Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings XX (2016) XXX–XXX

www.materialstoday.com/proceedings

PMME 2016

Failure investigations of a first stage Ni based super alloy gas turbine blade

Sushila Rani[a]*, Atul K Agrawal[b], Vikas Rastogi[c]

[a]*Assistant Professor-Department of Mechanical, Production and Automobile Engineering, Delhi Technological University, Delhi-110042, India*

[b]*Assistant Professor-Department of Mechanical, Production, and Automobile Engineering, Delhi Technological University, Delhi-110042, India*

[c]*Professor -Department of Mechanical, Production, Industrial and Automobile Engineering, Delhi Technological University, Delhi-110042, India*

Abstract

This paper deals with the failure investigations of the first stage gas turbine blade of 30MW gas turbine. This blade is manufacture with of nickel based super alloy IN738. The main focus of the paper is to found the causes of failure of the blade. The investigations included the visual inspection, SEM fractrography, chemical analysis, microstructure analysis, X-ray diffraction and stress evaluation by using Finite Element Software ANSYS. By these investigations, it is found that the blade failure takes place due to the combined effect of erosion, oxidation, overheating, and hot corrosion.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: First stage gas turbine blade; Nickel based IN738LC alloy; SEM; overheating; hot corrosion.

1. Introduction

Turbine blade failure cause sudden stop of turbine which results in economic loss. In order to increase the reliability, efficiency of the turbine and to rectify the blade failure problems from the root it is necessary to perform the detailed failure analysis of turbine blade [1].The common failures found in gas turbine blade includes overheating [1], corrosion [2,3,4], oxidation [5,6], erosion [2], degradation of coating of turbine blade [3,5,7], creep [2,3] and fatigue [8, 9]. The failure of gas turbine blade is due to the combination of aforesaid failure mechanisms.

* Corresponding author. Tel.: 09873575460
E-mail address: sranidtu@gmail.com

2214-7853 © 2016 Elsevier Ltd. All rights reserved.
Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

This paper presents failure investigations of a first stage gas turbine blade. Gas Turbine blade material composition analysis, visual inspection, SEM fractrography, chemical analysis, microstructure analysis, X-ray diffraction and stress evaluation by using Finite Element Software ANSYS were performed.

2. Background

A first stage gas turbine blade of 30 MW gas turbine with operating temperature 1100^0C having service exposure of 1,30,000 hrs was investigated (Fig. 1). The blade is manufactured with nickel-base super alloy Inconel 738LC by means of investment casting process, containing directional solidified grain structure. The blade has aluminide coating ($Pt–Al_2$) provided by means of diffusion process. Different views of gas turbine blade are shown in (Fig. 2).

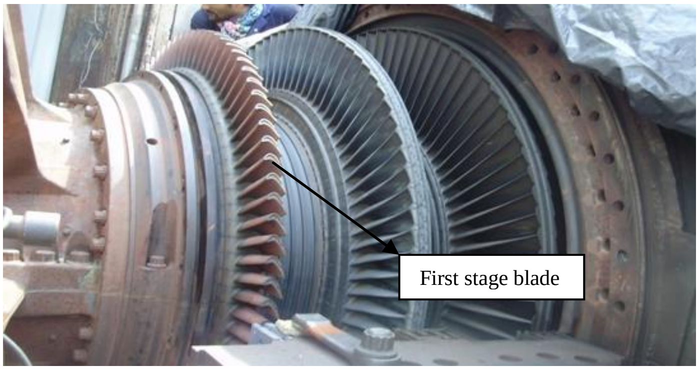

Fig. 1: General view of Gas turbine showing position of first stage blade

Fig. 2: Views of failed gas turbine blade (a) front view, (b) Rear view & (c) side view

3. Experimental details

The failed gas turbine blade is collected from Indraprastha Gas Power Plant, located in India. The blade has tip crack on both leading edge and trailing edge [4]. Two specimens about 15x10x5 mm^3 from the cracked tip of trailing edge and three specimens called as reference samples about 10x10x5 mm^3 from the bottom of trailing edge were cut by means of wire cutting process. Next, these specimens are polished using standard metallographic techniques and etched with acetone [5]. The scanning electronic microscope (SEM), Hitachi S-3700N equipped with an X-ray energy dispersive spectrometer (EDS) as shown in Fig. 3 were used to observe surface morphology, chemical compositions and microstructure of these specimens [4]. The stress analysis of a gas turbine blade was carried out using finite element software ANSYS [9].

