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THERMAL STRUCTURAL ANALYSIS OF A THERMAL BLADE

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ABSTRACT

Cooling of gas turbine blades is a major consideration because they are subjected to high temperature working conditions. Several methods have been suggested for the cooling of blades and one such technique is to have radial holes to pass high velocity cooling air along the blade span. The forced convection heat transfer from the blade to the cooling air will reduce the temperature of the blade to allowable limits. Finite element analysis is used in the present work to examine steady state thermal & structural performance for N155, Inconel 718and Titanium T6. The analysis is carried out using ANSYS software package. While comparing these materials, it is found that Inconel 718 is better suited for high temperature applications. On evaluating the graphs drawn for temperature distribution, von-mises stresses and deflection, the blade with 13 holes is considered as optimum.

1. INTRODUCTION

With the advent in Gas turbine technology, its usage as a prime mover has become prominent, since last few decades. One of the most important applications of gas turbines is in power generation, though it has been in use for aircraft propulsion since long time. The efficiency and power output of gas turbine plants is dependent on the maximum temperatures attained in the cycle. Advanced gas turbine engines operate at high temperatures (1200 oC – 15000 oC) to improve thermal efficiency and power output. With the increase in temperatures of gases, the heat transferred to the blades will also increase appreciably resulting in their thermal failure. With the existing materials, it is impossible to go for higher temperatures.

Taking into account the metallurgical constraints, it is necessary to provide cooling arrangement for turbine blades to keep their metal temperature with in allowable limits. Therefore, developments in turbine cooling technology play a critical role in increasing the thermal efficiency and power output of advanced gas turbines. The following three types of cooling methods have been adapted to varying degree of success.

1. Convection cooling
2. Film cooling
3. Transpiration cooling

While all three methods have their difference, they all work by using cooler air (bled from the compressor) to remove heat from the turbine blade. transferred by conduction to the blade and then by convection into the air flowing inside of the blade. A large internal surface area is desirable for this method, so the cooling passages are generally provided with small fins.

2. LITERATURE SURVEY

Extensive work has been reported in the literature on cooling of gas turbine blade.

Deepanraj et.al. Have considered titanium – aluminium alloy as the blade material and performed structural and thermal analysis with varying number of cooling passages. They also studied the effect of varying the cooling air temperature on the temperature distribution in the blades. It is concluded that the blade configuration with 8 holes gives an optimum blade temperature of 8000C.

Bhatt et al. performed transient state stress analysis on an axial flow gas turbine blade and disk using finite element techniques. They have chosen Inconel 718, a high heat resistant alloy of chromium, nickel & niobium. The study was focused on centrifugal & thermal stress arising in the disk.

A.K.Mattaet.al. studied the stress analysis for N – 155 & Inconel 718 material. On solid blades it is reported that Inconel 718 is better suited for high temperature operation. It is suggested by **Ervin** that high turbine efficiency can be obtained by minimising the air flow required for cooling by effectively utilising its cooling

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potential. He suggested a cooling technology which has three main parts: a) The leading edge is provided with impingement cooling; b) the middle section of blade contains cooling pipes with obstacles provided along the length to enhance turbulence in the cooling air and c) The trailing edge of the blade is provided with pin – fins for effective cooling.

K hari brahmaiah et.al. Examine the heat transfer analysis of gas turbine with four different models consisting of blade with and Without holes and blades with varying number of holes(5,9&13) were analyzed. Transfer rate and temperature distribution, the blade with 13 holes is considered as optimum. Steady state thermal and structural analysis is carried out using ANSYS software with different blade materials of Chromium steel and Inconel 718. While comparing these materials Inconel 718 is better thermal properties and induced stresses are lesser than the Chromium steel.

R d v Prasad et.al. Examine steady state thermal& structural performance for N155& Inconel 718 nickel chromium alloys. Using finite element analysis Four different models consisting of solid blade and blades with varying number of holes (5, 9&13 holes) were analyzed of cooling holes. The analysis is carried out using ANSYS software package. While comparing materials, it is found that Inconel 718 is better suited for high temperature .the graphs drawn for temperature distribution, von misses stresses and deflection, the blade with 13 holes is considered as optimum. The induced stresses are minimum and the temperature of the blade is close to the required value of 800C.

G. Narendranath et.al. examine the first stage rotor blade off the gas turbine analyzed using ANSYS 9.0. The material of the blade was specified as N155. Thermal and structural analysis is done using ANSYS 9.0 Finite element analysis software. The temperature variations from leading edge the trailing edge on the blade profile is varying from 839.5310C to 735.1620C at the tip of the blade. It is observed that the maximum thermal stress is 1217 and the minimum thermal stress is the less than the yield strength value i.e., 1450

V.Vijaya Kumar et.al. examine the “preliminary design of a power turbine for maximization of an existing turbojet engine”. For a clear understanding of the combined mechanical and the thermal stresses for the mechanical axial and centrifugal forces. The peripheral speed of rotor and flows velocities is kept in the reasonable range so to minimize losses. In which the base profiles is analyzed later for flow condition through any of the theoretical flow analysis method such as “potential flow approach” .

