International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 04 | July-2015 www.irjet.net p-ISSN: 2395-0072

COMPARATIVE STUDY OF GAS TURBINE BLADE MATERIALS, GEOMETRIES USING FINITE ELEMENT ANALYSIS

G.D. Ujade[1] Prof. M.B. Bhambere[2]

[1]Student, II year M.E. ,*Mechanical Engineering, SSGMCE Shegaon, Maharashtra,India*
[2]Assistant Professor ,*Mechanical Engineering, SSGMCE Shegaon, Maharashtra,India*

***

Abstract - The turbine blades are responsible for extracting energy from the high temperature gas produced by the combustor. Operating the gas turbine blade at high temperatures would provide better efficiency and maximum work output. These turbine blades are required to withstand large centrifugal forces, elevated temperatures and are operated in aggressive environments. To survive in this difficult environment, turbine blades often made from exotic materials. A key limiting factor in gas turbine engines is the performance of the materials available for the hot section of the engine especially the gas turbine blades. Gas turbine is an important functional part of many applications. Cooling of blades has been a major concern since they are in a high temperature environment. Various techniques have been proposed for the cooling of blades and one such technique is to have axial holes along the blade span. Finite element analysis is used to analyse thermal and structural performance due to the loading condition, with four different material like ZiCr5 Zirconium Chromite (existing material), mullet, AlSi Aluminum Silicate, Titanium Alloy.Two different models with different number of holes perforated 4 and 6 were analysed in this paper to find out the optimum number of holes for good performance. Using ANSYS, Equivalent stress, deflection, temperature distribution for 4 and 6 number of perforated holes are analysed. It is found that when the numbers of holes are increased in the blade, the temperature distribution falls down.

Key Words: Turbine blade, Thermal analysis, Structural analysis, FEM

1. Introduction:

The gas turbine obtains its power by utilizing the energy of burnt gases and the air which is at high temperature and pressure by expanding through the several rings of fixed and moving blades, to get a high pressure of order of 4 to 10 bar of working fluid which is essential for expansion a compressor is required. The quantity of working fluid and speed required are more, so generally a centrifugal or axial compressor is required. The turbine drive the compressor so it is coupled to the turbine shaft, If after compression the working fluid were to be expanded in a turbine, then assuming that there were no losses in either component, the power developed by the turbine can be increased by increasing the volume of working fluid at constant pressure or alternatively increasing the pressure at constant volume. Either of there may be done by adding heat so that the temperature of the working fluid is increased after compression. To get a higher temperature of the working fluid a combustion chamber is required where combustion of air and fuel takes place giving temperature rise to the working fluid. The turbine escapes energy from the exhaust gas. Like the compressor, turbine can be centrifugal or axial. In each type the fast moving exhaust gas is sued to spin the turbine, since the turbine is attached to the same shaft as the compressor at the front of the engine, and the compressor will turn together, The turbine may extract just enough energy to turn the compressor. The rest of the exhaust gas is left to exit the rear of the engine to provide thrust as in a pure jet engine. Or extra turbine stages may be used to turn other shafts to power other machinery such as the rotor of a helicopter, the propellers of a ship or electrical generators in power stations. The present paper deals with the first type is centrifugal stresses that act on the blade due to high angular speeds and second is thermal stresses that arise due to temperature gradient within the blade material. The analysis of turbine blade mainly consists of the following two parts: Structural and thermal analysis. The analysis is carried out for 4 and 6 no. of perforated holes on gas turbine blade with different material like mullet, AlSi, ZiCr5 and Titanium Alloy and compared the result of both geometry and suggested best one.

2.FINITE ELEMENT METHOD

The stress analysis in the field of gas turbine engineering is invariably complex and for many of the problems, it is extremely difficult and tedious to obtain analytical solutions. The finite element method is a numerical analysis technique for obtaining approximate solutions. It has now become a very important and powerful tool for numerical solution of wide range of engineering problems. The method being used for the analysis of structures solids of complex shapes and complicated boundary conditions. The advance in computer technology and high-speed electronic computers enables complex problems to model easily. Various researches have done lot of work to develop analysis of gas turbine rotor blade using finite element analysis.

