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Steady State Structural Analysis of Single Crystal Turbine Blade

Mrinaline Mishra
B.Tech,
Department of Mechanical Engineering
College of Engineering & Technology, Bhubaneswar,
India

Abstract **– Gas turbines are used extensively for aircraft propulsion, land based power generation and industrial application. Thermal efficiency and power output of gas turbine increases with increasing turbine rotor inlet temperature. This leads to building up of extreme stresses on the grain boundaries of turbine blades which may result in failure of blades. Development of single crystal nickel based alloys eliminated all the grain boundaries from the micro structure which lead to the increment in blade life.**

In this paper, steady state structural analysis is carried out for a high temperature nickel based alloy (Rene 41) and single crystal nickel based alloy (Rene N5). It is observed that stress and strain developed in a single crystal nickel alloy is less as compared to that of nickel alloy.

Keywords – Gas turbine blade, Single crystal alloy, Von misses stress, Rene N5

I. INTRODUCTION

Turbine blades are one of the most important components in a gas turbine application. Blades can be defined as the medium of transfer of energy from the gases to the turbine rotor [1]. Damage to the turbine blade is of critical importance in aircraft engines and is therefore considered as the limiting components of the gas turbine [2]. Turbine blades are susceptible to damage and crack formations in the region of component contact that experience both centrifugal and oscillatory vibrations [3].

Blades are subjected to very strenuous environment inside a gas turbine. They face high temperature, high stress and a potential environment of high vibration. All three of these factors can lead to blade failures, potentially destroying the engine. Therefore turbine blades are carefully designed to resist these conditions [4].

The major failure mechanism for gas turbine airfoils involved nucleation and growth of cavities along the transverse grain boundaries. Elimination of transverse grain boundaries through directional solidification casting of turbine blades made an important step in temperature capability of these castings [5].

The use of single crystal blades in gas turbine engines has considerable advantages over conventional cast blades since they don’t posses grain boundaries which in conventional castings are weak points along which premature damage can occur. Because grain boundary voids and vacancies are almost entirely eliminated, single crystal blades exhibit more uniform properly characteristics, higher thermal fatigue resistance (even at temperature close to melting point) hence superior reliability [6].

II. MATERIALS

Turbine efficiency is a vital factor on which the performance of heavy duty gas turbines for power plants, air turbines or turbo expanders depends [7]. The thermal efficiency and power output of gas turbine varies directly with increasing blade inlet temperature [8].

In the past few decades, the operating temperatures of a gas turbine engines have been on the rise to achieve higher and higher engine power and efficiency. This has necessitated continuing advancement in the temperature withstand capabilities of materials used in the air construction [9].

Among the materials that have been found to be suitable for use in blades are steels, titanium alloys and nickel based alloys. The main disadvantage of titanium alloys has been the reactivity at high temperature. Nickel alloys have superior strength and oxidation resistance even at high temperature. So blades of gas turbine are made up of nickel alloys [1].

Rene 41 is a high temperature nickel based alloy developed by general electric. It is used in jet engines, missile components and other applications that require high strength at extreme temperatures. Rene N5 is a second generation single crystal nickel based alloy intended for high temperature applications (to withstand loading and retain their shape).

III. MODELLING AND ANALYSIS

The blade profile is generated using CATIA V5R19 software and then imported to ANSYS WORKBENCH 17.0. The bottom edge is fixed and a pressure load of 3.06 MPa and speed 10,000 rpm are taken as boundary conditions along with temperature 1200°C for both the nickel based alloys.

