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Heat Transfer Analysis of Gas Turbine Blade Through Cooling Holes

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ABSTRACT

In advanced gas turbines, the turbine blade operated temperature is for above the melting point of blade material. A sophisticated cooling scheme must be developed for continuous safe operation of gas turbines with high performance. 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. In the present work to examine the heat transfer analysis of gas turbine with four different models consisting of blade with without holes and blades with varying number of holes (5, 9&13) were analysed The analysis is carried out using commercial CFD software FLUENT (a turbulence realizable k-є model with enhanced wall treatment) has been used. On evaluating the graphs drawn for total heat 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 Inconel718. While comparing these materials Inconel718 is better thermal properties and induced stresses are lesser than the Chromium steel.

KEY WORDS: *Radial holes, realizable k-є model, enhanced wall treatment, Heat transfer rate*

I. INTRODUCTION

Gas turbines are the prime mover in critical industries such as power generation; processing plant and aircraft propulsion. Gas turbine inlet temperature have been increasing over the years due to positive economics of higher efficiency and higher firing temperatures. In 1960s, material properties limited gas turbine firing temperature and turbine blade temperature around 800C.Advanced gas turbine engines operate at high temperatures (1200-1500C) to improve thermal efficiency and power output. With the increase in temperature of gases, the heat transfer to the blades will also increase appreciably resulting in their thermal failure. With the existing materials, it is impossible to go for higher temperatures. Therefore a sophisticated cooling scheme must be developed for continuous safe operation of gas turbines with high performance. Gas turbine blades are cooled internally and externally. Internal cooling is achieved by passing the coolant through several enhanced serpentine passages inside the blades and extracting the heat from the outside of the blades. The following types of cooling methods have been adopted to varying degree of success.

1. Convention cooling
2. Impingement cooling
3. Film cooling
4. Transpiration cooling

While all four methods have their difference, they all work by using cooler air (bled from the compressor) to remove heat from the turbine blade. Convection cooling works by passing cooling air through passages internal to the blade. Heat is transferred by conduction through 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 paths tend to be serpentine and full of small fins. The internal passages in the blade may be circular or elliptical in shape. Cooling is achieved by passing the air through these passages from hub towards the blade tip. This cooling air comes from an air compressor. The second type of cooling is Impingement cooling. A variation of convection cooling, impingement cooling, works by hitting the inner surface of the blade with high velocity air. This allows more heat to be transferred by convection than regular convection cooling. In case of turbine blades, the leading edge has maximum temperature and thus heat load. Impingement cooling is also used in mid chord of the vane. Cooling air enters from the leading edge region and turns towards the trailing edge.

Film cooling is the third major type of cooling which works by pumping cool air out of the blade through small holes in the blade. This air creates a thin layer (the film) of cool air on the surface of the blade, protecting it from the high temperature air. The air holes can be in many different blade locations, but they are most often along the leading edge. Besides cooling blade surface it decreases heat transfer from metal surface to the hot fluid. One consideration with film cooling is that injecting the cooler bleed into the flow reduces turbine efficiency. That drop in efficiency also increases as the amount of cooling flow increases. The drop in efficiency, however, is usually mitigated by the increase in overall performance produced by the higher turbine temperature. The fourth type of cooling is transpiration cooling. It is similar to film cooling in that it creates a thin film of cooling air on the blade, but it is different in that air is "leaked" through a porous shell rather than injected through holes. This type of cooling is effective at high temperatures as it uniformly covers the entire blade with cool air. Air flows through internal channels of the strut and then passes through the porous shell to cool the blade.

The present paper attempts to study the effect of variation in number of cooling passages on the temperature distribution and heat transfer rate. It has to be emphasised that the blade has to be analysed to find out the optimum number of cooling holes. The analysis of turbine blade mainly consisting of following three parts: Cfd, thermal and structural analysis. Cfd analysis is carried out using Cfd Fluent software. The thermal and structural analysis is carried out under steady state condition using Ansys software with two different materials of chromium steel and inconel718.

