THERMAL AND STRUCTURAL ANALYSIS OF GAS TURBINE BLADE COOLING SYSTEM WITH NICKEL-CHROMIUM ALLOY

[1]R.D.V.Prasad, [2]M.Sailaja, [3]V.Raviteja Behera, [4]Yathish Ramena, [5]M.S.S.Srinivasa Rao
[1, 2, 3]Asst.Professor, [4]Scientist [5]Sr.Asst.Professor
Department of Mechanical Engineering,
ANITS, Sagivalasa, Visakhapatnam, Andhra Pradesh, INDIA

***Abstract*:** In the present work the gas turbine rotor blade has been analyzed for structural and thermal by using ANSYS13.0, which is powerful finite element software. In the process of getting the thermal stresses, the temperature distribution in the rotor blade has been evaluated using this software. The design features of the turbine segment of the gas turbine have been taken from the preliminary design of a power turbine for maximization of an existing turbojet engine. It was observed that in the above design, the rotor blades after being designed were analyzed only for the mechanical stresses but no evaluation of thermal stress was carried out. As the temperature has a detail study can be carried out on the temperature effects to have a clear understanding of the combined mechanical and thermal stresses.

Cooling of gas turbine blades is a major consideration to improve their efficiency. 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. In the present work, Finite element analysis is used extensively to examine steady state thermal & structural performance of blades fabricated with Inconel X-750, Hastelloy X nickel-chromium alloys. Their suitability to withstand high temperature in the range of 1200^0C is studied. Further the effect of cooling on the thermal and structural behaviour of the blade materials is also evaluated. Three different models consisting of 5holes and blade with 9, 13 numbers of holes was analysed. In this paper, an attempt has been made to analyse the cooling of a gas turbine blade made of Nickel based Super alloy through Mechanical analysis. The turbine rotor blade was analysed for Thermal stress, Deformation and Temperatures distribution.

Index Terms- Gas turbine, Temperature, stress, deformation, Thermal and structural analysis.

I. INTRODUCTION

The increased awareness that the world's energy resources are limited has caused many countries to re-examine their energy policies and take drastic measures in eliminating waste. It has also sparked interest in the scientific community to take a closer look at the energy conversion devices and to develop new techniques to better utilize the existing limited resources.

Gas turbines are used extensively for aircraft propulsion, land-based power generation, and industrial applications. Developments in turbine cooling technology play a critical role in increasing the thermal efficiency and power output of advanced gas turbines. Gas turbine blades are cooled internally by passing the coolant through several rib-enhanced serpentine passages to remove heat conducted from the outside surface. Cooler air from the internal coolant passages out of the blade surface to form a protective layer between the blade surface and hot gas-path flow.

Advanced gas turbine engines operate at high temperatures (1200–1500C) to improve thermal efficiency and power output. The turbine inlet temperature increases, the heat transferred to the turbine blade also increases. The level and variation in the temperature within the blade material, which cause thermal stresses, must be limited to achieve reasonable durability goals. The operating temperatures are far above the permissible metal temperatures. Therefore, there is a critical need to cool the blades for safe operation.

II. LITERATURE REVIEW

In a journal B. Deepanraj et.al [1] 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 blade sand 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 material properties of Titanium- Aluminium Alloy. Six different models with different number of holes (7, 8, 9, 10, 11, and 12) were analysed in this paper to find out the optimum number of holes for good performance. In Finite element analysis, first thermal analysis followed by structural analysis is carried out. Graphs are plotted for temperature distribution for existing design (12 holes) and for 8 holes against time. 2D and 3D model of the blade with cooling passages are shown. Using ANSYS, bending stress, deflection, temperature distribution for number of holes are analysed. It is found that when the numbers of holes are increased in the blade, the temperature distribution falls. For the blade configuration with 8 holes, the temperature near to the required value i.e., 800ºC is obtained. Thus, a turbine blade with 8 holes configuration is found to be the optimum solution.

In a journal Sanjay Kumar et.al[2] investigates the advantages of transpiration cooling technology over film cooling used in simple aero gas turbine cycle. The effects of variation of TIT and compressor pressure ratio on cycle performance are

presented.TSFC with transpiration cooling is slightly higher than with film cooling in higher TIT range. However comparatively greater specific thrust is obtained with transpiration cooling than with film cooling.