3.1 Material Titanim Alloy

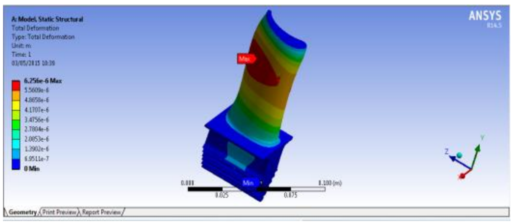

Fig. 3.1 shows the total deformation in the turbine blade made of Titanium Alloy due to centrifugal force and it is observed a deformation of 6.25 × 10^{-6} m which is maximum at leading edge near to the centre of the blade and the value is minimum at the root of the blade.

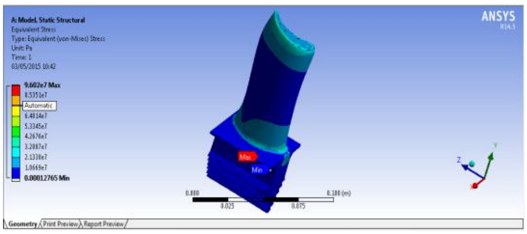

Fig 3.2 indicates the equivalent (von-mises) stress distribution in the turbine blade made of Titanium Alloy due to centrifugal force and it is observed a stress of 9.60 × 10^7 N/m^2 which is maximum at leading edge near to the tip of the blade and the value is minimum at the root of the blade.

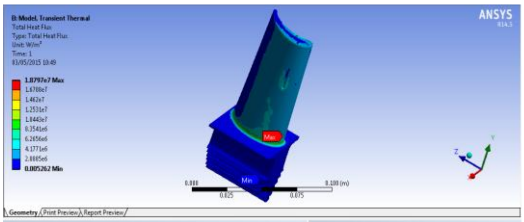

Fig 5.6 shows the total heat flux in the turbine blade made of Titanium Alloy. It is observed that maximum heat flux of 1.87 × 10^7 W/m^2 occurs near to the center of the blade and minimum heat flux occurs at the root of the turbine blade.

3.2 Material Mullite

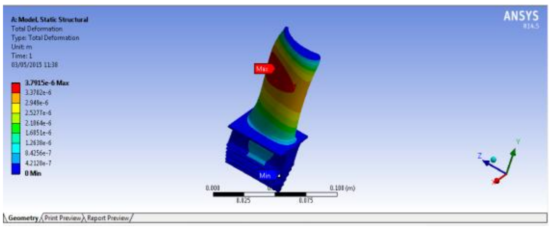

Fig. 3.4 shows the total deformation in the turbine blade made of mullite due to centrifugal force and it is observed a deformation of 3.79 × 10^{-6} m which is maximum at leading edge near to the center of the blade and the value is minimum at the root of the blade.

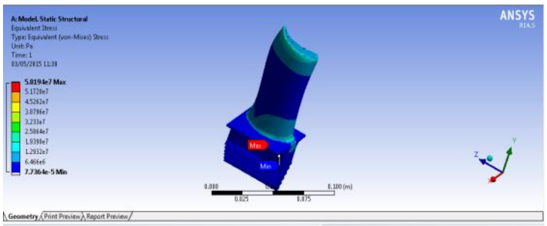

Fig 3.5 indicates the equivalent (von-mises) stress distribution in the turbine blade made of mullite due to centrifugal force and it is observed a stress of 5.81 × 10^7 N/m^2 which is maximum at leading edge near to the tip of the blade and the value is minimum at the root of the blade.