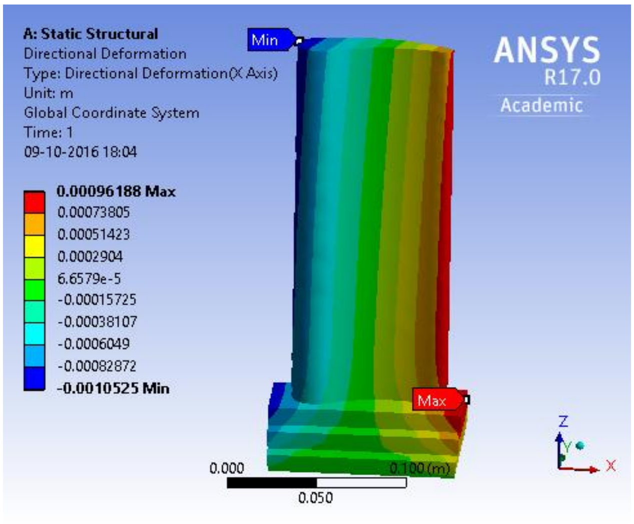

Fig. 1. Directional Deformation in Rene 41

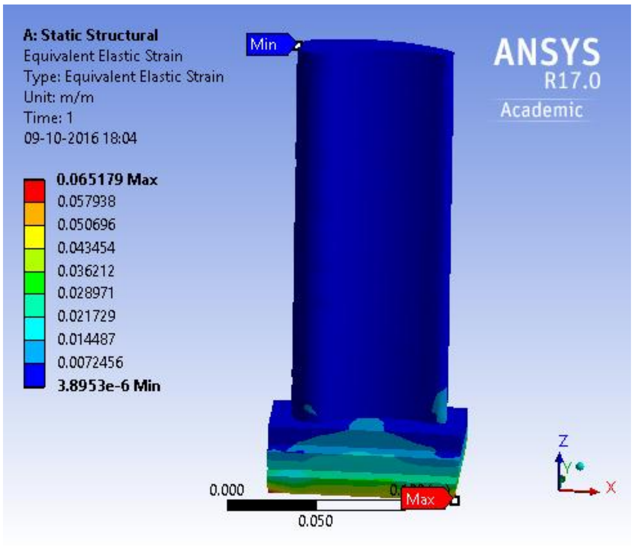

Fig. 2. Equivalent Strain in Rene 41

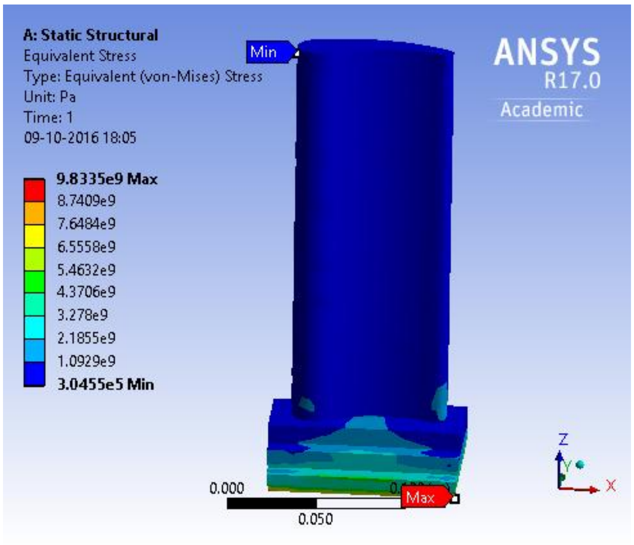

Fig. 3. Von Misses Stress in Rene 41

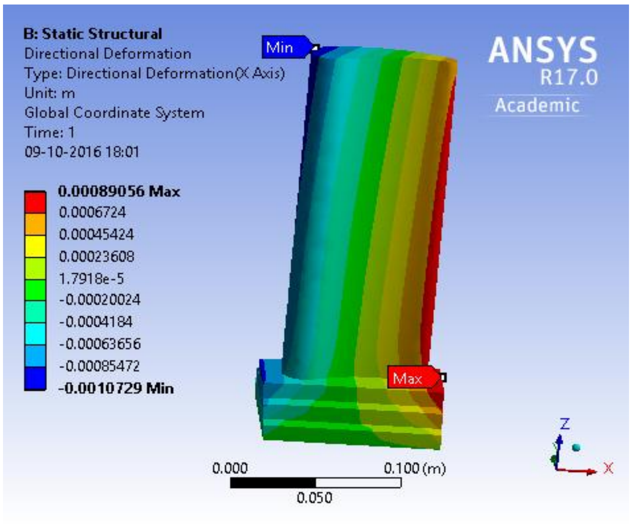

Fig. 4. Directional Deformation in Rene N5

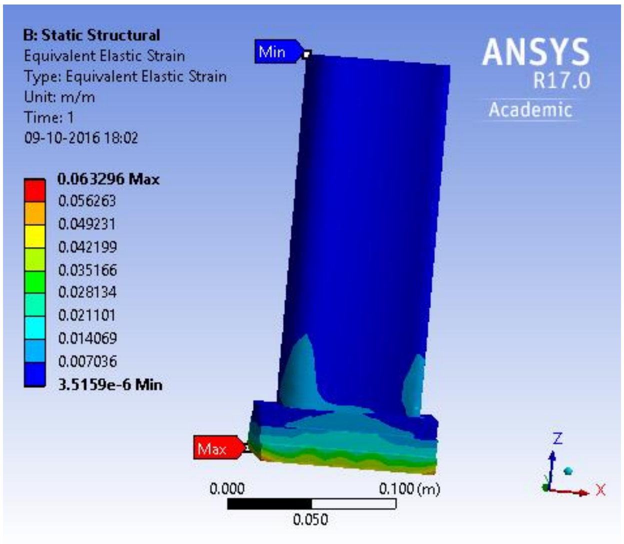

Fig. 5. Equivalent Strain in Rene N5

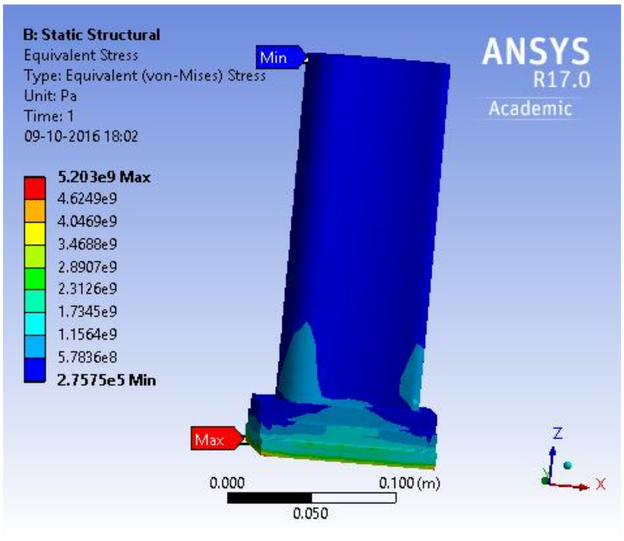

Fig. 6. Von Misses Stress in Rene N5

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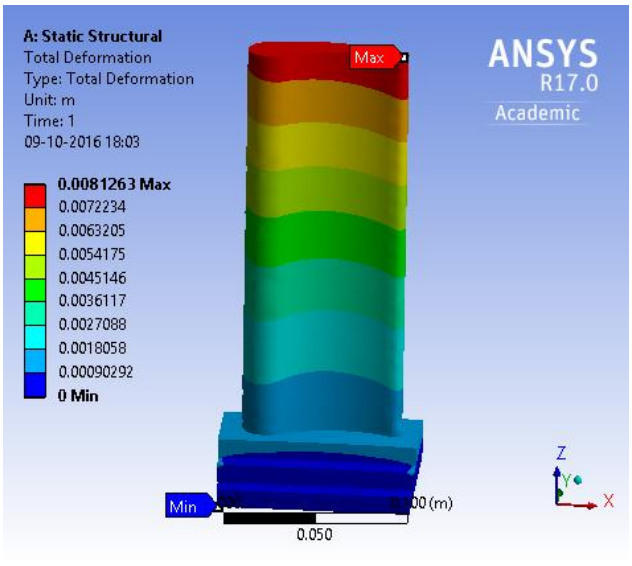

Fig. 7. Total Deformation in Rene 41

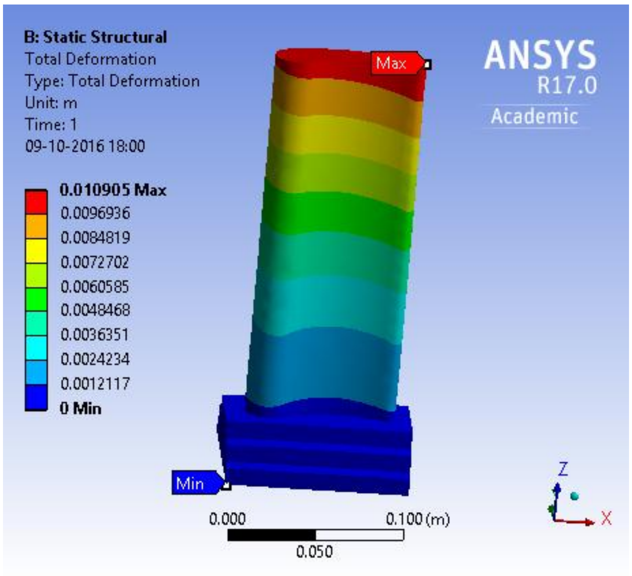

Fig. 8. Total Deformation in Rene N5

IV. RESULTS AND DISCUSSSION

From the steady state structural analysis of gas turbine blade the following results are obtained. The results are tabulated in TABLE I and II.

TABLE I. VON MISSES STRESS AND EQUIVALENT STRAIN

Materials	Min Von Misses Stress (MPa)	Max Von Misses Stress (MPa)	Min Equivalent Strain (m/m)	Max Equivalent Strain (m/m)
Rene 41	0.30455	9833.5	3.8953e-6	0.065179
Rene N5	0.27575	5203.0	3.5159e-6	0.063296

TABLE II. TOTAL DEFORMATION AND DIRECTIONAL DEFORMATION

Materials	Min Directional Deformation (m)	Max Directional Deformation (m)	Min Total Deformation (m)	Max Total Deformation (m)
Rene 41	-0.0010525	0.00096188	0	0.0081263
Rene N5	-0.0010729	0.00089056	0	0.010905

From the above results, it is observed that Von Misses Stress and Equivalent Strain developed in a gas turbine blade made up of a single crystal nickel based alloy Rene N5, at a very high temperature, is very less as compared to that of blades made up of high temperature nickel based alloy Rene 41. Results also convey that with the same amount of deformation (both total and directional), Rene N5 exhibits more resistance to the pressure applied than Rene 41.

V. CONCLUSION

Steady state structural analysis of a gas turbine blade made of single crystal alloy and nickel based alloy was studied. From the above study, it can be observed that single crystal alloys offer superior properties than any nickel based alloy. Complete removal of grain boundaries reduced the chances of formation of cracks at different regions due to high temperature because of which single crystal alloys can withstand more loads. This also increases the blade life. Therefore, it can be concluded that single crystal nickel based alloys are the best suited materials for a gas turbine blade in the present scenario.

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