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Structural Design and Analysis of Gas Turbine Blade using CAE tools

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***Abstract*— In today's industrial scenario, gas turbine is one of the most important parts of a power plant. In order to maximize the overall performance and efficiency of all modern turbines, it should operate at high temperatures and speeds. Due to high operating temperatures and speeds, failure of the turbine blades is inevitable. Hence there is a pressing need for analysis of turbine blades. The steady state thermal and static structural analysis of turbine blade is carried out using ANSYS 14.0 for different titanium alloys.**

In the analysis, it is observed that the bottom trailing edge of the blade section has higher stress value than the tip of the blade. The value of Von-Mises stress and deformation is obtained and it is seen that at 1000^{0}C, Alloy 685 and at 2000^{0}C, Ti 6242S exhibits least amount of stress and undergoes less deformation for a constant turbine speed of 10000 rpm with a pressure of 3.06 MPa.

Keywords—Turbine Blade, Titanium alloys, Von-Mises stress, Ansys 14.0.

I. INTRODUCTION

The turbine is a mechanical power generating rotary device which uses energy of flowing fluid and convert it into useful work. The turbine is designed to extract maximum amount of energy to produce maximum thermal efficiency [1].

In the turbine, a rotary compressor compresses the working fluid and then sends it into the combustion chamber where it gets mixed with the fuel and is heated at elevated temperatures. Now these hot gases are passed on to the turbine blades where they expand and the heat energy gets converted to rotary motion of turbine shaft. The generator coupled to turbine shaft converts mechanical work to electrical output [2].

The thermal efficiency and power output of gas turbine varies directly with the increasing blade inlet temperature. The current inlet temperature is far more than the melting point of blade material. Hence the blade material should sustain the high temperature to increase the thermal efficiency [3].

In a gas turbine, high temperature is created by flowing fluid which tends to fail the blade after some time. Some types of failure are being discussed here: When 150 MW gas turbine was analyzed, it failed by highly intensified vibrations. All blades including stationary blades were damaged. The blade completed 1800 Hrs of life in running mode. More important is that there is no damage to any other section in the securing pin hole located at the root [4].

II. LITERATURE REVIEW

Zuniga [5] explains the design of a turbine in detail and the trajectory of air flow along the blades with various angles of fluid flow with respect to blade are schematically shown thus aiding in development of the blade profile of rotor and stator of turbine through various blade parameters.

Patsa and Mohammed [6] presented analysis of turbine blade geometries, by applying boundary conditions to various blade materials like Monel-400, Haste alloy –x & Inconel 625, steady state thermal and structural performance is carried out.

The works of Homji and Gabriles [7] provides an insight to various modes of failures of gas turbine blades. The prominent of these are fatigue, creep, erosion wear and environmental attacks and combined failure mechanisms.

Jianfuhou, Bryon J. Wicks, Ross A. Antoniou [8] did an investigation of fatigue failures of turbine blades in a gas turbine engine by mechanical analysis which categorized that (i) Fatigue includes both HCF (high cycle fatigue) & LCF (low cycle fatigue) & also (ii) Creep. Which upon investigation by FE (finite element) modelling showed results that the maximum stress occurs at the tip, it indicates thermal expansion, centrifugal load & gas pressure during operation & crack propagation.

G. Narendranath, S. Suresh analyzed [9] the result of gas forces namely tangential and axial which is constructed using velocity triangle by ANSYS. Material of blade is iron based super alloy. They have used finite element method for obtaining approximate results. They found that the thermal stress is less than the yield strength value.

III. MODELLING AND ANALYSIS

The blade model profile is generated by using Solid Edge software. This model of turbine blade is then imported into ANSYS software. Meshing of the model is performed using SOLID 186 elements (since the element supports creep, stress stiffening, large deflection, and strain capabilities).

The bottom edge is fixed and a pressure load of 3.06 MPa and speed is 10000 RPM are taken as boundary conditions along with varying temperatures (10000C and 20000C) for different Titanium alloys.

