

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

G.D. Ujade<sup>1</sup> Prof. M.B. Bhambere<sup>2</sup>

<sup>1</sup>Student, II year M.E., Mechanical Engineering, SSGMCE Shegaon, Maharashtra, India

<sup>2</sup>Assistant Professor, Mechanical Engineering, SSGMCE Shegaon, Maharashtra, India

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**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 ZrCr5 Zirconium Chromite (existing material), Molybdenum, 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 these 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 used 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 Molybdenum, AlSi, ZrCr5 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 Titanium Alloy

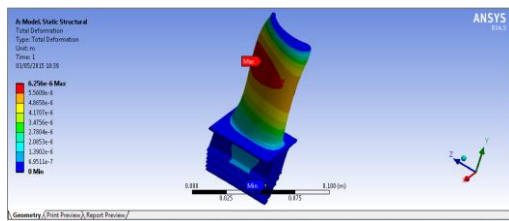


Fig. 3.1 shows the total deformation in the turbine blade made of Titanium Alloy due to centrifugal force and it is observed a deformation of  $6.25 \times 10^{-6}$  m which is maximum at leading edge near to the centre of the blade and the value is minimum at the root of the blade.

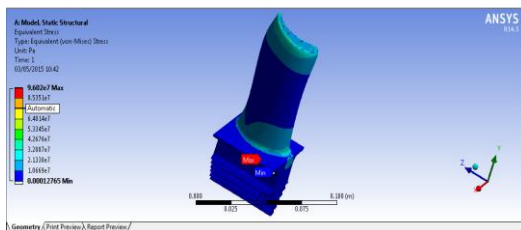


Fig 3.2 indicates the equivalent (von-mises) stress distribution in the turbine blade made of Titanium Alloy due to centrifugal force and it is observed a stress of  $9.60 \times 10^7$  N/m<sup>2</sup> which is maximum at leading edge near to the tip of the blade and the value is minimum at the root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

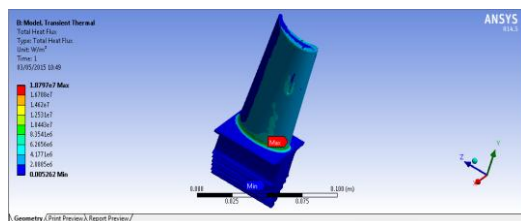


Fig 5.6 shows the total heat flux in the turbine blade made of Titanium Alloy. It is observed that maximum heat flux of  $1.87 \times 10^7$  W/m<sup>2</sup> occurs near to the center of the blade and minimum heat flux occurs at the root of the turbine blade.

### 3.2 Material Mullite

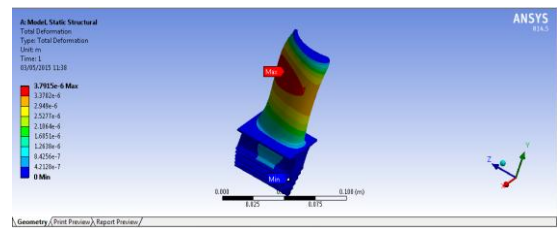


Fig. 3.4 shows the total deformation in the turbine blade made of mullite due to centrifugal force and it is observed a deformation of  $3.79 \times 10^{-6}$  m which is maximum at leading edge near to the center of the blade and the value is minimum at the root of the blade.

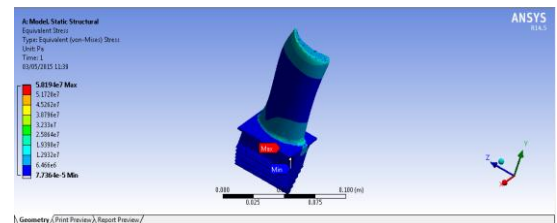


Fig 3.5 indicates the equivalent (von-mises) stress distribution in the turbine blade made of mullite due to centrifugal force and it is observed a stress of  $5.81 \times 10^7$  N/m<sup>2</sup> which is maximum at leading edge near to the tip of the blade and the value is minimum at the root of the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

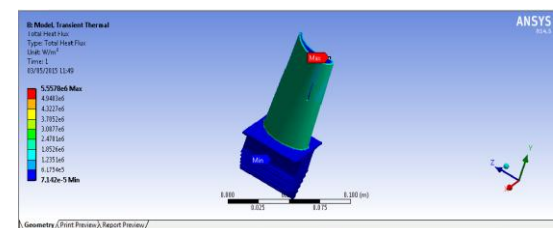


Fig 3.6 shows the thermal error in the turbine blade made of Titanium Alloy. It is observed that maximum thermal error of 1031.7 J occurs above the root of the blade and minimum thermal error occurs at the root of the turbine blade.

