Comparative Stress Analysis of Gas Turbine Blades

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***Abstract*— In turbomachinery, the turbine blades play an important role. While operating these blades rotate at high speed and as a result, are subjected to high centrifugal force. The gas turbine transforms the natural gas into mechanical energy, and then the mechanical energy generated by the turbine exit shaft is then transferred through a gearbox to the generator shaft. Due to high rotation speed, the centrifugal stresses act on the blade. Then, due to the presence of different blade material, along with the temperature dependency, thermal stress and deformation are developed. So, this paper is a review of various factors affecting the turbine blade.**

Keywords—Turbine blade; thermal stress; centrifugal stress; temperature dependency; deformation

I. INTRODUCTION

The gas turbine has been using since nearly the twentieth century in different sectors like aviation, marine, and power generation. Gas turbines became one of the foremost important prime movers especially in aircraft propulsion, land-based power generation, and industrial applications. The turbine may be a power station, which produces comparatively greater energy per unit size and weight. With increasing technological development customer's demands are increasingly focusing on engine efficiency, low maintenance cost, long service life, flying hours, weather conditions, the corrosive environment surrounding conditions, etc. Compressors and turbines 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 the turbine. So there are possibilities of blade fail at both turbine and compressor. Its compactness, low weight, and multiple fuel application make it a natural power station for several applications. It is clear from the Brayton cycle that the increase in pressure ratio increases the gas turbine thermal efficiency accompanied by an increase in Turbine Entry Temperature (TET). The increase in pressure ratio increases the general efficiency at a given temperature. However, increasing the pressure ratio beyond a particular value at any given TET can actually end in lowering the general cycle efficiency.

S. Gowreesh et al. [1] studied the first-stage rotor blade of a two-stage gas turbine that has been Analyzed for structural, thermal, modal analysis using software which is powerful Finite Element Method software. Using this software, the temperature distribution in the rotor blade has been evaluated. To extract the maximum quantity of energy from the working fluid the turbine technology is used to convert it into useful work with maximum efficiency by means of a plant having a maximum turbojet engine. It has been felt that a detailed study can be carried out on the temperature effects to have a clear understanding of the combined mechanical and thermal stresses. Wanshui Yu et al. [2] studied the influence of the Metal Mesh on the Attachment Manner of CFRP Wind Turbine Blades. carbon fiber reinforced plastics (CFRP) is the next-generation material for the beam of wind turbine (WT) blade, especially for offshore wind farms. However, it has a fatal problem for the aspect of lightning protection. The CFRP beam can be regarded as an external conductor through the whole blade, which may cause it, hit by the lightning strikes directly, to be damaged. S. Gokulraj, K. Ramraji studied structural analysis of blade. By extrusion the contour (2D model) is then converted into the area, and then the volume (3D model) was generated. The hub is also generated similarly. These two volumes are then combined into a single volume. The blade is then analyzed sequentially with structural analysis. The surface of the blade is applied with the Surface element for applying the convection loads. For structural analysis, the loads considered are centrifugal, axial & tangential forces.

II. PHYSICAL PROBLEM AND MODELLING

The definition of the problem is a gas turbine blade is exposed to the highest temperature along with all types of turbine blading. So its stress analysis is quite popular to know the response of the stresses on the blade to the variations in maximum temperatures & material combinations. In this project, we performed structural and thermal analysis by applying various gas temperatures, high pressure, and at certain loads. The model of the blade is taken from the NACA airfoil profile (NACA 0012 AIRFOIL). In the present analysis stresses developing on the blade in a pressurized high-temperature environment have been assessed. A three-dimensional model of the turbine blade with cooling holes have been generated as shown in (Fig. 1). It also shows the boundary conditions considered for the analysis. A dedicated finite element package has been used for determining the variation of stress and deformation across the turbine blade.

