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Research Paper

ANALYSIS OF TURBINE DISC FOR CREEP LIFE

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The deformation and fracture of gas turbine parts like turbine blades which are subjected to high temperature and other mechanical loads, depends mainly on temperature and time and hence due to creep. For reliable operation of a gas turbine, life prediction of the components of the turbine is of prime importance so that the damages can be detected and repaired before it gets problematic. In the present study, a low-pressure turbine disc is analyzed for the stress field under mechanical and thermal loading. The mechanical thermal loads and boundary conditions are imposed in the finite element analysis software ANSYS. A time hardening model is used to predict the stress relaxation and creep strain accumulations in the component with respect to time. The Larson-Miller Parameter (LMP) data is used to evaluate the constants used in this creep analysis. 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% was calculated. The time required for the accumulation of the creep strain, without considering the stress relaxation phenomena was observed to be conservative by an order. Thus the considerations given to creep play a vital role in the design of machine components especially the aero gas turbine engine components, which are primarily subjected to severe mechanical and thermal loads.

Keywords: Gas turbine, Creep life, Larson miller parameter, Stress relaxation

INTRODUCTION

Metals subjected to a constant load at elevated temperatures will undergo ‘creep’, a time dependent increase in length. The terms ‘high’ and ‘low’ temperature in this context are to the absolute melting temperature of the metal. At homologous temperatures of more than 0.5 Tm, creep is of engineering significance.

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 most be met by the aero engine components subjected to

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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.

Unlike ordinary strength calculations, which have the object of determining the absolute strength of a component, the object creep calculations is to ensure that the component will not fail to perform its structural function within a certain specified life period of time.

The following requirements are applied to the component. The total deformation should not exceed a certain predefined value in accordance with the structural function of the component. Failure should not occur during service life.

The blade is expected to exhibit a reasonable short time creep life of the order of 10 hours, in this condition. Such a low value of life is acceptable as the total time spent by the blade in this condition would be very short during its service life whereas, in the cruise condition the blade is subjected to less severe thermal and mechanical environments and also the component spends comparatively longer period in this condition in its service. Hence, it is expected to have a much longer creep life in this condition. The blade has to meet the specified safety standards in each of such operating conditions.

CREEP ANALYSIS

Time-Hardening Hypothesis

The time hardening model, suggested for the first time by Davenport (1838) and developed by Kachanov (1960), is also known as the flow theory or the second variant of the ageing theory. It assumes that at constant temperature there exists the relationship between the creep strain rate the stress ±, and the time t.

$$F(\pm, t, T) = 0 \quad \text{...(1)}$$

The creep strain is generally assumed to depend on the stress, temperature and time (or strain) and is generally written in rate form in order to include, in some measure, the history dependence of the creep process.

$$£^c = A\pm^{n} t^m \quad \text{...(2)}$$

It is assumed to be valid for uni-axial creep under constant stress and temperature. A,n,m are parameters, depend on temperature and time. If at a time t_i the total stress is $\pm_i$, it is represented in the creep curve by point M_i If the stress is assumed to remain constant for a small time step, creep follows the curve that corresponds to the stress $\pm_i$ and starts from point M_i. In a time interval Δt, a creep deformation of $\Delta £_c$ accumulates. This way the change in creep strains in the time interval is calculated. Adding these incremental creep strains to the corresponding free strains of each linear element the redistributed stress at that point is evaluated.

Now creep occurs along the curve that corresponds to new stress value $\pm_i + 1$ commencing from the point at which elapsed time is $t_{i+1} = t_i + \Delta t$. In order to find this point on the new creep curve a vertical line is drawn from the end of the incremental creep strain on the previous creep to meet the new curve at point M_{+1}. Continuing this process the relaxation curves are constructed. The total elapsed time gives the creep life for the accumulated creep strain at that point.

FINITE ELEMENT OF THE DISC

The solid model of the disc and the 2-d axisymmetric model with dimensions are presented in the Figures 1 and 2 respectively. The 2-d axisymmetric 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-axisymmetric element. The method model is then imported to ansys and further analysis is carried. Here the geometry, 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 and the analysis has to be performed at critical time points using eight node isoperimetric 2-d axisymmetric elements.