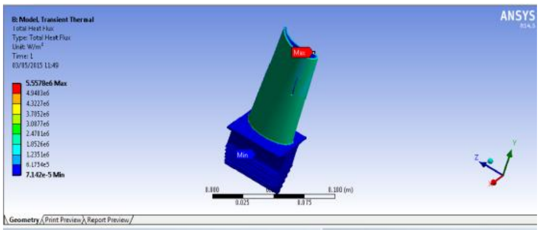

Fig 3.6 shows the thermal error in the turbine blade made of Titanium Alloy. It is observed that maximum thermal error of 1031.7 J occurs above the root of the blade and minimum thermal error occurs at the root of the turbine blade.

3.3 Material ZiCr5

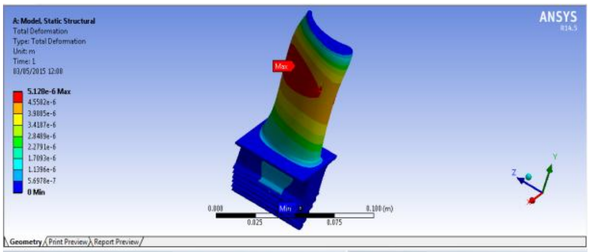

Fig. 3.7 shows the total deformation in the turbine blade made of ZiCr5 due to centrifugal force and it is observed a

deformation of 5.12 × 10^{-6} m which is maximum at leading edge near to the center of the blade and the value is minimum at the root of the blade.

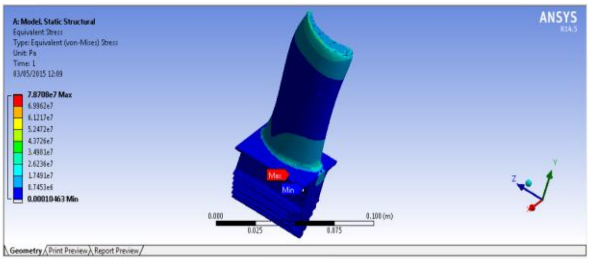

Fig 3.8 indicates the equivalent (von-mises) stress distribution in the turbine blade made of ZiCr5 due to centrifugal force and it is observed a stress of 7.87 × 10^7 N/m^2 which is maximum at leading edge near to the tip of the blade and the value is minimum at the root of the blade.

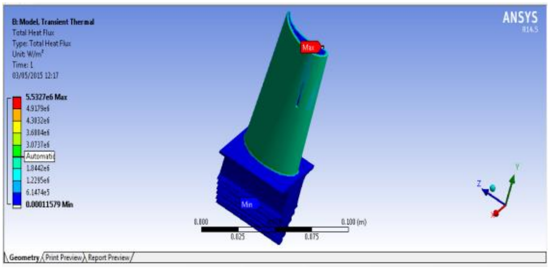

Fig 3.9 shows the total heat flux in the turbine blade made of Titanium Alloy. It is observed that maximum heat flux of 5.53 × 10^6 W/m^2 occurs near to the center of the blade and minimum heat flux occurs at the tip of the turbine blade.

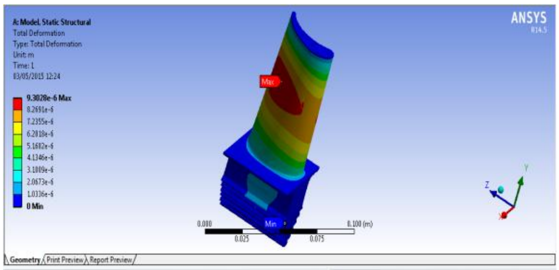

Fig. 3.10 shows the total deformation in the turbine blade made of AlSi due to centrifugal force and it is observed a deformation of 9.30 × 10^{-6} m which is maximum near to the center of the blade and the value is minimum at the root of the blade.

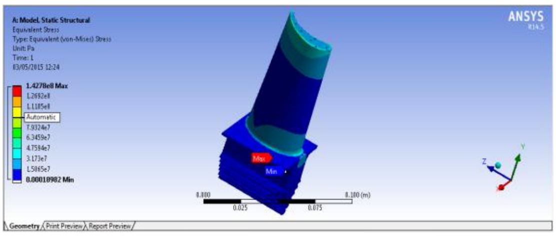

Fig 3.11 indicates the equivalent (von-mises) stress distribution in the turbine blade made of AlSi due to centrifugal force and it is observed a stress of 1.42 × 10^8 N/m^2 which is maximum at leading edge near to the tip of the blade and the value is minimum at the root of the blade.

