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DYNAMIC ANALYSIS ON R31 STEAM TURBINE BLADE

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Abstract

The Steam turbine blades are subjected to in-plane load because of fluid or aerodynamic pressures so the blades are subjected to high dynamic loadings. It is necessary to do vibration analysis to know the dynamic characteristics of the material as they are working at high speeds. The X20cr13 steel material R31 turbine blades are used in 7.5MW BBC as turbine rotor in power plants. Flow of the super heated steam in steam turbines causes failure of blades due to high temperature working condition, high rotational speeds and corrosion of blade due to the purity of steam.

The existing X20 turbine blade is replaced with the composite material without the increase in the stresses. Two types of composites are taken with a matrix and reinforcements. One is glass-ceramic matrix systems reinforced with silicon carbide and silicon carbide reinforced with the aluminum matrix. Aluminum silicon carbide compare the mode of vibrations for the existing and newly design composite plates by using CATIA V5 R21 and ANSYS 15.0 software's.

Secondly, the existing blade made of X20Cr13 is replaced with the metal matrix composite aluminum silicon carbide. Metal matrix Composites possesses high-temperature capability, high thermal conductivity, low CTE, and high specific stiffness and strength. Addition of SiC into the aluminium matrix produces a resulting composite with the low density of aluminium but a higher modulus similar to steel. When the existing X20 material turbine blade is replaced with the composite material AlSiC MMC and Pyrosic, the von mises stresses are very much reduced. The life of the blade is also increased by using composite materials.

Keywords:

ANSYS;
CATIA V5;
Stress Analysis;
Composite;
Fatigue;
Modal Analysis.

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1. Introduction

A steam turbine is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Steam turbines are made in a variety of sizes ranging from small 0.75 kW units used as mechanical drives for pumps, compressors and other shaft driven equipment, to 15,00,000 kW turbines used to generate electricity. There are several classifications for modern steam turbines.

The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency from the use of multiple stages in the expansion of the steam, which results in a closer approach to the ideal reversible expansion process. The main of parts of turbine are rotating shaft, turbine blades, nozzles, gears and driven mechanism. In this turbine blade is one of the fundamental element of steam turbine where the steam flows is hits the turbine.

Turbo machinery blades are classified into two categories depending on their manner of operation as either impulse or reaction blades. The failures of these blades in practical working conditions cause several damage and loss. So this leads to study of turbine blades for better performances of steam turbines. The break down and failures of turbine machineries have been influencing such as consequential damages, hazards to public life and most importantly the cost repairs.

To avoid these, it is obvious that the blade of turbo machinery must be made structurally stronger, that means not in dimensions and/or use of materials of construction, but keeping the operating stresses well within the limits. The blade fatigue failure is one of the major sources of outages in any steam turbines and gas turbines which are due to high dynamic stresses caused by blade vibration and resonance within the operating range of machinery.

To protect blades from these high dynamic stresses, friction dampers are used. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings.

2. Literature Review

One of the important thing is material selection with respective operating conditions and quality of steam. The vast use of turbo machinery blades lead to significant amount of research over the years. Due to its wide range of application in the practical field, it is important to understand the nature of deformation, vibration and stability behavior of X20 turbine blades.

Philip Dowson and derrick Bauer [1] stated a thesis on turbine blade “Selection of materials and material related process for steam turbiSpediel [2] highlighted the satisfactory corrosion fatigue resistance of x20CrMoV121 steel in a good purity steam. However, the growth of fatigue cracks in 12 percent chromium steels in greatly enhanced by the chloride solutions at low cyclic stress intensities and high mean loads. Spediel also illustrated how the deltakth greatly reduced by the presence of the certain environments.