III. BLADE MATERIALS AND PROPERTIES UNDER ANALYSIS

Titanium, however, has long been viewed as having a desirable balance of properties for applications towards the front of the turbine engine (i.e. fan discs/blades, compressor discs/blades, alongside other smaller components). The data is

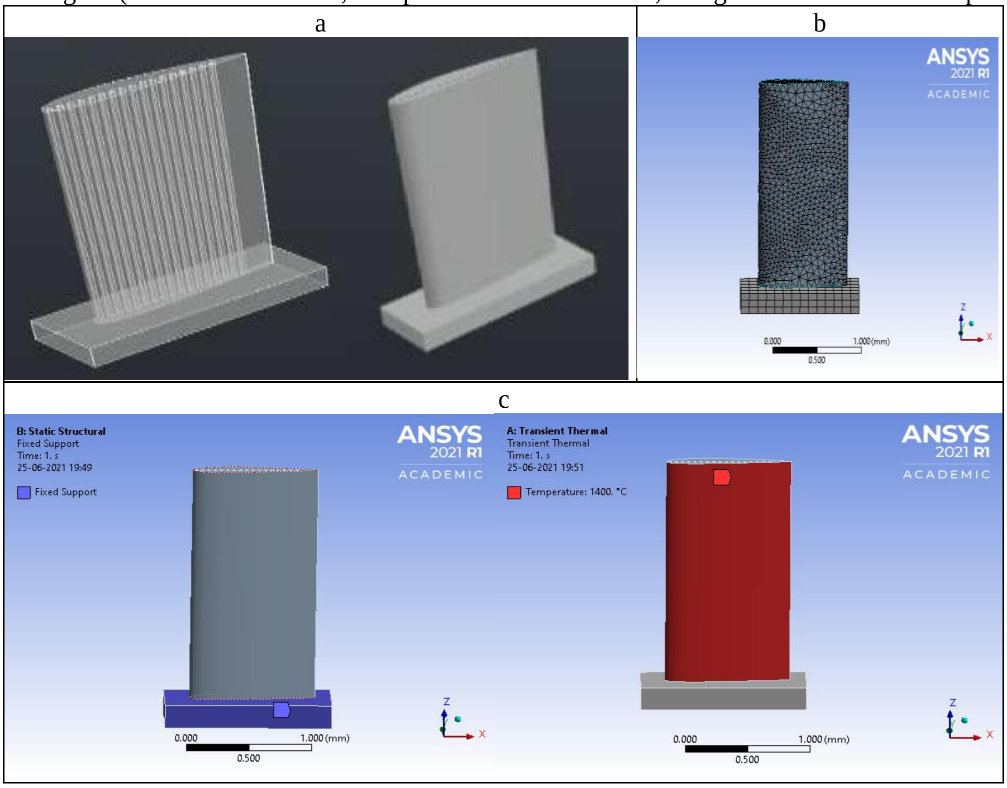

Fig. 1 (a) Model of blade (b) FEM meshing (c) Boundary conditions

TABLE 1. MATERIAL DETAILS

Ti alloy	Steel alloy	E Glass
Density: 4620 kg/m^3	Density: 7850 kg/m^3	Density: 2600 kg/m^3
Young's Modulus: 9.6e+10 Pa	Young's Modulus: 2e+11 Pa	Young's Modulus: 7.3e+10 Pa
Poisson Ratio: 0.36	Poisson Ratio: 0.3	Poisson Ratio: 0.22

shown in Table 1. Alloy steel is steel that's alloyed with a spread of elements in total amounts between 1.0% and 50% by weight to enhance its mechanical properties. Alloy steels are weakened into two groups: low alloy steels and high alloy steels [3]. The following could even be a spread of improved properties in alloy steels (as compared to carbon steels): strength, hardness, toughness, wear resistance, corrosion resistance, hardenability, and hot hardness. To achieve a variety of those improved properties the metal may require heat treating. For electrical wiring E-Glass or electrical grade glass was originally developed. It was later found to possess excellent fiber-forming capabilities and is now used almost exclusively because the reinforcing introduces the fabric commonly referred to as fiberglass. E-glass fibers have relatively low elastic moduli in comparison to other reinforcements. In addition, E- glass fibers are vulnerable to creep rupture [4].

