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Analysis of Creep Life Prediction for Gas Turbine Disc

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Abstract- For many components of aero gas turbine engine, the design for creep is conservative because of close control of dimensions required over the engine life. The maintenance of critical dimensions, such as clearance between rotating and static parts, through the service life is the basic requirement that dictate the creep design of the aero gas turbines. Blades are one of the most important components in the gas turbine power plants. There are components across which flow of air takes place to produce work. Blade is the medium of transfer of energy from the air to the turbine rotor. However the compressor blade does work in the air by compressing the air. So as the increase its pressure above the atmospheric pressure and then delivers it to the combustion chamber. The blades as an entity is subjected to a large number of forces, some are inevitable and some are caused by the rotating of blade. Further the blade is subjected to differential thermal stress, erosion, corrosion and a host of other hostile parameters hampering its smooth functioning. Blade and disc growth occur due to the thermal and centrifugal loading. The complexity in the shape of the disc makes it difficult to estimate its life using finite element analysis can be used. Hence there is a need to analyze the temperature distribution stresses and creep strains experienced by the turbine blade. The objective of this work is to determine the life of typical aero gas turbine disc, to accumulate creep strain and hence to emphasize on the considerations given to creep in the design of aero gas turbine discs.

Index Terms- Blades, Creep Life, Finite element analysis (FEA), Gas turbine disc, Larson-Miller parameter (LMP) and Thermal analysis.

1. INTRODUCTION

The Gas Turbine is an internal combustion rotary engine and the example is the jet aircraft engine. The engine burns a lean mixture of fuel with compressed air. The hot pressurized combustion gases expand through a series of rotating turbine wheel and blade assemblies. It results in shaft power output, propulsive thrust or a combination of two. Metals subjected to a constant load at elevated temperatures will undergo 'creep', a time dependent increase in length [1]. The terms 'high' and 'low' temperature in this context are to the absolute melting temperature of the metal. Operating temperatures in applications like steam power plant, chemical plant and oil refineries seldom exceeded 500 0C. Since the development of the gas turbine in the 1940's successive designs have pushed this temperature up to typically 10000 C. Developments in high temperature alloys with improved high temperature strength and oxidation resistance has had to keep pace with these demands, and applications like rocket engines present greater problems [2].

Creep, which is the continuous accumulation of deformations and hence strains of a material, most of which is irreversible, under constant loads at elevated temperatures maintained over a period of time, is a life limiting criterion for the design of the turbine discs. Creep resistance is one of the many requirements that must be met by the aero engine components subjected to elevated temperatures. Precise information on the deformation is, therefore, required for the analysis and design of aircraft engine components particularly the turbine discs and blades.

The Creep Curve, Creep in metals is defined as time dependent plastic deformation at constant stress (or load and temperature). The form of a typical creep curve of strain versus time is shown in Fig.1 [3]. The slope of this curve is the creep rate (d ε / dt). The curve may show the instantaneous elastic and plastic strain that occurs as the load is applied, followed by the plastic strain, which occurs over time.

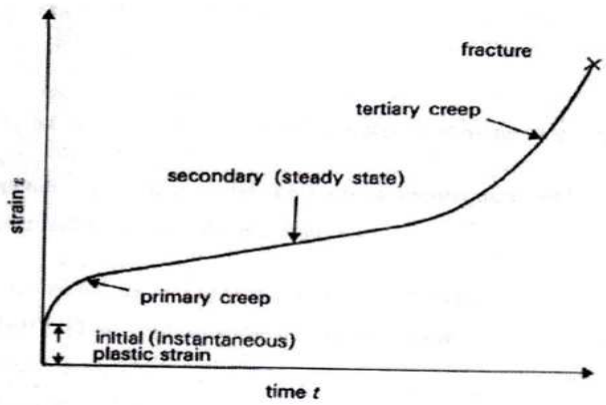

Fig. 1. Strain in a typical creep curve

Three stages to the creep curve kl may be identified. Primary creep is one in which resistance increases with strain leading to a decreasing creep strain rate.

Secondary (Steady State) creep is one in which a balance between work-hardening is and recovery processes, leading to a minimum constant creep rate [4]. Tertiary creep is one in which an accelerating creep rate due to the accumulating damage, which leads to creep rupture, and which may only be seen at high temperatures and stresses and in constant load machines.

2. MODELING OF THE DISC

2.1. *2-D Axi -sysmetric cross sectional view of a gas turbine disc*

Fig . 2. 2D Axi-sysmetric cross sectional view of a gas turbine disc shows the detailed dimensions.