II. LITERATURE SURVEY

Extensive work has been reported in the literature on cooling of gas turbine blade. Narasaraju et.al.[1] have considered N155 and Inconel718 nickel chromium alloy as the blade material and performed steady state thermal and structural analysis with varying number of cooling passages. It is concluded that decreased temperature of the blade will reduce power out and efficiency of plant. Hence the number of cooling holes restricted to 13. Deepanraj et.al. [2] Have considered titanium-aluminum alloy as the blade material and it is concluded that blade configuration with 8 holes given as optimum blade temperature of 800°C. Hidekazu Iwasaki et.al.[3] performed thermal and fluid analysis for gas turbine cooled vane and blade, and conducted to validate the accuracy of factors static pressure, heat transfer coefficient and film cooling effectiveness. Vickery et.al.[4] studied computation of gas turbine blade film cooling by using a two equation turbulence realizable k- ϵ model and two layer zonal near-wall treatment method have been used, two cases at a boundary layer which involve three cooling holes.

III. MODELING, MESHING AND ANALYSIS OF GAS TURBINE BLADE

The blade model is generated by using GAMBIT software. Blade profile key points are imported through icem input. The points are joined by using edge command Nurbs operation. And by using the face command create the edges as face, by selecting the sweep face and mention magnitude finally volume is created. Using volume command and select brick it creates the blade boundary. And varying number of holes is created by selecting volume command cylinder and subtracts real volumes. Meshing is done in ICEM CFD for accurate meshing. By selecting the tetra elements then compute mesh it creates number of elements and nodes. And import mesh file in FLUENT, then define model is Realizable k-ϵ model, and mention the boundary conditions.
In ANSYS the blade is analysed sequentially with thermal analysis preceding structural analysis. The model is discretised using solid element (solid 20 node90). And apply the temperature and convection loads on surface elements. The thermal flux of the blade is determined by thermal analysis. The structural analysis is carried out by selecting solid element (solid 185).

IV. NOMENCLATURE

E Young's Modulus
μ Poisson's ratio
L Length of blade
l Cord length of blade profile
K Thermal conductivity
ρ Density
Cp Specific heat
D Diameter of cooling air passage

Details of turbine blade
L=200mm, l=115mm, D=1.2mm

Table 1 Mechanical properties of Chromium steel and Inconel718

Properties	units	Chromium steel	Inconel718
E	Mpa	80700	205000
ρ	Kg/cu m	7750	8190
K	W/m-k	24	25
µ	---	0.28	0.284
Cp	J/kg-k	435	586.2
Melting point	°C	1410	1344
Yield stress	Mpa	655	1067

V. RESULTS & DISCUSSIONS

The total heat transfer rate and temperature distribution of the blades depends on the heat transfer coefficient for gases and thermal conductivity of material. The cfd analysis is carried out with different models using a turbulence Realizable k-ϵ model. It is observed that the maximum temperature is attained at the leading edge of the blade. However the temperature distribution is very less in the blade is expected. It I observed for blade with without holes model from fig1, that the total heat transfer rate is also lower. It is observing that fig2 static pressure of the blade pressure side is at maximum than suction side. Because of the hot air enters at the velocity of 277.16 m/sec from leading edge to trailing edge of the blade.