### 3.3 Material ZrCr5

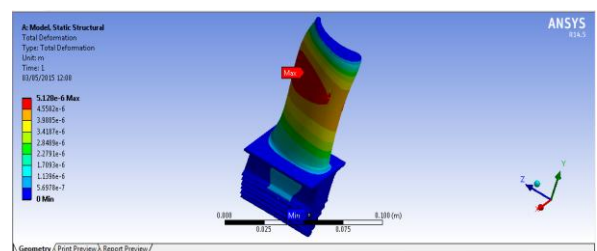


Fig. 3.7 shows the total deformation in the turbine blade made of ZrCr5 due to centrifugal force and it is observed a

deformation of  $5.12 \times 10^{-6}$  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.

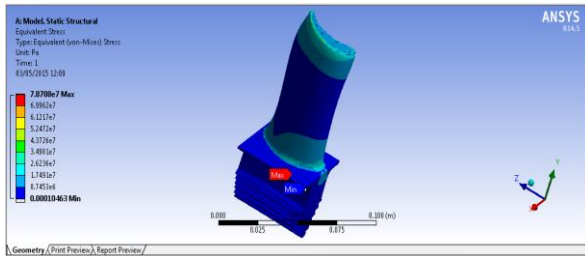


Fig 3.8 indicates the equivalent (von-mises) stress distribution in the turbine blade made of TiCr5 due to centrifugal force and it is observed a stress of  $7.87 \times 10^7$  N/m<sup>2</sup> which is maximum at leading edge near to the tip of the blade and the value is minimum at the root of the blade.

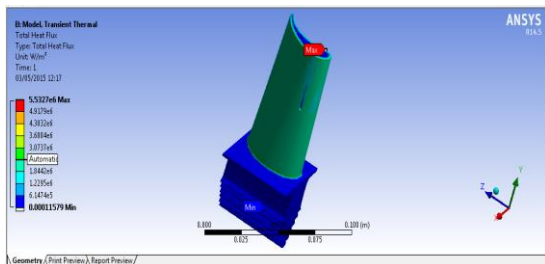


Fig 3.9 shows the total heat flux in the turbine blade made of Titanium Alloy. It is observed that maximum heat flux of  $5.53 \times 10^6$  W/m<sup>2</sup> occurs near to the center of the blade and minimum heat flux occurs at the tip of the turbine blade.

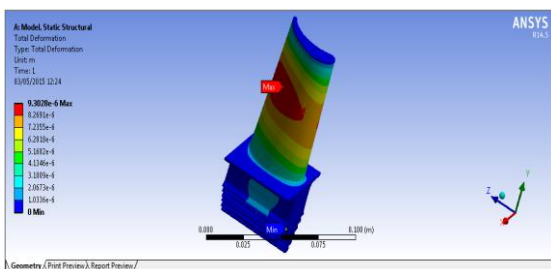


Fig. 3.10 shows the total deformation in the turbine blade made of AlSi due to centrifugal force and it is observed a deformation of  $9.30 \times 10^{-6}$  m which is maximum near to the center of the blade and the value is minimum at the root of the blade.

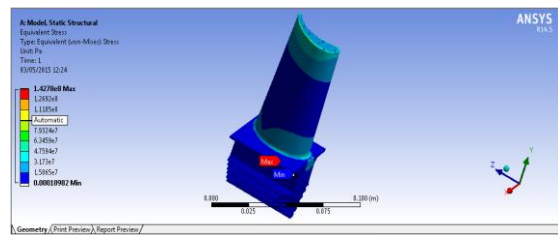


Fig 3.11 indicates the equivalent (von-mises) stress distribution in the turbine blade made of AlSi due to centrifugal force and it is observed a stress of  $1.42 \times 10^8$  N/m<sup>2</sup> which is maximum at leading edge near to the tip of the blade and the value is minimum at the root of the blade.

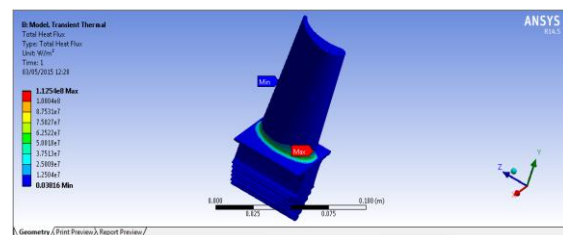


Fig 3.12 shows the total heat flux in the turbine blade made of AlSi. It is observed that maximum heat flux of  $1.12 \times 10^8$  W/m<sup>2</sup> occurs near to the centre of the blade and minimum heat flux occurs at the root of the turbine blade.