2.2 *3D modeling*

The 3D geometry of solid modeling of a typical aero gas turbine disc is created by using CATIA Software in the post processer. The solid model of the disc and the 2D axi-symmetric model with dimensions are shown in the fig. 2. and 3. respectively. The 2D axi-symmetric model was made into a surface and the free meshing of the surface was carried out in CATIA. The mesh was generated using the plane axi-symmetric element. Solid model is imported to Ansys. Material properties and loads are axial symmetric and hence the problem is mathematically two-dimensional. The turbine disc being thicker can have strong non-linear stress distribution across the thickness. The analysis has to be performed at critical time points using eight node isometric 2D axi-symmetric elements

3. NUMERICAL METHODOLOGY

3.1. *3D Modeling with Meshing*

The thermal gradient along the radius of the disc was determined by performing a heat transfer analysis. The element used for the thermal analysis in ANSYS is PLANE 55. The element can be used as a plane element or axi-symmetric element with a two-dimensional thermal conduction capability. The element is applicable to a 2D, steady state or transient thermal analysis. Four nodes and the orthographic material properties define the element. Orthographic material directions correspond to the element coordinate directions. As the model containing the temperature element is also to be analyzed temperature (PLANE 42). Element name is PLANE 55, nodes are I, J, K, L and degree of freedom is temperature.

3.2. *Meshing*

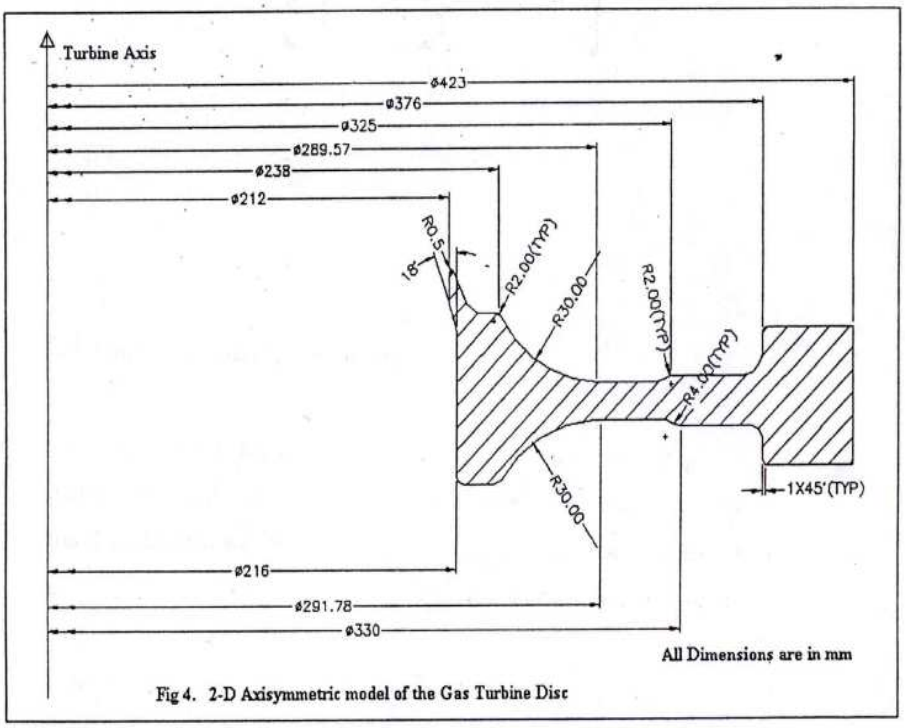

Fig. 2. 2D Axi-sysmetric cross sectional view of a gas turbine disc [6]