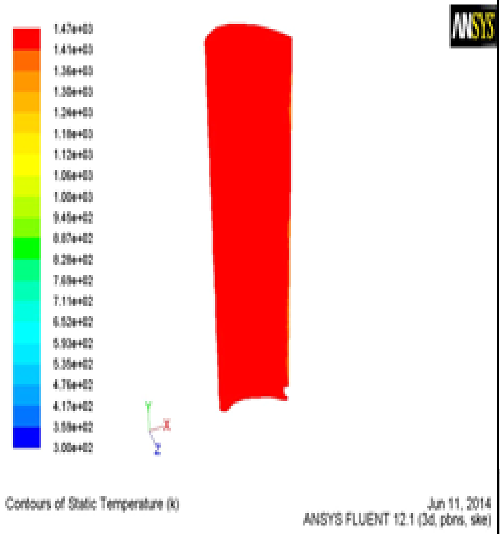


Fig1. Temperature of blade without holes

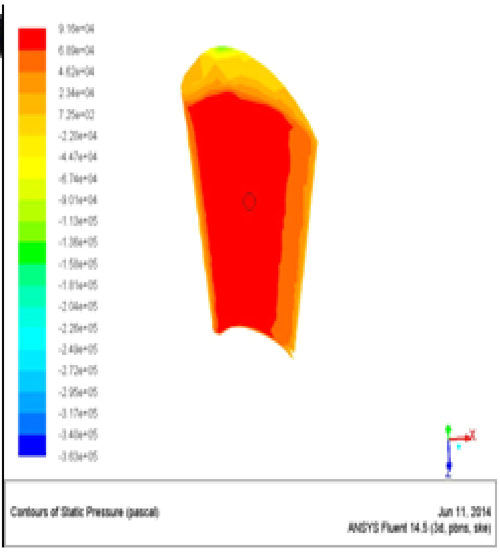
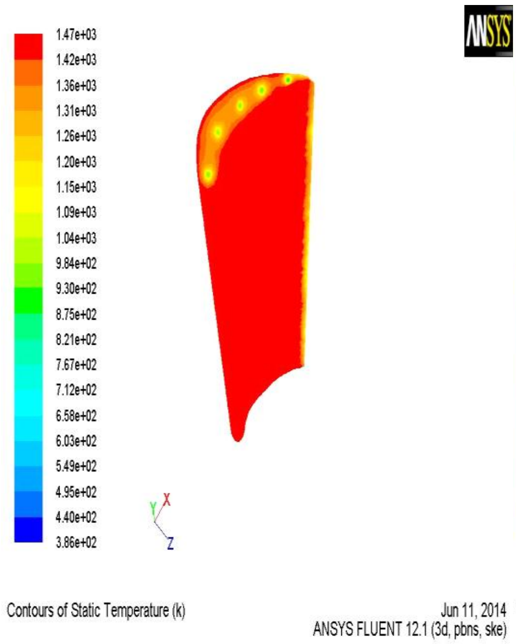


Fig 2.Static pressure of blade without holes

When holes are drilled radially to pass the cooling air through cooling holes, there is a small variation of temperature distribution within the blade. It can be observed from the fig3 (5 holes) that the temperature at the cooling holes is lower and it can be increased towards the leading edge and trailing edge of the blade. From fig 4 it is observed that the temperature distribution from cooling air inlet to the cooling air outlet is increases. This can be obtained from the cooling air is at its lowest temperature (573K) while pas through the tip of the blade to root of the blade and it goes on increasing along the radial direction.



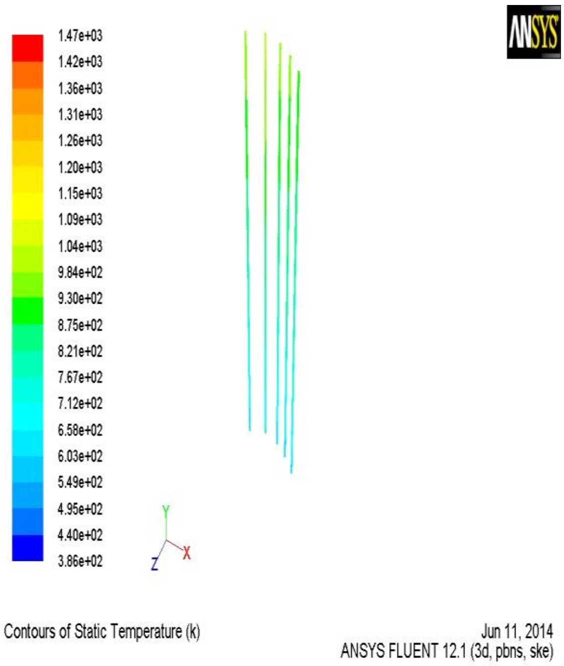
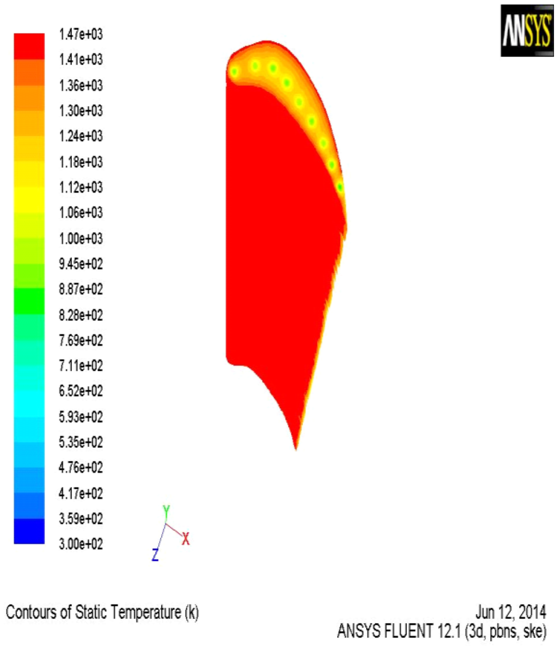


