Steady State Structural Analysis of High Pressure Gas Turbine Blade using Finite Element Analysis

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Abstract: In gas turbines the major portion of performance dependency lies upon turbine blade design. Turbine blades experience very high centrifugal, axial and tangential force during power generation. While withstanding these forces blades undergo elongation. Different methods have proposed for better enhancement of the mechanical properties of blade to withstand in extreme condition. Present paper describes the stress and elongation for blades having properties of different materials. Steady state structural analysis have performed in the present work for different materials (In 625, In 718, In 738, In 738 LC, MAR M246, Ni-Cr, Ti-alloy, Ti-Al, Ti-T6, U500). Remarkable finding is that the root of the blade is subjected to maximum stress for all blade materials and the blade made of MAR M246 has less stress and deformation among all other blade materials which can be selected as a suitable material for gas turbine blade.

Keywords: Finite Element Analysis, Gas Turbine Blade, Stress Analysis, Super alloys.

1. INTRODUCTION
Gas turbine has been using since nearly the twentieth century in different sectors like aviation, marine and power generation. With increasing the technological development customer’s demands are increasing focusing on the engine efficiency, low maintenance cost, long service life, flying hours, whether condition, corrosive environment surrounding conditions etc. Compressor and turbine are the major components of a jet engine. As temperature and pressure are gradually increased from the inlet of the compressor and decrease at the outlet of turbine. So there are possibilities of blade fail at both compressor and turbine. Khan et al. [1] investigated the effect of intergranular corrosion found in gas turbine blade made of Udimet 500 (U 500) superalloys. They observed that at high range of temperature de alloying and precipitation starts which results in Cr depletion at the grain and reduce the corrosion protection which leads to intergranular corrosion in the blade. Hollander et al. [2] investigated the microstructural changes and their effect on the tensile properties, and isothermal low cycle fatigue behavior of gas turbine blade made of In 738. They also investigated the residual fatigue life and the crack paths of specimen. They observed the microstructural degradation on grain boundaries. Which has a pernicious effect on hardness and tensile properties of blade leads to reduce in yield stress. Furthermore, micro crack at pores and Cr- rich topologically closed pack phase were found by them. Wear damage in gas turbine compressor blade is due to direct contact with environmental...
contamination. Chamacho et al. [3] measured the surface roughness of gas turbine Centaur 40GT blade at different zones using Atomic Force Microscopy (AFM) techniques. They observed that the value of surface degradation was higher in case of first stage compressor blades, because blades are exposed to the environmental contaminations. Rani et al. [4] investigated the failure analysis of first stage gas turbine blade made of In738LC. They observed that blade failed due to combined effect of surface degradation, hot corrosion, and oxidation, surface coating degradation and heavily oxidized coating but not due to material defects. Surface degradation occurs due to overheating. The surface coating failed to protect the base metal because the coating was heavily oxidized. Sun et al. [5] investigated the effect of microstructural degradation on gas turbine blades composed of nickel based superalloy GH4037. They observed that because of C diffusion into the gama matrix primary MC decomposed and Cr-rich M_{23}C_6 carbide formed. Qu et al. [6] analyzed four fractured blades composed of Inconel738 by visual examination, stereomicroscope and scanning electron microscope (SEM). They observed that initially the first blade failed due to multiple-source fatigue and after that this broken blade component pay the major rule for breaking other three blades. They also observed metallurgical porosity defects in the trailing edge of the blade which broke first. The fatigue crack was initiated and propagated due to stress concentration, which occurred due to porosity defects and caviations in the blade. Mokaberi et al. [7] investigated the actual reason of sudden and early failure of gas turbine compressor blade made of GTD 450 alloy for corrosive environment. They observed that corrosion pits occurred on the blade surface which was stress concentration site. Crack was initiated due to cyclic loading and propagated as fatigue cracks into the center of the blade. Kurmi et al. [8] performed a detailed metallurgical investigation to identify the cause of failure of turbine blades at different stages made of Ni based superalloys. They observed that oxides as well as pits formed due to damage of surface coating at several locations on the surface of the blades. Because of the pits fatigue crack was initiated and propagated which leads to blade fracture.

From the above studies it is found that the starting reason of blade fracture is the damage of surface coating which leads to oxide formation on the blade surface. Environmental contamination comes in direct contact with turbine blades forms dent and pits on the coating damage area of the blades. These dent and pits are the stress concentration sites. Cracks are initiated and propagated from stress concentration area and leads to blade damage.

