an inert gas (Katz, 2003). It is also similar to the BC-23 previously used on new HPT blades with the exception of the platinum layer present on the BC-23. The PBC-22 coating is applied to the blade using a plasma spray gun and can be as thick as required by the blade design. A gas phase aluminide-hafnium treatment increases the surface content of aluminum as well as coats the internal cooling passages. Hafnium present in the make up of the coating plays an important role by forming intermetallic compounds to lock an oxide layer to the metal. BC-22 can also be applied by a two step Electron Beam Physical Vapor Deposition (EB-PVD) of CoCrAl/pack cementation of aluminum and hafnium process which has been dropped for economic reasons. One disadvantage of this particular coating is that the blade pair must be coated separately and bonded after the coating process, which therefore adds to refurbishment time and overall cost.

During the initial visual inspection of this coating it appeared to be one of the better performers of this rotor. On the first stage blades, there appeared to be no signs of substrate penetration with minor corrosion visible on the concave surface. It was decided that the majority of the blades with this coating would be reinstalled because of the general performance. Figure 1 is a representation of the appearance of the blades.

During the metallurgical evaluation, the sample blade pair analyzed showed evidence of base metal attack with the worst areas being seen on the concave side at the 80% span near the trailing edge. The documented amount of base metal attack was 50.8 μm to 76.2 μm for the one blade examined. It is believed that the blade pair used during the analysis might have not been a true representation of all blades with that type of coating based on the results and classification of the original visual inspection. This substrate attack appeared only in very localized areas (Nagaraj, 2003).

**Figure 1: Typical PBC-22 Coated 1st Stage HPT Blade After 7,192 Hours**

### COMPOSITE BAJ BC-22

The composition of the BAJ BC-22 is almost identical to the PBC-22 (CoCrAlHf), differing primarily in the process used to apply the coating. The Bristol Aero Jet (BAJ) company developed this electroplating process for applying composite coatings. The developmental rights to this coating process have been purchased by Praxair Surface Technologies, Inc. and are being marketed as their Tribomet family of coatings. For this particular coating, the component is plated in a cobalt bath with a suspension of CrAlHf particles. After the plating is complete, the parts are given a diffusion heat treatment. One of the advantages of this process is that the airfoils can be coated in pairs vice performing the work needed to separate the doublets, coat each airfoil independently and finally reattach the pair. Another advantage is a low capital cost and operating cost versus the EB-PVD or LPPS processes. When using this electroplating process the composition and thickness profile can be tailored as needed and this process has a better coating transfer efficiency than other processes.

As the visual inspection results indicate, this coating was classified as having no coating damage. In this rotor, this coating was one of the most effective coatings in protecting the blades from corrosion. During the metallurgical evaluation it was found that there was no substrate attack on the lead or trailing airfoil and the corrosion seen on the convex and concave surfaces of the blades still had about 50.8 µm of coating remaining on the substrate (Nagaraj, 2003). The composite plated BC-22 coating was previously evaluated in an Industrial LM2500 Rainbow rotor. That evaluation was in a predominantly oxidizing environment and the performance of the composite plated coating was equal to or better than that of plasma sprayed BC-22 coating (Nagaraj et al., 1995).

Figure 2 represents a typical blade with the BAJ BC-22 Coating.

**Figure 2: Typical BAJ BC-22 Coated 1st Stage Blade After 7,192 Hours**

CHROMALLOY PLATINUM ALUMINIDE

This diffusion coating is applied by pack cementation or a gas phase process. The surface layer of this coating contains 20% to 30% platinum which improves the coating performance. One limiting factor of aluminide coatings is that they are typically held to a thickness of 51-76 µm.

The blades with this coating were classified as M1 with spalling present on the leading edge near the tip of the concave surface. The scanning electron microscopy (SEM) report shown below, Nagaraj, 2003, prior to destructive testing indicated that there was no platinum present in the spalled areas. Due to the visual classification and the SEM report, it was determined that none of the Chromalloy PtAl coated blades would be reinstalled.

Since none of the blades would be reinstalled, they were distributed to Chromalloy Nevada, General Electric Aircraft Engines, and John J. McMullen Associates, Inc. for destructive analysis.