Solid Model of a Typical Gas Turbine Disc

Material Composition

The commercial name of the material of the disc is INCONEL718, a nickel based super alloy. Its composition is presented below (http://www.hightempmetals.com/techdata/hitempInconel718data.php).

Figure 1: Solid Model of a Gas Turbine Disc

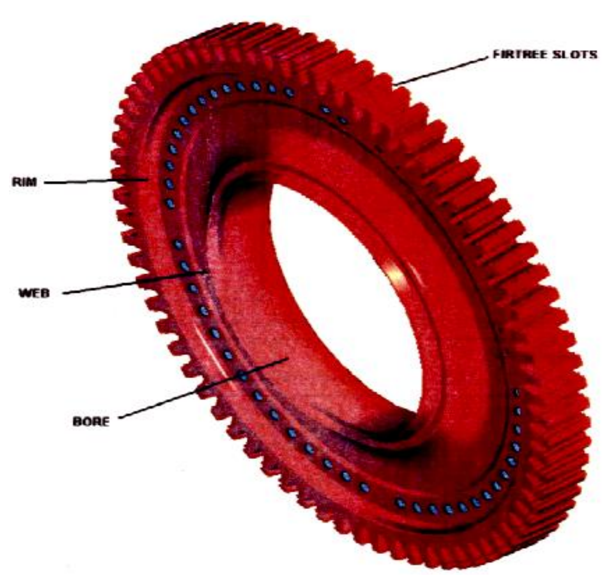
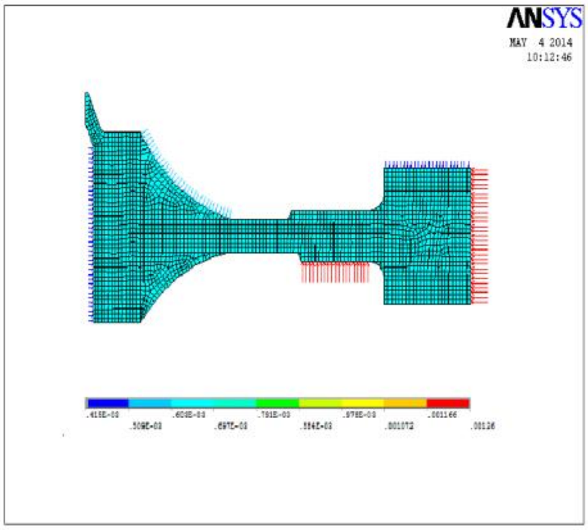


Figure 2: Loads for Thermal Analysis



A1 = 0.4%-1.0%

C = 0.08%

Cr = 14.0%-17.0%

Fe = 5.0%-9.0%

Ni = 0.7 min

Ti = 2.25%-2.75%

Cb +Ta = 0.7%-1.2%

Assumptions

In the computation of creep strain accumulation certain assumptions would need to be made.

1. The most important of them is that the disc material is perfectly elastic. There is considerable amount of literature on tension creep under constant load and constant temperature conditions. However, when one considers creep under compression loads extensive creep data are still lacking.

2. It is assumed that the material shows same creep and long time rupture behavior under compressive load as in the tensile load, apart from the sign of the creep strain.
3. Steady state conditions of temperature and centrifugal stress exist.
4. Plane section remains plane before and after creep deformation.

Practical creep strength calculations in components like gas turbine rotor blade and discs need a theoretical description of the creep process in order to evaluate the strain after a certain time and the conditions of failure. The dependency of creep rate on stress is very non-linear. A small increase in stress at high temperatures can cause a considerable increase in creep results between creep results obtained at different temperatures.

RESULTS AND DISCUSSION

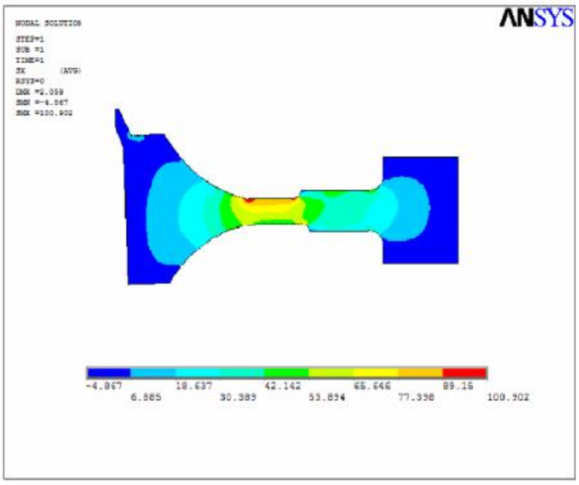
The results of the analysis performed in ANSYS with four different stages mentioned earlier are presented here. The radial stress and the vonmises stress distribution plots are presented for all the four cases.