4. Results and discussions

4.1. Visual examination

From the visual examination it is found that the failed gas turbine blade has crack on the tip of leading edge as well as on the tip of trailing edge. Both the leading edge and the trailing edge are found eroded along with the oxide scale formation in the airfoil region on both concave and convex sides.

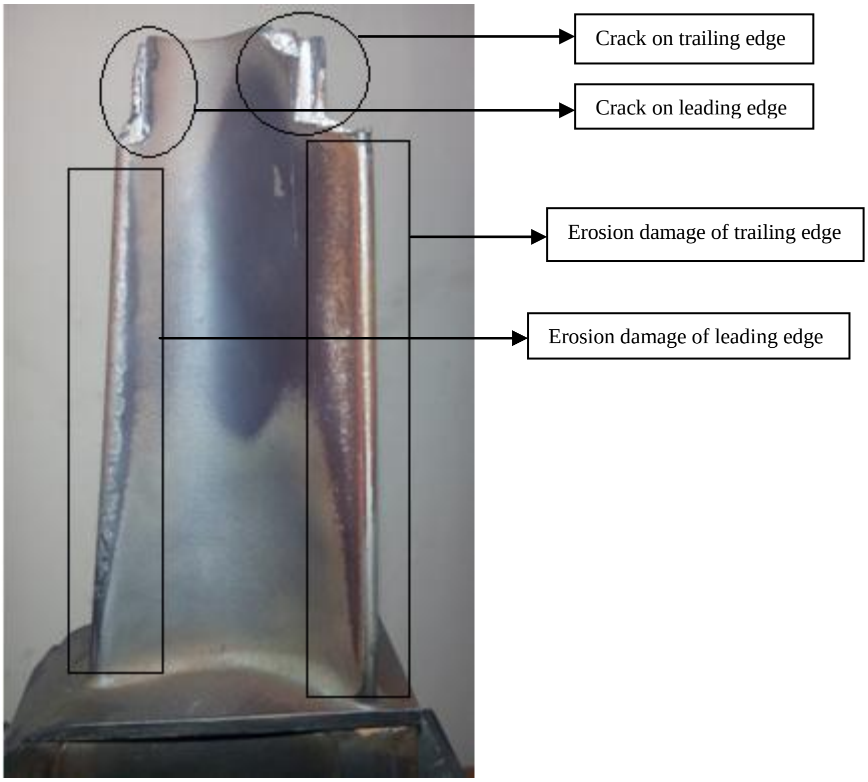

Fig. 3: Crack and Erosion damage found on leading and trailing edge of the first stage IN738 gas turbine blade

4.2 Chemical Analysis

From spectroscopy analysis, the composition (% wt) of blade material is given in Table 1 by using Optical Emission Analyzer spectrometer model- 49 DV4. The chemical analysis results shows that the blade material is in accordance with nickel based super alloy IN738 [12].

Table 1: *The Chemical composition of Inconel 738LC superalloy (wt%)*

Alloy	Cr	Co	Al	W	Ti	Ta	Mo	Ni
Std. IN738LC	16	8.3	3.4	2.6	3.38	1.75	1.7	Remaining
Failed turbine blade	14.63	10.49	2.83	3.54	4.65	0.31	1.11	62.28

4.3 Microstructure Evaluation

The microstructure investigation of the crack tip at the trailing edge was carried out. Two samples were cut by means of wire cutting operation over the trailing edge as shown in Fig. 4. For evaluating microstructure, a sample was prepared from the root region of the failed blade.