In a journal Majid Rezadeh Reyhani et.al[3] used methods for calculating bade temperature and life are demonstrated and validated. Using these methods, a set of sensitivity analyses on the parameters affecting temperature and life of a high pressure, high temperature turbine first stage blade is carried out. Investigated uncertainties are blade coating thickness, coolant inlet pressure,temperature and gas turbine load variation. Results show that increasing thermal barrier coating thickness by 3 times, loads to rise in the blade life by 9 times. In addition, considering inlet cooling temperature and pressure, deviation in temperature has greater effect on blade life. One of the interesting point that can be realized from the results is that 300 hours operation at 70% load can be equal to one hour operation at base load.

In a journal L.Umamaheswararao et.al [4] the first stage rotor blade of a gas turbine has been analysed for structural, thermal analysis using ANSYS (Finite Element Analysis Software). The material of the blade was specified as INCONEL 718. The thermal boundary conditions on the rotor blade are taken from the reference. The temperature distribution across the blade is obtained. The maximum stress up to which the blade can withstand is known and the stress distributions across the blade are obtained accordingly. The obtained results are compared with N-155, Mild Steel and the most suitable material is discussed. In final the actual fir tree model blade root compared with I-section model blade root, results are tabulated, and it is observed that stress distribution less in fir tree model that the I-section model

III. MODELLING OF GAS TURBINE BLADE

We have designed a Turbine blade model profile is generated by using CATIA V5 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.

Table 3.1 Mechanical Properties of Turbine blade (Inconel X-750 and Hastelloy X) materials

Properties	Units	INCONEL X-750	HASTELLOY X
E	Pa	31E09	205E09
P	Kg/cu m	8303	8220
K	W/m-K	26.55	18.7
M	--	0.344	0.331
A	E-06/^{0}C	14.12	16.0
Cp	J/Kg K	435	586.2

IV. RESULTS & DISCUSSION

The thermal & structural analysis of the blade is considered at for two different materials Inconel X-750 and Hastelloy X to determine their relative capability to withstand high temperatures of greater than 1200^{0}C that are generally encountered the gas that applications. The study involves the determination of temperatures at heat fluxes from thermal analysis. These temperatures are the impacted to structural analysis to evaluate the thermal stresses due to differential thermal expansion and the external forces applied on the blade. 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 tailing edge of the blade as expected. The analysis is carried out initially on the blade model of both materials.

To reduce the temperature and heat fluxes, air passages are drilled along the length of the blade from tip to root. The diameters of holes are taken as 2 mm and the holes are evenly placed and drilled through the hub and blade. When cooling passages are provided, there is an appreciable variation of temperature profile of the blade. Compared to solid blade it can be observed from the figure 1 & 2 (5holes) 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 (300^{0}C) while flowing through the hub and root of the blade and it goes on increasing along the radial direction. The heat is conducted within the blade from tip to root due to higher temperature prevailing at the tip. Similarly conclusion can be drawn the blade model with 9 holes. The maximum temperature falls further down to 997.3^{0}C from 1015.2^{0}C with the increasing number of holes from 5 to 9 it can be observed from the figure 3 & 4 (9holes). The maximum temperature occurs at the leading edge due to its expansion to the gasses at their highest temperature and also at the trailing edge section. This is due to lack of cooling effect at the trailing edge of cooling holes cannot be drilled at the smallest thickness of trailing edge.