Radial and Vonmises Stresses Distribution in Different Stages

Stage 1: Here, only the body force due to rotation was considered. The angular velocity, µ = 1156.8 rad/sec was imposed. Figure 3 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 seen as shown in the Figure 3.

Because of the body force and angular velocity of 1156.8 rad/sec, the maximum stress

Figure 3: Radial Stress Distribution (Stage 1)



(100.902) will be developed in the disc at the rim and minimum stress in seen at the end parts of the rim and bore.

The vonmises stress is also considered for the same body force and angular velocity of 1156.8 rad/sec the maximum stress of (176.162 MPa) is seen in the disc at the end part of rim and minimum stress is seen at the end part of the bore, as shown in the Figure 4.

Figure 4: Vonmises Stress Distribution (Stage 1)

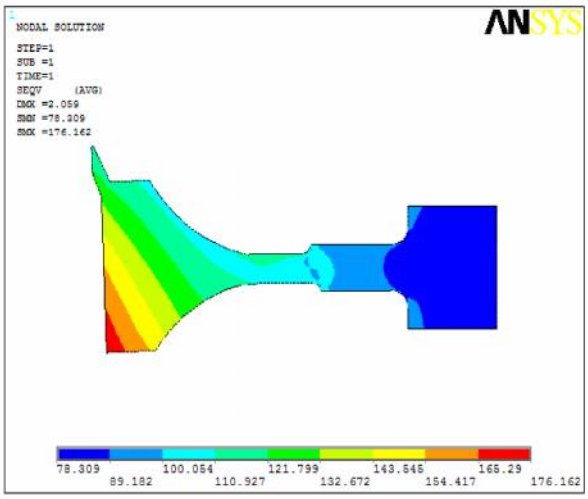


Table 1: Maximum Values of Radial and Vonmises Stage Distribution

S. No.	Stress	Value in MPa	Location in the Disc	Temperaure in C°
1.	Radial stress	100.92	Web	422.26
2.	Vonmises stress	176.162	Bore	390.29

Stage 2: In this stage the body forces due to rotation along with blade loads were considered. The calculated value of blade = 20104.2 Kgf

In the above case body force and angular velocity is considered but in this case along with this loads are considered. Here the calculated values of the blade load is taken, i.e. = 20104.2 Kgf as shown in Figure 5.

Because of this, maximum stress (112.424 MPa) will be seen in the disc at the rim lower end and minimum stress is seen at the end part of the rim and lower side of the bore. The disc was constrained along the axial direction and is allowed to grow in the radial direction.

Figure 5: Radial Stress Distribution (Stage 2)

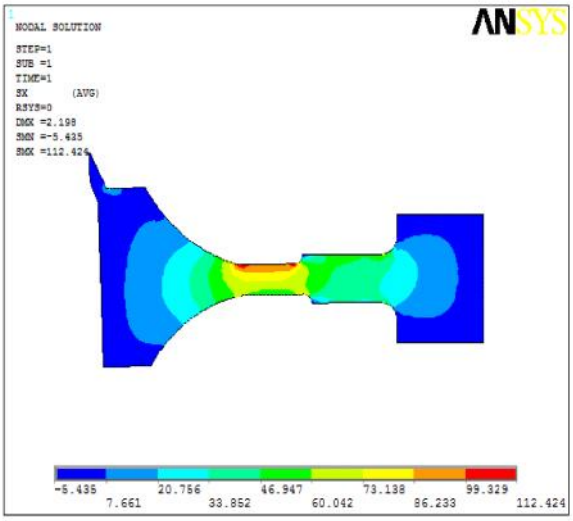
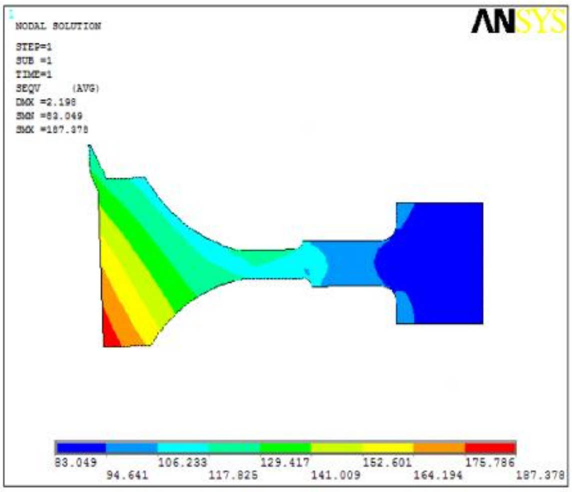


