Failure Analysis of a Compressor Blade of Gas Turbine Engine

Swati Biswas*, MD Ganeshachar, Jivan Kumar and VN Satish Kumar

Materials Application Group, Gas Turbine Research Establishment, Bangalore-560093, India
E-mail ID: swati@gtre.drdo.in, swati.gtre@gmail.com

Abstract

The stage II compressor stator blade of a developmental gas turbine engine was found damaged during dismantling of the engine after test run. A portion of the blade was found fractured from the hub region at leading edge. A crack was also observed extending from the fractured surface towards the centre of the airfoil region of the blade. Low magnification stereo-binocular observation revealed presence of beach marks on the fractured surface indicating the blade failure in progressive mode. This observation was further confirmed by scanning electron microscopy. The crack origin was at the blade hub-stem junction on the leading edge side. Presence of machining/filing marks appeared to be the reason for the fatigue crack initiation from this region. No metallurgical abnormalities were present at the crack origin. However, deep filing/machining lines were observed at the stem region of the blade attributing to the cause of failure.

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1. Introduction

The propulsion system for an aircraft is the engine which is designed to accelerate a stream of gas that is used to produce the reactive thrust necessary to propel the aircraft. A typical engine consists of different modules like compressor, combustor, turbine, exhaust system etc.[1]. The frontal part of the engine, the compressor consisting of a number of stages of alternate rotating and stationary aerofoil, draws air in, compresses and delivers it into the combustion chamber. Both rotor and stator blades of compressor experience severe aerodynamic, mechanical and thermal loads in service. Despite best efforts, failures are encountered during testing due to various reasons, namely design, manufacturing, material selection, assembly etc. The common modes of failure in compressor blades is fatigue failure as a result of improper assembly, fretting, mechanical abnormalities induced during manufacturing or by foreign and internal object damage during engine run [2-4]. Systematic investigation helps in identifying the root cause of the failure and helps in preventing recurrence of the incident both during design & development as well as operational phases.
Present paper describes failure incident of a stage II compressor stator blade which was found distressed after disassembling the engine after a test run. The blade was machined from a near α titanium alloy forged bar stock and was in use for approximately 100 hours.

2. Observations

2.1 Visual & Stereo binocular

The photograph of the damaged blade is shown in fig. 1. A portion of the blade was found fractured from the hub region at leading edge. A crack was also observed extending from the fractured surface towards the centre of the airfoil region of the blade (fig. 1 & 2).

To study the mode of the fracture, the crack was opened and observed under stereo zoom microscope (SZM). The fractured surface revealed crack arrest marks, i.e. beach marks, typical in fatigue failure (fig. 3). Tracing back the orientation of the beach marks, the fatigue crack origin was found to be located at the junction of the airfoil and stem region of the blade at the leading edge side (fig. 3).

Fig. 1 Photograph of the damaged stage II compressor stator blade
Fig. 2 Damaged blade under stereo zoom microscope revealing crack path

Fig. 3 Fractured surface exhibiting beach marks (at vertical fracture surface) and crack origin
2.2 Scanning Electron Microscopy

The fractured surface of the blade was cleaned ultrasonically and observed under scanning electron microscope (SEM). The fractured surface was found to be heavily oxidized (fig. 4). Vaguely delineated striations were observed near the crack origin (fig. 4).

![SEM fractograph revealing presence of oxide layer and vaguely delineated striations near the crack origin (at vertical fracture surface)](image)

Away from the crack origin (on the vertical fracture surface, refer fig. 2), the extent of oxidation was less and striations were distinctly visible (fig. 5). This observation indicated exposure of the cracked/fractured surface near to the crack origin to the hot gas flow for considerable duration compared to the region shown in fig. 5. The orientation of the striations was also found to be changed. On the horizontal fracture surface (refer fig. 2), striations (fig. 6) were oriented from concave to convex surface. This confirmed that the horizontal fracture surface was a result of the crack that branched from the vertical one and not from the leading edge of the air foil.

![Striation orientation](image)
2.3 Microstructure

Suitable sample was extracted from the failed blade to examine the material microstructure just below the fracture surface near the crack origin. Microstructure (fig. 7) revealed presence of primary α phase in a transformed β matrix typically observed in this class of alloy.

3. Analysis

Fractographic features indicated that fatigue crack initiated from the junction of blade airfoil hub region and stem (fig. 3). When, the stem region of the blade was observed under stereo zoom microscope, deep filing/machining marks were observed (fig. 8(a) & 8(b)). Fatigue crack origin was found to be located at the junction of stem-airfoil hub region where these deep machining lines were present. These machining marks were quantified using surface roughness measurement technique (using Surftest SJ 210). Surface roughness measurements were carried out in the smooth aerofoil region of the blade as well as in the regions containing the machining marks near the stem. While the aerofoil roughness was found to be 0.2micrometer, the rough region near the stem exhibited surface roughness of 0.8 micrometer.
Fig. 6 Striations on the horizontal fracture surface

Fig. 7 Microstructure of the blade material near the fatigue crack origin
Presence of such marks is detrimental as they can act as the stress concentration sites and results in fatigue crack initiation [5, 6]. Effect of presence of such notch on fatigue life reduction of engineering component is well reported in literature [7-9]. In the present case of blade failure, it appears that fatigue crack initiated from the notch present at the stem-airfoil junction.

4. Conclusions and Recommendation

The Compressor stator blade was found to have failed in progressive mode, i.e. by fatigue. The crack origin was at the blade hub-stem junction at the leading edge side. Presence of machining/filing marks appeared to be the reason for the fatigue crack initiation from this region.

The machining/filing marks are to be avoided as they raise the local stress concentration level and can lead to fatigue failure. Therefore, sufficient care to be excercised to avoid usage of blades containing such notches / abrasion marks.

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