The metallurgical evaluation yielded results indicating that the corroded/eroded regions were missing base material on the concave surface ranging from 35.6 µm to 88.9 µm deep (Mocaby, 2003 and Rampolla, 2003). The areas of corrosion appeared to be worst at the 80% span near the trailing edge. There were also coating cracks present on the convex side of the blade.

HOWMET (GE) PLATINUM ALUMINIDE

The composition of this coating is identical to the Chromalloy PtAl, differing only by manufacturer. The performance of the coating was also very similar to the other tested PtAl. Again, this PtAl was classified originally in the M1 category and from learning of the results from the provided SEM report, shown in Figure 4, the blades with this coating were kept from reinstallation.

Metallurgical analysis by two different parties indicated corrosion present on both the concave side and leading edge with the heaviest degradation seen on the 80% span near the trailing edge on the concave surface. In general, substrate attacks were seen at all spans near the trailing edge on the concave side. There were also coating cracks found on the convex side of the airfoil. Maximum penetration into the substrate was 98.0 µm.

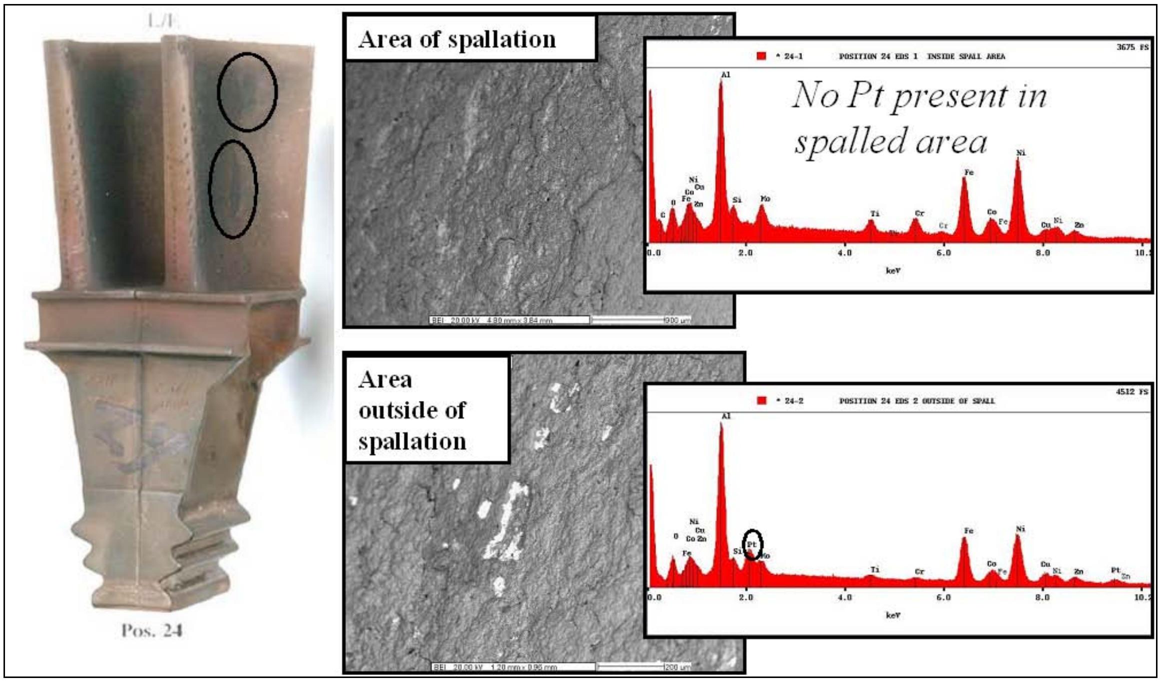


Figure 3: Results of SEM Report for Chromalloy PtAl Coating (Nagaraj, 2003)