Distribution of Temperature for Inconel X-750 and Hastlloy X

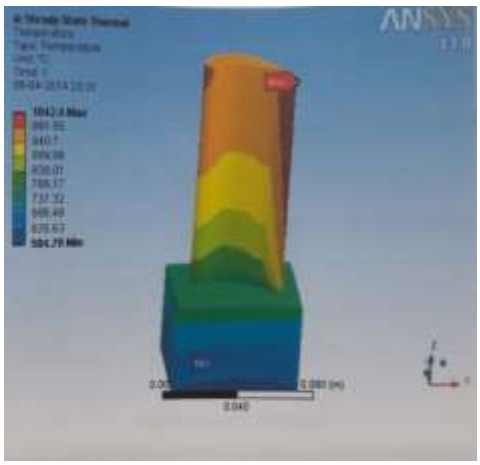

Fig1: Inconel X-750(5holes)

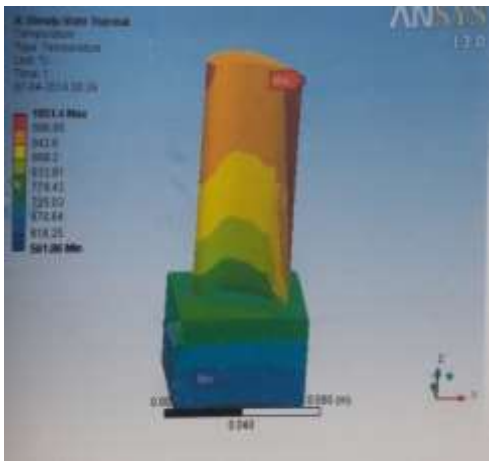

Fig 2: Hastelloy X (5holes)

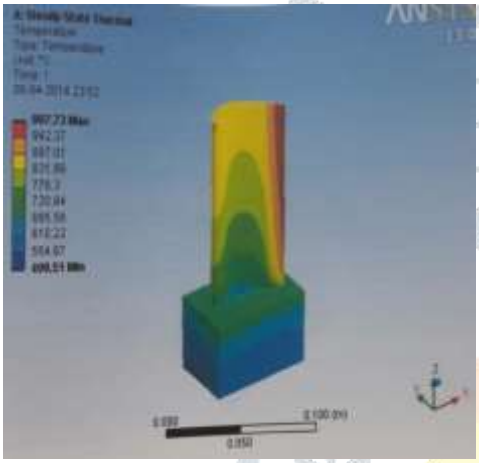

Fig3: Inconel X-750(9holes)

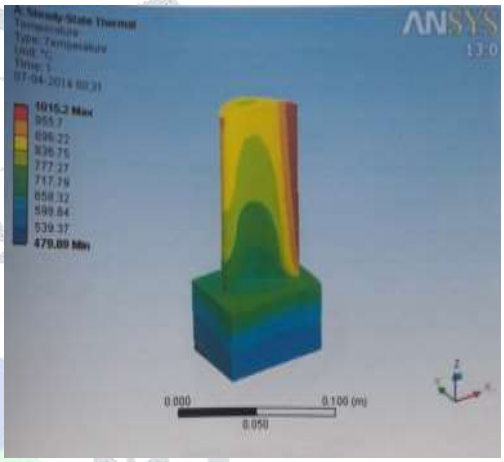

Fig4: Hastelloy X (9holes)

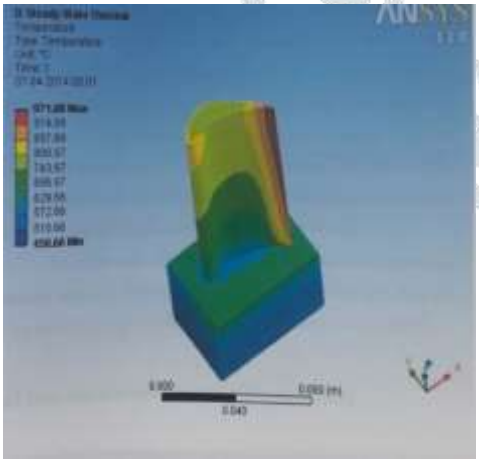

Fig 5: Inconel X-750(13holes)

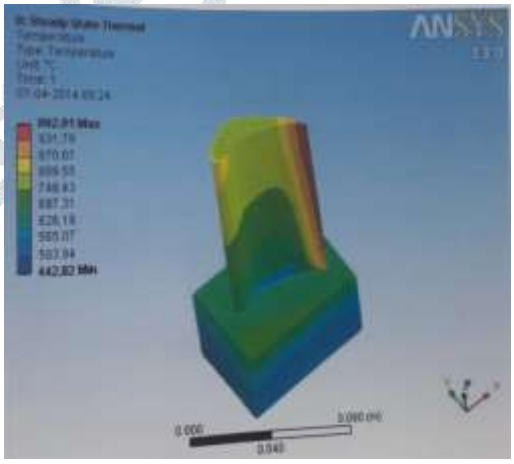

Fig6: Hastelloy X (13holes)