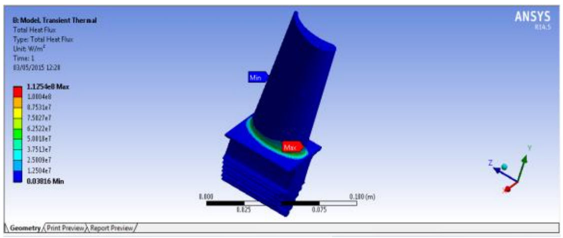

Fig 3.12 shows the total heat flux in the turbine blade made of AlSi. It is observed that maximum heat flux of 1.12 × 10^8 W/m^2 occurs near to the centre of the blade and minimum heat flux occurs at the root of the turbine blade.

4. RESULTS AND DISCUSSIONS

The research work deals with the analysis 4 and 6 nos of perforated holes on gas turbine blade of four different material. The thermal-structural finite element analysis was performed for the turbine blade using ANSYS 14.5 software. Four materials such as Titanium alloy, ZiCr5 and mullet and AlSi the material which is used in the manufacturing of gas turbine blade have been considered for the analysis under the operating conditions from gas turbine handbook and previous research. Compared these results of two geometry with four different materials. The results for 4 nos of perforated hole on gas turbine blade are tabulated as

Table.1 Values of stresses, deformation for 4 materials.

Specifications	Titanium Alloy	Mullite	ZiCr5	AlSi
Total deformation (m)	5.51×10^{-6}	1.14×10^{-6}	1.70×10^{-6}	3.08×10^{-5}
Equivalent Stress (N/m^2)	1.57×10^{8}	5.98×10^{7}	8.31×10^{7}	1.52×10^{8}
Shear Stress(N/m^2)	3.70×10^{7}	1.02×10^{7}	1.37×10^{7}	2.48×10^{7}
Maximum Principal Stress(N/m^2)	5.81×10^{7}	2.69×10^{7}	3.67×10^{7}	6.67×10^{7}

Table.2 Values of temperature distribution, total heat flux,

thermal error of 4 materials.

Ambient Temperature (°C)	35			
Applied Temperature (°C)	1150			
Specifications	Materials			
	Titanium Alloy	Mullite	ZiCr5	AlSi
Temperature Distribution Min. (°C)	33.133	31.209	38.634	35.01
Total Heat Flux (W/m^2)	1.95×10^{7}	7.59×10^{6}	1.39×10^{8}	1.57×10^{8}
Thermal Error (J)	4745.1	1795.2	14962	23800

Table.3 Comparative values of stresses, deformation of

both blade geometries for 4 materials.

Specifications	Materials							
	Titanium Alloy		Mullet		ZiCr5		AlSi	
	4 Holes	6 Holes	4 Holes	6 Holes	4 Holes	6 Holes	4 Holes	6 Holes
Total deformation (m)	5.51×10^{-6}	6.25×10^{-6}	1.14×10^{-6}	3.79×10^{-6}	1.70×10^{-6}	5.12×10^{-6}	3.08×10^{-5}	9.30×10^{-6}
Equivalent Stress (N/mm^2)	1.57×10^{8}	9.60×10^{7}	5.98×10^{7}	5.81×10^{7}	8.31×10^{7}	7.87×10^{7}	1.52×10^{8}	1.42×10^{8}
Shear Stress (N/mm^2)	3.70×10^{7}	1.93×10^{7}	1.02×10^{7}	1.17×10^{7}	1.37×10^{7}	1.59×10^{7}	2.48×10^{7}	2.88×10^{7}
Maximum Principal Stress (N/mm^2)	5.81×10^{7}	5.25×10^{7}	2.69×10^{7}	3.18×10^{7}	3.67×10^{7}	4.30×10^{7}	6.67×10^{7}	7.81×10^{7}

Table.4 Comparative values of temperature distribution, total heat flux, thermal error of both blade geometries for 4 materials.