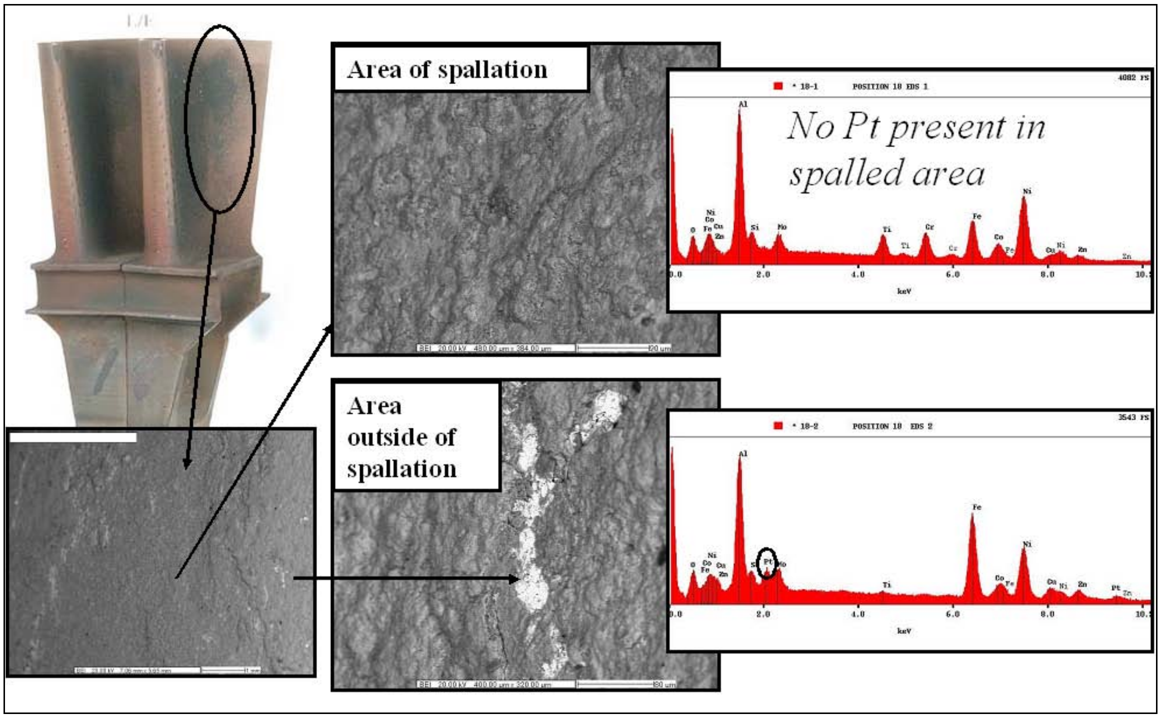


Figure 4: Results of SEM Report for Howmet PtAl Coating (Nagaraj, 2003)

## THERMAL BARRIER COATING

This is a coating produced by General Electric consisting of a bottom layer of Howmet Platinum Aluminide applied by a diffusion process and a top layer of 8% Yttrium-stabilized Zirconia Thermal Barrier Coating (TBC) applied by an EB-PVD process. By utilizing this coating on the HPT blades, the theory is that the engine will be able to run with higher firing temperatures.

This was the only coating that was visually categorized in the M2 category and had the most visible spallation present. Figure 6 shows a typical TBC coated first stage HPT blade.

Metallurgical analysis reveals that at the 80% span there were areas of TBC spalling with base metal attack ranging from 20.3 to 76.2 µm. At the 20% span however, there was no spalling or base metal attack.

**Figure 6: Typical TBC Coated 1st Stage Blade After 7,192 Hours**

## SERMALOY J

SermaLoy J is an intermetallic nickel aluminide, similar to the General Electric Codeposition diffusion coating (CODEP) and platinum aluminide; however, this composition has been modified with silicon. Just as additions of platinum had been shown to improve durability of the alumina scale, adding silica had also been demonstrated to improve the hot corrosion resistance of β-NiAl. The SermaLoy J coating contains about 10% silicon by weight. This coating has been shown to uniquely resist both Type-1 and Type-2 hot corrosion on nickel and cobalt base alloys. A uniform layer of the slurry is applied to the doublet and head treated. As the SermaLoy J aluminide forms by inward diffusion, aluminum selectively reacts with nickel in the substrate, forming β-NiAl. The silicon in the slurry segregates to chromium from the alloy to form chromium disilicide ($CrSi_2$). Since the last of the aluminide forms by isothermal solidification as the concentration of Ni and Cr increase within the molten slurry, the outer third of the SermaLoy coating is comprised of alternating layers of β-NiAl and $CrSi_2$. (McMordie 2003). SermaLoy J had been included in this test because of its successful use by the Royal Navy and Rolls Royce in their marine gas turbine engines.