Stress Distribution for Inconel X-750 and Hastlloy X

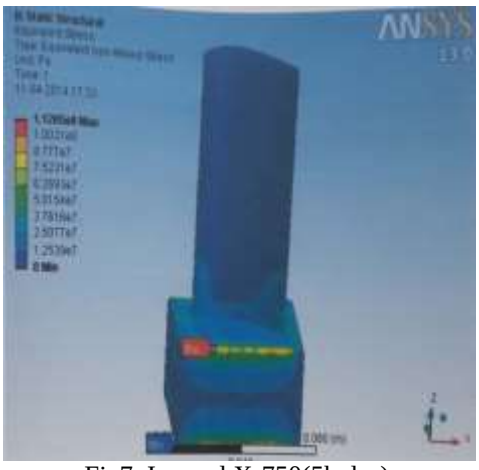

Fig7: Inconel X-750(5holes)

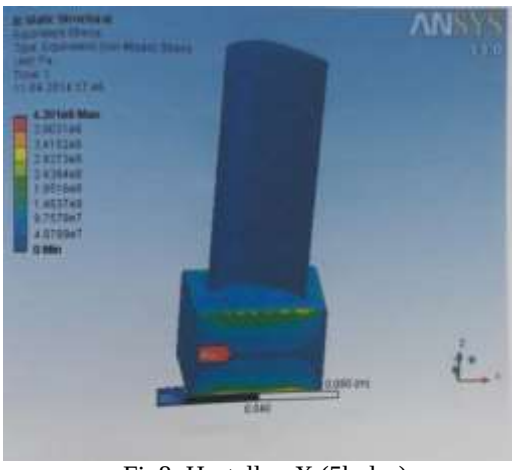

Fig8: Hastelloy X (5holes)

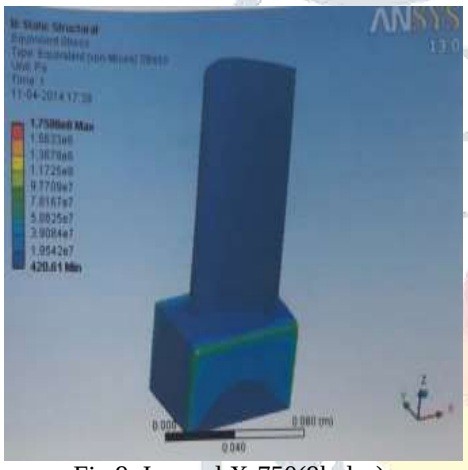

Fig 9: Inconel X-750(9holes)

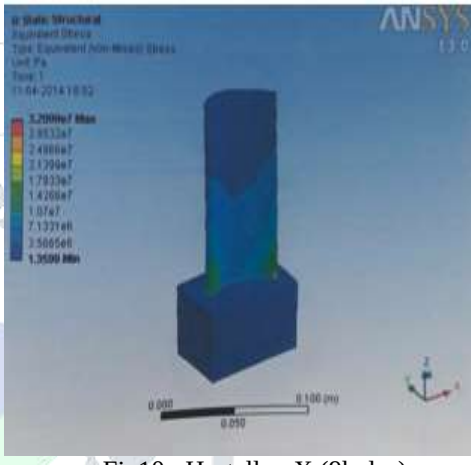

Fig10: Hastelloy X (9holes)

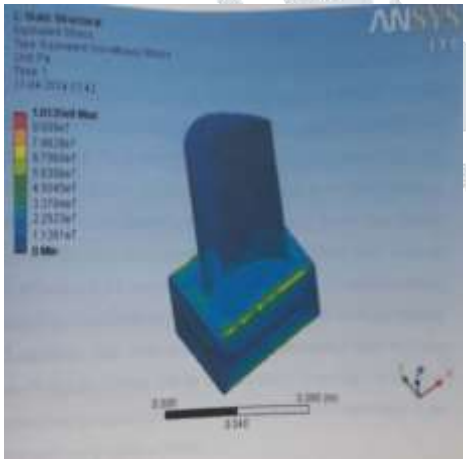

Fig11: Inconel X-750(13holes)

