CONJUGATE HEAT TRANSFER ANALYSIS OF JET IMPINGEMENT AND FILM COOLING ON LEADING EDGE OF GAS TURBINE BLADE

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Abstract
This paper deals with the numerical analysis of 3d model of a Leading Edge of Nozzle Guide Vane of a Gas turbine Blade, Here we can used the different types of blade materials like Steel,Nickle,Titanium and Inconel.Initially compare the computationally analysis values and graphs of a Steel to the experimentally values and graphs are matches to each other. The difference is appearance for temperature to non-dimensional blade length is 1k and for the non-dimensional temperature to the non-dimensional blade length is 0.06, while compare to experimental and CFD Analysis. Also for the low temperature and high temperature materials, Compare to the thermal analysis for steel, Inconel, Nickel and Titanium materials, The thermal flux is more for Inconel than above given materials. Also the strength of Inconel is better than other materials. However its limitation is weight science its density is more than other materials.

KEYWORDS: Computational Fluid Dynamics; Leading Edge of Gas Turbine blade; Jet impingement cooling; Film Cooing; Blowing ratio; Numerical Simulation.

INTRODUCTION
The leading edge of a gas turbine nozzle guide vane is subjected to high thermal load; hence combined film cooling and impingement cooling is adopted for high heat transfer rates. The impinging jets after striking the blade interior surface comes out through the film cooling holes and makes a layer over the blade surface and prevents it from hot mainstream.

Most of the earlier investigations were reported by comparing the adiabatic effectiveness (η) on the leading edge Surface, which is defined as follows:

$$\eta = \frac{(T - T_c)}{(T_m - T_c)}$$

Where T, T_c and T_m are the the mainstream, coolant, and the adiabatic wall temperatures, respectively.

In this equation we determine the value of adiabatic wall temperature from the CFD analysis and mainstream temperature and coolant temperature values are obtained from the boundary condition.

A short discussion of the previous studies of authors who attempted to focus on the Turbine Bladecooling technology within by design parameters are presented here.Holl worth et al [1]. They had investigations on air jet impingement with film holes on a flat plate jet impingement with same diameter effusion holes.in there analysis they had found that on increase of 35% in heat transfer rate by arranging holes in staggered potion. Metzger et.al [2]. They done the analysis on the concave surface of circular jet impingement higher the heat transfer coefficient than the two dimensional jet impingement on a plane surface. Bunker and Meltzer [3] pointed out that the jets in the line with film would yield higher heat transfer coefficient than when they are in staggered configuration. Ramakumar and Prasad [4] demonstrated that k-ω SST model and predicted the result closely with the experimental data on the concave surface on the multiple impingement jets. Moritz et al [5] used a CHT for a 3-Dimensional thermal load on blades with complex cooling technology. They analysis that the key parameter used in CHT calculation the overall cooling effectiveness (ф). This is the variable to indicate the actual vane temperature in the non-dimensional form by coupling the convective heat transfer due to internal and external in the conduction in the blades. Deepanraj et.al [6] used

the curved shape of the turbine blade made of Titanium-Aluminum Alloy.Insvestigate to finite element analysis to analyses thermal and structural performance due to loading condition.

The present study hence focuses on these aspects by considering a NGV cascade with the leading edge of a typical gas turbine provided with showerhead holes and impingement holes.The main objective of this project is to carry out the numerical simulation leading edge Gas Turbine blade by made up from the different materials to comparing the result obtain from CFD POST and experimental values and graphs.

MATHEMATICAL FORMULATION
THE PHYSICAL MODEL LEADING EDGE GAS TURBINE BLADE.

Consider a curved plate of the leading edge region a high temperature and pressure turbine NGV having the radius of curvature is 21mm and thickness 5mmprovided with 2.5mmdiameter. The coolant is supplied through the four rows of jet holes arranged in staggered fashion each alternative row contains16 (jet row 1 and 3) and15 (jet row 2 and 4) on the leading edge of GT blade. Above the jet impingement surface the film surface is created having the radius of curvature 26mm and diameter 2.85mm.five rows of this holes, middle row is the stagnation region and the remaining rows are positioned $\pm30^0$ and $\pm60^0$ with respect to the middle row. Also this holes are inclined in the span wise direction from 55^0 to 0^0 in each row. The distance between the target surface and impingement holes is 2.8mm. The computationaldomain is 3-Dimensional cascade sections with two passages, maintaining a space chord ratio of 0.88
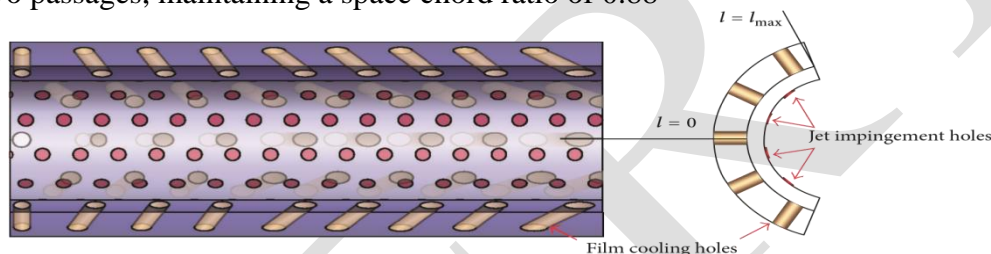