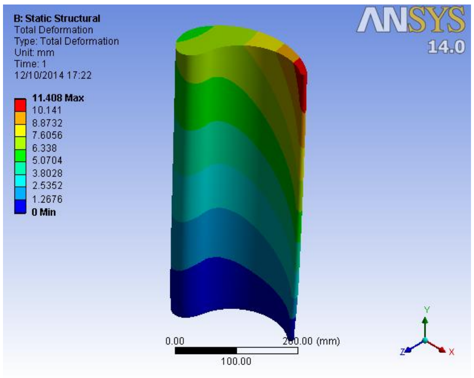

Fig 1. Total Deformation in Ti6242 at 1000° C

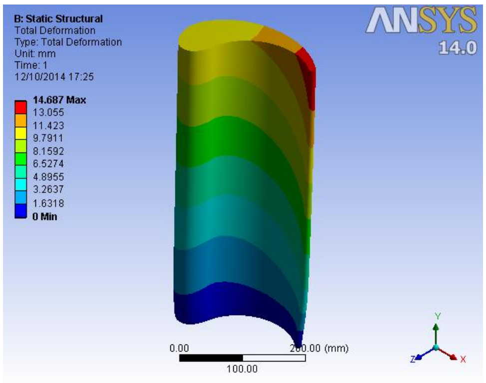

Fig 2. Total Deformation in Ti6242 at 2000° C

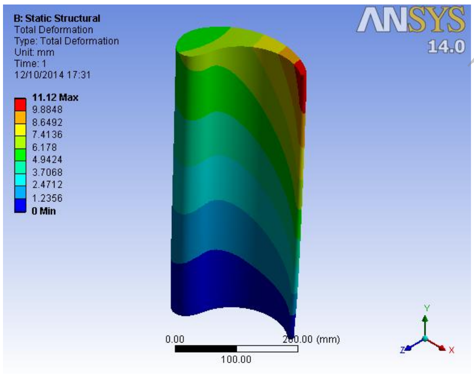

Fig 3. Total Deformation in Ti6242S at 1000° C

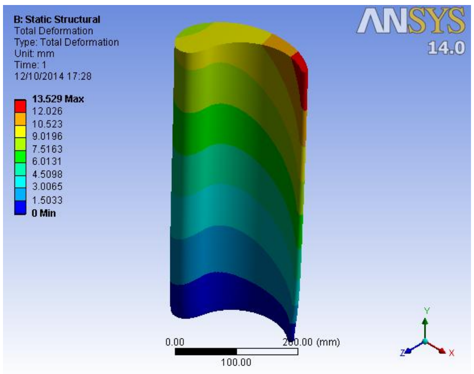

Fig 4. Total Deformation in Ti6242S at 2000° C

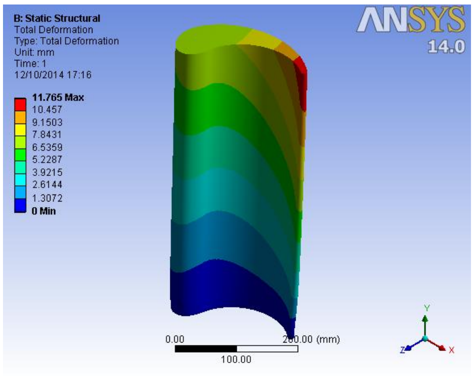

Fig 5. Total Deformation in Alloy 832 at 1000° C

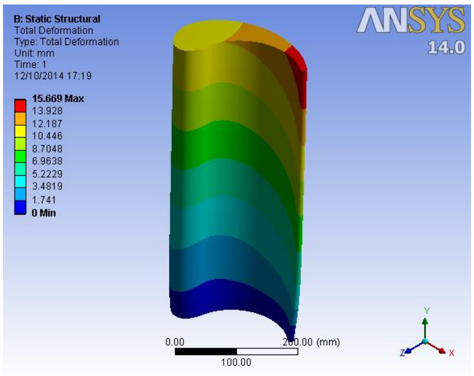

Fig 6. Total Deformation in Alloy 832 at 2000° C

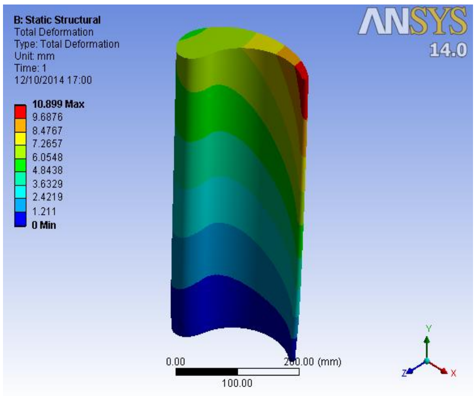

Fig 7. Total Deformation in Alloy 685 at 1000° C