Fig 3 Temperature of blade with 5 holes **Fig 4 Temperature distribution in holes**

It is observed that the fig5 the blade consisting of 9 holes, the leading edge temperature is lesser than the blade consisting of 5 holes model. The temperature distribution is also varied for increasing the number of holes. The temperature at the leading edge is lower than the blade consisting of 13 holes by observing four models. From fig6 it can be observed that the temperature near the leading edge is 1112K. It has been reported by narasaraju [1] that the decreasing temperature will lead to lower thermal efficiency. Hence the number of holes is restricted to 13.



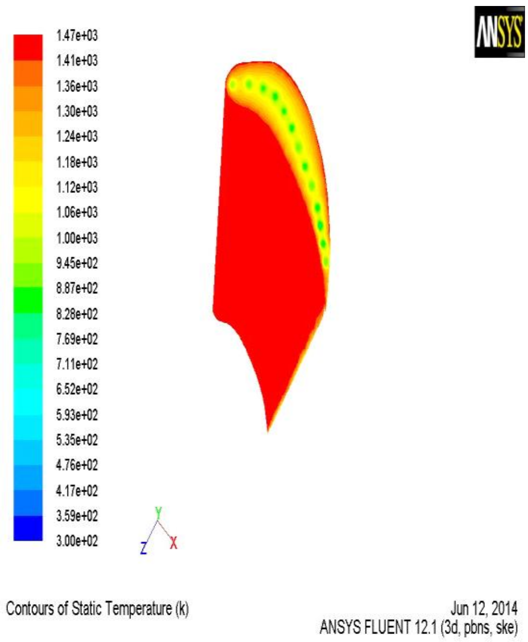


Fig 5 Temperature of blade with 9 holes **Fig 6 Temperature of blade with 13 holes**