Forces on Large Steam Turbine Blades is investigates RWE Npower Mechanical and Electrical Engineering power industry [3] in Germanynes in these oil and petrochemical industry”. Steam Turbine rotors are designed with a significant factor of safety, the operating forces and stresses calculated, large steam turbine blades are manufactured from 12% chrome high alloy steels where maximum design stress values of 200-300 N/mm^2 are permissible. vibration analysis of a steam turbine by R.s.Mohan, A.Sekhar and A.s. Shekar [4] stated that dynamic steam turbine blade in computational environment is carried out by the reliability of these blades very important for the successful operation of steam turbines . In order to gain physical insight into the flexural dynamics of such turbine blade with the inclusion of the rotor dynamics effect the turbine blade was approximated as symmetry air foil cross section fixed on rigid disc. Wear Characteristics in Al-SiC Particulate Composites and the Al-Si Piston Alloy Z. Hasan1, R. K. Pandey, D.K. Sehgal [6] Al-Si alloy with near eutectic composition has been conventionally used as a piston material for automobile applications. It is required to possess high abrasive wear resistance for enhanced life of the engine. The alloy is known to have fairly good wear resistance due to increased percentage of silicon present in fine form. In the present investigation, Al-SiC particulate composites have been studied for their wear resistance against emery paper (400 grit SiC particles) counter f ace and a comparison has been made with existing piston alloy i.e. Al-Si alloy. Aluminum (Al-6063)/SiC Silicon carbide reinforced particles metal-matrix composites (MMCs) are fabricated by melt-stirring technique by K.L.Meena, Dr.A.Manna [7]. The MMCs bars and circular plates are prepared with varying the reinforced particles by weight fraction ranging from 5%, 10%, 15%, and 20%. The average reinforced particles size of SiC are 220 mesh, 300 mesh, 400 mesh respectively.

3. Calculation Of Forces On Blades

Forces acting on the blades of the rotor in general have two components namely tangential (Ft) and axial (Fa). These forces result from the steam momentum changes and from pressure differences across the blades. These steam forces are evaluated by constructing velocity triangles at inlet and outlet of the rotor blades. The rotor blades considered for analysis are untwisted and same profile is taken throughout the length of the blade. If the steam forces are assumed to be distributed evenly, then the resultant acts through the centroid of the area. At the inlet of the steam turbine rotor blades,

Absolute flow angle $\alpha_2 = 23.85^0$

Absolute velocity V_2 $= 462.21$ m/s

The velocity triangles at inlet of Gas turbine rotor blades are constructed as shown.

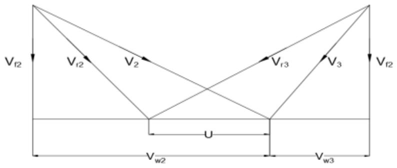


Figure 3.1 Inlet & Exit velocity triangles of steam turbine rotor blades

Diameter of blade midspan D = 1.65 m.

Design speed of turbine N = 1800 r.p.m.

Peripheral speed of rotor blade at its midspan $U = \pi DN/60 = 60\pi$ m/sec-- (1)

From the velocity triangles in figure we get,
Whirl velocity $Vw_2 = 422.74$ m/s
Flow Velocity $Vf_2 = 198.89$ m/s
Relative velocity $Vr_2 = 265.09$ m/s
Blade angle at inlet $\theta_2 = 45^{0}$

At the exit of Gas turbine rotor blades,
Flow velocity $Vf_3 = 189.42$ m/s
Relative flow angle $\theta_2 = 37.88^{0}$
From the velocity triangles (Figure), we get

Whirl velocity at exit $V_{w3} = 2.805$ m/s
Relative velocity at exit $V_{r3} = 293.83$ m/s

4. Modelling Of Turbine Blade

Using Catia module the profile drawing in the figure 4.1of blade is converted into 2D drawing as in the figures 4.2 and 4.3, root section of the blade and area foil section of the respectively by the various commands in the Catia module as same as measurements in the profile drawing. Commands like points, circles splines, rectangles, squares and work bench are used to generate 2D drawing. In 2d diagram is extrudes in the work bench by pad and pocket commands. The figure 4.3 Catia model of the blade shows the 3D view of the blade.