On average, more than 61 µm of SermaLoy J remained on the first stage airfoil surface (88.9 to 114.3 µm was the original coating thickness). The most damage to this blade was seen on the 80% span near the trailing edge of the blade. Hot corrosion appeared to have consumed approximately 5 µm of the aluminide on the leading edge of the sectioned airfoil however there were no deep corrosion pits found around the perimeter of this surface (McMordie, 2003). Some coating cracks could also be seen around this same effected area (Nagaraj, 2003). Figure 7 represents a typical stage 1 HPT blade that was coated with SermaLoy J.

**Figure 7: Typical Sermaloy J Coated 1st Stage Blade After 7,192 Hours**

## COATING PERFORMANCE COMPARISION

Since this is the second rainbow rotor that the US Navy has analyzed, two types of comparisons can be made. One comparison is between the coating performance on the Australian rainbow rotor and this most recent rotor and the second is between the coatings unique to this rotor.

The first engine, on HMAS DARWIN, had a borescope inspection performed, after accumulating 8,689 hours while the most recent engine had 7,192 hours when it was removed from service. Since these two periods are similar, relative to the coating's life span, they will be used for the comparison. In general, it appeared that the coatings gave comparable performances. The Chromalloy PtAl refurbished blades had performed worse in both engines although the performance in the Australian engine seemed better than in the USN engine. Based upon the results of the first rainbow rotor, a statistical analysis placed an expected coating life for PtAl at approximately 12,000 hours of operation where a standard deviation of 1,000 hours produced a 3-sigma lower boundary of 9,000 hours (Driscoll, 2002). This life expectancy was based on the estimation that the coating exceeded maximum serviceable limits at around 10,000 hours and the Navy acceptance criteria would permit the blades to run for an additional 1,800 hours once the exceeded condition was identified. Table 4 represents the coating life values table developed from the first rainbow rotor results. Although the PtAl blades from the USN engine did not perform as well as those from the Australian engine, it is roughly estimated that the blades would fall within the lower boundary predicted for this coating.

| Coating | Expected Average Coating (HRS) | Expected Coating Life Standard Deviation(HRS) | 3 Sigma Range 99% of Data(HRS) | |
|---|---|---|---|---|
| PtAl | 12,000 | 1,000 | 9,000 | 15,000 |

**Table 4: PtAl Life Expectancy Analysis (Driscoll, 2002)**

Typical PtAl coated blades from both engines are shown in Figure 8 and typical overlay coated blades are shown in Figure 9.

The Australian engine contained refurbished blades with BC-21 coating (CoCrAlY) and a three-step BC-23 coating (CoCrAlHfPt) on new blades while the recent subject engine contained PBC-22 (CoCrAlHf) coating. The BC-22 and BC-23 coatings are considered nearly equivalent, with the BC-23 possibly slightly better; however, not enough to justify the cost differential. It should be noted that the performance of BC-23 is documented on new blades while the results of BC-22 in this rotor were on refurbished blades and as previously noted, the BAJ BC-22 still had approximately 50 µm of coating left on the surface of the airfoil. BC-21 is considered to be less effective than either of the two Hafnium containing coatings (BC-22 / BC-23) and the PtAl coatings are even less effective. The appearances of the three coatings in these two engine tests support this ranking of the overlay coatings.

When considering coating performance as a function of substrate attack alone, a simple bar graph can illustrate the overall effectiveness of each coating used in this test. Figure 10 represents a comparison of substrate attack for each coating after 7,192 hours of operation.

**Figure 8: Typical Stage 1 PtAl Coated Blade After 8,689 (left) and 7,192 (right) Hours of Operation**

**Figure 9: Typical Stage 1 BC-23 Coated Blade After 8,689 Hours (HMAS DARWIN (left) and BC-22 after 7,192 (right) Hours of Operation (CG-52)**