3. MODELLING AND ANALYSIS OF GAS TURBINE BLADE

The blade model profile is generated by using CATIA software. Key points are created along the profile in the working plane. The points are joined by drawing B spline curves to obtain a smooth contour. The contour (2D model) is then converted into area and then volume (3D model) was generated by extrusion. The hub is also generated similarly. These two volumes are then combined into single volume.

This model of turbine blade is then imported into ANSYS software. The blade is then analysed sequentially with thermal analysis preceding structural analysis. The model is discretised using 10 noded tetrahedral solid element (Solid 87).The surface of the blade is applied with Surface element (Surf 152) for applying the convection loads. The temperatures of blade are then determined by thermal analysis. Followed by this, the structural analysis is carried out by importing the temperatures determined in thermal analysis. 10 noded tetrahedral solid element (Solid 187)was used for structural analysis. The loads considered for structural analysis are centrifugal, axial & tangential forces.

4. Nomenclature

α Coefficient of thermal expansion
E Young’s Modulus
μ Poisson’s ratio
L Length

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D Diameter of shaft
N Speed of turbine in RPM
K Thermal conductivity
d Diameter of cooling air passage
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4.1 Details of Turbine blade

D = 1308.5 mm, N = 3426 Rpm, L = 117 mm,
d = 2mm

Table 1 Mechanical properties of N155 & Inconel 718

Properties	Units	N 155	Inconel 718
E	Pa	143 E09	149 E09
ρ	Kg/cu m	8249	8220
K	W/m-K	20.0	25.0
μ	---	0.344	0.331
α	E-06/^{0}C	17.7	16.0
C_p	J/Kg K	435	586.2
Melting Point	^{0}C	1354	1344
Yield stress	MPa	550	1067

5. RESULTS & DISCUSSIONS

The Temperature distribution of the blade depends on the heat transfer coefficient for gases and the thermal conductivity of the material. The heat transfer coefficients are calculated by iterative process and the same were adopted. The analysis was carried out for steady state heat transfer conditions. It is observed that the maximum temperatures are prevailing at the leading edge of the blade due to the stagnation effects. The body temperature of the blade doesn’t vary much in the radial direction. However, there is a temperature fall from the leading edge to the trailing edge of the blade as expected. It is observed for solid blade model from fig1(N - 155) and fig2 (Inconel 718),
that the blade temperatures attained for Inconel 718 are marginally lower. This can be attributed to the lower thermal conductivity of Inconel 718.

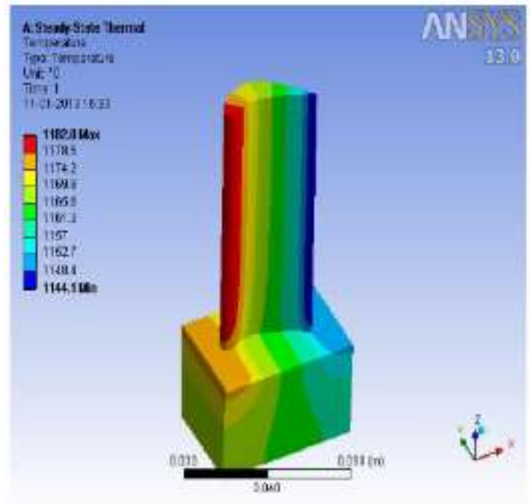

Fig 1.Temperature distribution for solid(N155)

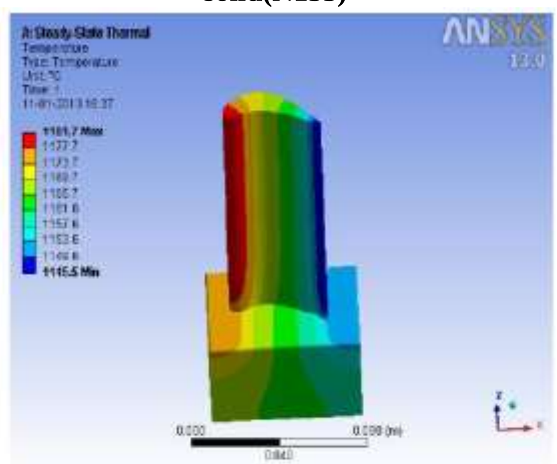

Fig 2.Temp distribution for solid(Inconel718)

When holes are drilled radially for passage of cooling air, there is an appreciable variation of temperature profile of the blade. It can be observed from the figs. 3&4(5 holes) that the temperature at the root of the blade is lower and it increases towards the tip of the blade. This characteristic can be explained from the fact that the cooling air is at its lowest temperature (3000 C) while flowing through the hub and root of theblade and it goes on increasing along the radial direction. This phenomenon is also observed in blade models of 9 & 13 holes, figs.(5,6,7&8).