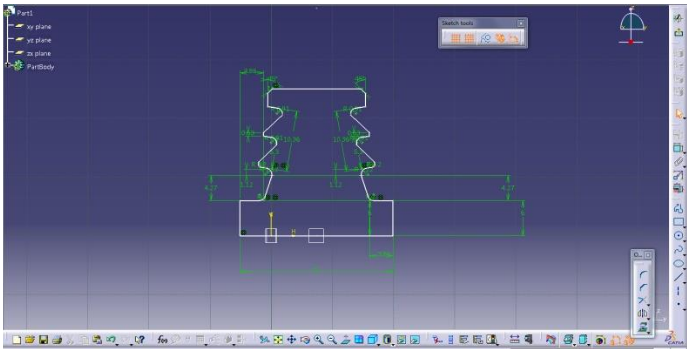


Figure 4.1 Root Section of the Blade

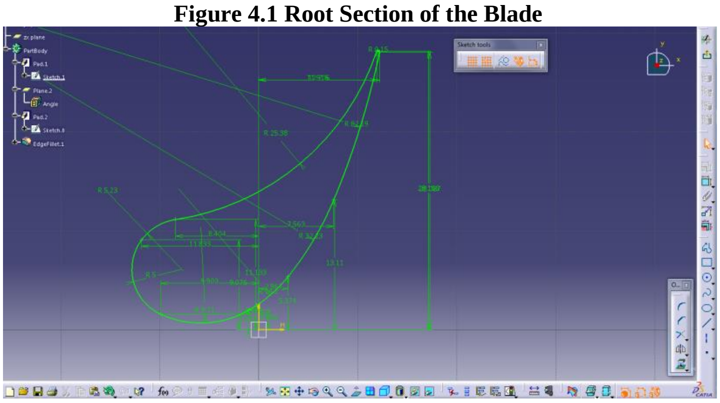


Figure 4.2 Aerofoil Section of the Blade

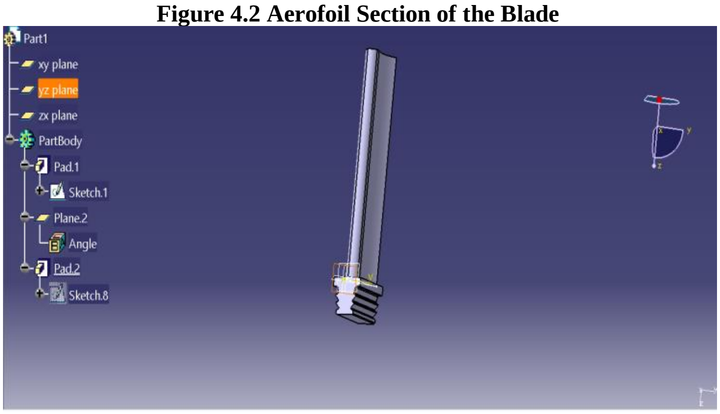


Figure 4.3 CATIA Model of the Blade

5. Analysis Of Tubine Blade By Ansys

Auto mesh is done in ANSYS workbench to solve the differential equations, which are a combination of structured and unstructured mesh. The imported file geometry undergoes meshing after which boundary conditions are applied to the physical domain

Tetra Mesh is done in ansys solver as shown in below figure 5.1

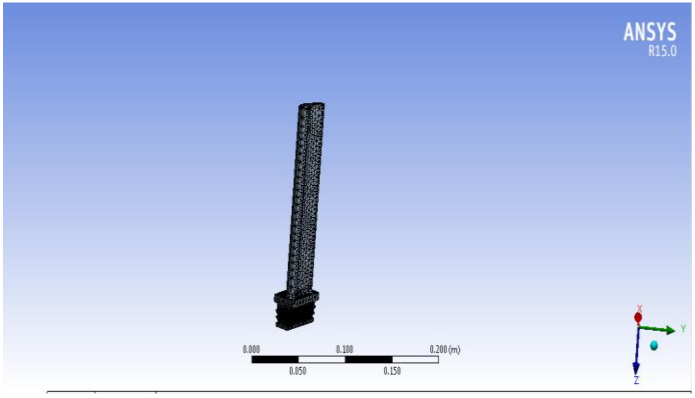
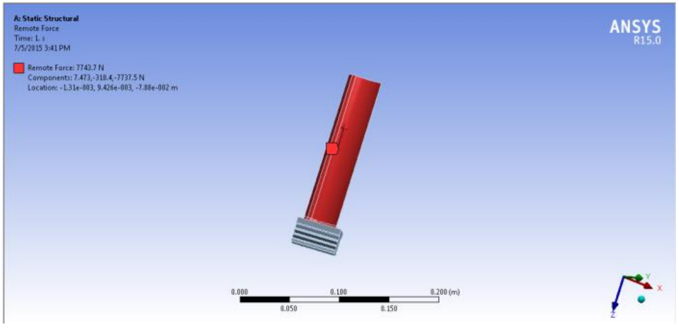


Figure 5.1 Tetra- Mesh

Tangential force Ft =310.4N
Axial force Fa = 7.473 N
Centrifugal force Fc = 7737.5 N
The above three forces are applied as boundary conditions to the turbine blade as shown in fig.5.2


A: Static Structural
Remote Force
Time: 1. s
7/5/2015 3:41 PM

🟥 Remote Force: 7743.7 N
Components: 7.473,-310.4,-7737.5 N
Location: -1.31e-003, 9.426e-003, -7.88e-002 m

Figure 5.2 Static loading on X20 material rotor

Static structural analysis is carried for existing blade material and by followed the two new proposed composite blade material and the solution data for them is presented below.