IV. RESULT AND DISCUSSION

The solution from the computational analysis of the blade was recorded in the form of various parameters like maximum stress, deformation, etc. The analysis was carried out three sets of temperatures, like 1000˚C, 1200˚C and 1400˚C, as applicable in actual gas turbines. The blades modeled with three different materials is then analyzed sequentially with same maximum pressure as ambient conditions. The minimum element size of the generated mesh was 183.78 m, whereas the average surface area was 2.7×10^{4} m^2. The solution from the FEM simulations were analyzed for all combinations of stress vs maximum temperature of different alloy combinations. In this paper, the effect of different stresses on the turbine blade is studied with respect to different temperatures applied on turbine blade of different element. This stress filled in gas turbine blade is looked in to using finite element method (FEM). Understanding the convolution of the geometry, a 3 dimensional modelling of a blade is created. The details of this up to the minute proposition are presented by stresses developed due to turbine operation at different temperatures. M. J. Hyder 1 and H. Rehman, they investigated stress distribution of gas turbine blade, different failures. Selection of material and functioning to be mount on turbine blade mass produce has become crucial. Thus blade failures in gas turbine have a dire impact on the potentiality generation system. Abortion condition may comment due to several occurrences, where one of them has the aptness to prohibit a unit from service [6]. A. Mokaberi, R. Derakhshandeh-Haghighi, and Y. Abbaszadeh, they explored the actual grounds of sudden and pre mature nonsuccess, failure of gas turbine blade of GTD 450 alloy for corrosive environment. They spotted that degeneration pits chanced on the blade surface which was stress gathering site. Crack was commenced due to cyclic pack and generated fatigue cracks the blade center [7].

A. *Structural and thermal analysis of Ti alloy*

The stress and deformation of contours for steel alloy based turbine blade have been shown in Fig. 2. At the given boundary condition, the maximum deformation is 2.76×10^{-5} m, the maximum principle stress is 2.37×10^{3} MPa. And finally the maximum shear stress is 6.04×10^{3} MPa. Then steady state thermal analysis is done at three different temperatures and hence change in maximum heat flux and maximum principal stress is studied.

TABLE 2. RESULTS

Material	Temperature	Maximum Heat Flux (W/m2)	Maximum Deformation (m)	Maximum Principal Stress (MPa)	Maximum Shear Stress (MPa)
Titanium Alloy	1000°C	1.79E+03	1.96E-05	1.68E+03	4.29E+03
	1200°C	2.14E+03	2.36E-05	2.02E+03	5.17E+03
	1400°C	2.50E+03	2.76E-05	2.37E+03	6.04E+03
Steel Alloy	1000°C	2.03E+02	2.49E-05	3.44E+03	1.13E+04
	1200°C	2.43E+02	3.00E-05	4.74E+03	1.36E+04
	1400°C	2.84E+02	3.51E-05	5.55E+03	1.59E+04
E Glass	1000°C	5.27E+05	1.03E-05	5.37E+02	1.57E+03
	1200°C	6.34E+05	1.24E-05	6.46E+02	2.12E+03
	1400°C	7.42E+05	1.45E-05	7.56E+02	2.48E+03