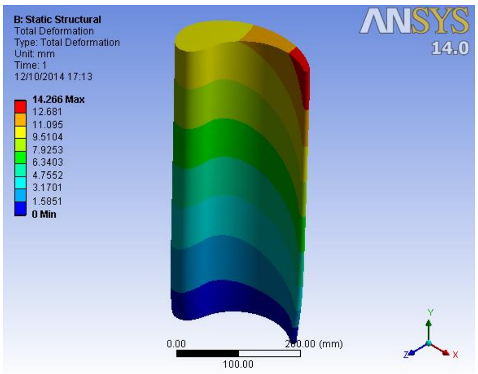

Fig 8. Total Deformation in Alloy 685 at 2000° C

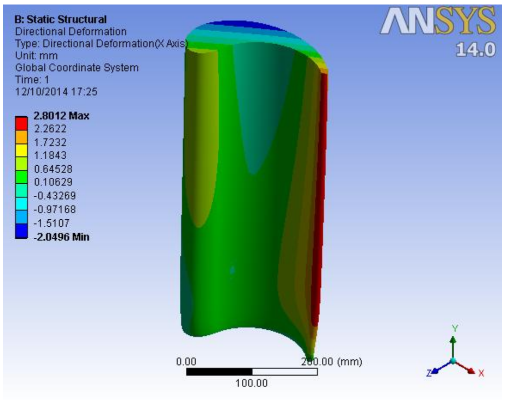

Fig 9. Directional Deformation in Ti6242 at 1000° C

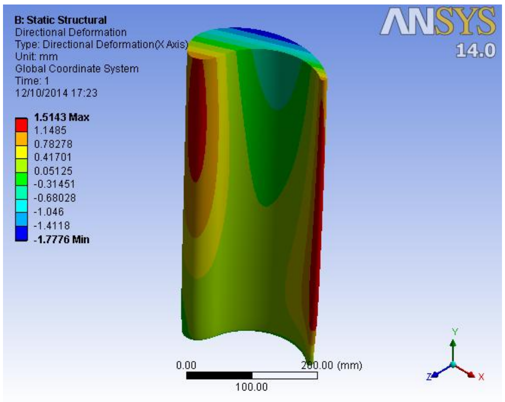

Fig 10. Directional Deformation in Ti6242 at 2000° C

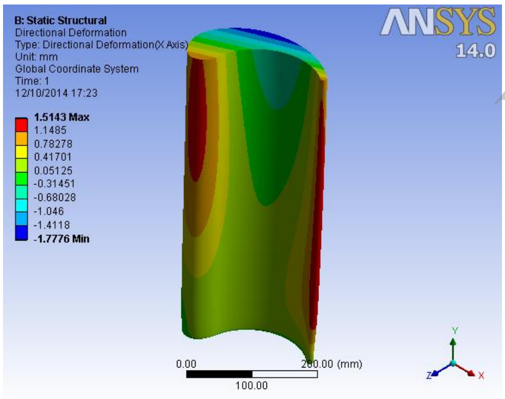

Fig 11. Directional Deformation in Ti6242S at 1000° C

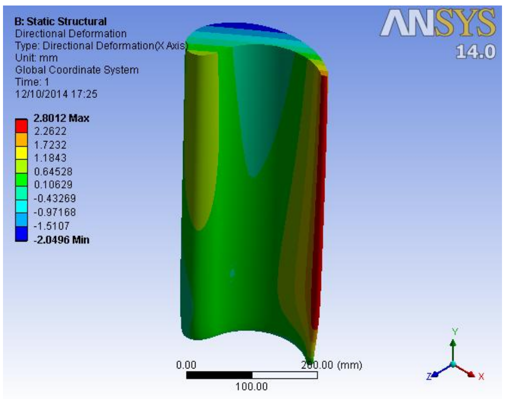

Fig 12. Directional Deformation in Ti6242S at 2000° C

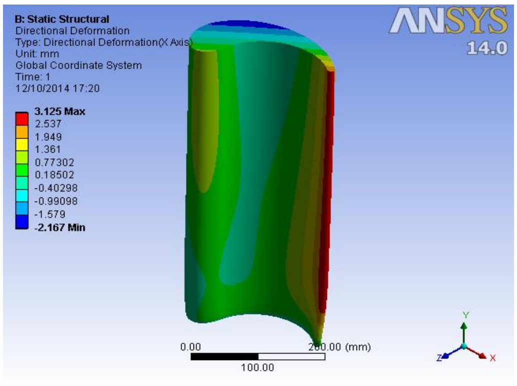

Fig 13 Directional Deformation in Alloy 832 at 1000° C

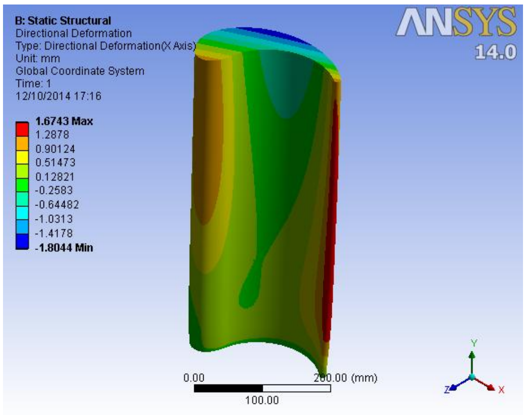