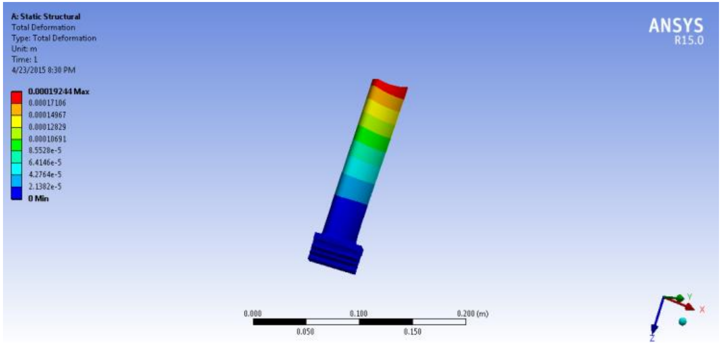

A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
4/23/2015 8:30 PM

Figure 5.3 X20 Blade deformation

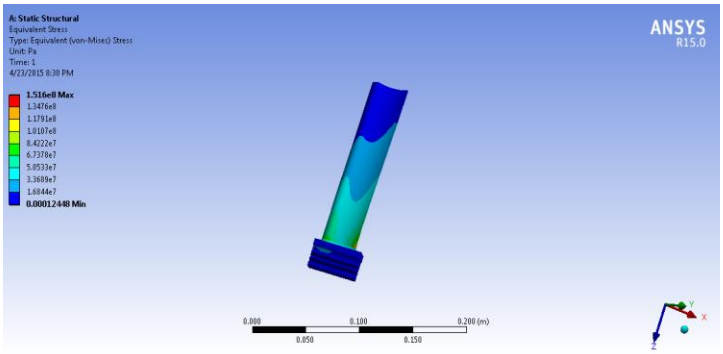


Figure 5.4 X20 Blade Von-Mises Stress

From the above figure 5.3 and 5.4 of X20 Cr13 material blade from Static analysis solution, have a deformation 0.192mm and the von mises stress is 1.516Pa for the loading condition of tangential force 310.4N, axial force 7.473 N and centrifugal force 7737.5 N.

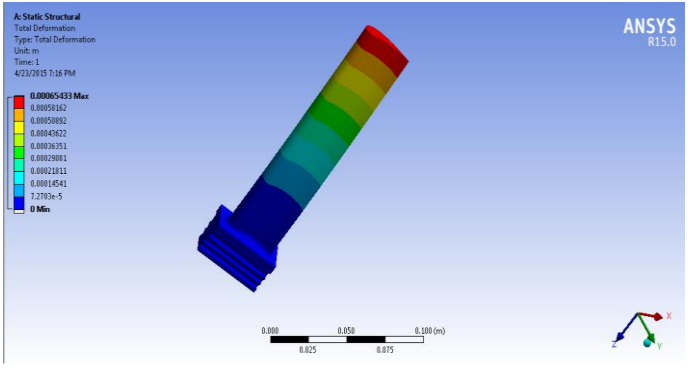


Figure 5.5 AlSiC blade deformation

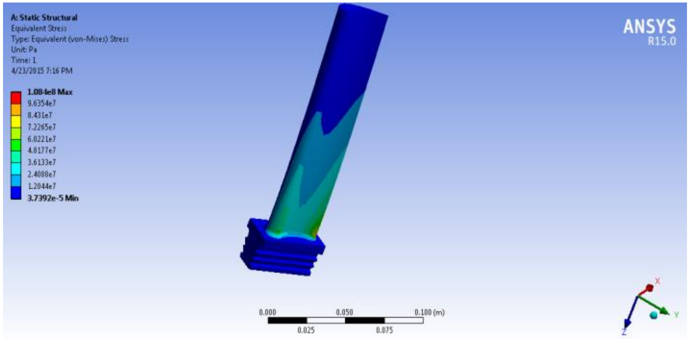


Figure 5.6 AlSiC Von-Mises Stress

From the above figure 5.5 and figure 5.6 of Al/SiC material blade from Static analysis solution have a deformation 0.65mm and the von mises stress is 1.084e8Pa for the loading condition of tangential force 310.4N, axial force 7.473 N and centrifugal force 2612.6 N.