Figure 6: Vonmises Stress Distribution (Stage 2)



Vonmises stress is obtained for the same above case which is as shown in the above Figure 6. The maximum vonmises stress (187.378 MPa) is developed at the end part of the rim and minimum stress developed at the lower end part of the bore.

Stage 3: Here the thermal gradient was super imposed in addition to the above two stages of loading. The thermal gradient was obtained by performing a heat transfer analysis on the

Table 2: Maximum Values of Radial and Vonmises Stage Distribution

S. No.	Stress	Value in MPa	Location in the Disc	Temperaure in C°
1.	Radial stress	112.424	Web	422.26
2.	Vonmises stress	183.378	Bore	390.29

disc. The stress plots obtained in the stage 3 are the pre-stressed relaxation plots. In stage 3, all the three, i.e., body forces, blade loads and thermal gradient were considered.

Figure 7: Radial Stress Distribution (Stage 3)

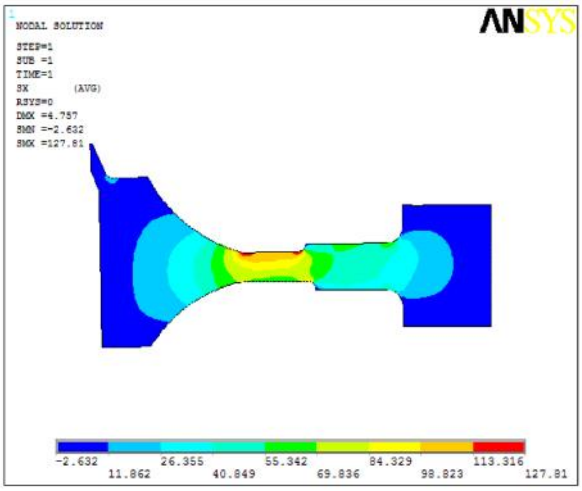
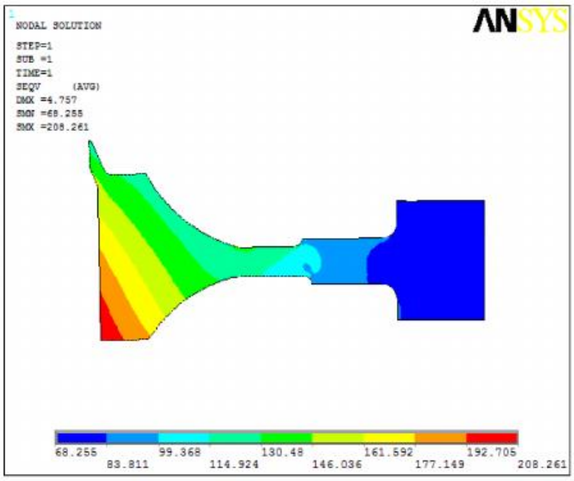


Figure 8: Vonmises Stress Distribution (Stage 3)



For the above same stage vonmises stresses are obtained which is shown in the Figure 8. The maximum vonmises stress (208.261 MPa) is seen at end part of the rim

Figure 9: Radial Stress Distribution (Stage 4)