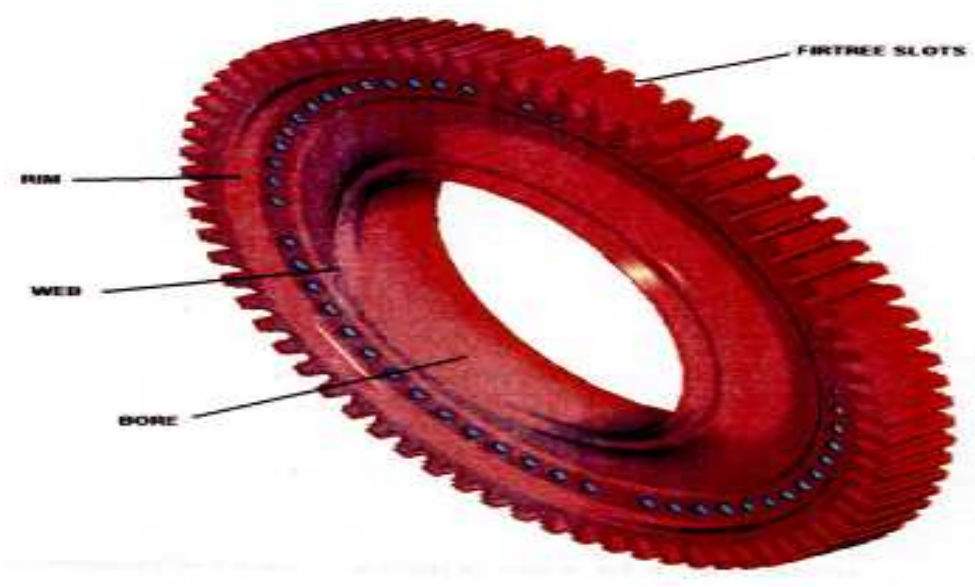

Fig. 3. Solid Model of a gas turbine disc generated using CATIA software

Fig. 4. 3D model of the disc was meshed using the plane element in ANSYS.

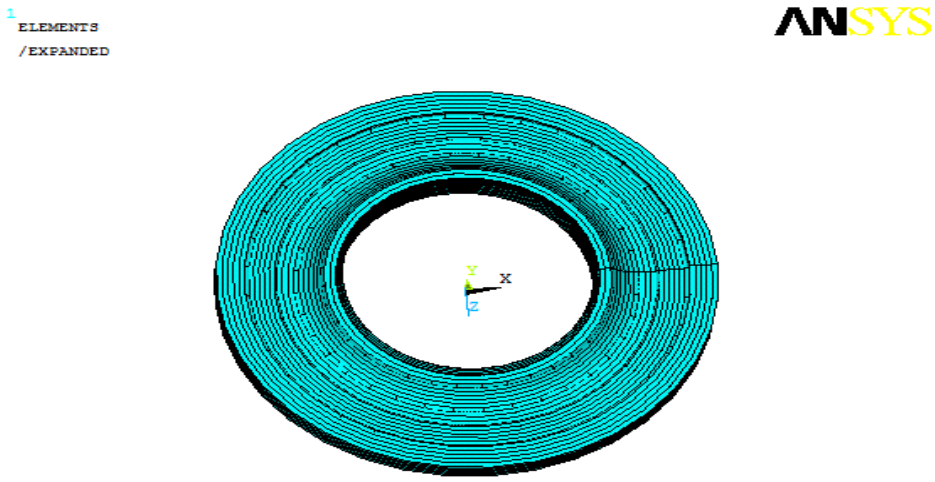

Fig. 4. 3D model of a gas turbine disc with mesh

3.3. *Material Properties*

Nickel based super alloys are used, because their superior resistance to creep and strength at high temperature. The material has precipitation hardening with good corrosion and oxidation resistance along with strength and creep rupture properties [5]. Properties are Mass Density $=8.39*10^{-10}$ Kg / mm^3, Thermal conductivity =0.016 W/mm ^oC and other physical properties of the alloy INCO-718 are presented in

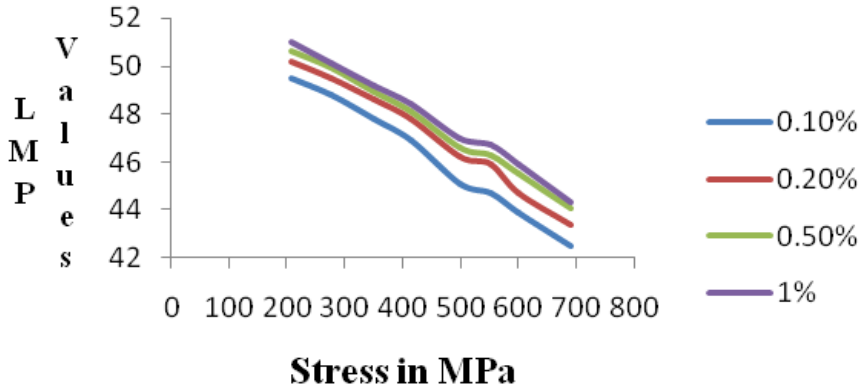

Fig. 5. Variation of LMP values with respect to stress for different percentage Accumulation of creep strain

Table 3.1 Properties of INCO -718

Property	Temperature (^{0}C)						
	20	**100**	**200**	**300**	**400**	**500**	**600**
Young's Modulus, E(Kgf /mm^2)	20387	19932	19426	18849	18272	17644	16971
Coefficient of Linear Thermal Expansion, α(10^{-6} / ^{0}C)	12.15	12.22	13.24	13.70	14.04	14.31	14.67
Poisson's ratio,γ	0.2940	0.2870	0.2800	0.2728	0.2719	0.2717	0.2768

The LMP values, for the accumulation of various amounts of creep strains corresponding to different stress levels are presented in Table 3.2. The graph showing the variation of LMP values with respect to the stress, for different percentage accumulation of creep strains is shown in the fig. 5.