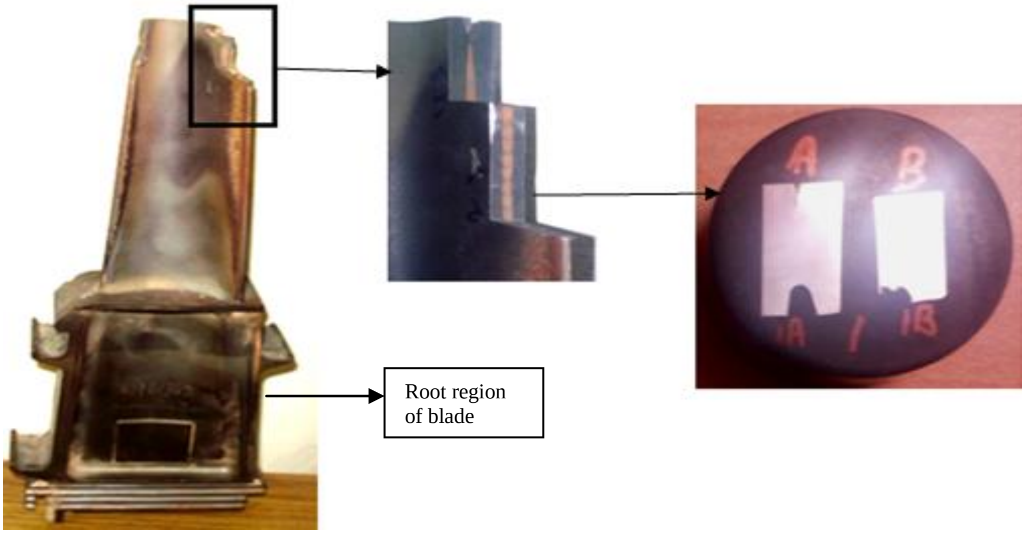

Fig. 4: Specimens cut from failed turbine blade

Fig. 5 shows the microstructure of the reference sample. It consists of carbides of MC precipitated on grain boundaries, grain interior and matrix. An EDS spectrum of turbine blade material is shown in Fig. 6.
Fig. 7 shows X-ray diffraction pattern of reference sample of turbine blade [13].