Fig 14. Directional Deformation in Alloy 832 at 2000° C

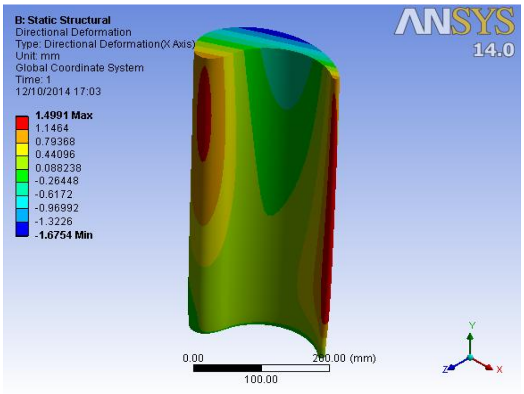

Fig 15. Directional Deformation in Alloy 685 at 1000° C

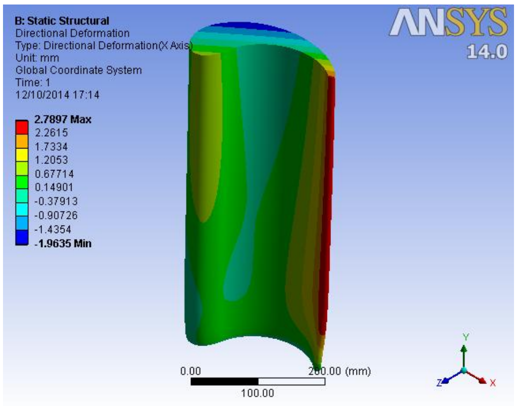

Fig 16. Directional Deformation in Alloy 685 at 2000° C

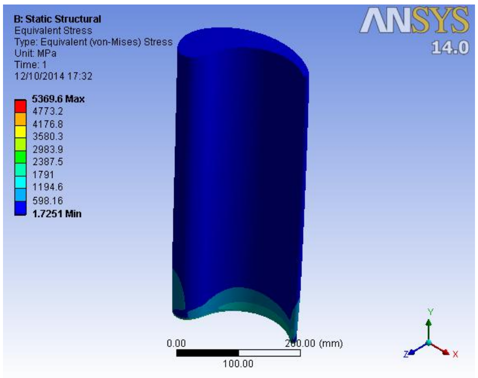

Fig 17. von-Mises Deformation in Ti6242 at 1000^o C

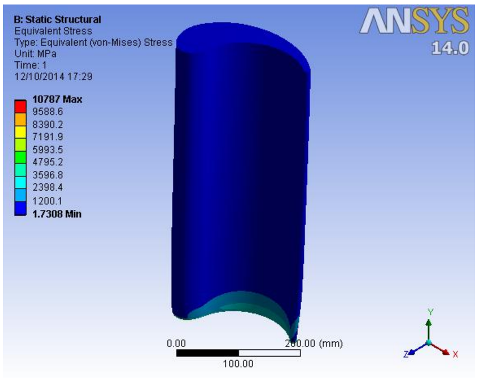

Fig 18 von-Mises Deformation in Ti6242 at 2000^o C

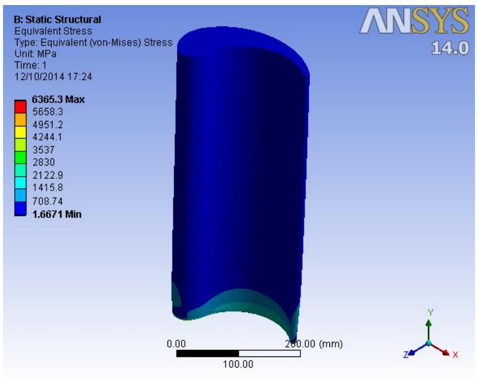

Fig 19. von-Mises Deformation in Ti6242S at 1000^o C

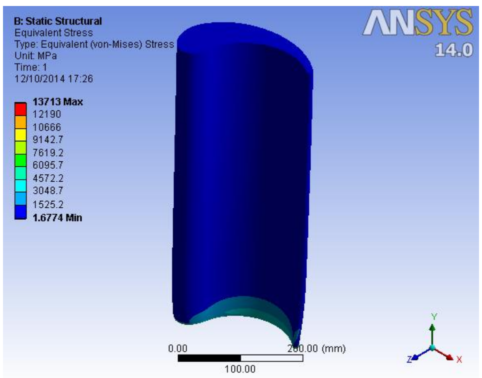