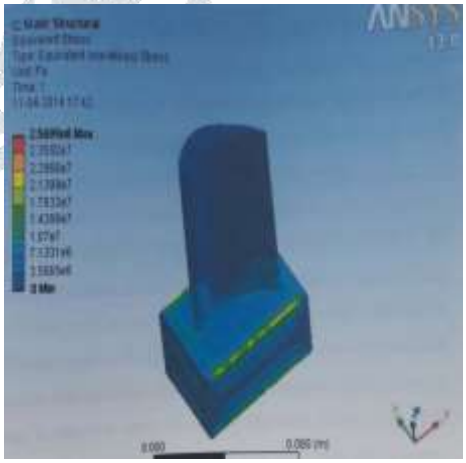

Fig12: Hastelloy X (13holes)

Deformation for Inconel X-750 and Hastlloy X

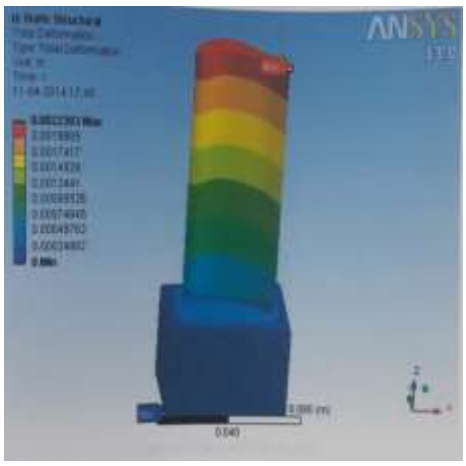

Fig13: Inconel X-750(5holes)

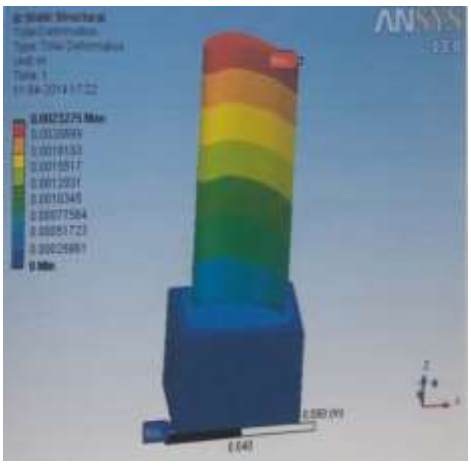

Fig14: Hastelloy X (5holes)

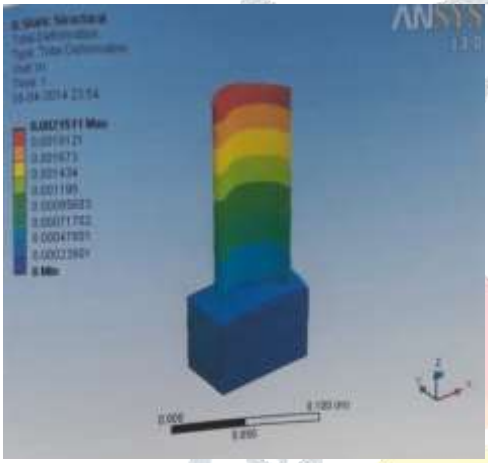

Fig 15: Inconel X-750(9holes)

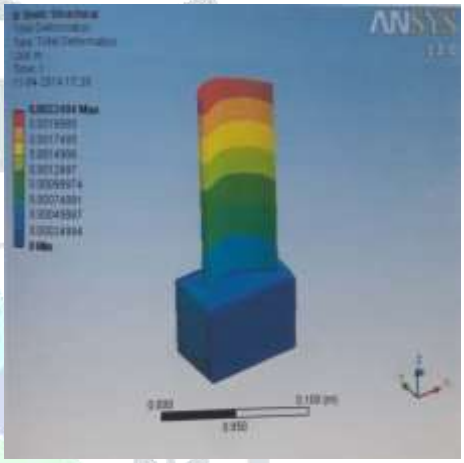

Fig16: Hastelloy X (9holes)

