

Comparison of Fatigue Life between Two High Temperature Materials that can be used in Turbofan Turbine Blade by using ANSYS 12.0 Fatigue tool

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ABSTRACT: Fatigue analysis and life estimation of turbo machine balding needs the stress load history the blade. A blade designed for safe operation at particular constant rotor speed may incur distortion stresses during start up and shut down operations. During such operations the blade experiences sudden fluctuation of stress distribution over the blade profile which may reach the critical value in such speed range when the rotor is accelerated. This cyclic loading or fluctuated load accumulation is known as Fatigue which may leads to catastrophic failure of turbine blade. Two high temperature materials (Gamma- Titanium aluminide and Mo-TZM) are used in comparative analysis with their own mechanical and thermal properties. For our modelling and analysis we have taken Trent7000 engines blade available with us. The turbine blade analysis has done on fatigue analysis by means of comparing good man diagram for both of the materials. This comparative analysis will give a decent way to estimate engine life for those two materials while they can be used as turbine blade of turbofan engine.

KEYWORDS: Fatigue analysis, turbo machine balding, distortion stresses, Gamma- Titanium aluminide, Mo-TZM, Trent7000, good man diagram, engine life.

I. INTRODUCTION

A gas turbine is a typical type of internal combustion engine which has a compressor rotated by its upstream and coupled with downstream Turbine. It has combustion chamber in between the compressor and turbine section. The basic principle of the gas turbine is very similar to that of the steam power plant with an exception of here air is used instead of water. Ambient air flows through a compressor that leads to higher pressure and by increasing pressure it heated up the air. By spraying fuel into the compressed heated air ignition takes place in combustion chamber which generates high-temperature flow, that flows through the compressor coupled turbine and gets higher exhaust velocity by random rotation of turbines and comes out as the hot exhaust via a nozzle available with the turbo fan engine. The turbine shaft is used to drive the compressor in returns as well as other devices like an electric generator that coupled to the shaft. A turbine section is made up of a disk which contains many turbine blades. This turbine section is connected to a compressor section through the shaft (or "spool"). A turbine blade is the single individual functional unit of a whole turbine stage. There are many combination of stages may be available with the turbine section, like Rotor and stator consequently fitted after each other to form a stage of the turbine. Here we have worked with the rotor blades of turbine available in turbofan engines. The high temperature and high pressure exhaust gases passes through the turbine stages and turbine blades do extract energy from this flow. That is why turbine blades are so prone to failure due to thermal (creep) and structural loads like axial, transverse and centrifugal forces. So fatigue will build up in blade and thus weaken its strength and thus reduced the engine life as they are the functional units of turbine. Turbine blades are

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made out of exotic materials like super alloys, molybdenum based alloys, titanium based metal matrix composites, ceramic matrix composites, inconel etc. These materials are mostly comes under high temperature materials due to they retain good dimensional stability and mechanical properties like yield strength and ductility over prolonged time exposure to high temperature near about 1200°C - 1600°C . Here we have taken Trent7000 engine turbine blade (Fig.1) which is little bit shorter compare to the turbofan turbine blades but we have assume its length to be elongated and same to that of turbofan turbine blades.



Fig. 1 Turbine Blade

II. LITERATURE SURVEY

Gas turbine blades will be subjected to high tangential, axial and centrifugal forces during their working conditions. While withstanding these forces gas turbine blades may subjected to a considerable elongation. Various methods have been suggested for the better improvement of the mechanical properties of blade to withstand these extreme conditions. The project of George and Titus [1] summarizes the design, analysis and modification of the cooling passage in the gas turbine blade design. Therefore the overall efficiency and performance of the gas turbine blade will increasing and it also increase the number of operating cycles and it reduce the cost due periodic maintenance. High cycle fatigue (HCF) in gas turbine is one of the major problems experienced by the components of gas turbine. Since this high cycle fatigue can cause catastrophic failure this leads to damage of the blades and casing. Materials also play an important role in reducing the failure and increasing the life of the blade. Nickel base single crystal material is used due to the effectiveness over polycrystalline blade materials. HCF caused by large resonance stresses is one of the main problems in turbine blade design. . Fatigue analysis is done for the notched linearly varying rotating blade, the alternating stress, strain energy, stress intensity and life of the rotating blade is found by Madan Kumara and Nandish, Madhu[2]. Blade failures in gas turbine engines often lead to loss of all downstream stages and can have a dramatic effect on the availability of the turbine engines. Thorough failure investigation is essential for the effective management of engine airworthiness. A non-linear finite element method was utilized to determine the steady-state stresses and dynamic characteristics of the turbine blade. The steady-state stresses and dynamic characteristics of the blade were evaluated and synthesized in order to identify the causes of blade failures. An experimental procedure has been developed for the investigation of fatigue, crack growth resistance of materials and real compressor blades and for predicting the life of blades with cracks by Troshchenko and Prokopenko [3]. Damage to materials used in rotating components of gas turbine engines can be present in the form of manufacturing defects, or more often can appear during service operation. Low Cycle Fatigue (LCF), Foreign Object Damage (FOD), and fretting are the major sources of in-service damage. These sources can alter the HCF resistance individually or altogether. Methodologies for treating