#### 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, TiCr5 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)                       | $5.51 \times 10^{-6}$ | $1.14 \times 10^{-6}$ | $1.70 \times 10^{-6}$ | $3.08 \times 10^{-5}$ |
| Equivalent Stress (N/m <sup>2</sup> )       | $1.57 \times 10^8$    | $5.98 \times 10^7$    | $8.31 \times 10^7$    | $1.52 \times 10^8$    |
| Shear Stress(N/m <sup>2</sup> )             | $3.70 \times 10^7$    | $1.02 \times 10^7$    | $1.37 \times 10^7$    | $2.48 \times 10^7$    |
| Maximum Principal Stress(N/m <sup>2</sup> ) | $5.81 \times 10^7$    | $2.69 \times 10^7$    | $3.67 \times 10^7$    | $6.67 \times 10^7$    |

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 <sup>2</sup> ) | $1.95 \times 10^7$ | $7.59 \times 10^6$ | $1.39 \times 10^8$ | $1.57 \times 10^8$ |
| 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×<br>10 <sup>-6</sup> | 6.25×<br>10 <sup>-6</sup> | 1.14×<br>10 <sup>-6</sup> | 3.79×<br>10 <sup>-6</sup> | 1.70×<br>10 <sup>-6</sup> | 5.12×<br>10 <sup>-6</sup> | 3.08×<br>10 <sup>-5</sup> | 9.30×<br>10 <sup>-6</sup> |
| Equivalent Stress (N/mm <sup>2</sup> )        | 1.57×<br>10 <sup>8</sup>  | 9.60×<br>10 <sup>7</sup>  | 5.98×<br>10 <sup>7</sup>  | 5.81×<br>10 <sup>7</sup>  | 8.31×<br>10 <sup>7</sup>  | 7.87×<br>10 <sup>7</sup>  | 1.52×<br>10 <sup>8</sup>  | 1.42×<br>10 <sup>8</sup>  |
| Shear Stress (N/mm <sup>2</sup> )             | 3.70×<br>10 <sup>7</sup>  | 1.93×<br>10 <sup>7</sup>  | 1.02×<br>10 <sup>7</sup>  | 1.17×<br>10 <sup>7</sup>  | 1.37×<br>10 <sup>7</sup>  | 1.59×<br>10 <sup>7</sup>  | 2.48×<br>10 <sup>7</sup>  | 2.88×<br>10 <sup>7</sup>  |
| Maximum Principal Stress (N/mm <sup>2</sup> ) | 5.81×<br>10 <sup>7</sup>  | 5.25×<br>10 <sup>7</sup>  | 2.69×<br>10 <sup>7</sup>  | 3.18×<br>10 <sup>7</sup>  | 3.67×<br>10 <sup>7</sup>  | 4.30×<br>10 <sup>7</sup>  | 6.67×<br>10 <sup>7</sup>  | 7.81×<br>10 <sup>7</sup>  |

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

|                                     |                      |                     |                      |                      |                      |                      |                      |                      |
|-------------------------------------|----------------------|---------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Ambient Temperature (°C)            | 35                   |                     |                      |                      |                      |                      |                      |                      |
| Applied Temperature (°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. (°C)  | 33.133               | 34.99               | 31.209               | 17.87                | 38.634               | 13.19                | 35.01                | 34.99                |
| Total Heat Flux (W/m <sup>2</sup> ) | 1.95×10 <sup>7</sup> | 1.8×10 <sup>7</sup> | 7.59×10 <sup>6</sup> | 5.55×10 <sup>6</sup> | 1.39×10 <sup>8</sup> | 5.53×10 <sup>6</sup> | 1.57×10 <sup>8</sup> | 1.12×10 <sup>8</sup> |
| 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.

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

### 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 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.

error is  $13.19^\circ\text{C}$ ,  $5.53 \times 10^6 \text{ w/m}^2$  and  $1021.8 \text{ J}$  respectively for geometry of turbine blade having 6 nos of perforated holes of ZrCr5 material. which is minimum as compared with other material. So, It can be conclude that ZrCr5 can reduces temperature more quickly and resistance to flow of heat is less in ZrCr5 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  $11.7 \times 10^7 \text{ MPa}$  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 ZrCr5 with 6 nos of hole is best suited for gas turbine blade from the above results.

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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

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