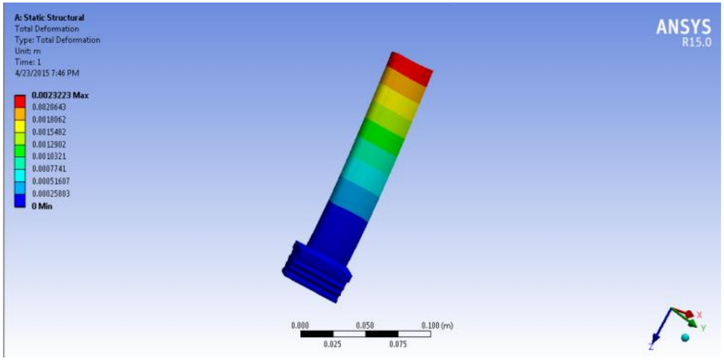


Figure 5.7 Pyrosic blade deformation

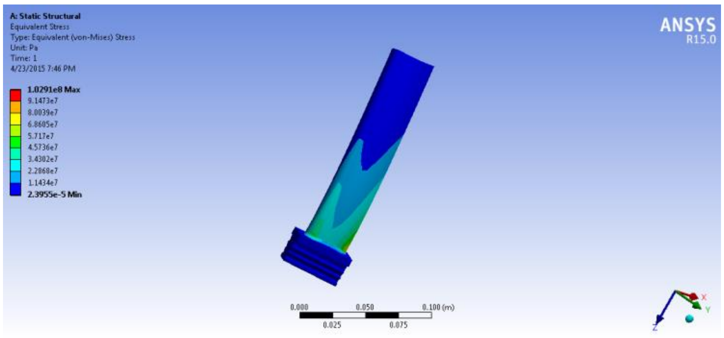


Figure 5.8 Pyrosic Von-Mises Stress

From the above figure 5.7, figure 5.8 of Pyrosic composite blade from Static analysis solution have a deformation 0.65mm and the von mises stress is 1.084e8Pa for the loading condition of tangential force 310.4N, axial force 7.473 N and centrifugal force 1848.9 N.

Fatigue analysis

In operating conditions many parts may does not fail initially, they often fail in service due to fatigue failure caused by repeated cyclic loading. In practice, loads significantly below static limits can cause failure if the load is repeated sufficient times. The main objective of fatigue analysis is to characterizing the capability of a material to survive and how many cycles can a component may experience during its lifetime. Types of Fatigue Analysis available in ansys are Strain Life, Stress Life, and Fracture Mechanics.

Stress Life is based on S-N curves (Stress – Cycle curves). This is concerned with total life and does not distinguish between initiation and propagation. In terms of cycles, Stress Life typically deals with a relatively high number of cycles. High number of cycles is usually refers to more than 10e5 cycles.

After completing the static structural analysis the solution module is transferred into Fatigue analysis module, and the boundary conditions are same as structural analysis. In setup select the fatigue analysis type as stress life. In solution insert life as a required output, and then run for solution.

After performing the fatigue analysis, the following results are presented below. Figure 5.9 figure 5.10 and figure 5.11 shows the fatigue results of the blade.