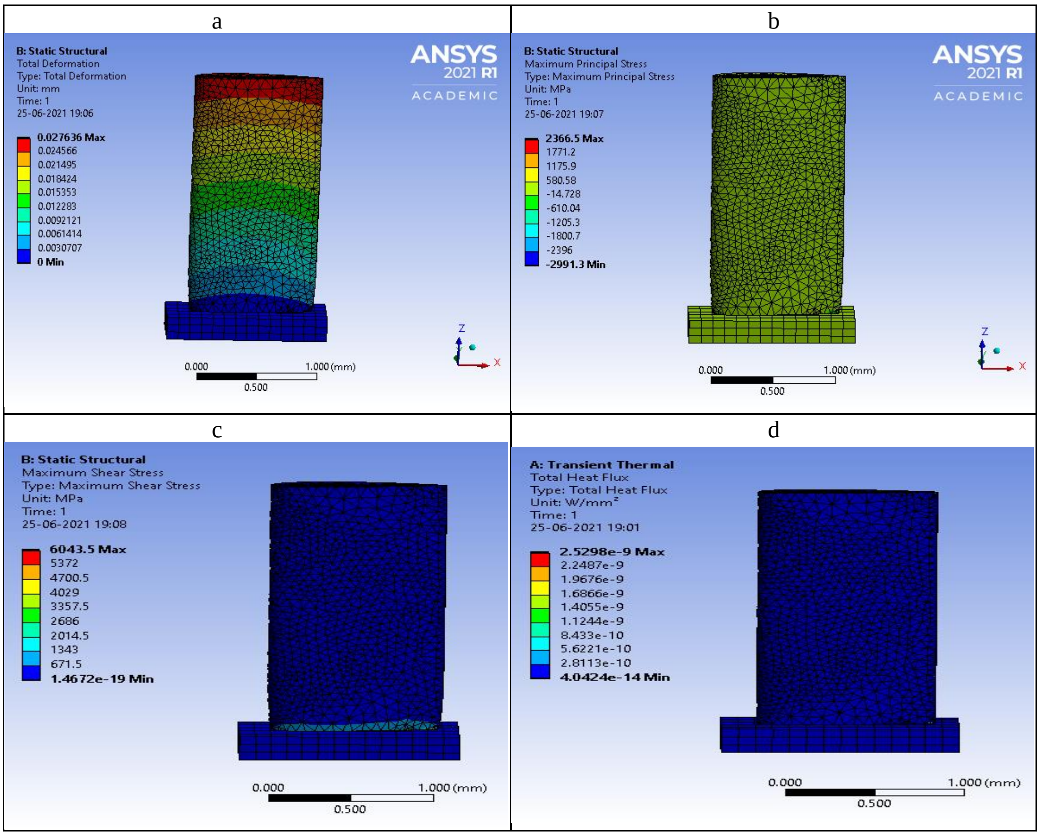

Fig. 2 (a) Maximum deformation (b) Maximum principal stress (c) Maximum shear stress (d) Maximum heat flux

B. *Structural and thermal analysis of Steel alloy*

The stress and deformation of contours for steel alloy based turbine blade have been shown in Fig. 3. At the given boundary condition, the maximum deformation is 3.51×10^{-5} m, the maximum principle stress is 5.55×10^{3} MPa. And finally the maximum shear stress is 1.59×10^{4} MPa. Then steady state thermal analysis is done at three different temperatures and hence change in maximum heat flux and maximum principal stress is studied.

C. *Structural and thermal analysis of E Glass*

The stress and deformation of contours for steel alloy based turbine blade have been shown in Fig. 4. At the given boundary condition, the maximum deformation is 1.45×10^{-5} m, the maximum principle stress is 7.56×10^{2} MPa. And finally the maximum shear stress is 2.48×10^{3} MPa. Then steady state thermal analysis is done at three different temperatures and hence change in maximum heat flux and maximum principal stress is studied.

D. *Comparative effect of Temperature on mechanical properties*

Effect of temperature on maximum shear stress for various alloying materials have been compared in Fig. 5.

We know that maximum yielding occurs when the largest principal stress equals the yield strength. In this case, we can see that E Glass has the lowest principal stress at maximum temperature.

