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An investigation into the cracking of platinum aluminide coated directionally solidified CM247 LC high pressure nozzle guide vanes of an aero engine

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ABSTRACT

In service inspection of RT-22 platinum aluminide coated directionally solidified CM247LC high pressure turbine nozzle guide vanes of an aero engine which underwent 134 runs as an assembly set revealed cracking in 23 out of the total 34 vanes(17 pairs). A detailed investigation was launched on one of the cracked vanes which revealed that thermomechanical fatigue was the root cause of the failure. Incipient melting, in addition, was observed in platinum aluminide coating and at the interior of the vanes. A relook at the engine shut down procedure and an operating temperature not exceeding safe maximum limit were recommended to protect the vanes against these degradations.

1. Introduction

Major causes for the failure of gas turbine vanes are low cycle fatigue, thermo mechanical fatigue, creep, oxidation, corrosion, erosion [12] and Calcium Magnesium Aluminium Silicate (CMAS) attack [18]. Degradation of vanes of Udimet 710 due to overheating was studied by Tawancy et al. [20] who brought out that carbide which are dispersed in the matrix phase as discrete particles at grain boundaries get rapidly coarsened resulting in grain boundary embrittlement and coarsening of gamma prime phase. The vane showed multiple fractures on the surface of the aerofoil. Mazur et al [11] carried out failure analysis of overheated FSX-414 cobalt alloy nozzle which experienced cracks in different aerofoil sections along with base alloy degradation. Carbide precipitation in the grain boundaries and grain coarsening were identified as the causes for the vane degradation. Fatigue crack initiated ad propagated in the vane which was aided by embrittlement of grain boundaries. Malikburmi et al [13] investigated the premature failure of cast X-45 cobalt based alloy vane to bring out that the thermal fatigue mechanism was the cause. Crack initiation and propagation were due to brain boundary embrittlement which was caused by the continuous formation of M23C6 carbides along the grain boundaries.

Thermomechanical fatigue occurs during rapid shut down of the engine [4, 10, 22]. During start up, the outer surface of the aerofoil heats up faster than the inner surface, creating compressive stresses on the outer surface by the prevention of its expansion by the inner surface. During shut down, the outer surface cools down faster, creating tensile stress on the outer surface due to the cause that the inner surface prevents it contracting Compressive stresses exceeding local flow stress can cause crumbling of the material [1] which is rare. Tensile stresses lead to cracking of the aerofoil.

At temperatures below the ductile to brittle transition temperature (DBTT), due to the tensile component of the stress, strain on the coating exceeds the strain to fracture. The nickel aluminide intermetallic phase of the coating that has got only three independent

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Table 1
FPI inspection results of the HPNGVs.

Doublet no	Vane no	No of cracks	Crack location	Crack length	Machining source	Service duration
1	05836C -2	–	–	–	Centrax	113 h: 33 min: 31Sec
	00107 A -1	One	On convex side of inner shroud fillet	2 mm	Centrax	113 h: 33 min: 31Sec
2	03350 B -2	–	–	–	Centrax	113 h: 33 min: 31Sec
	04935 B -1	Multiple cracks separated with less than 0.5 mm extended up to 20 mm length	On convex side of inner shroud near to fillet & fusion zone	Length of all crack approximately 20 mm	Centrax	113 h: 33 min: 31Sec
3	00636C -2	Approximately 15 nos. of cracks separated by less than 0.5 mm extended up to 15 mm in length Minor indication noticed from scratch	On convex side of inner shroud near to fillet On convex side of L/E of inner shroud on fillet	Length of all crack approximately 3 mm to 4 mm Scratch length is 15 mm	Centrax	113 h: 33 min: 31Sec
	00636 B -1	Approximately 10 nos. of cracks separated by less than 0.5 mm, extended up to 10 mm in length	On convex side of inner shroud near fillet	Length of all crack approximately 5 mm	Centrax	113 h: 33 min: 31Sec
4	21195 B -2	–	–	–	Centrax	113 h: 33 min: 31Sec
	09969 A	Two	On convex side of inner shroud near to fillet	1) 3 mm 2) 2) 2 mm	Centrax	113 h: 33 min: 31Sec
5	02895 B -2	–	–	–	Centrax	113 h: 33 min: 31Sec
	20672 A -1	5 nos. of cracks extended up to 20 mm length	On convex side of inner shroud started from fusion zone and extended up to fillet	1) 5 mm 2) 5 mm 3) 3 mm 4) 2 mm 5) 3 mm	Centrax	113 h: 33 min: 31Sec
6	17742C -2	–	–	–	Centrax	113 h: 33 min: 31Sec
	01310C -1	Three	On convex side of inner shroud started from fusion zone extended up to fillet	1) 3 mm 2) 3 mm 3) 3) 10 mm	Centrax	113 h: 33 min: 31Sec
7	18806C -2	Two	On convex side of inner shroud near to fillet	1) 5 mm 2) 2 mm	Centrax	113 h: 33 min: 31Sec
	20681 A -1	Three	On convex side of inner shroud near to fillet and fusion zone	1) 10 mm 2) 3 mm 3) 3) 2 mm	Centrax	113 h: 33 min: 31Sec
8	04474C -2	–	–	–	Centrax	113 h: 33 min: 31Sec
	19517 A -1	Two	On convex side of inner shroud in fusion zone	1) 5 mm 2) 2) 8 mm	Centrax	113 h: 33 min: 31Sec
9	21192 B -2	Two	On convex side of inner shroud towards L/E	Both of 2 mm	Centrax	113 h: 33 min: 31Sec
	05839 A	One	On convex side of inner shroud near to fillet	1) 5 mm	Centrax	113 h: 33 min: 31Sec
10	19046 B -2	Three	On convex side of inner shroud near to fillet	1) 3 mm 2) 2 mm 3) 3) 1 mm	Centrax	113 h: 33 min: 31Sec
	2902 A -1	Five	On convex side of inner shroud near to fillet	All are 5 mm	Centrax	113 h: 33 min: 31Sec

(continued on next page)