Fig 20. von-Mises Deformation in Ti6242S at 2000^o C

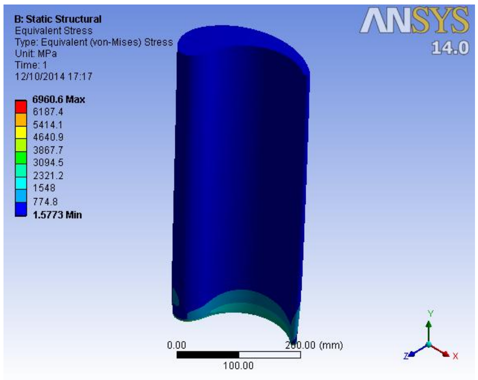

Fig 21. von-Mises Deformation in Alloy 832 at 1000^o C

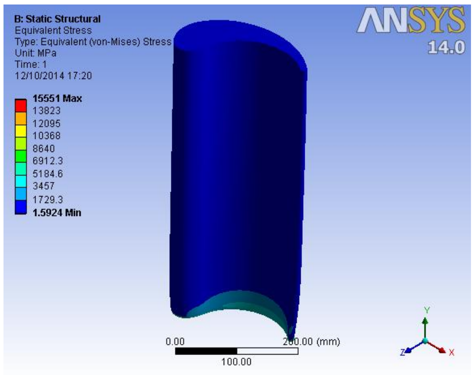

Fig 22. von-Mises Deformation in Alloy 832 at 2000^o C

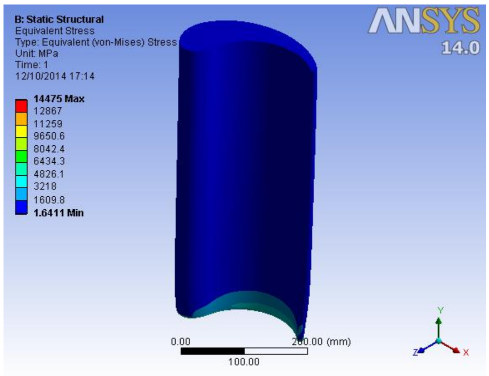

Fig 23. von-Mises Deformation in Alloy 685 at 1000^o C

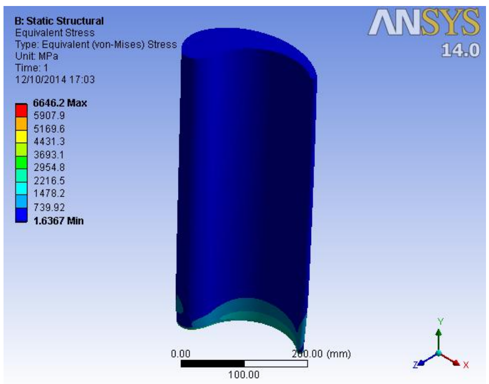

Fig 24. von-Mises Deformation in Alloy 685 at 2000^o C

IV. RESULTS AND DISCUSSION

From the steady state thermal and static structural analysis of turbine blade the following results are obtained. The results are tabulated in Table I, II and Table III.