Table 3.2 Creep Properties of INCO-718

Stress, σ (MPa)	Larson-Miller parameter (LMP) Values for different % of Creep Strains			
	0.1%	0.2%	0.5%	1.0%
207	49.5	50.2	50.6	51.0
276	48.8	49.5	49.9	50.1
350	47.8	48.6	48.9	49.2
414	46.9	47.8	48.1	48.4
500	45.1	46.2	46.6	47.0
552	44.7	45.9	46.3	46.7
600	43.9	44.7	45.5	45.9
690	42.5	43.4	44.1	44.3

3.4. *Loads and Boundary Conditions*

The temperature along the radial direction (x axis) given and the corresponding convection heat transfer coefficients in the various regions of the disc. Fig. 6. shows the loads and the boundary conditions for thermal analysis. The thermal analysis is carried and the nodal temperature distribution plot is obtained

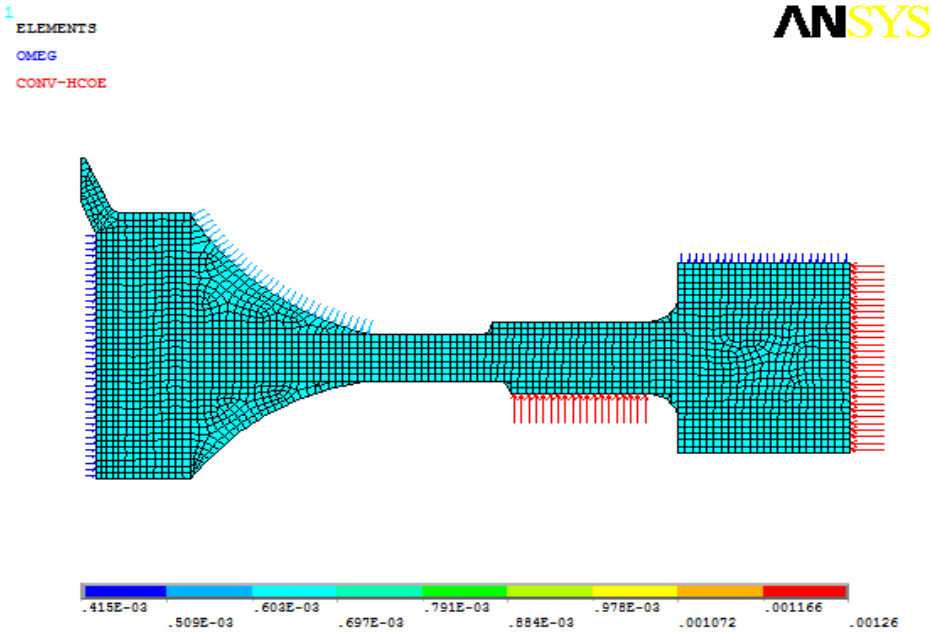

Fig. 6. Loads for thermal analysis

4. RESULTS AND DISCUSSION

The results of the analysis carried in the ANSYS with four different stages mentioned earlier. The radial stress and the von mises stress distribution plots are presented for all the four cases.

4.1. *First Stage for Radial and Von mises Stresses Distribution in Different Stages*

The body force due to the consideration of rotation. The angular velocity, ω =1156.8 rad/sec is imposed. Fig. 7. shows the distribution of radial stress for disc. The disc was constrained along the axial direction and is allowed to grow in the radial direction. Then radial stress is shown in the Fig. 7. The body force and angular velocity of 1156.8 rad/sec, the maximum stress (100.902) will be developed in the disc at the rim and minimum stress is observed at the end parts of the rim and bore. Fig. 8. shows the von mises stress is considered for the same body force and angular velocity of 1156.8 rad/sec the maximum stress (176.162 MPa) is observed in the disc at the end part of the rim and minimum stress is observed at the end part of the bore.

4.2. *Second Stage for Radial and Von mises Stresses Distribution in Different Stages*

The body force due to the consideration of rotation. The calculated value of blade is 13402.8Kgf. Fig.9. shows the body force and angular velocity is considered along with loads. Maximum stress (112.424 MPa) is observed in the disc at the rim lower end and minimum stress is observed at the end of the rim and lower side of the bore. The disc was constrained along the axial direction to radial direction. Fig.10. shows the Von mises stress. The maximum von mises stress (187.378 MPa) is appeared at the end of the rim and minimum stress developed at the lower end of the bore.