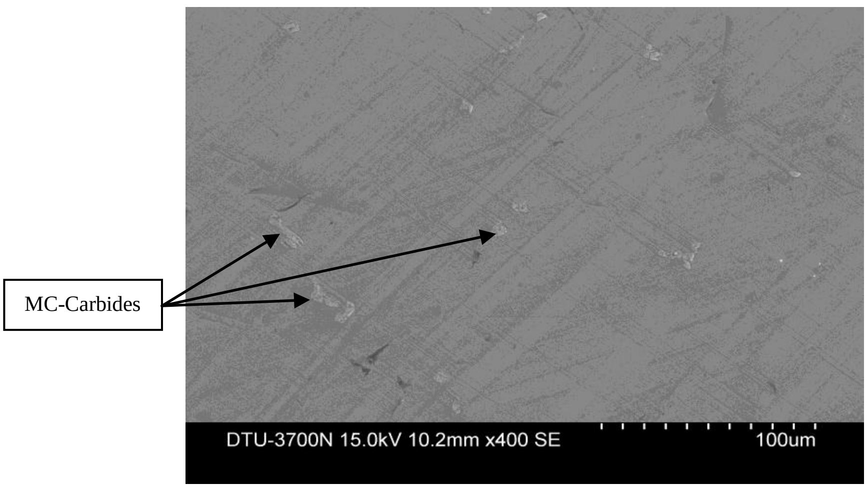

Fig. 5 : MC-carbides precipitated on grain boundaries and matrix

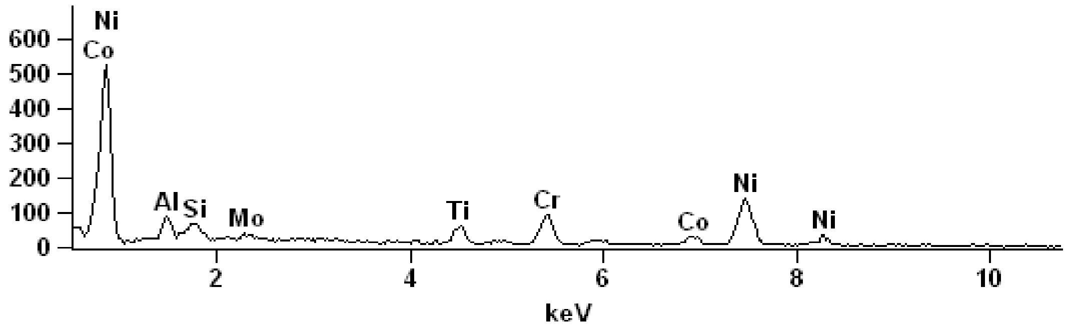

Fig. 6: An EDS spectrum of reference sample of turbine blade

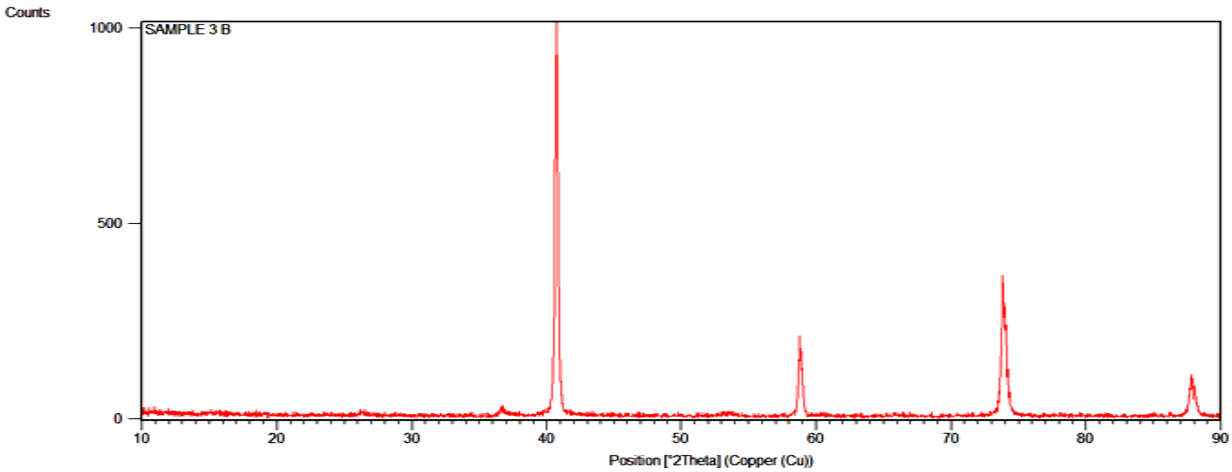

Fig. 7: X-ray diffraction pattern of reference sample of turbine blade

At high temperature working of turbine blade for long period results in the formation of topologically closed packed (TCP) phases as shown in Fig. 8. The mechanical properties of the blade material are degraded due to structure instability of the alloy which further results in decrease of turbine life.

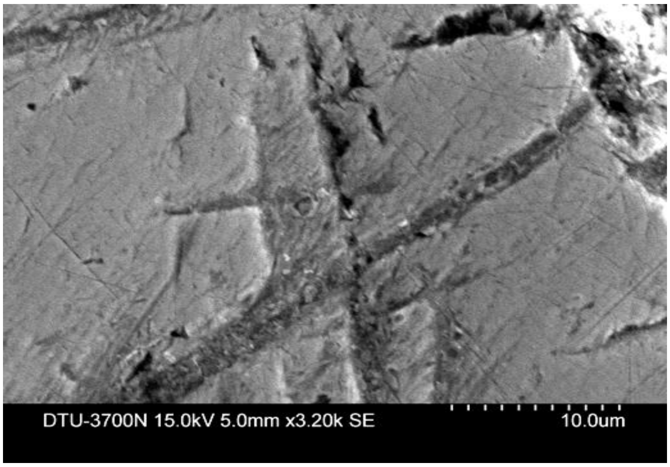

Fig. 8: Topologically Closed Packed (TCP) phase of the first stage IN738 gas turbine blade after service of 1,30,000 hrs