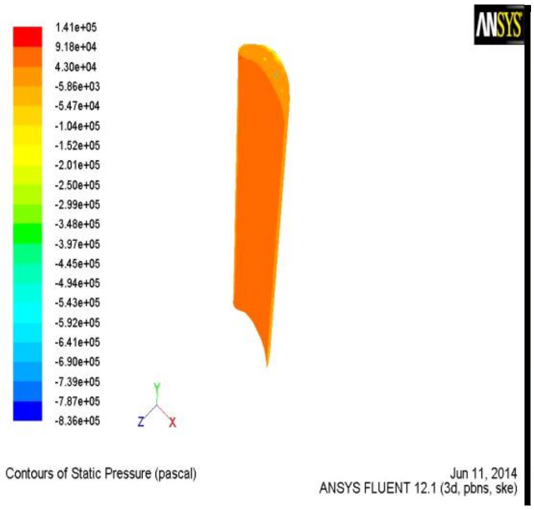


Fig 7.Static pressure of blade with 5 holes

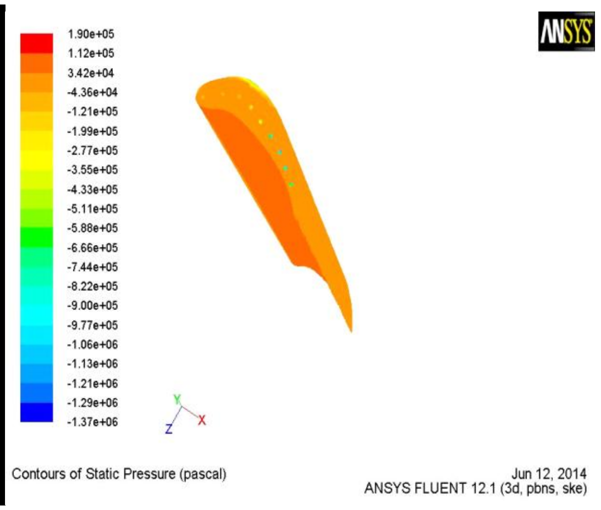


Fig 8.Static pressure of blade with 9 holes

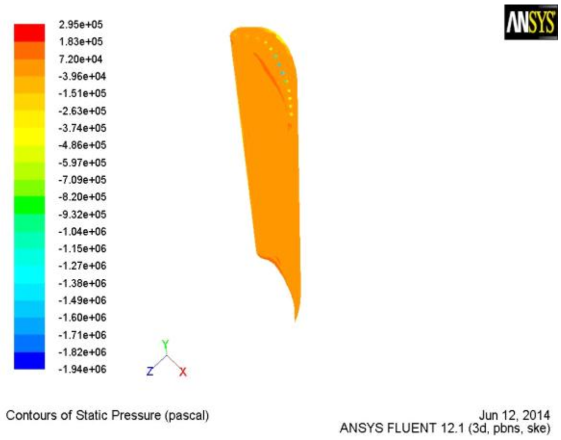
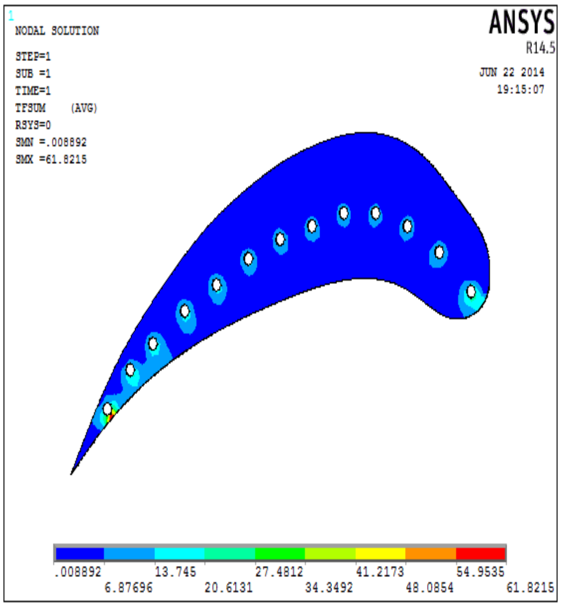


Fig 9.Static pressure of blade with 13 holes

Chromium steel **Inconel718**



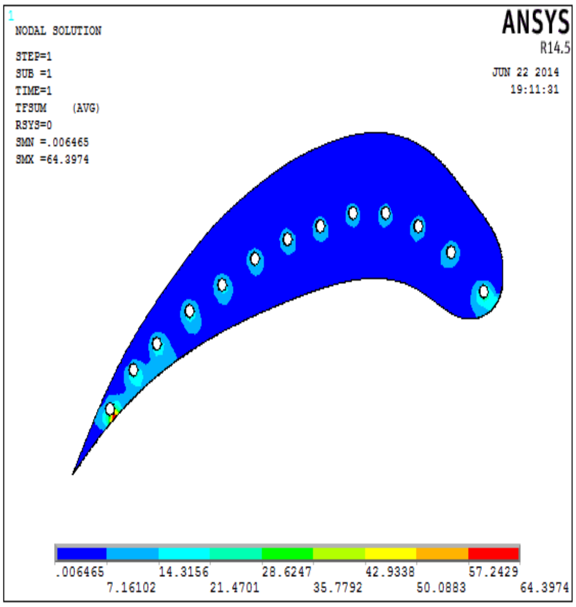


Fig 10 Maximum Thermal Flux For 13 holes Fig 11 Maximum Thermal Flux For 13 holes