4.3. *Third Stage for Radial and Von mises Stresses Distribution in Different Stages*

The thermal gradient is super imposed in the above two stages of loading. The thermal gradient is obtained by performing a heat transfer analysis on the disc. Fig.11. shows the stress plots obtained in the stage 3. In stage 3 body forces, blade loads and thermal gradient have considered. Fig.12. shows the von mises stresses. The maximum von mises stress (208.261 MPa) is observed at end of the rim and minimum stress is observed the end of the bore.

4.4. *Fourth Stage for Radial and Von mises Stresses Distribution in Different Stages*

In addition to the above-mentioned four stages of loadings, the creep material properties were defined here. The values of the three constants already evaluated are defined and the disc is made to run for 10 hours. The creep analysis was carried out. Fig.13. shows the stress plots for stage 4. Fig.15. shows the Von mises stress distribution for stage 4.The maximum von mises stress (209.434 MPa) is found at upper end

of the rim and minimum stress is observed at end the of bore.

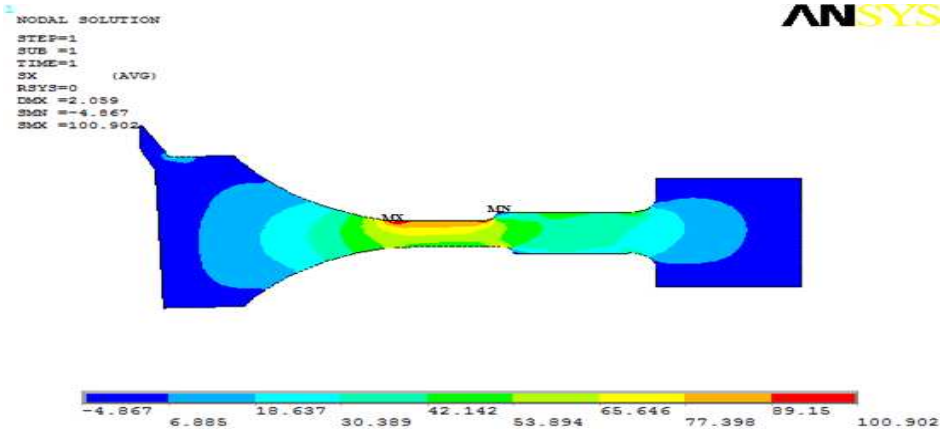

Fig.7. Radial stress distribution (stage 1)

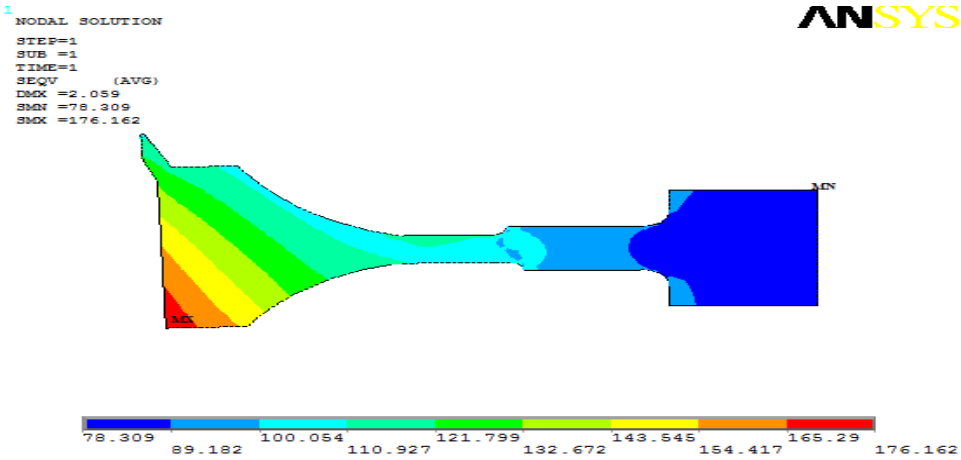

Fig.8. Von mises stress distribution (stage 1)