4.4 Crack evaluation

Fig. 9 shows rapid oxidation at high temperature in the presence of sodium sulfate which form by the combination of sulphur, oxygen and sodium. Sodium sulfate combine with chromium to form a mixture of salts and sulphur which is released due to the reduction of sodium sulphate. This released sulphur penetrates inward and react with chromium to form chromium sulfide in the substrate. Further, sulfides are converted to complex unstable metal oxides as corrosion proceeds and sulphur which is released penetrates deeply to form more sulfides into the substrate. An EDS spectrum confirmed the presence of corrosion products shown in Fig. 10. Fig. 11 shows X-ray diffraction pattern of sample collected from failed blade [13].

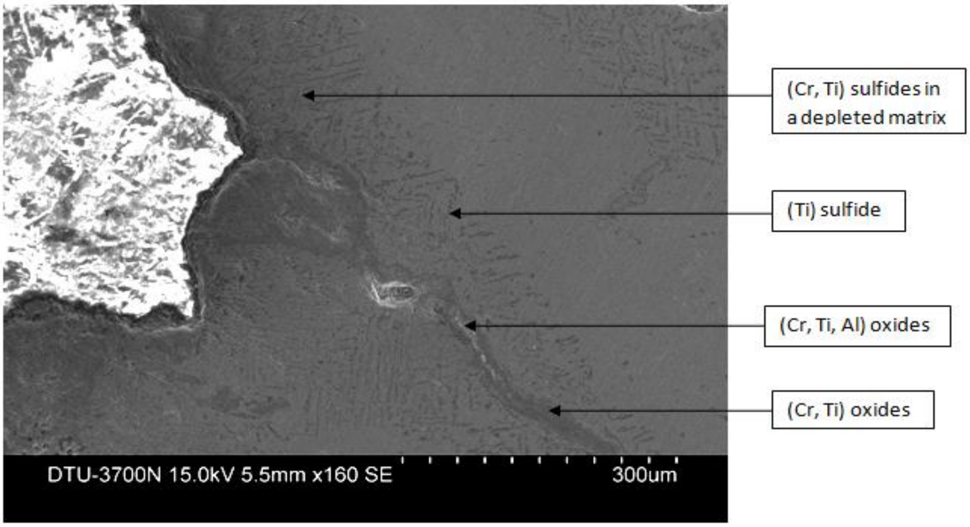

Fig. 9: Hot corrosion: subscale oxides and sulfides are visible in the substrate

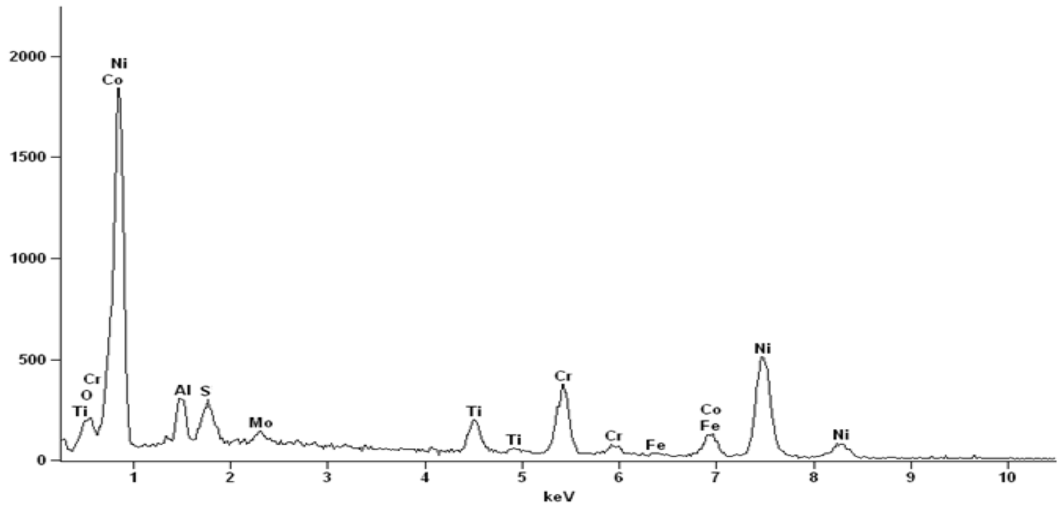

Fig. 10: The EDS spectrum of corrosion products confirm hot corrosion

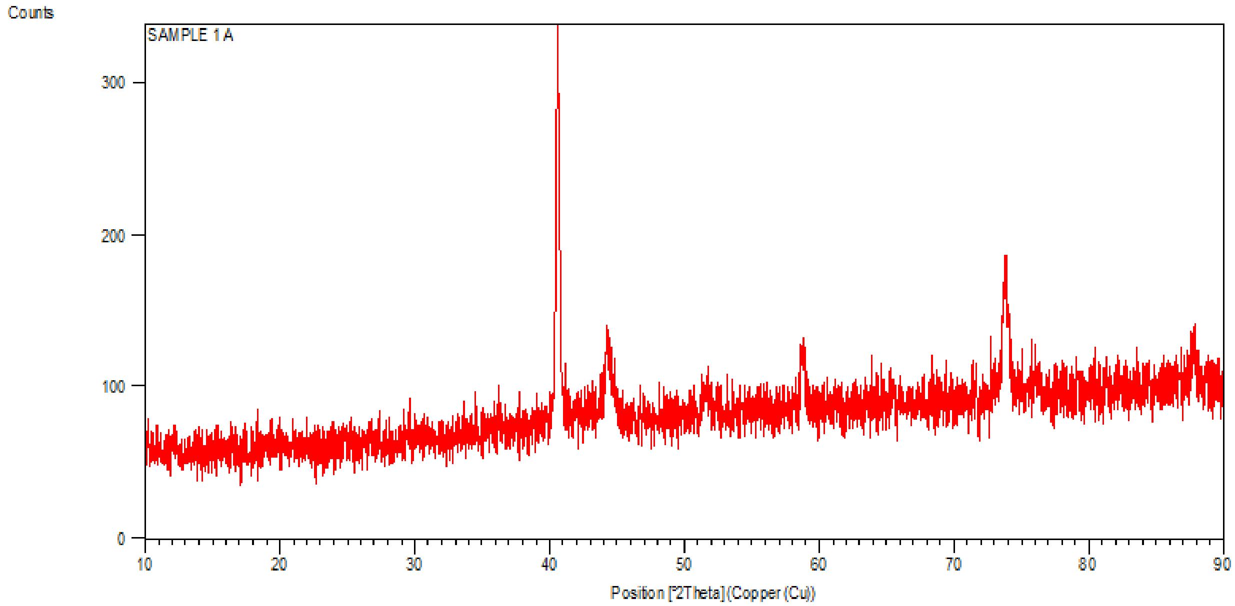

Fig. 11: X-ray diffraction pattern of failed blade

4.5 Stress Evaluation

The stress of first stage IN738 gas turbine blade is evaluated by performing static structural analysis of gas turbine blade on finite element software ANSYS [10]. The maximum tensile stress found approximately 393 MPa as shown in Fig. 12.