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such damage in establishing material allowable are considered. Some recent results on the effects of damage on the Haigh (Goodman) diagram and a discussion of the life management aspects of HCF are presented by Nicholas [4]. In order to realize fatigue tests, the HCF method is based on nominal tension level; its tension level, lower or bigger, depends on possible breaks of the test piece. During this application, HCF begins with a nominal tension level equal to 297 MPa causing the break of the test piece. During the second phase, the tension is reduced of the 30%, reaching the value 267 MPa. According to row of tests (hot, cold, HCF) we record natural frequencies, stress values, vibration amplitudes, cycle's numbers and event of the break. This experiment was performed by Massimo Cavacece, Pier Paolo Valentini and Leonardo Vita [5]. In order maximize the overall performance and efficiency of all modern turbines, which theoretically operate according to Brayton cycle, they are operated at a very high temperature. These temperatures are so high that, which may fall in the region of turbine blade material melting point temperatures. Due to such high temperatures there is a possibility that the turbine blades may get damaged due to produced thermal stresses and presents a possible threat to the turbine system as well as the operators. Hence to ensure safe and reliable working of the turbines an effective and reliable cooling system is necessary. Various experimental setups developed for turbine blade tip cooling includes the pioneer work of Metzger, D., Bunker, R., and Fan. C [6] and Ronald S. Bunker[7] to the recent efforts put by the S. Gupta, A. Chaube, Verma [8]. Reviews of Sushil Sunil Gaikwad and Sonawane[9] will help and provide the detailed guidelines for planned numerical and experimental investigations required for the cooling of turbine blade tip, which help to provide the feasible and practically usable solution for cooling turbine tip. As cooling is also necessary to reduce thermal stress built up in the turbine blade and will affect the fatigue life. As the thermal stress developed, it will tend to weaken the intermolecular bonds of the materials of the blade, which leads to failure due to fatigue load.

III. CATIA MODEL

For doing modeling we have used CATIA V5 R17. At first we have generated 6409 NACA series airfoil by using spline. We have gathered coordinates from NACA airfoil tools generator. After creating the airfoil, pad the airfoil to the distance with offset command. Then, we have gone for multi-section to make a similar airfoil with twist angle. For twisting we have used rotate commands. We increased angle for each section with equal interval of degrees. Finally, we completed our modeling of turbine blade with base (Fig.2).

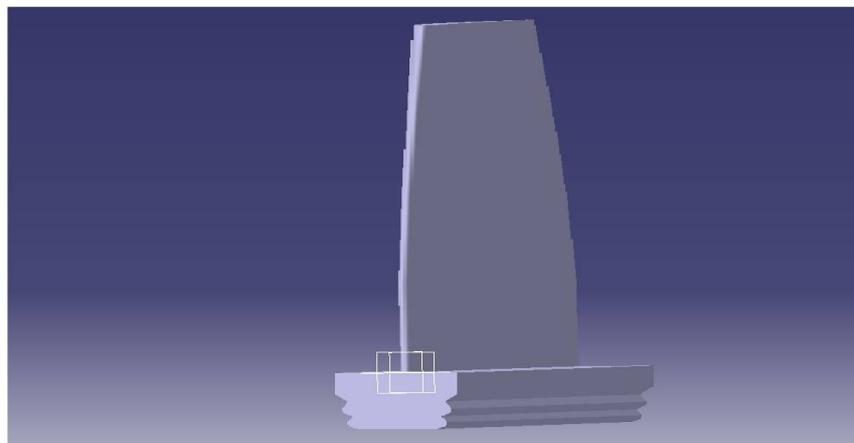


Fig. 2 CATIA Diagram Of Turbine Blade

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IV. ANALYSIS REPORT

For analyzing our created model of gas turbine blade with base, we have ANSYS V12.0 WORKBENCH. We have collected the boundary conditions with materials mechanical and thermal properties from various useful resources, which have been mentioned in our references. We have imported the CATIA modeling in IGS format to ANSYS workbench. Then, update the model. After updated, in mechanical ANSYS window, we have meshed our model.(Fig.3).

