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CONDITION MONITORING OF HEAVY DUTY GAS TURBINE STATIONARY AND ROTARY BLADES

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ABSTRACT

Remaining lives of third and fourth (last) stage vanes and blades of a heavy duty gas turbine were evaluated by using condition monitoring techniques. The components had been in operation for over 100,000 hours in base load condition and has not been rejuvenated or repaired. The evaluation, including destructive and non-destructive testing, was carried out in order to consider the applicability of these components to operate for an extra 25,000 hours period.

Keywords: gas turbine, blade life, condition assessment

INTRODUCTION

Blade and vane of gas turbines are subjected to degradation during service by the combined effects of high temperature, mechanical stresses, and environmental aggressive conditions. Many time dependent degradation mechanisms such as creep, fatigue, erosion, corrosion act in combination (Viswanathan, 1984). The parts are, therefore, designed for a finite life. In order to avoid premature failures, margins of safety are provided and the service exposed blades and vanes are recommended for replacement at fixed intervals. Adding safety margins into the calculation of design life result in the components recommended for replacement while large percentage of their life still remaining.

In this paper residual life of third and fourth stage stationary and rotary blades of a heavy duty gas turbine were evaluated using condition assessment techniques. The blades and vanes had been in service for over 100,000 EOH in base load and has not been rejuvenated or repaired. The blades and vanes were made of four different Ni based superalloys: IN738LC, IN939, Udimet520 and Nimonic90. The evaluation was carried out in order to consider the applicability of these blades and vanes for an extra 25000 EOH. Condition assessment of the selected blades and vanes was carried out by using the techniques comprising visual inspection, radiography, Eddy-Current testing, replication and destructive evaluations. Destructive testing included the evaluation of the microstructure, hardness, tensile and stress-rupture properties. Testing of each blade and vane were carried out and judged according to the materials specifications.

EXPERIMENTAL

The experimental procedure comprised both non-destructive and destructive evaluations. Non-destructive evaluations were applied on the five blades of each stage that were chosen because of their worst appearance. Rotary blades roots were inspected by Eddy Current

Testing method. In addition, Flouresent Penetrant Inspection (FPI) method and X-ray radiography were used to detect probable surface and volume cracks, respectively.

Moreover, replication and hardness testing using a portable hardness tester from a similar location on airfoils were carried out to select one blade of each stage for destructive evaluations.

Destructive evaluations comprised metallographic examinations and mechanical testing. Metallographic examination was made on specimens from three sections of airfoils and one from the roots by means of optical and scanning electron microscopes.

Additionally, room temperature tensile, hot tensile and stress-rupture tests were carried out according to DIN EN2002-1, EN2002-2 and ASTM E139, respectively. Mechanical test conditions have been selected according to alloy specifications.

RESULTS

NON-DESTRUCTIVE EVALUATIONS

All the blades and vanes were visually investigated in order to select five components with the most severe condition from each stage. For visualization part, FOD and erosion marks were considered. Then, NDE methods were utilized for final selection.

- **FPI, Eddy Current Testing and Radiography**

Fluorescent penetrant inspection (FPI) revealed some pits on the mid-span and fillet of four 3rd stage vanes, and also some FOD marks on airfoil of a 4th stage vane. Eddy current testing of the blades fir-tree, X-ray and γ-ray radiography of the bulk material of blades and vanes were done, which revealed no problem in the evaluated components.

- **Replication**

Replication was taken from the selected blades; although, third stage rotary blades were not considered because of the coating which had been applied on the airfoils. Fig.1 shows typical SEM images of one blade from each turbine stage. In all the three alloys, dissolution of fine gamma prime precipitates and coarsening of primary precipitates were observed. In addition, replica images displayed continuous carbide layers along grain boundaries in IN738LC and an unknown coarse phase located along grain boundaries in IN939.