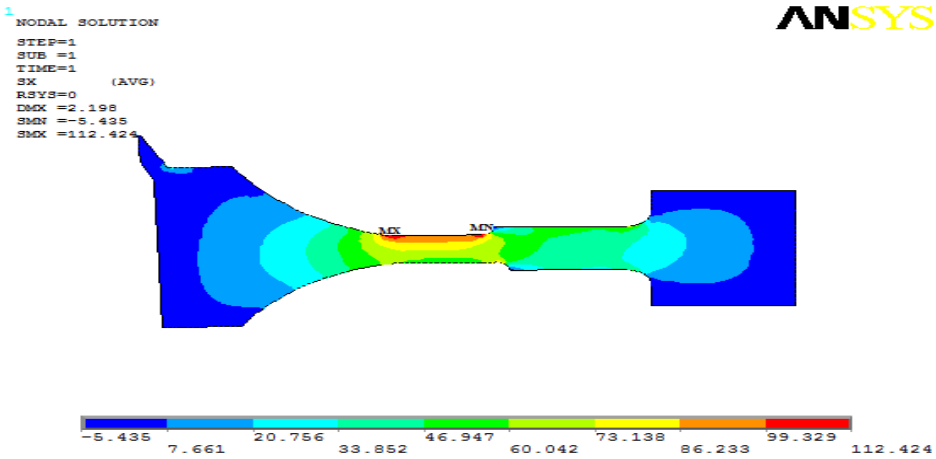

Fig.9. Radial stress distribution (stage 2)

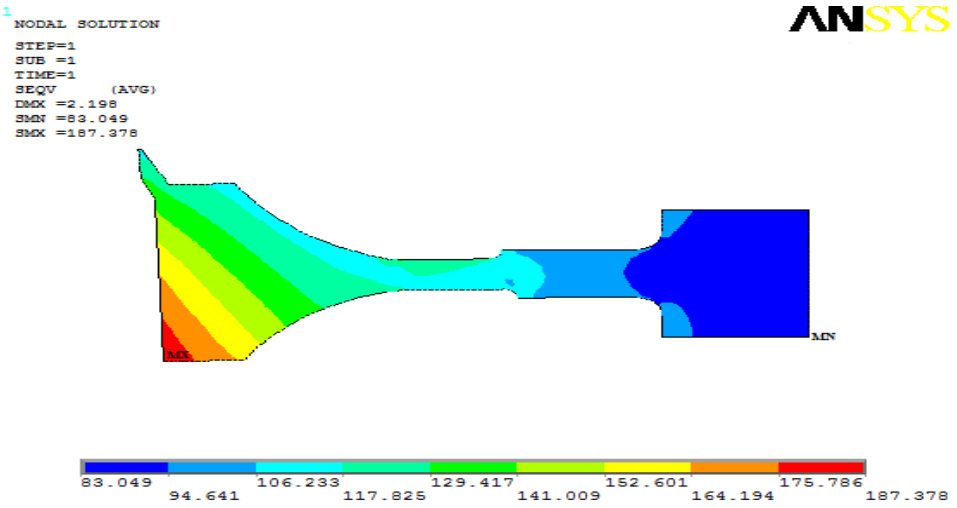

Fig.10. Von mises stress distribution (stage 2)

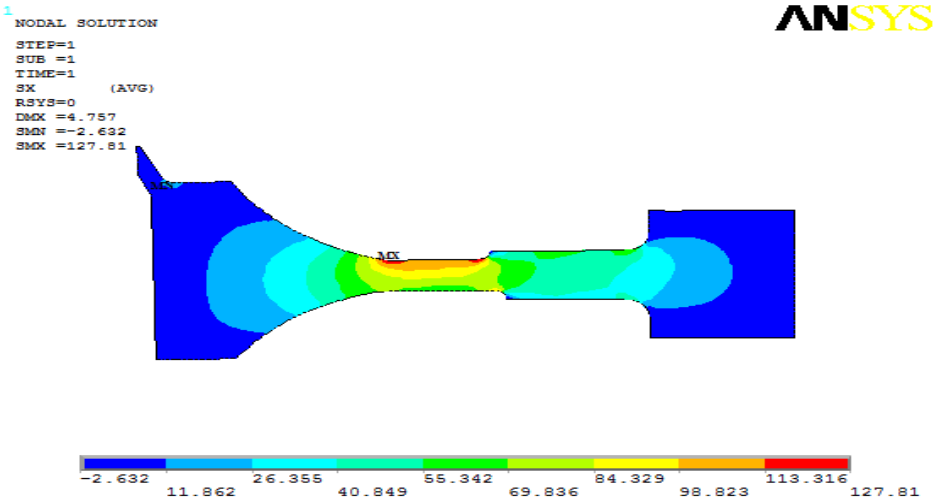

Fig.11. Radial stress distribution (stage 3)