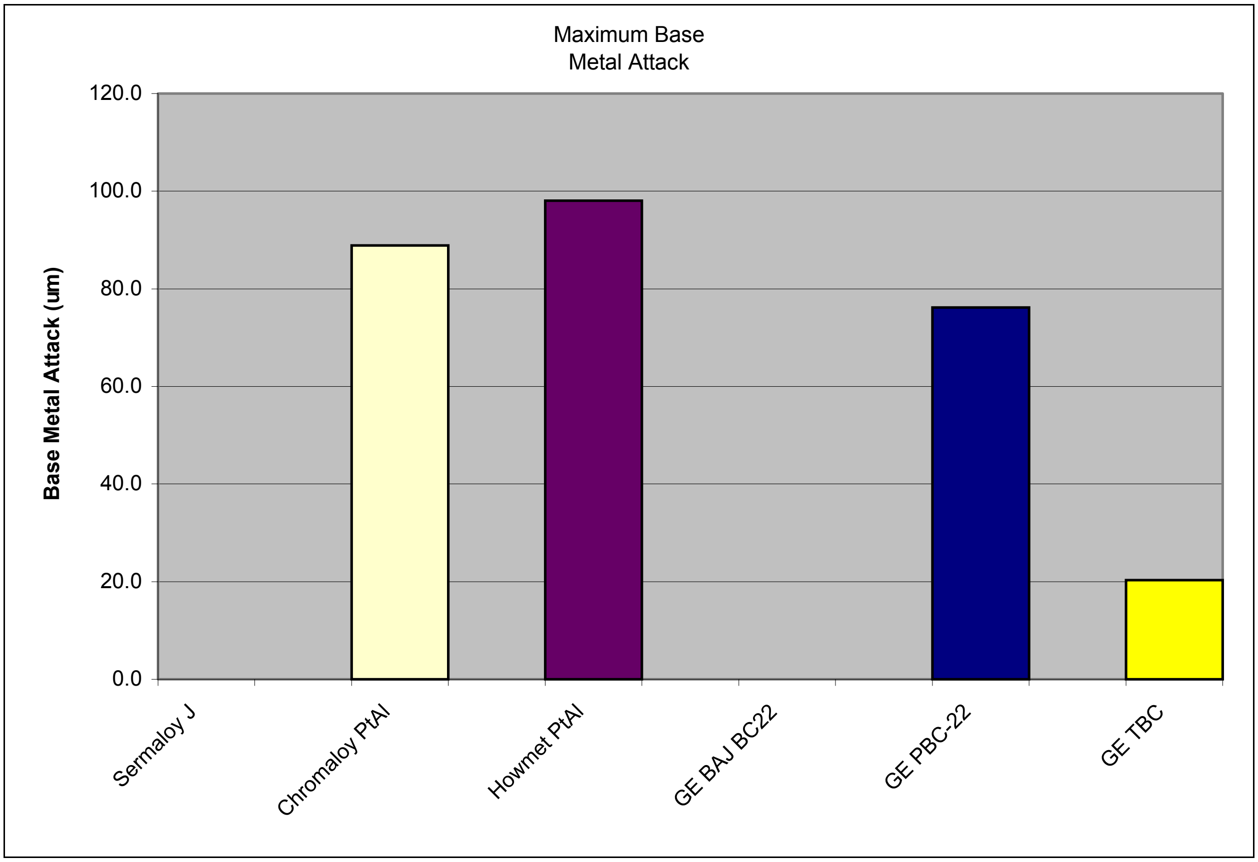


**Figure 10: Representation Of Depth Of Substrate Attack For Each Coating**

## CONCLUSIONS

The rainbow rotor test in a Fleet LM2500 engine demonstrated that several of the test coatings performed well. Some of the conclusions apply only to one stage of the turbine while others can be applied to both stages. The conclusions of this engine test included the following:

- The corrosion of stage 1 blades was more severe than that of the stage 2 blades.
- All the coatings performed adequately on stage 2 blades. Because no substrate attack was observed on the stage 2 blades, the use of a lower cost coating, such as PtAl or the Composite BC-22, should be considered for use.
- Composite plated (BAJ) BC-22 and SermaLoy J coatings performed the best on stage 1 blades with no corrosion of the substrate. The degradation of the SermaLoy J coated blades was no worse than the CoCrAlHf (PBC-22) standard coating. Additional at sea testing would be required before any Fleet usage of the silicon modified aluminide coating would be recommended or considered.
- Substrate attack was observed on all the platinum aluminide coated stage 1 blades and in localized areas of plasma sprayed BC-22 coated blades.
- The PVD TBC provided low temperature corrosion protection, at 25% span and on the stage 2 blades. The TBC did not protect the blades from high temperature corrosion. At the 80% span, salt deposits penetrated the TBC, caused the TBC to spall and attacked the underlying platinum aluminide bond coat.
- Additional evaluations should be done after the blades from this engine that were returned to service and the second US Navy rainbow rotor, GGA-150, are removed from service.

## ACKNOWLEDGEMENTS

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