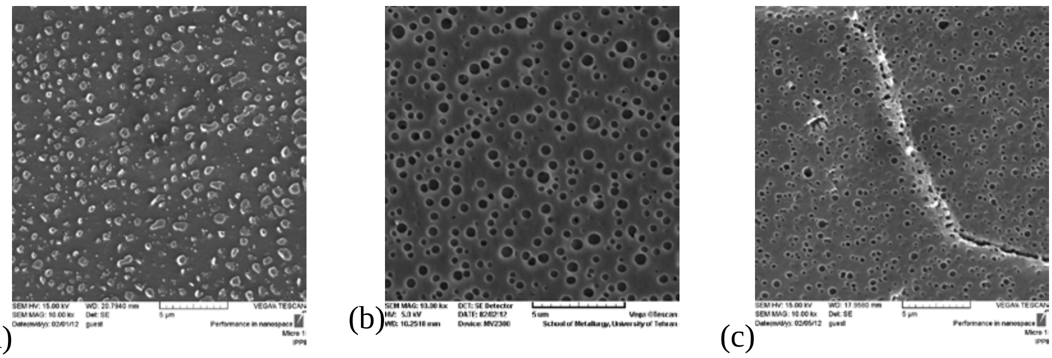

(a) (b) (c)

Fig.1 Typical replica SEM image of (a) 3rd stage vane made of IN738LC, (b) 4th stage vane made of IN939, (c) 4th stage blade made of Nimonic90

- **Hardness Testing**

Hardness testing were carried out by means of a portable hardness tester on three points of each component and an average value were reported (Table 1). It should be mentioned that 3rd stage blades were not considered because of coating.

Table 1 Vickers hardness of all blades and vanes

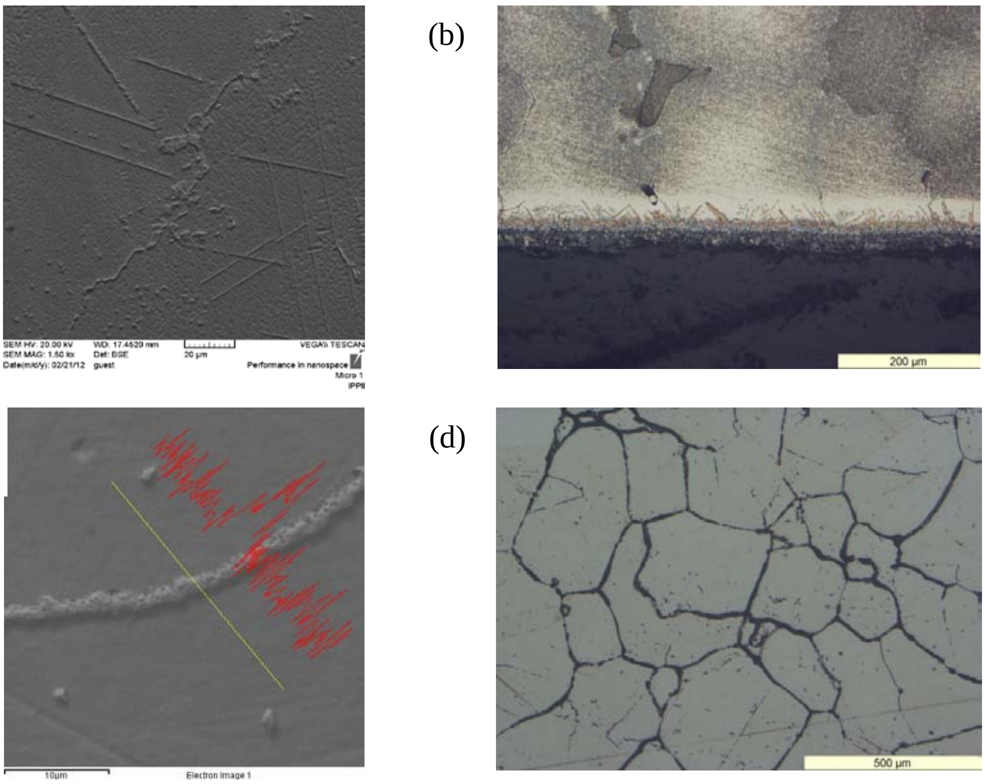
No.	**1**	**2**	**3**	**4**	**5**
Vane 3	302	302	288	306	281
Blade 4	326	322	326	329	327
Vane 4	418	405	389	410	386

DESTRUCTIVE EVALUATIONS

- **Microstructure Evaluation**

Microstructural changes due to long-term operation were investigated for one selected component from each turbine stage. In all cases, the mid-height sections had the most severe microstructural degradation.