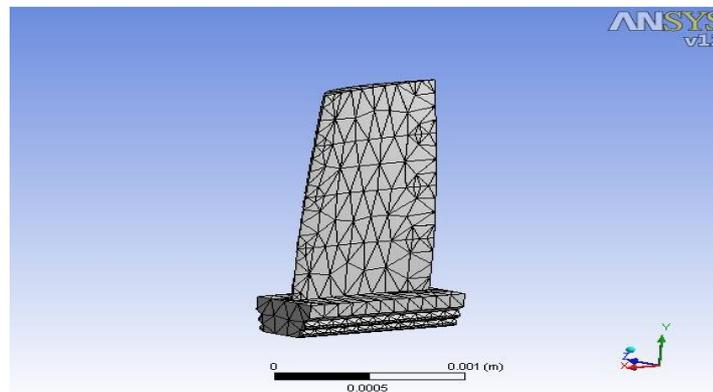


Fig. 3 Meshed Gas Turbine Blade for Turbofan Engine

STATISTICAL ANALYSIS

- ✓ **Physical Reference-** Mechanical
- ✓ **Nodes-** 3628
- ✓ **Elements-** 1783
- ✓ **Transmission Ratio-** 0.272
- ✓ **Maximum Layer-** 5
- ✓ **Growth Ratio-** 1.2

In ANSYS workbench, we have planned to do fatigue analysis of gas turbine blade. So, we have selected two materials Gamma-Titanium aluminide and Mo-TZM. We get the result of fatigue life estimation with fatigue tools; here we get life, damage, safety factor, alternating stress on Goodman diagram.

IV. ANALYSIS REPORT

The following table shows various boundary conditions whatever we have used for our analysis purpose.

SL No.	Material	Rotational Velocity	Temperature(K)		Pressure(Mpa)	
1.	g-Titanium Alumiade	3500	477	877	0.12	0.14
		7000	677	1277	0.14	0.18
		1400	877	1677	0.18	0.28
2.	MO-TZM	3500	477	877	0.12	0.14
		7000	677	1277	0.14	0.18
		1400	877	1677	0.18	0.28

Table 1 Various Boundary Condition

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This table explains various material properties of our chosen two materials i.e. g-TitaniumAluminide, Mo-TZM.

SL No.	Properties	Symbols	Units	g-Titanium aluminide	Mo-TZM
1.	Young modulus	E	pa	176x10 ⁶	325x10 ⁶
2.	melting point	⁰ c	⁰ c	1480	2625
3.	Density	P	Kg/m ³	3910	10160
4.	Thermal conductivity	K	W/m-K	23	118
5.	Thermal expansion	α	⁰ c	8.6x10 ⁻⁶	5.3x10 ⁻⁶
6.	Poisson ratio	μ		0.3	0.32
7.	Yield strength	σ	Mpa	525	860
8.	Specific heat	c _p	J/Kg-K	425	250

Table 2 Various Material Properties

The fatigue life estimation for four materials has been given with Goodman diagram. These diagrams give details about the endurance and fatigue life of each material for our comparative study.

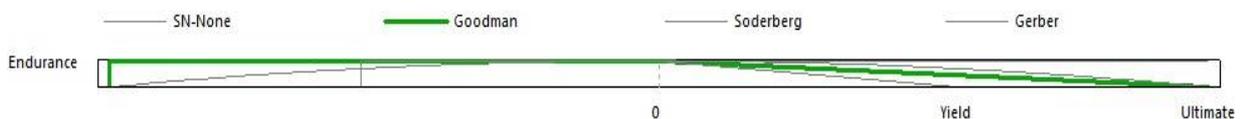


Fig. 3 Goodman Diagram For g-TiAl

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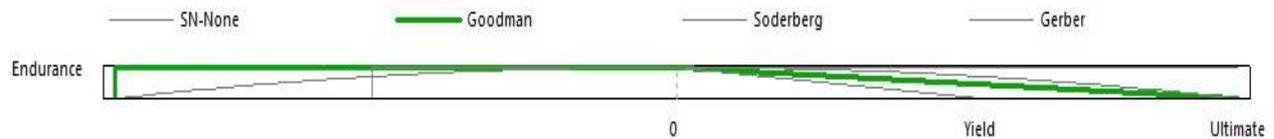


Fig. 3 Goodman Diagram For Mo-TZM

V. CONCLUSION

We have compared the fatigue life of both Gamma- Titanium aluminide and Mo-TZM by analyzing the CATIA V5 R17 modeled turbine blade with ANSYS WORKBENCH 12.0. While comparing with the output Goodman diagram Mo-TZM has slightly better endurance than γ - titanium aluminide. Gamma- Titanium aluminide shows excellent creep resistance in its “gamma” phase and stability in elevated temperature which can be the prime criteria for selecting this material from Titanium family. But as of considering the best fatigue life as depicted from Goodman diagram, we can clearly state Mo-TZM shows higher fatigue life and excellent mechanical property over a long range of temperature. Further work should be continued to compare these two materials by their structural analysis and deformation in higher temperature and pressure.

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