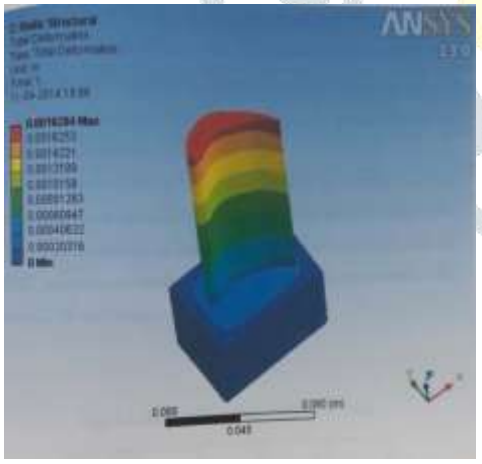

Fig17: Inconel X-750(13holes)

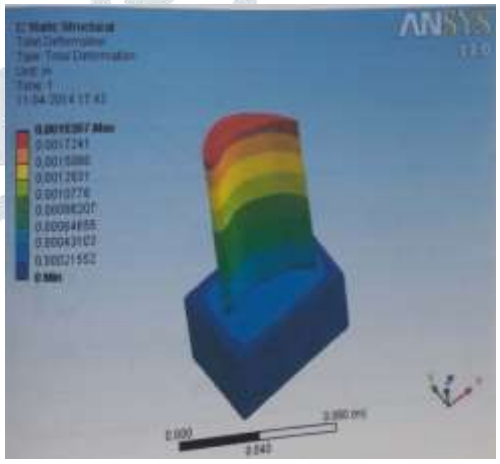

Fig18: Hastelloy X (13holes)