TABLE I. TOTAL AND DIRECTIONAL DEFORMATION

Material	Result For 1000°C		Result For 2000°C	
	Total Deformation (mm)	Directional Deformation (mm)	Total Deformati on (mm)	Directional Deformation (mm)
Ti6242	11.408	1.5143	14.687	2.8012
Ti6242S	11.12	1.3581	13.529	2.3438
Alloy 832	11.761	1.6743	15.669	3.125
Alloy 685	10.899	1.4991	14.266	2.7897

TABLE II. VON-MISES STRESS

Material	von-Mises stress			
	Result For 1000°C		Result For 2000°C	
	Throughout the body (MPa)	At a point in Bottom Trailing Edge (MPa)	Throughout the body (MPa)	At a point in Bottom Trailing Edge (MPa)
Ti6242	1.6671	6365.3	1.6774	13713
Ti6242S	1.7251	5369.6	1.7308	10787
Alloy 832	1.5773	6960.6	1.5924	15551
Alloy 685	1.6367	6646.2	1.6411	14475

TABLE III. HEAT FLUX (THERMAL ANALYSIS)

Material	Static Thermal Analysis			
	Result For 1000°C		Result For 2000°C	
	Total Heat flux (W/mm2)	Directional Heat flux (W/mm2)	Total Heat flux (W/mm2)	Directional Heat flux (W/mm2)
Ti6242	1.08E-11	5.62E-12	2.16E-11	1.13E-11
Ti6242S	1.08E-11	5.67E-12	2.16E-11	1.13E-11
Alloy 832	1.08E-11	5.63E-12	2.16E-11	1.13E-11
Alloy 685	1.08E-11	5.63E-12	2.16E-11	1.13E-11