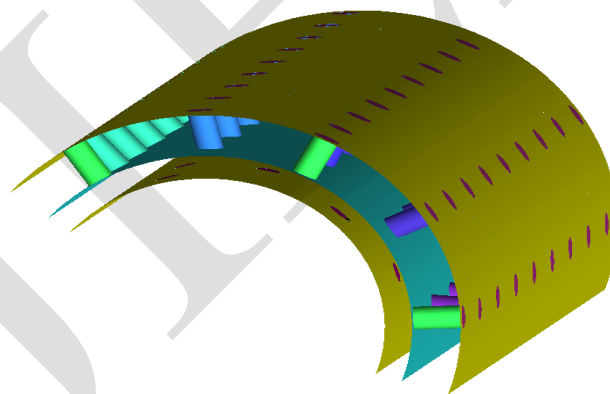**Fig.2.1Leading edge film cooling holes and impingement holes arrangement.**

Fig.2.2 Staggered arrangement of impingement holes and film tubes.

MESHING

- ➢ The model created using ICEM CFD software.
- ➢ The whole model is divided into different parts namely inlet, pressure outlet, wall and axis.
- ➢ Global Mesh parameters are defined which gives information regarding type of mesh. The global element seed size, part parameters are setup and mesh is computed which gives the mesh information regarding total number of elements.
- ➢ Anstructured hexahedral mesh is generated in order to perform computations with the Octree approach. And unstructured mesh to blade because of the curved shape structure after setting up part parameters for various parts, a mesh is generated with nearly 2029893 lakh elements and total nodes nearly 377162.
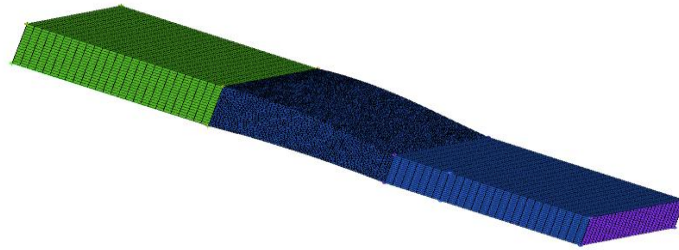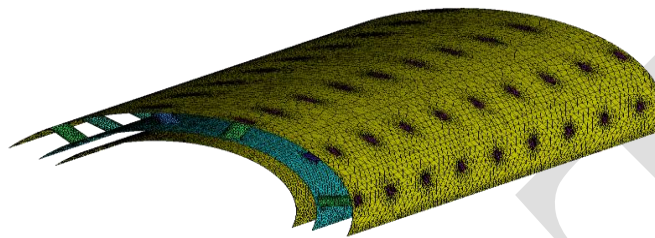
Fig.3.1 Domain with blade meshing.
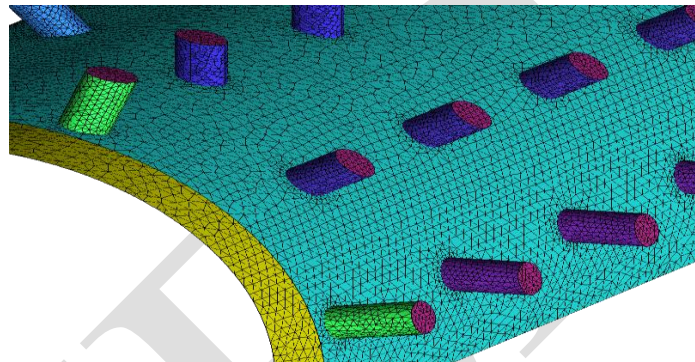

Fig.3.2 Mesh on different layer

Fig3.3 Film holes with outer leading edge (zoomed view mesh).
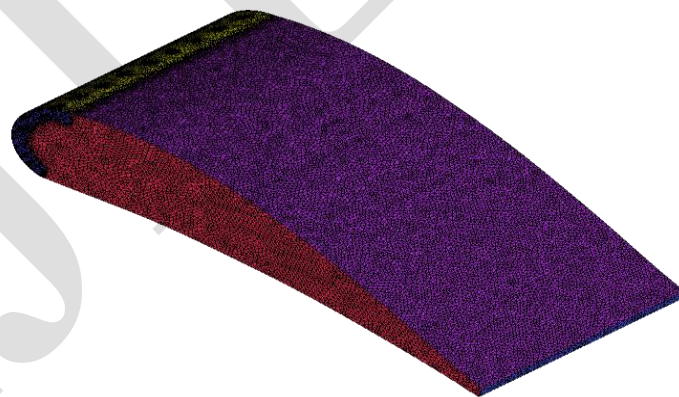

Fig.3.4 Blade mesh

BOUNDARY CONDITIONS

(i) Mainstream inlet temperature, T_m=308K,Coolant temperature,T_c=288K mainstream velocity,$V_{m=}$30m/s and coolant air velocity,V_c=25.5m/s.(for low temperature materials);

(ii) Main steam inlet temperature,T_m=1112.22k,Coolant temperature,T_c=573k and mainstream velocity,$V_{m=}$265m/coolant velocity,V_c=30m/s(for high temperature materials);

(iii) No slip boundary condition at wall, V_m =0;

(iv) Coolant inlet condition,V_C calculated from blowing ratio(M) =$\frac{\rho_c V_c}{\rho_m V_m}$

(v) Outlet boundary condition, P=P_{amp} at exit;

(vi) Conjugate boundary condition at solid plate, $T_s = T_f$, $k_s \dfrac{dT_s}{dy} = k_f \dfrac{dT_f}{dy}$ at leading edge walls.