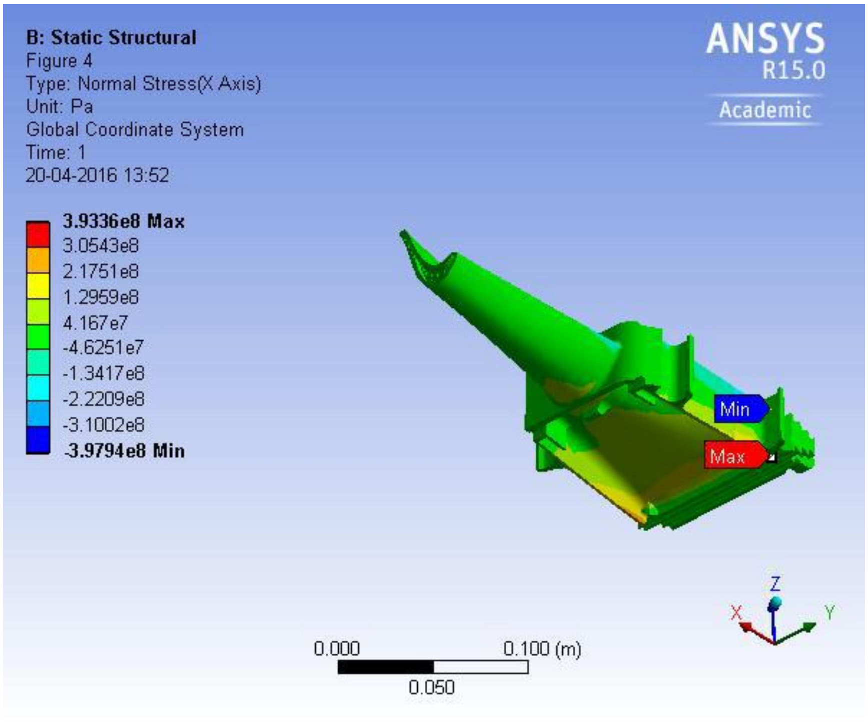

Fig. 12: Normal stress of the first stage gas turbine blade

Fig. 13(a) and 13(b) shows a very good agreement between crack location at the tip of trailing edge and leading edge of the failed first stage gas turbine blade and FEM results [10].

Fig. 13(a): Failed first stage gas turbine blade

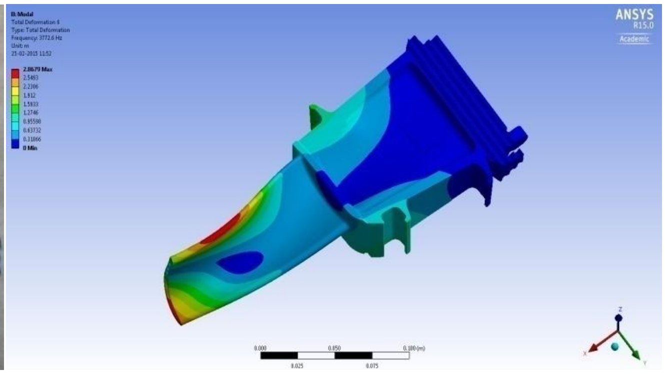

Fig. 13(b): Total deformation of the first stage gas turbine blade

5. Discussions:

The reddish color of blade surface is due to presence of aluminum oxide (Al_2O_3), which results due to oxidation of Al-Pt coating. The inclusions that flow in the hot gas stream are responsible for erosion of blade surface. These inclusions form oxides and impinge on the blade surface.
The alloy composition (% wt) of blade material obtained by using Optical Emission Analyzer spectrometer shows that the material of gas turbine blade has similar chemical composition as of the nickel based super alloy IN738. From the chemical composition, microstructure evolution and stress evaluation it is clear that blade was not failed due to material defects [11].
At high temperature operation of gas turbine blade carbides of MC type transforms to carbides of $M_{23}C_6$ type.
SEM images obtained by Hitachi S-3700N scanning electronic microscope shows the presence of sulfides and oxides in the substrate which are the by products of hot corrosion, and Topologically Closed Packed (TCP) phase of the first stage IN738 gas turbine blade which results due to overheating. The EDX spectrum confirms hot corrosion and overheating. X-ray diffraction patterns of samples collected from failed turbine blade are also shown. There x-ray patterns are similar to IN-738 nickel based alloy found in literature.
Therefore, the ultimate failure of gas turbine blade takes place due to the combined effect of erosion, oxidation, overheating and hot corrosion.