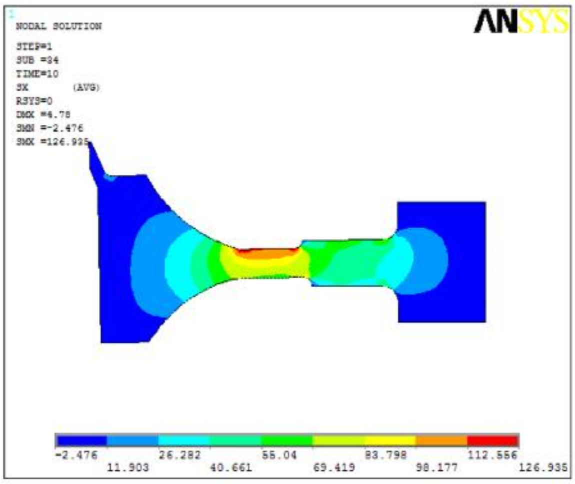


Figure 10: Vonmises Stress Distribution (Stage 4)

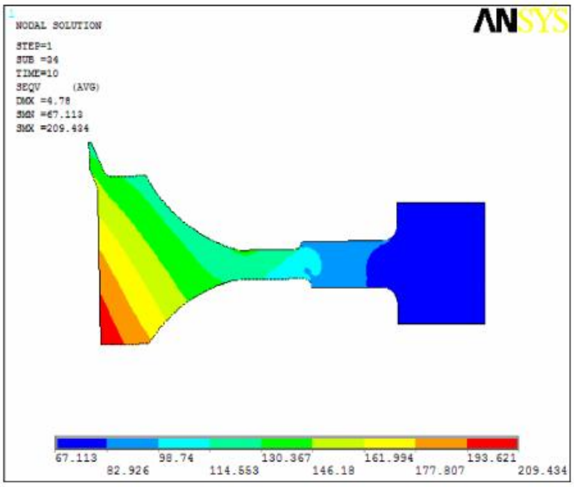


Table 3: Maximum Values of Radial and Vonmises Stage Distribution

S. No.	Stress	Value in MPa	Location in the Disc	Temperaure in C°
1.	Radial stress	127.81	Web	422.26
2.	Vonmises stress	208.261	Bore	390.29

Table 4: Maximum Values of Radial and Vonmises Stage Distribution

S. No.	Stress	Value in MPa	Location in the Disc	Temperaure in C°
1.	Radial stress	126.935	Web	422.26
2.	Vonmises stress	209.434	Bore	390.29

and minimum stress is seen at the end of the bore.

Stage 4: In addition to the above-mentioned four stages of loadings, the creep material properties were defined here. The values of the three constants evaluated previously were defined here and the disc was made to run for 10 hours and the creep analysis was carried out. The stress plots obtained in the stage 4 are the post stress relaxation plots.

Vonmises stress distribution for stage 4 is as shown in Figure 9. The maximum vonmises stress (209.434 MPa) is found to be at upper end part of the rim and minimum stress is seen at end part of bore.

Figure 10 shows the deformed shape of the disc at end of rim quenching. Figure 10 shows the deformed shape of the disc along with un-deformed shape at end of rim quenching. Figure 11 shows the deformed shape of the disc along with un-deformed edge at end of rim quenching

Figure 11: Deformed Shape of the Disc at End of Rim Quenching

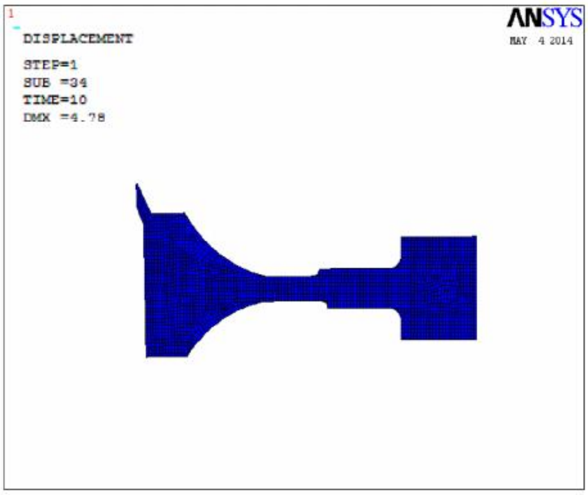


Figure 12: Deformed Shape of the Disc Along with Undeformed Shape at End of Rim Quenching