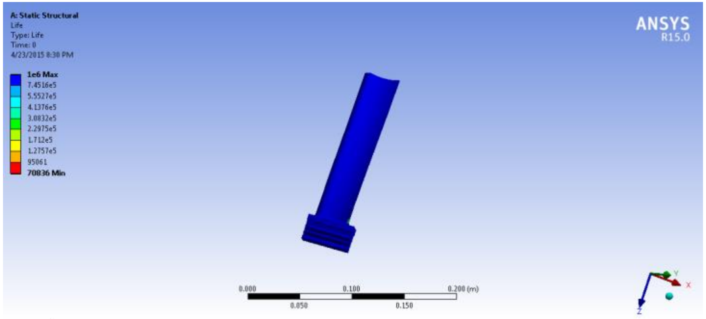


Figure 5.9 X20 Blade Fatigue Life

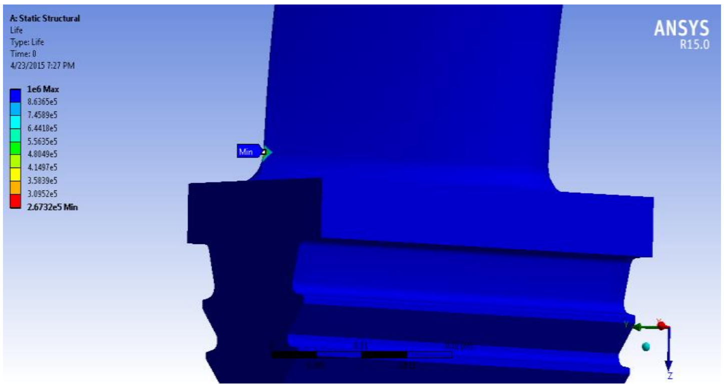


Fig 5.10 AlSiC Blade Fatigue Life

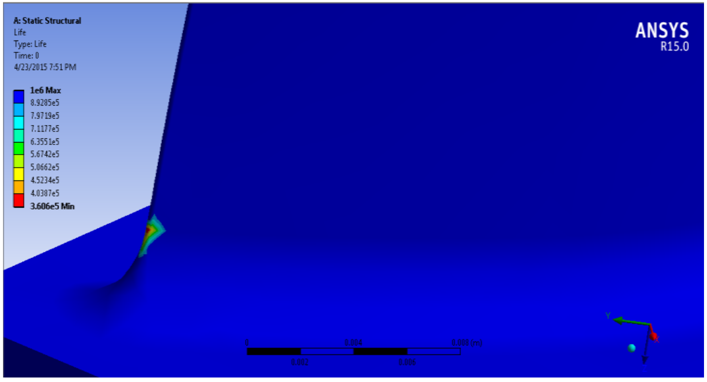


Figure 5.11 Pyrosic Blade Fatigue Life

From the above figures 5.9 5.10 and 5.11 of different material blades by fatigue analysis solution have a fatigue life as 70836 cycles for X20 cr13, 2.6732e5 cycles for AlSiC, 3.606e5 cycles Pyrosic respectively.

6. Results And Discussions

From the solution of Static structural analysis results, we have the following data

Blade Material	Von-Mises Stress (Pa)	Deformation (m)
X20 cr13	1.516e8	0.00019244
AlSiC	1.084e8	0.00023223
Pyrosic	1.029e8	0.00065433

Table 6.1 Comparison of Stress, Deformation of different Materials

The tangential and axial forces acting on the X20, Al/SiC and Pyrosic blade are same ie 310.4N and 7.473N, but the centrifugal force acting on the blades are vary ie. X20, Al/SiC and Pyrosic blades are 7737.5N, 2612.6N and 1848.9N. The Von misses stresses for X20, Al/SiC, Pyrosic are 1.516e8Pa, 1.084e8Pa, 1.029e8Pa. There is much variation in the centrifugal force acting on the blades of three materials these variation caused the reduced stresses.

The Von mises stresses induced in the blade by three materials are below the corresponding material yield stresses, so all the designs are safe in this working condition. The factor of safety for the existing X20 material is slightly high when compared to Al/SiC MMC. The factor of safety for the Pyrosic composite blade is high when compared to X20 material blade.

Result and discussion on fatigue analysis

This result contour plot shows the available life for the given fatigue analysis. In this the loading is of constant amplitude, this represents the number of cycles until the part will fail due to fatigue. In the given load history represents one hour of loading and the life was found to be 120, the expected model life would be 120 hours

Blade Material	Fatigue Life (cycles)
X20 cr13	70836
AlSiC	267320
Pyrosic	360600

Table 6.2 Fatigue life of different blade materials

By the results of the above table X20 material blade has low life of 70836 cycles when compared to Al/SiC 2.6e5 cycles and Pyrosic 3.6e5 cycles. The composite materials have good strength and stiffness there by fatigue life is increased in the results. The fatigue failure is occurred at the end of the aerofoil profile nearer to the root section, here increase the thickness of the aero foil may increase the blade life.

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