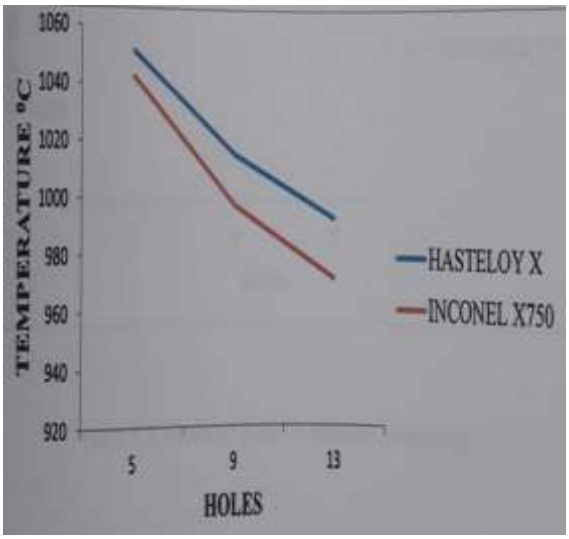

Fig 19: Number of Holes Vs Maximum Temperature

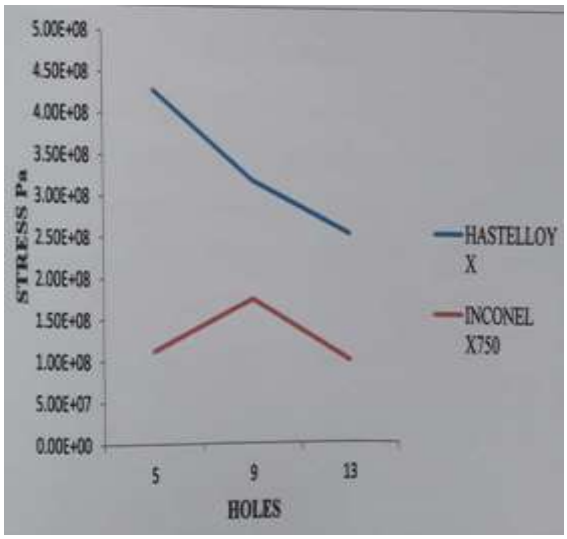

Fig 20: Number of Holes Vs Maximum Stress

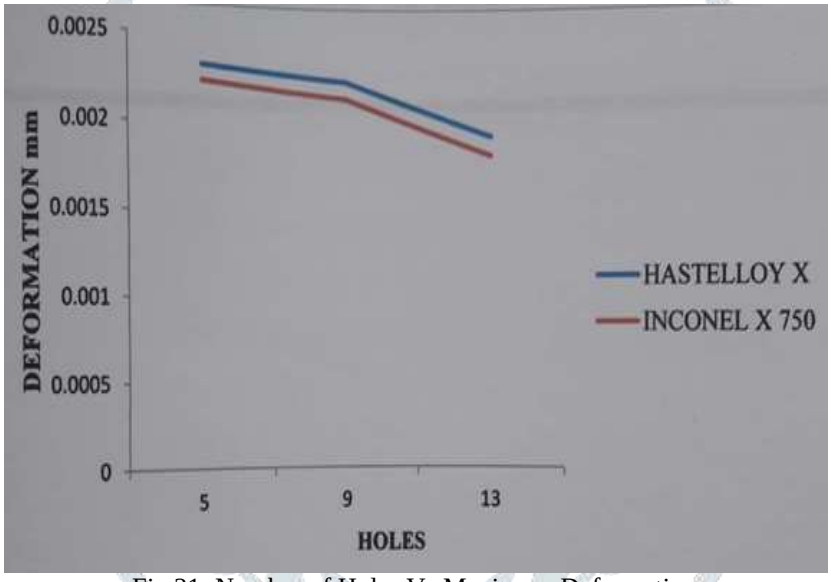

Fig 21: Number of Holes Vs Maximum Deformation

From the graph 1, it can be seen that the maximum temperature attained in the blade goes on decreasing with increasing number of holes; it is found that for 13 holes the minimum temperature attained is about 971.68^{0}C. It has been reported that a decreasing temperature will lead to lower thermal efficiency, as larger portion of air is utilised for cooling purpose and reduced quantities of air flows into the combustor chamber of gas turbine plant. The reduced mass flow rate of the gas and the decreased temperature of the blade will reduce the power output and efficiency of the plant. Hence the number of holes is restricted to 13.

The temperatures obtained from the thermal analysis are imported to structural analysis to determine the thermal stresses. The Centrifugal, Axial and Tangential forces acting on the blade are considered as loads in structural analysis.

The provision of cooling passages reduces the body temperature of the blade and hub and the temperature drops with the increase in number of holes. It is also observed that the stresses induced in the hub while slight increases in the stresses induced in the blade portion are observed. There is an appraisable decreasing in the induced stresses when holes are provided. This can be due to reduced thermal expansion of the blade which in turn can be attributed to drop in temperatures when holes are provided. The maximum stresses induced for 5 holes model are 113Mpa and 429 Mpa for Inconel X-750 and Hastelloy X respectively. These values are within limits. The corresponding value for 9 holes are 176Mpa and 321Mpa, With the increasing cooling by provided 9 holes, it may appeared that the induced stresses reduce but what is observed is contraversary to this abnormally can be explain as follows

Cooling in general reduces the temperature and their by thermal stresses but if the cooling is uneven a section of the blade can be subjected to higher cooling levels compared to adjacent sections. Such a situation will produce higher differential explanation between these two sections and there by the thermal stresses induced will increase instated of decreasing this effect is observed in the blade model with 9 holes with the further increase number of holes to 13 there is a drop in thermal stresses. The minimum value of stresses 105Mpa and is produced in the hub. The decreasing in stresses is due to increase in cooling passages which are closely spaced. The cooling is more uniform and the passages are provided will allow the blade material to expand freely. This phenomenon is responsible for reduction in the stresses.

Generally when the temperature of the body rises above the ambient temperature, the body will deform. The deformation of body is directly proportional to this temperature deference similarly when the gas turbine blade is exposed to high temperature, it will have tendency to deform. The deformation being proportional to its raising temperature. The solid blade has a maximum deformation is observed at the tip of the blade close to the leading edge where the temperature is highest. When the blade is subjected to cooling the maximum temperature attained by the blade decreases. Hence the maximum deformation of blade also decreases with the increase in number of holes, the deformation levels decrease. The maximum deformations for Inconel X-750 are observed to be 2.375mm, 2.2494mm and 1.9397mm for 5,9 and 13 holes. The corresponding values are Hastelloy X are 2.2393mm, 2.1511mm, 1.8284mm.