The aim of the present investigation is to analyze the stress and deformation of turbine blade for different blade materials.

2. NOMENCLATURE AND MODELLING OF BLADE

\[ E = \text{Young’s modulus} \]
\[ \mu = \text{Poisson’s ratio} \]
\[ \rho = \text{Density of the material} \]
\[ K = \text{Thermal conductivity} \]
\[ F = \text{Centripetal force} \]
\[ m = \text{mass of the moving object} \]
\[ r = \text{distance of the object from the center of rotation} \]
ω = angular velocity of the object
A = cross-sectional area of the blade
N = revolution per minute
σ = stress of the blade

CAD modelling software was used to create the blade model, model was analyzed using FEA software to determine the stress and elongation for different materials. Tetrahedral element was used to generate the mesh. Relatively finer mesh was used in the region of failure. Boundary conditions namely displacement and force were applied on the model. Centripetal, axial and tangential force were applied to the blade for analyzing.

\[ F = m r \omega^2 \]  
\[ F = \rho A \omega^2 \int r dr \]  
\[ \omega = \frac{2\pi N}{60} \]  
\[ \sigma = \frac{F}{A} \]  

The above equations are taken from [9]
Table 1. Mechanical properties for different blade materials

| Alloy      | E(Pa)   | ρ(kg/m³) | K(W/m-k) | µ   |
|------------|---------|----------|----------|-----|
| In718      | 1.49E+11| 8249     | 25       | 0.344|
| In625      | 1.50E+11| 8400     | 10       | 0.331|
| Ni-Cr      | 2.07E+11| 8900     | 90.7     | 0.33 |
| Ti-Alloy   | 2.05E+11| 4700     | 10       | 0.33 |
| U500       | 2.10E+11| 7800     | 16.2     | 0.3  |
| In738      | 1.49E+11| 8550     | 14.3     | 0.3  |
| Ti-Al      | 1.18E+11| 4507     | 7        | 0.3  |
| Ti-T6      | 1.06E+11| 4420     | 10       | 0.3  |
| MAR M246   | 2.11E+11| 8440     | 16.8     | 0.289|
| In738LC    | 2.05E+11| 8110     | 16.2     | 0.33 |

3. RESULTS AND DISCUSSION

The turbine blade was analyzed using FEA software for determining the stress and the elongation in steady state condition. It was observed that the maximum von-Misses stress was 591.3 MPa for Inconel 625, Inconel 738LC, Ni-Cr alloy and Ti-alloy; 590.75 MPa for Inconel 718; 590.39 MPa for Inconel 738; 590.38 MPa for Ti-Al alloy, Ti-T6 alloy; 590.39 MPa for U500; 589.9 MPa for MAR M246 alloy. It was clearly observed from the figures that blade made of different materials shows the same behavior. But value of stress was found minimum in the case of MAR M246 alloy.
Fig. 2 (a-j). Equivalent (von-Mises stress) for In-625, In-718, In-738, In-738LC, MARM-246, Ni-Cr, Ni-Alloy, Ti-Alloy, Ti-Al, Ti-T6 and U500 respectively.
Similarly, it was also observed that the maximum deformation is 0.62202 mm for Ti-T6 alloy, 0.55876 mm for Ti-Al alloy, 0.44251 mm for Inconel 738 alloy, 0.43844 mm for Inconel 625 alloy, 0.3294 mm for Inconel 718 alloy, 0.032081 mm for Inconel 738LC and Ti-alloy, 0.31796 mm for Ni-Cr alloy, 0.31397 mm for U500, 0.31275 mm for MAR M246 alloy. It was clearly observed from the figures that blade made of different materials shows the same behavior. But value of elongation was found minimum in the case of MAR M246 alloy.
Fig. 3(a-j). Maximum deformation of In-625, In-718, In-738, In-738LC, MARM-246, Ni-Cr, Ni-Alloy, Ti-Alloy, Ti-Al, Ti-T6 and U500 respectively

4. CONCLUSIONS

Finite Element Analysis was carried out for determining the value of stress and deformation of gas turbine blade made of different alloys. Maximum stresses were observed at the root of the turbine rotor blade. It was observed from the analysis that maximum stress and deformation are less in case of MAR M246 among all turbine blade materials. On the basis of the above results it can be concluded that MAR M246 can be selected as suitable material for gas turbine blade.

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