Ambient Temperature (^{o}C)	35							
Applied Temperature (^{o}C)	1150							
Specifications	Materials							
	Titanium Alloy		Mullet		ZiCr5		AlSi	
	4 Holes	6 Holes	4 Holes	6 Holes	4 Holes	6 Holes	4 Holes	6 Holes
Temperature Distribution Min. (^{o}C)	33.133	34.99	31.209	17.87	38.634	13.19	35.01	34.99
Total Heat Flux (W/m^2)	1.95×10^{7}	1.8×10^{7}	7.59×10^{6}	5.55×10^{6}	1.39×10^{8}	5.53×10^{6}	1.57×10^{8}	1.12×10^{8}
Thermal Error (J)	4745.1	1031.7	1795.2	1031.7	14962	1021.8	23800	16007

It is observed that the stress distribution, deformation and temperature distribution patterns are same for all four materials. Maximum deformation is and temperatures are observed at the blade tip section and minimum elongation and temperatures at the root of the blade. Maximum stresses are observed at the root of the turbine blade and upper surface along the blade roots four different materials of construction.

5. CONCLUSIONS

The main goal of the gas turbine technology is to extract maximum amount of energy from the gases at high temperature which could be achieved by improving the thermal efficiency of the gas turbine engine. The efficiency of gas turbine is a direct function of turbine inlet temperature (TIT) and operating the gas turbine blade at high temperature would provide better efficiency and maximum work output. The turbine blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. These turbine blades and are subjected to high mechanical stresses, elevated temperatures and are operated in aggressive environments. To survive in this difficult environment, turbine blades often made from exotic materials. Four different materials such as ZiCr5, Titanium Alloy, Mullite, AlSi used for manufacture of turbine blades of a gas turbine. The turbine blade is analysed for its thermal as well as structural performance due to the loading condition and the temperature gradients for both type of geometries having 4 nos and 6 nos of perforated holes. Maximum temperatures are observed at the blade tip sections and minimum temperature at the root of the blade. Temperature distribution is almost uniform and is linearly decreasing from the tip of the blade to the root of the blade section.

The distribution of temperature is same for turbine blades made of four different materials. It can be seen that the temperature distribution and total heat flux and thermal error is 13.19 ° C, 5.53 $\times 10^6$ w/m^2 and 1021.8 J respectively for geometry of turbine blade having 6 nos of perforated holes of ZiCr5 material. which is minimum as compared with other material . So, It can be conclude that ZiCr5 can reduces temperature more quickly and resistance to flow of heat is less in ZiCr5 with 6 nos of perforated holes. Maximum elongations (deformations) observed at the blade tip sections and minimum elongations at the root of the blade. The minimum elongation is for mullet under same loading conditions. So mullet is better as deformation is less. To avoid the failure of a gas turbine blade due to creep, the elongation of the blade should be as less as possible. Maximum stresses induced for mullet is 11.7 $\times 10^7$ MPa which is minimum for 4 nos of perforated hole on blade geometry. Hence, mullet is safer material for gas turbine blade.

From the above results, it might be concluded that as the structural performance is consider the mullet with 4 nos of hole is best suited and as the thermal performance is consider the ZiCr5 with 6 nos of hole is best suited for gas turbine blade from the above results.

REFERENCES

[1] P.V.Krishnakanth Structural & Thermal Analysis of Gas Turbine Blade by Using F.E.M International Journal of Scientific Research Engineering & Technology (IJSRET) Volume 2 Issue2 pp 060-065 May 2013.