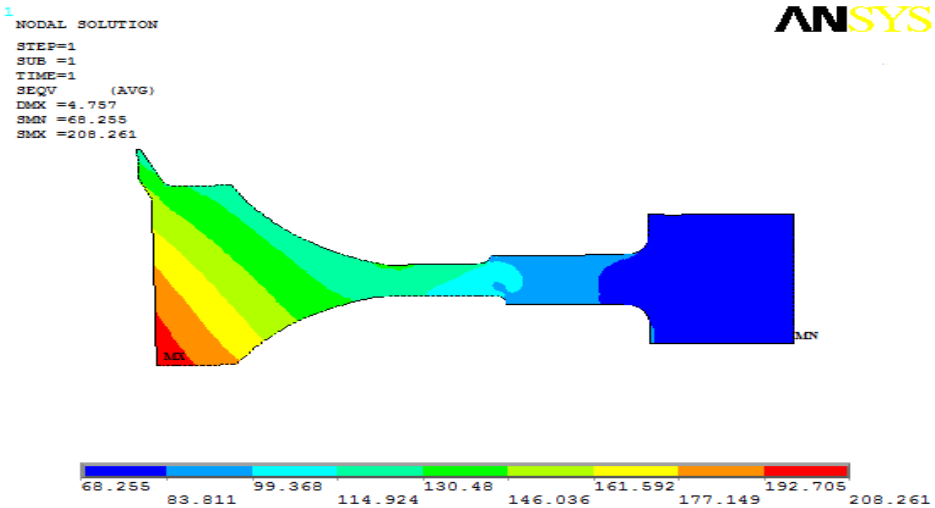

Fig.12. Von mises stress distribution (stage 3)

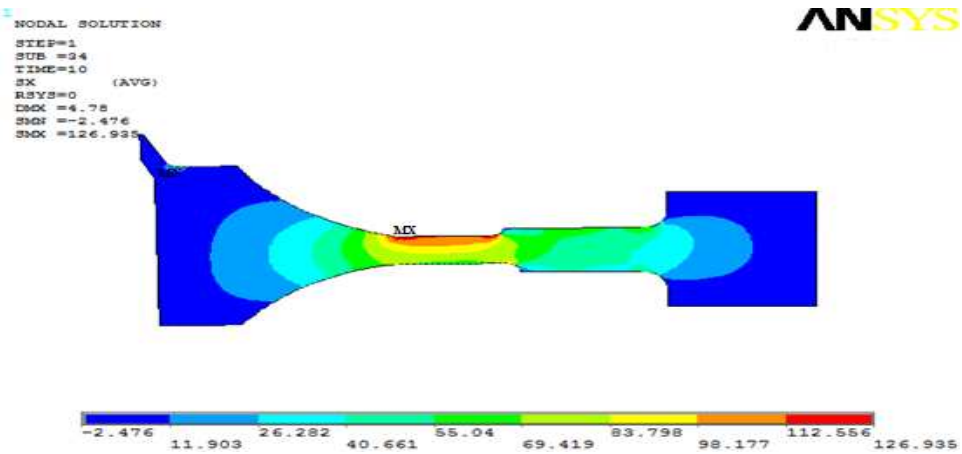

Fig.13. Radial stress distribution (stage 4)

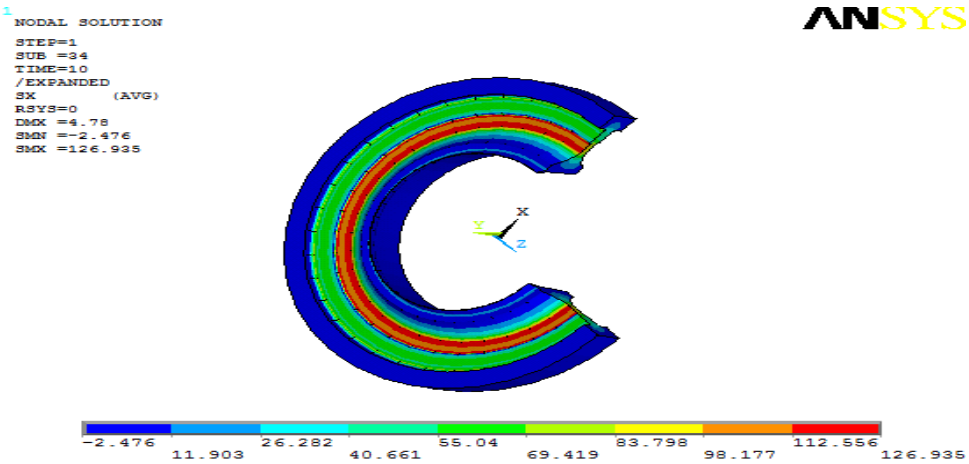

Fig .14. 3D model of a gas turbine disc with 3/4 expansion (stage4)