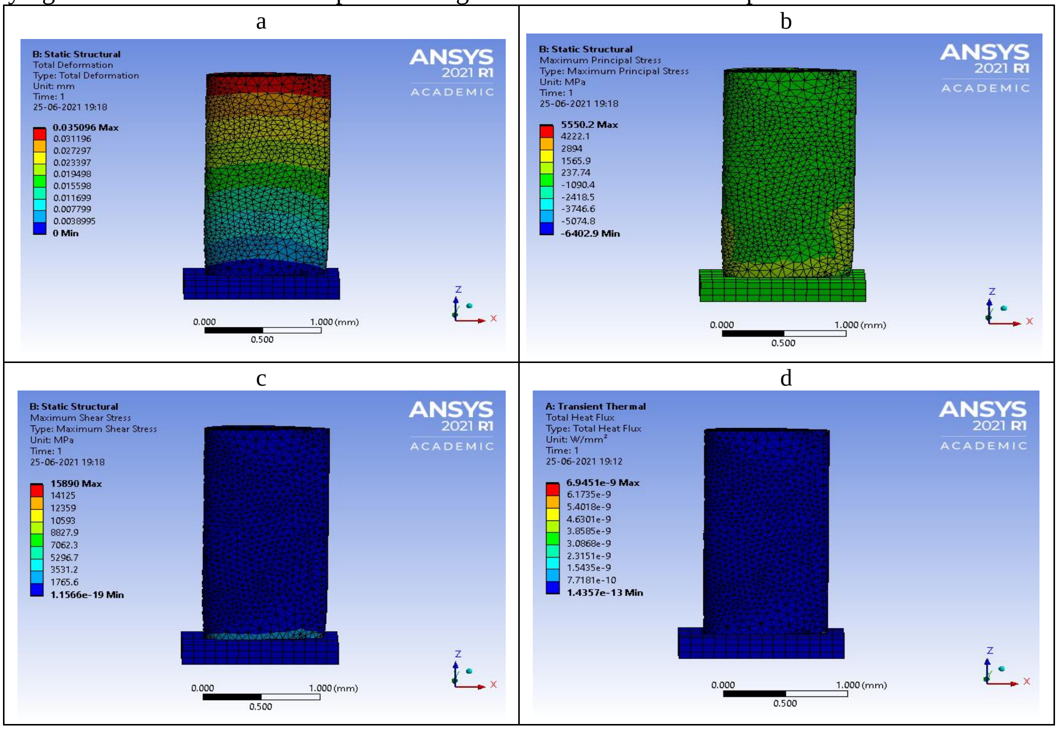

Fig. 3 (a) Maximum deformation (b) Maximum principal stress (c) Maximum shear stress (d) Maximum heat flux

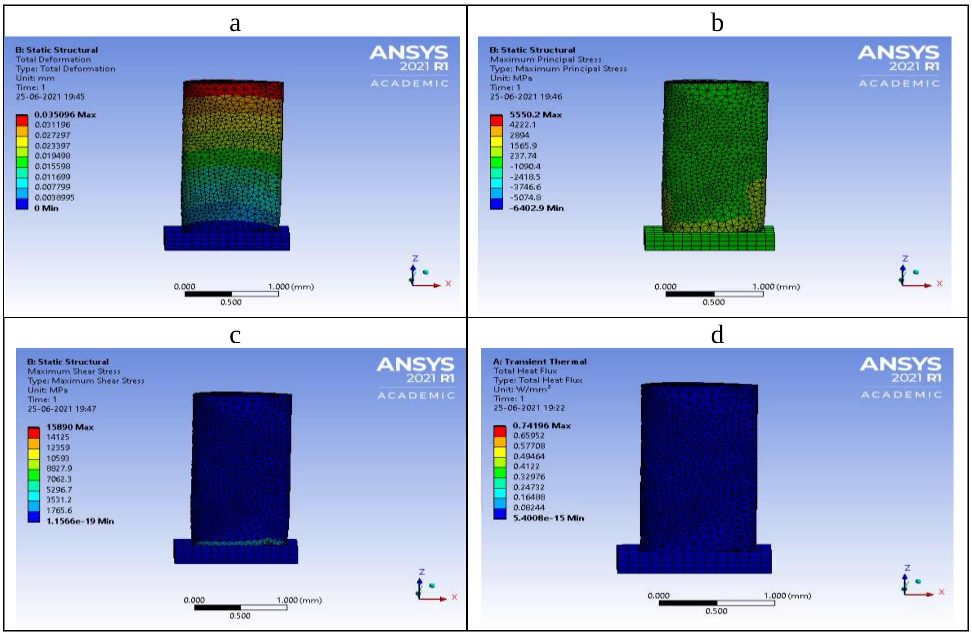

Fig. 4 (a) Maximum deformation (b) Maximum principal stress (c) Maximum shear stress (d) Maximum heat flux