[2] Michel Arnal "Fluid Structure Interaction Makesfor Cool Gas Turbine Blades" ANSYS Advantage • Volume I, Issue 1, 2007

[3] Sagar P.Kauthalkar "Analysis of Thermal Stresses Distribution Pattern on Gas Turbine" International Journal Of Engineering, Education And Technology (ARDIJEET) ISSN 2320-8

[4] Soo-Yong Cho "A Study on an Axial-Type 2-D Turbine Blade Shape for Reducing the Blade Profile Loss" KSME International Journal, Vol. 16 No. 8, pp. I154~1164, 2002.

[5] John.V, T.Ramakrishna. "THE DESIGN AND ANALYSIS OF GAS TURBINE BLADE", International Journal of Advanced Research and Studies, Vol 2, No.1, Dec 2012.

[6] B. Deepanraj "THEORETICAL ANALYSIS OF GAS TURBINE BLADE BY FINITE ELEMENT METHOD" Scientific World, Vol. 9, No. 9, July 2011.

[7] Avinash V. Sarlashkar "BladePro™ : An ANSYS-Based Turbine Blade Analysis System"Impact Technologies, LLC, Rochester, NY 14623, U.S.A

[8]Jorgen M. Anders "A Parametric Blade Design System (Part I + II)" Hans Heukenkamp atech GmbH engineering software technology, Germany.

[9] Patil A.A "Study of Failure Analysis of Gas Turbine Blade" IOSR Journal of Engineering (IOSRJEN) ISSN: 2250-3021 ISBN: 2878-8719 PP 37-43.

[10] Ganta Nagaraju "DESIGN OPTIMIZATION AND STATIC & THERMAL ANALYSIS OF GAS TURBINE BLADE" International Journal of Engineering, Business and Enterprise Applications (IJEBEA).

[11] Daniel K. Van Ness II "Turbine Tip Clearance Flow Control using Plasma Actuators"

Center for Flow Physics and Control (FlowPAC), University of Notre Dame, Notre Dame, IN, 46556

[12] V.NagaBhushana Rao "ANALYTICAL COMPARATIVE STUDY OF GAS TURBINE BLADE MATERIALS USED IN MARINE APPLICATIONS USING FEA TECHNIQUES" International Journal of Engineering Sciences & Management Research, ISSN: 2349-6193

[13] Arif Sugianto "Failure Analysis of a First Stage High Pressure Turbine Blade in an Aero Engine Turbine" on PK-GSG Boeing B747-400.

[14] V. NagaBhushana Rao " Mechanical Analysis of 1st Stage Marine Gas Turbine Blade" International Journal of Advanced Science and Technology Vol.68 (2014), pp.57-64.

[15] Naresh Gurajarapu " Selection of a Suitable Material and Failure Investigation on a Turbine Blade of Marine Gas Turbine Engine using Reverse Engineering and FEA Techniques" International Journal of u- and e- Service, Science and Technology Vol. 7, No. 6 (2014), pp. 297-308,

[16] Mehdi Tofighi Naeem "Failure Analysis of Gas Turbine Blades" Paper 120, ENG 108Proceedings of The 2008 IAJC-IJME International Conference ISBN 978-1-60643-379-9.

[17] Handbook of "SIEMENS Industrial Power Industrial Gas Turbines The compressive range from 5 to 50 MW".

[18] Józef Błachnio and Wojciech Izydor Pawlak (2011). Damageability of Gas Turbine Blades – Evaluation of Exhaust Gas Temperature in Front of the Turbine Using a

Non-Linear Observer, Advances in Gas Turbine Technology, Dr. Ernesto Benini (Ed.), ISBN: 978-953-307-611-9.

[19] Xijia Wu (2010). Life Prediction of Gas Turbine Materials, Gas Turbines, Gurrappa Injeti (Ed.), ISBN: 978-953-307-146-6.

[20] P.Satyanarayana “PARAMETRIC MODELING AND DYNAMIC CHARACTERIZATION FOR STATIC STRENGTH OF STEAM TURBINE MOVING BLADES” International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 7, July 2013.