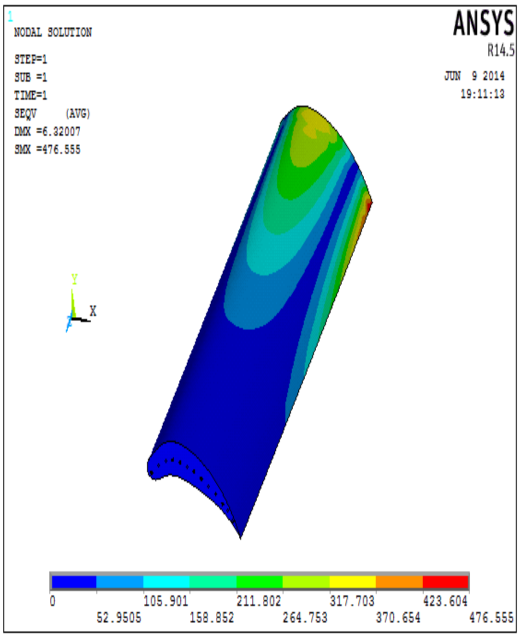


Fig 12 Von Misses Stress For 13 holes

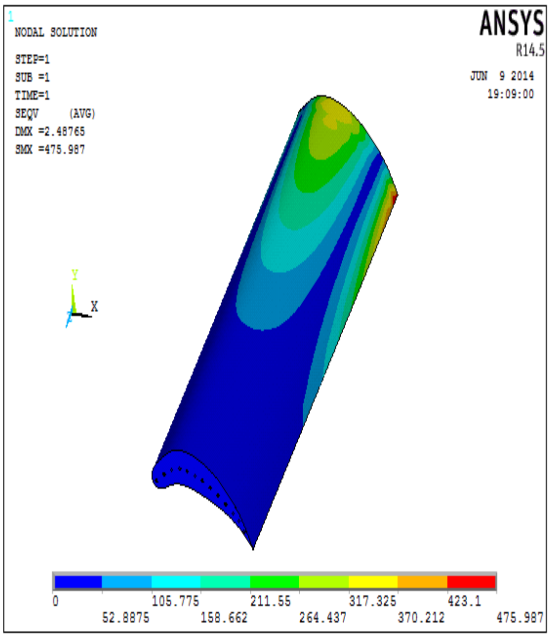


Fig 13 Von Misses Stress For 13 holes

By observing figs 7, 8&9 the maximum static pressure of the blade is increasing with increasing number of holes. The steady state thermal and structural analysis is carried out with different blade materials of chromium steel and Inconel718 to determine the thermal flux and stresses induced in the blade. The temperature and convection loads are applied for thermal analysis and pressure loads are applied for structural analysis. It can be observed that figs 10&11, the thermal flux for 13 holes is higher side for Inconel718 material compared to chromium steel. By observing figs that the maximum thermal flux is at blade trailing edge region compared to leading edge and mid cord of the blade. It is reduces the blade failures at the trailing edge region. From figs 12&13 it can be observed that the stresses induced for the material of Inconel718 is lesser than the chromium steel. By observing the fig 14, the total heat transfer rate is increasing with increasing number of holes and maximum heat transfer rate is obtained for the blade consisting of 13 holes. And it can be observed from figs 15 the temperature at leading edge portion is decreased by increasing number of holes. It can be observed from fig 17& 18 that the induced stresses and strains are higher than the chromium steel material compared to Inconel718 and these are obtained with in allowable limits. Hence it is concluded that blade consisting of 13 holes has the maximum heat transfer rate, and the chromium steel has poor thermal properties than Inconel718.

Table2 Total Heat Transfer Rate Vs No of Holes

No of holes	0	5	9	13
Total heat transfer rate(watts)	66.6	640.66	3118.09	6714.21

Table3 Leading Edge Temperature Vs No of Holes

No of holes	0	5	9	13
Leading edge temperature(k)	1454	1360	1245	1112

Table 4 Maximum Thermal Flux and stress of Chromium steel Vs No of Holes

No of holes	0	5	9	13
Thermal flux(w/mm^2)	2.30	54.32	57.26	61.82
Stress(n/mm^2)	471.54	472.48	474.87	476.55

Table 5 Maximum Thermal Flux and stress of Inconel718 Vs No of Holes

No of holes	0	5	9	13
Thermal flux(w/mm^2)	2.31	56.89	60.17	64.39
Stress(n/mm^2)	470.992	471.71	474.31	475.31