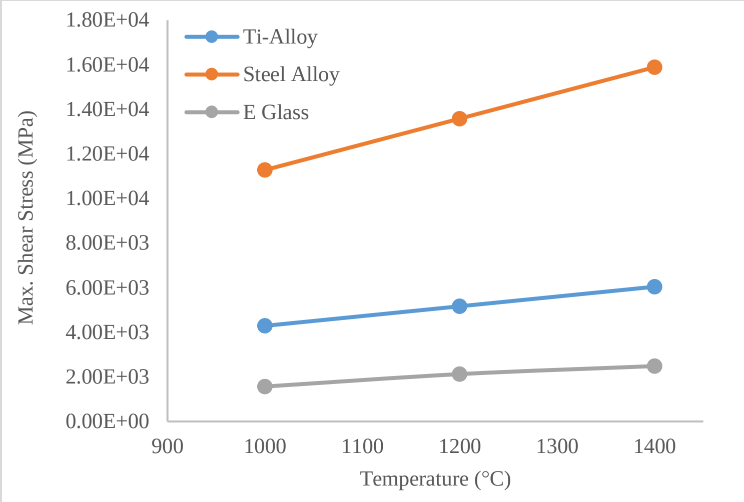

Fig. 5 Effect of Temperature on Max. Shear Stress developed in blade

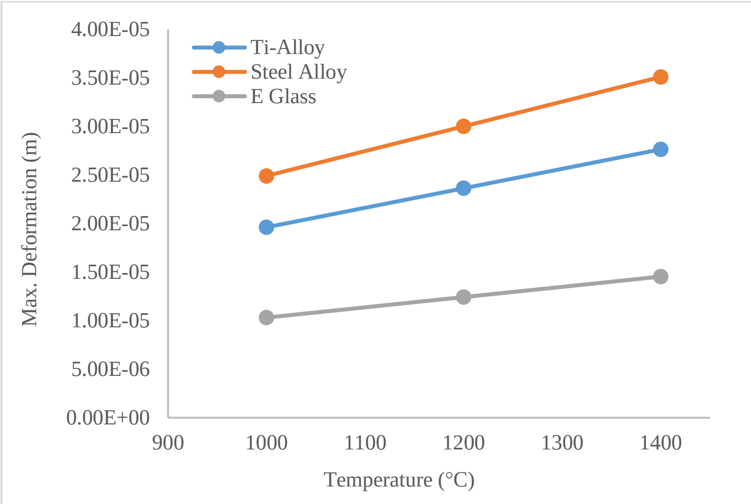

Fig. 6 Effect of Temperature on Max. Deformation developed in blade

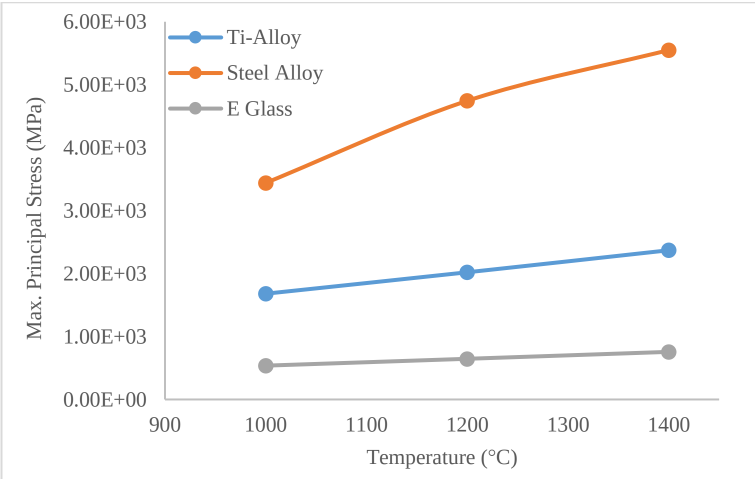

Fig. 7 Effect of temperature on maximum principal stress developed in blade

In Fig. 5, we can see that E Glass possesses the least shear stress compared to the other materials at different temperature slots. Again in Fig. 6, evidently E Glass has the least deformation at varying temperature after Ti-Alloy. As per in Fig. 7, seemingly E Glass possess the least principal stress in the wake of Ti-Alloy. So, E Glass is the most effective material. We can see that at the highest temperature E Glass has the lowest deformation and stresses.

V. CONCLUSION

At same boundary condition it is seen that E glass is showing less deformation than titanium alloy at 1400°C. And steel alloyis showing the maximum deformation. So, the most effective material is E glass. Maximum principal stress and maximum shear stress is also found low in E glass compared to the other two materials. More analysis can be fruitful to gain confidenceon the behavior analyzed in the present work.

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