(a) (b) (c) (d)



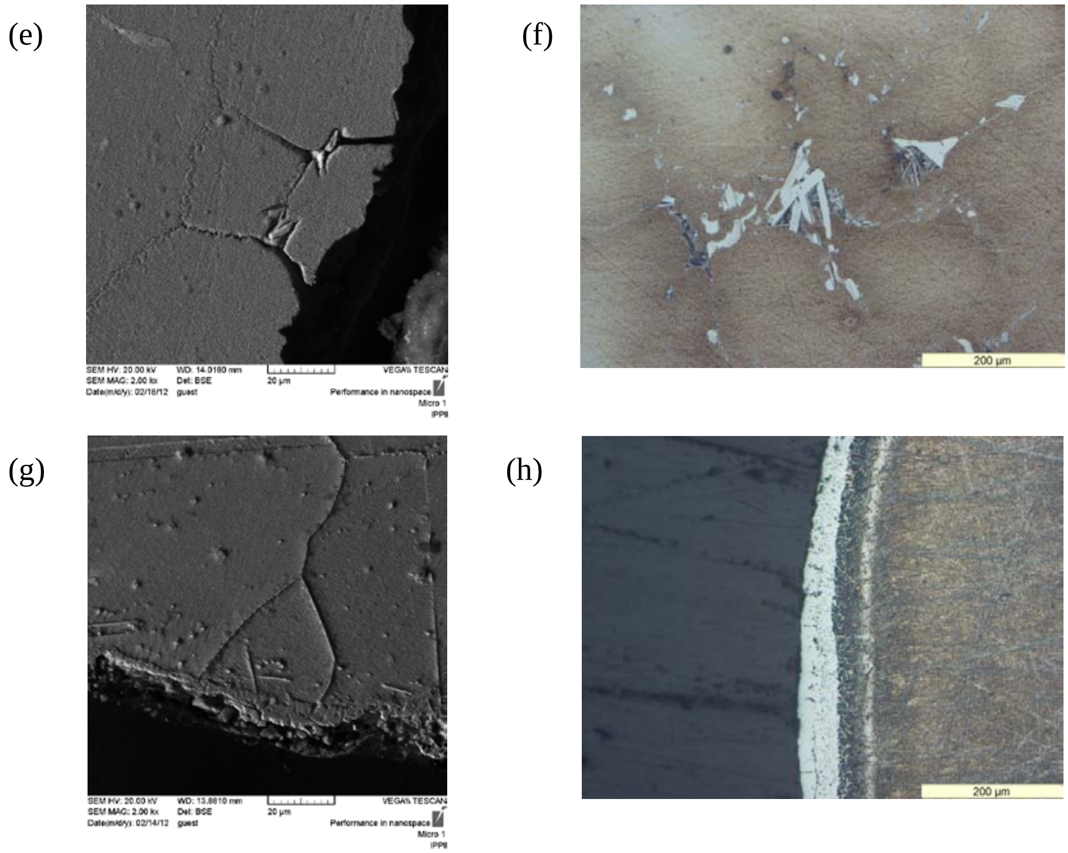


Fig .2 Microstructural degradation in blades: (a, b) 3rd vane made of IN738LC, (c, d) 3rd blade made of Udimet520, (e, f) 4th vane made of IN939, (g, h) 4th blade made of Nimonic90

IN738LC vane had revealed large amount of needle-like TCP phase as well as thick layers of continuous carbides along grain boundaries (Fig. 2a). Furthermore, a 50 microns surface oxide layer was detected on external and internal surfaces of all three airfoil sections, under which needle-like nitride precipitates has been formed (Fig. 2b).