6. Conclusions:

1. Based upon the chemical composition, microstructure evolution and stress evaluation, it is clear that the blade was not failed due to material defect.
2. The surface metal of the blade degraded due to erosion and oxidation. The coating is heavily oxidized and offers no protection to base metal.
3. Formation of Topologically Closed Packed (TCP) phase results due to overheating.
4. Presence of sulfides and oxides in the substrate results due to hot corrosion.
5. The combination of erosion, oxidation, overheating and hot corrosion is responsible factors for ultimate failure of gas turbine blade.

Acknowledgements

The first stage failed gas turbine blade is collected from Indraprastha Gas Power Plant. The authors would be thankful to physics department of Delhi Technological University for help in conducting experiments in physics laboratory.

References:

1. Tawancy, H.M., Hadhrami, L.M., "Degradation of turbine blades and vanes by overheating in a power plant", Engineering Failure Analysis, vol. 16, 2009, pp-273-280.
2. Xie, Y., Wang, M., Zhang, G., "Analysis of super alloy turbine blade tip cracking during service", Engineering Failure Analysis, vol. 13, 2006, pp-1429-1436.
3. Khajavi, M.R., Shariat, M.H., "Failure of first stage turbine blades", Engineering Failure Analysis, vol. 11, 2004, pp-589-597.
4. Eliaz, N., Shemesh, G., Latanision, R.M., "Hot corrosion in gas turbine component", Engineering Failure Analysis, vol. 9, 2002, pp-31-43.
5. Mazur, Z., Ramirez, A., Amezcua, C.A., "Failure analysis of a gas turbine blade made of Inconel 738LC alloy", Engineering Failure Analysis, vol. 12, 2005, pp-474-486.
6. Vardar, N., Ekerim A., "Failure analysis of gas turbine blade in a thermal power plant", Engineering Failure Analysis vol. 14, 2007, pp-743-749.
7. Rybhinov,A.I., Gestov, L.B., Mozhaiskaya, N.V., " Operation experience with cast rotor blades made of Russian alloys in stationary gas turbines", Thermal Engineering, 2012, Vol. 59, No. 3, pp. 242–249. © Pleiades Publishing, Inc., 2012.
8. Kim, H., "Crack evaluation of the fourth stage blade in a low – pressure steam turbine", Engineering Failure Analysis, vol. 18, pp-907-913, 2011.Naeem, M.T., Jazayeri, S.A., Rezamahdi, N., "Failure analysis of gas turbine blades", Proceedings of The 2008 IAJC-IJME International Conference, paper 120,ENG 108.
9. Dowson,P., Dowson, D., " Selection of material and material related processes for FCC power recovery turbines" , Thirty eight turbo machinery symposium,2009, pp 187-212.
10. Naeem, M.T., Jazayeri, S.A., Rezamahdi, N., "Failure analysis of gas turbine blades", Proceedings of The 2008 IAJC-IJME International Conference, paper 120, ENG 108.
11. Bhagi, L., Rastogi, V., Gupta, P., "Fractographic investigations of the failure of L-1 low pressure steam turbine blade", case studies in Engineering Failure Analysis, vol. 1, 2013, pp-72-78.
12. Alloy IN738 technical data, Inco the international nickel company, Inc. One New York plaza, New York, N.Y. 10004.
13. Shishkovsky, I. V., Nazarov, A.P., "Comparison of Additive Technologies for Gradient Aerospace Part Fabrication from Nickel-Based Superalloys", Intech open science, chapter-10, 2015, pp-211-245.