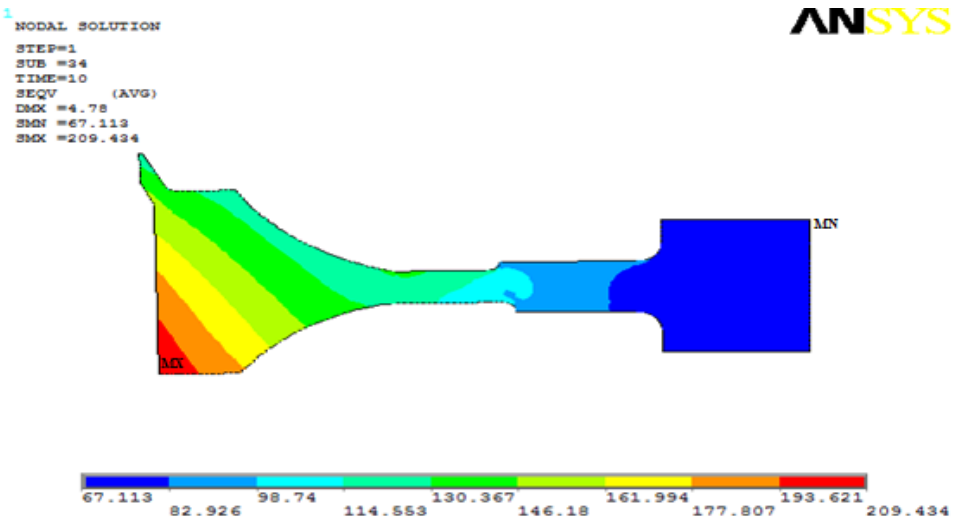

Fig.15. Vonmises stress distribution (stage 4)

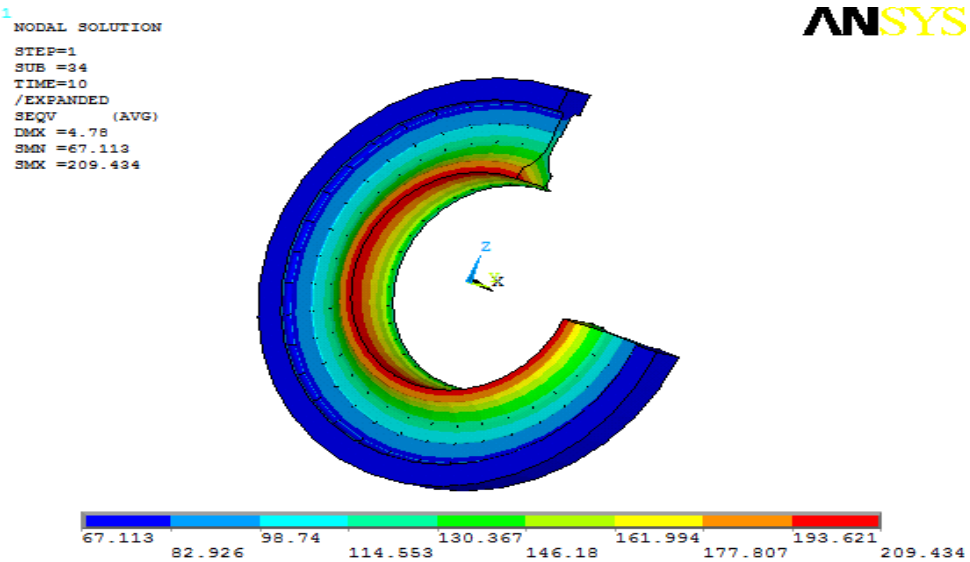

Fig.16. 3D model of a gas turbine disc with 3/4 expansion (stage4)

5. CONCLUSIONS

From the above results we have sought to explain the creep life estimation of aero gas turbine disc. Some of the salient features of this work are as follows.

- The FEA of the 2D axi-symmetric model of the disc is carried out, considering the mechanical and thermal loads. The material constants required for the time hardening model are evaluated using LMP data for different values of percentage accumulation of creep strain in the disc.
- The least square error approximation was employed to evaluate the value of the three constants. By defining the model through these constants, stress relaxation feature was captured and the total time in hours for an accumulated creep strain of 0.1% is calculated. The time required to accumulate the creep strain without considering the stress relaxation phenomena is observed conservative by an order.
- The evaluated value of life of the aero gas turbine disc, upon considering the creep properties was higher than the case without that consideration. Thus it can be concluded that the process of evaluating the life of the aero gas turbine disc would be an underestimation, if the creep properties are ignored.

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