The microstructure of Udimet520 blade showed formation of continuous networks of grain boundary carbides (Figs. 2c & 2d). EDS analysis revealed high Cr content in such carbides which is characteristic of $M_{23}C_6$ carbides (Fig. 2c).

IN939 vane likewise showed continuous grain boundary carbides at hot regions as well as some white-colored plate-like TCP phases which were rich in Ti, Ta and Cr (Fig. 2f). Formation of these phases along grain boundaries had made the material so brittle that crack nucleation could easily occur (Fig. 2e).

The microstructure of the Nimonic90 blade, especially at mid-span section, included continuous carbide layers and a thick oxide layer. Additionally, needle-like TCP phases were observed at hot regions near the surface (Figs 2g & 2h).

- **Mechanical Properties**

Mechanical tests comprising environmental and hot tensile in addition to stress-rupture tests were applied on specimens from both high and low temperature location of the blades and vanes.

Tensile tests revealed that strength of airfoil for all cases has been slightly increased; however, ductility had a remarkable reduction (Table 2). As it was mentioned in pervious section, component microstructures has been changed in a way that the amount of brittle phases i.e. TCP phases and $M_{23}C_6$ were increased which was consistent with reduced ductility in tensile testing.

Table 2 Tensile test results for selected blades and vanes in room and high temperature conditions

		Room Temperature			**High Temperature**			
		Yield Strength (MPa)	**Ultimate Tensile Strength (MPa)**	**Elongation, %**	**T, °C**	**Yield Strength (MPa)**	**Ultimate Tensile Strength (MPa)**	**Elongation, %**
Blade 3 (Udimet520)	**Airfoil**	820	1108	10.2	700	1104	806	22.5
	Root	838	1101	17.1	700	955	644	33
Vane 3 (IN738LC)	**Airfoil**	793	815	1.4	760	789	906	2
	Shroud	755	804	3.9	760	873	929	5.5
Blade 4 (Nimonic90)	**Airfoil**	929	1236	15.3	600	709	1112	12.1
	Root	911	1184	27	600	782	1058	19.6
Vane 4 (IN939)	**Airfoil**	917	954	3	600	882	972	3.1
	Shroud	745	899	7	600	671	990	5.5

Stress-rupture tests were carried out on specimens from airfoils according to table 3. The results showed that creep life and elongation were acceptable in comparison to each alloy specification.

Table 3 Stress-Rupture test results for selected blades and vanes

	T, °C	**Stress (MPa)**	**Creep life (hr)**	**Elongation, %**
Blade 3 (Udimet520)	802	345	128	9.4
Vane 3 (IN738LC)	760	590	37	7
Blade 4 (Nimonic90)	870	150	122.5	4.5
Vane 4 (IN939)	870	255	203	14.5

CONCLUSION

Condition assessment of 3rd and 4th stage blades and vanes which had been operated for more than 100,000 EOH was carried out. Non-destructive evaluation did not reveal any remarkable problem. However, microstructure of all investigated components had been degraded as following:

- Formation of a high amount of TCP phases in the mid-height of the 3rd stage vane made of IN738LC.
- Formation of continuous carbide layers along the grain boundaries; as well as complete consumption of coating in the 3rd stage blade made of Udimet520.
- Formation of continuous grain boundary carbides at hot regions as well as some white-colored plate-like TCP phases in the 4th stage vane made of IN939.
- Formation of continuous carbide layers, needle-like TCP phases and a thick oxide layer on the surface of the 4th satge blade (Nimonic90).

In addition, mechanical testing showed a decrease in ductility of all alloys which were consistent with microstructural results showing brittle phases formation. Accordingly, these blades and vanes were not able to tolerate possible FOD or trip overloads and an extra 25000 hours application of these components was not recommended.

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