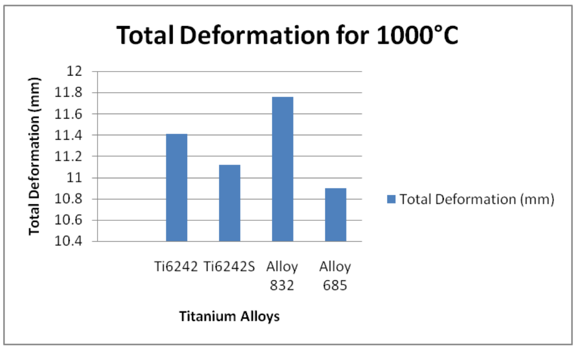

Fig 25. Total Deformation at 1000° C

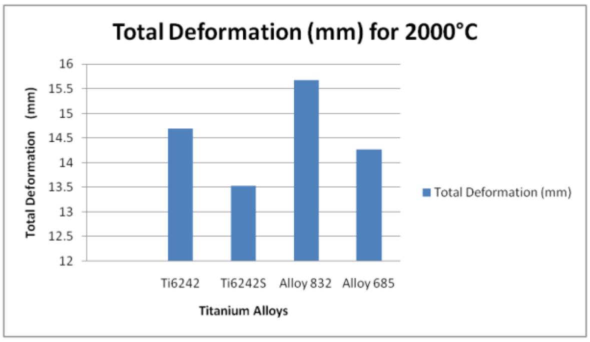

Fig 26. Total Deformation at 2000° C

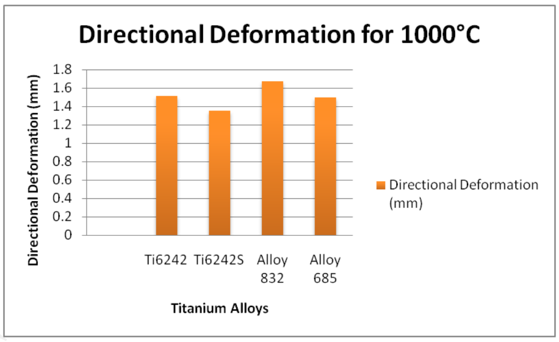

Fig 27. Directional Deformation at 1000° C

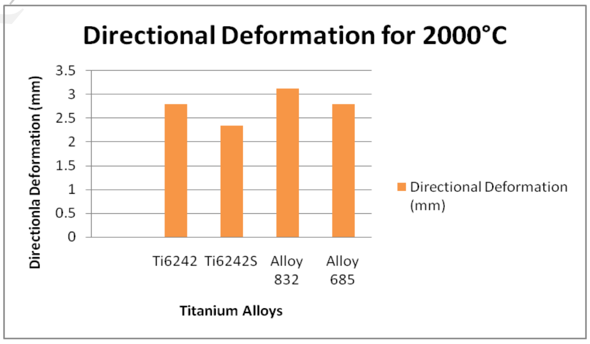

Fig 28. Directional Deformation at 2000° C

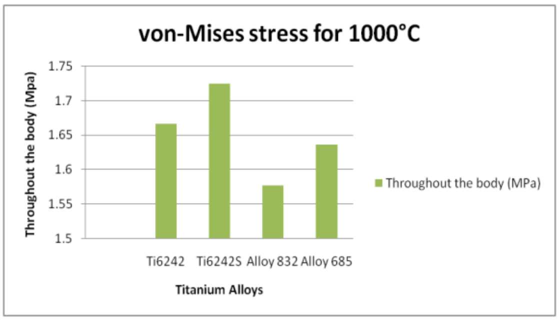

Fig 29. von-Mises Stress throughout the body at 1000° C

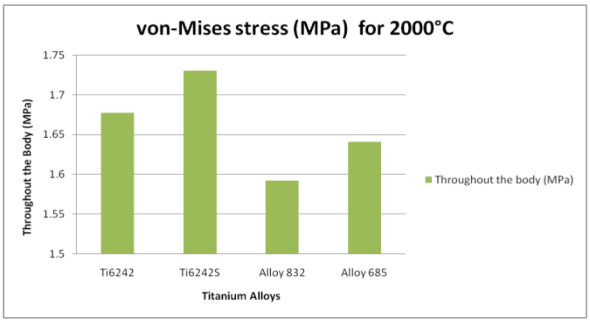

Fig 30. von-Mises Stress throughout the body at 2000° C

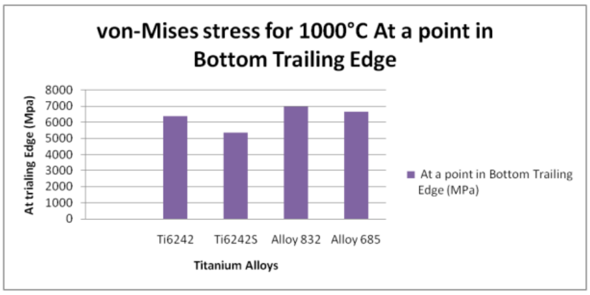

Fig 31. von-Mises stress in bottom trailing edge at 1000° C

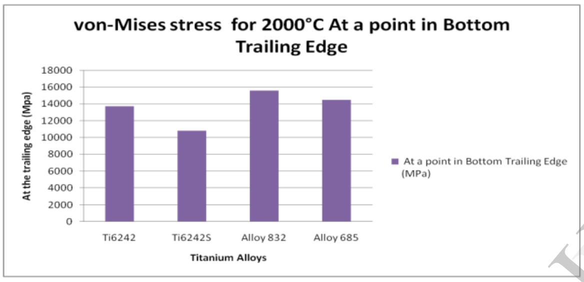

Fig 32. von-Mises stress in bottom trailing edge at 2000° C

From the above results, it is observed that, the fixed end exhibits maximum stress and deformation compared with the overall blade. From the above used materials Alloy 685 has the least deformation at 10000C and Ti6242S has the least deformation at 20000C (Fig. 1-16).

It can be seen that for 10000C and 20000C, Alloy 685 and Ti 6242S respectively exhibit least stress as compared to other materials (Fig 17-24).

V. CONCLUSION

From the above study it can be observed that the bottom trailing edge of the blade is prone to failure. The top trailing edge of the blade exhibits large deformation as compared to overall blade. For the temperature range for 7500C-12500C, Alloy 685 is best suited and from temperature range of 12500C-22000C, Ti6242S is suited and can be used. It is also found that with the use of thermal barrier coatings the above materials will exhibit greater stability and longer life.

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