It can also be observed that the minimum temperature, stresses and deflection produced in the blade are maximum for 13 holes. Hence the optimum number of holes that are to be provided stands at 13. Any further increasing in number of holes will reduce the blade temperature further adversely affecting the thermal efficiency and power output of the turbine.

It can be observed from the figures.19,20 & 21 that the temperatures, stresses and deflection are on higher side for Hastelloy X material compared to Inconel X-750. Hence, it can be concluded that Inconel X-750 is best suited for gases higher than the 1200^0C temperature, as Hastelloy X has poor themal properties when compared with Inconel X-750 and it is highly unsuitable for such applications.

V CONCLUSIONS

The effect of cooling of gas turbine blades is studied for two different materials of construction i.e., Hastelloy X & Inconel X-750. It is found that the temperature has a significant effect on the overall stresses induced in the turbine blades

Table 5.1 Maximum Temperature Vs. Number of holes

No. Of Holes	5	9	13
HASTELOY X	1051.4^0C	1015.2^0C	992.91^0C
INCONEL X750	1042.4^0C	997.3^0C	971.68^0C

1. The blade temperature attained and thermal stresses induced are lesser for Inconel X-750 as it has better thermal properties.
2. The provision of cooling passages in the blades is found to alleviate the problem of high temperatures and thermal stresses in both the materials.
3. On analyzing 3 different models with varying number of holes, it is inferred that the blade model with 13 holes is best suited as the stresses produced are lower and the maximum temperature of the blade is around 971.68^0C.
4. There will be a further drop in temperature with increase number of holes which is undesirable. Maximum deformation and temperatures are observed at the blade tip section when holes are provided.

VI. REFERNCES

[1] B. Deepanraj, P. Lawrence and G. Sankaranarayanan "**THEORETICAL ANALYSIS OF GAS TURBINE BLADE BYFINITE ELEMENT METHOD**" Scientific World, Vol. 9, No. 9, July 2011

[2] Sanjay Kumar, Onkar Singh and M.V.Mallikarjun "**PERFORMANCE EVALUATION OF SIMPLE AERO GAS TURNINE CYCLE WITH TRANSPIRATION COOLING OF GAS TURBINE BLADES**" International Journal of Emerging Technology and Advanced Engineering,Special Issue 3:Icertsd 2013, Volume 3, Feb 2013,pp416-420.

[3] Majid Rezazadeh Reyhani, Mohammad Alizadeh, Alirezafathic and Hiwa Khaledi "**TURBINE BLADE TEMPERATURE CALCULATION AND LIFE ESTIMATION**" A Sensititvity Analysis Propulsion and Power Research (2):148-161 In 2013.

[4] L.Umamaheswararao, Dr. K. Mallikarjunarao **"Design and analysis of a gas turbine blade by using FEM"** International Journal of Latest Trends in Engineering and Technology (IJLTET) Vol. 4 Issue 4 November 2014 ISSN: 2278-621X

[5] Amjed Ahmed Jasim AL-Luhaibi1, Mohammad Tariq **"THERMAL ANALYSIS OF COOLING EFFECT ON GAS TURBINE BLADE"** IJRET: International Journal of Research in Engineering and Technology ISSN: 2319-1163 ISSN: 2321-7308

[6] Pedaprolu Venkata Vinod, T.Seshaiah, T.Victor Babu "**THE DESIGN AND ANALYSIS OF GAS TURBINE BLADE"** International Journal of Advanced Engineering Research and Studies E-ISSN2249–8974

[7] R Yadav, "Steam and Gas turbine", Central Publishing House, Allahabad.

[8] ANSYS inc.U.S.A." Help Manual", ANSYS 5.4.

[9] V.Ramamurti, "Computer Aided Design in Mechanical Engineering", Tata McGraw Hill publishing company Ltd. New Delhi, 1999.

[10] T.R.Chandrupatla, Belegundu A.D., "Finitite Element Engineering", Prentice Hall of India Ltd, 2001.