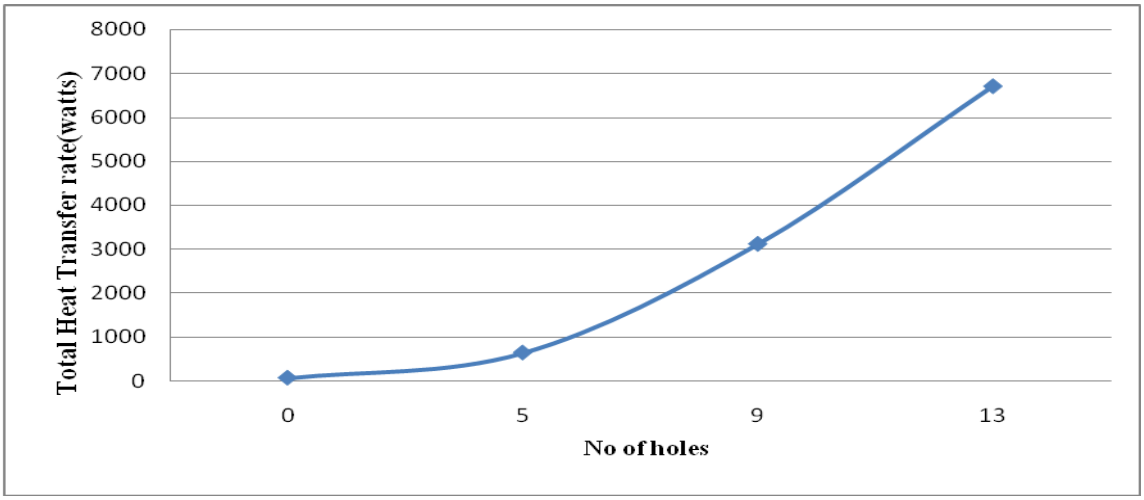


Fig 14 Total Heat Transfer Rate Vs No of Holes

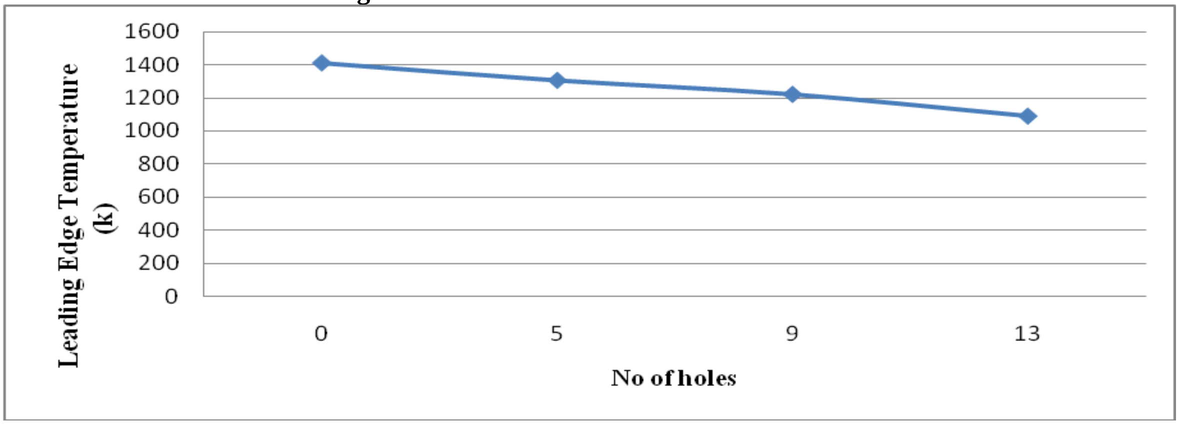


Fig 15 Leading Edge Temperature Vs No of Holes

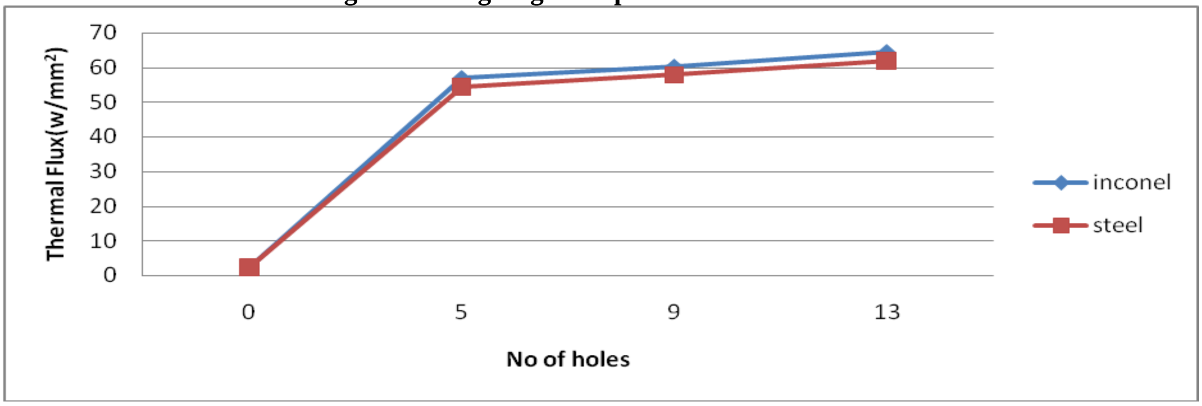


Fig 16 Maximum Thermal Flux Vs No of Holes

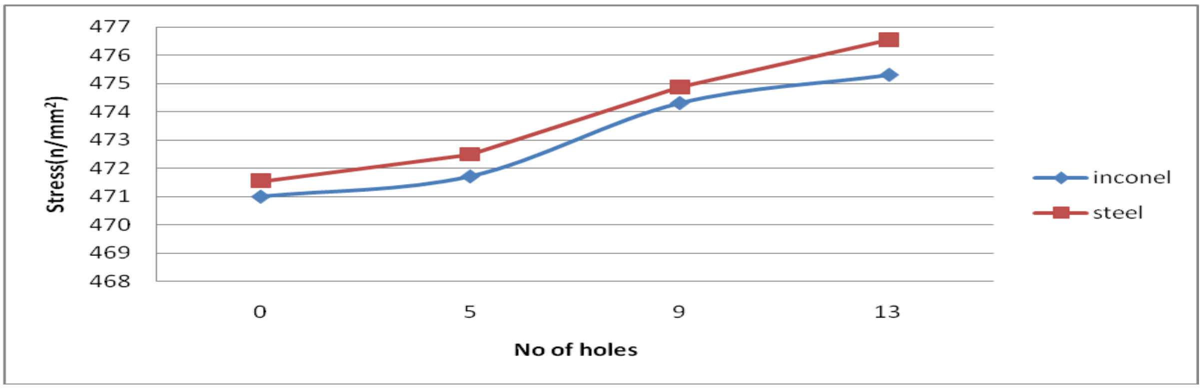


Fig 17 Maximum Stresses Vs No of Holes

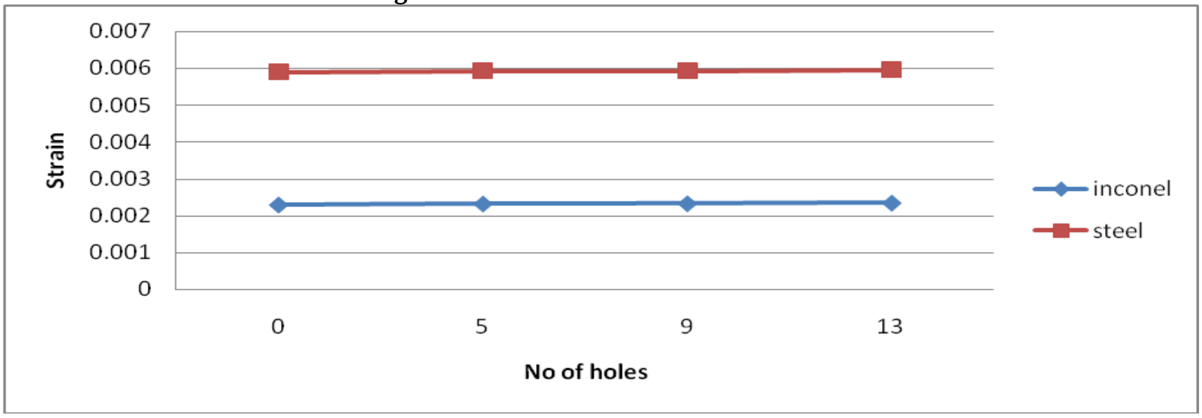


Fig 18 Maximum Strain Vs No of Holes

VI. CONCLUSIONS

Heat transfer analysis of gas turbine blade is carried out with different models consisting of blade with without holes and blade with varying number of cooling holes. It is found that total heat transfer rate is maximum and the temperature of the blade leading edge is minimum for the blade consisting of 13 holes. The thermal and structural analysis is studied for two different materials constructions that is Chromium steel and Inconel718. By observing the graphs the thermal flux is maximum of Inconel718 blade with consisting of 13 number of holes, and the induced von misses stress and strain are within allowable limits. It is found that Inconel718 is better than Chromium steel.

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