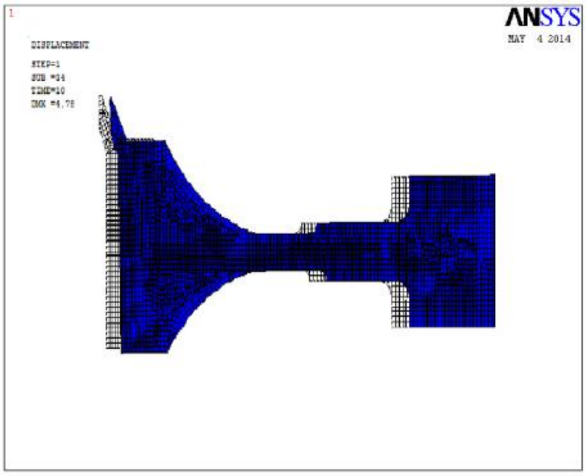
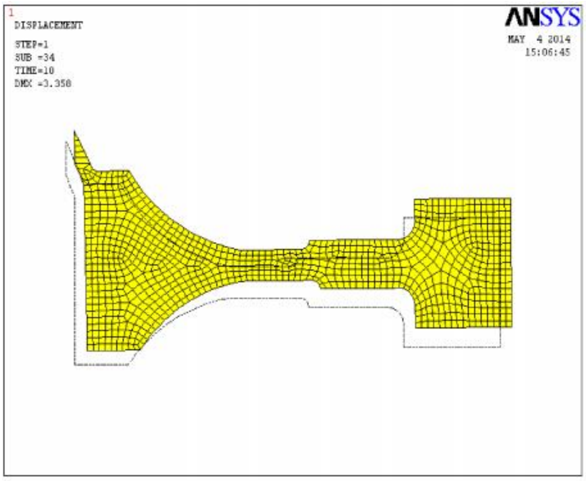


Figure 13: Deformed Shape of the Disc Along with Undeformed Edge at End of Rim Quenching



Life Estimation

The maximum value of the radial stress and Vonmises stress obtained in stage 3 are shown in figure 10 and 11 respectively. Table 5, given below lists the maximum value of the radial stress and vonmises stress with location of occurrence of the maximum value and the temperature at that location for stage 3. The stage 3 presents the result prior to the stress relaxation.

Similarly, the maximum value of the radial stress and vonmises stress obtained in the stage 4 are shown in the Figures 10 and 11 respectively. The Table 6, given below lists the maximum value of the radial stress and vonmises stress with location of occurrence of the maximum value and temperature at the location for stage 4. The stage 4 presents the result after the stress relaxation.

It can be noticed that the radial stress has relaxed from a value of 127.81 mpa in stage 3 to a value of 126.935 mpa in stage 4. Similarly vonmises stress has relaxed from a value of 208.261 mpa in stage 3 to a value of 209.434 mpa in stage 4.

The life of the disc was estimated from the relaxed stress value in the Table 7 and their corresponding LMP values for the four stress values were interpolated from the available creep properties of INCONEL-718.

The estimated life value for stage 3 and stage 4 and their comparison is made in the table.

Hence it is evident from the result that on incorporating the creep properties, the stress relaxation is more, hence the exact life of the disc is evaluated from the relaxed value of the stresses. If the creep effects are not considered, the stress will not be relaxed and the value of life obtained with that stress value would be an under estimation of the life of the disc.

Table 5: Pre-Relaxation Result (Stage 3)

S. No.	Stress	Value in MPa	Location in the Disc	Temperaure in C°
1.	Radial Stress	127.81	Web	422.26
2.	Vonmises stress	208.261	Bore	390.2

Table 6: Post-Relaxation Result (Stage 4)

S. No.	Stress	Value in MPa	Location in the Disc	Temperaure in C°
1.	Radial stress	126.935	Web	422.26
2.	Vonmises stress	209.434	Bore	390.29

Table 7: Evaluated Life Value of the Disc

S. No.	Stress	Life, t, in hours	
		Pre-Relaxation (Stage 3)	Post-Relaxation (Stage 4)
1.	Radial stress	9.457e6	26.5e6
2.	Vonmises stress	1.115e5	1.404e5

CONCLUSION

In this project 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 Finite Element analysis of the 2-D axi-symmetric model of the disc was carried out, considering the mechanical and thermal loads.
- The material constants required for the time hardening model were 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% was calculated.
- The time required for the accumulation of the creep strain, without considering the stress relaxation phenomena was observed to be conservative by an order. Thus the considerations given to creep play a vital role in the design of machine components especially the aero gas turbine engine components, which are primarily subjected to severe mechanical and thermal loads.
- 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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