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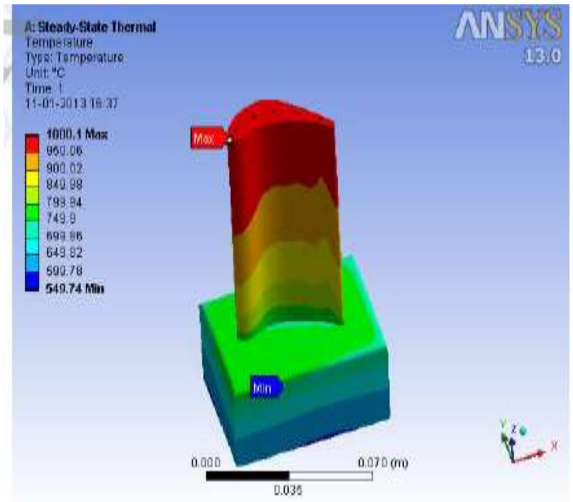

Fig 3.Temp.Distribution for 5 holes(N - 155)

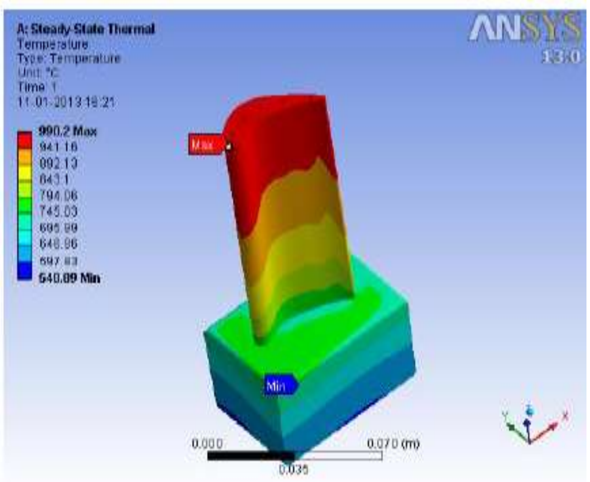

Fig 4.Temp.distribution for 5holes (Inconel 718)
N – 155 Material

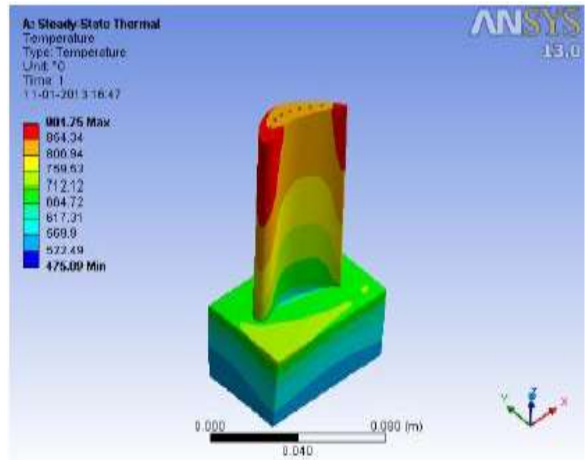

Fig 5 .Temperature distribution for 9holes

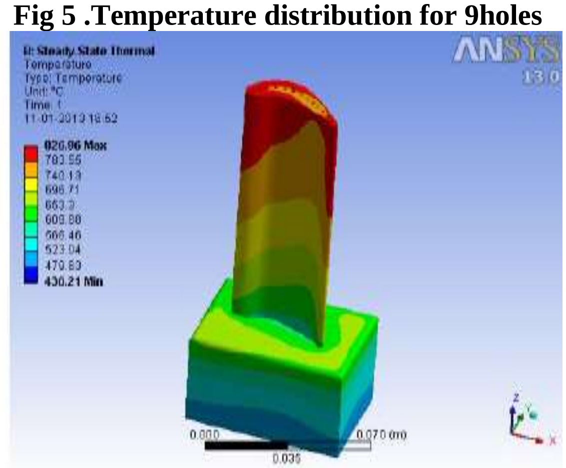

FIG 7.TEMPERATURE DISTRIBUTION FOR 13HOLES

CONCLUSIONS

Gas turbine blade cooling is studied for two different materials of constructions that is N – 155 & Inconel 718. It is found that Inconel 718 has better thermal properties as the blade temperatures and thermal stresses induced are lesser. The provision of cooling passages in the blades is found to alleviate the problem of high temperatures and thermal stresses. On analysing 4 different models with varying number of holes, it is inferred that the blade model with 13 holes is best suited.

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