Formulation of 3-Dimensional conjugate heat transfer problem is done with the following assumptions:
(i) The fluid is incompressible (Density is remains constant).
(ii) The fluid properties are constant (viscosity and specific gravity).
(iii) Natural and Radiation convection are neglected
(iv) Viscous dissipation is absent
(iiv) The flow is steady

Table 1: Parameters varied.

Blowing ratio (M)	Main stream velocity (m/s)	Main stream Re	Jet velocity (m/s)	Jet Re
M=1	30	418550	25.5	4350

VALIDATION

The problem is solved using ANSYS CFX, the existing code is validated with the results of a research paper titled "Effects of design parameters on flow and temperature fields of a leading edge NGV blade by "CFD simulation".
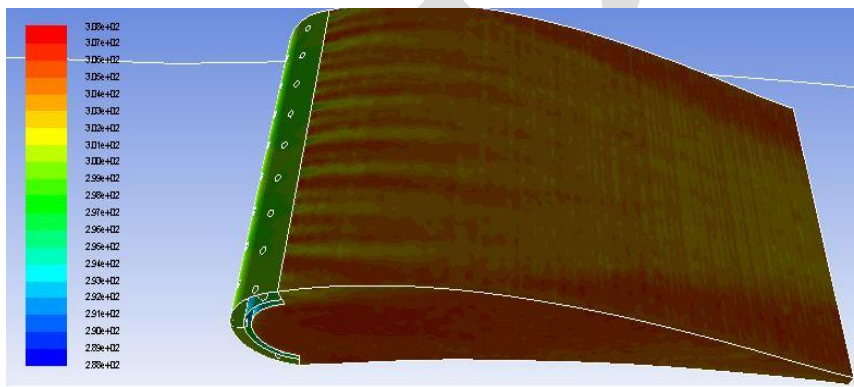

Fig: 4.1Temperature distribution on top surface of the blade.

The coolant air is passed through the impingent holes resulting the cooling of the inner surface takes place. After that coolant air supply from the film tubes for the external cooling of the blade, so coolant air comes from the tubes and stream temperature changes as shown in fig (4.1).

Turbine having some melting point so the hot gases come from the combustion chamber to heats the leading edge so cooling is required to the blade.
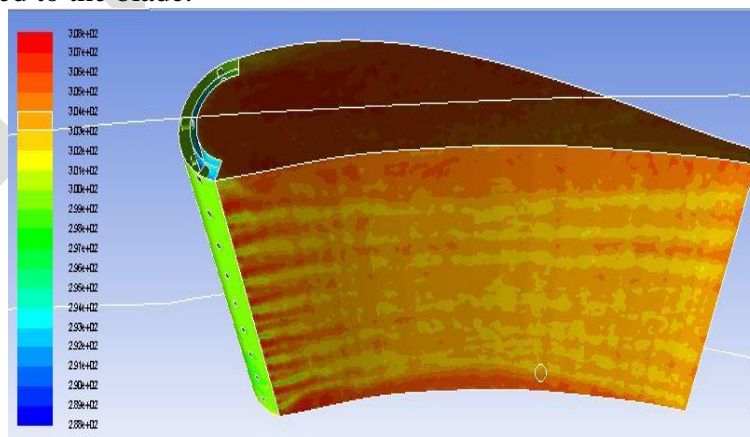

Fig.4.2 Temperature steam line from bottom surface of blade.
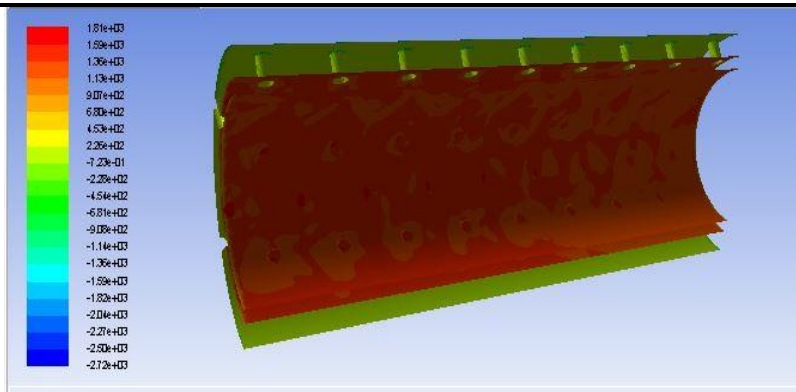
Fig.6.4 Temperature on inner surface of the blade.

The inner wall of turbine blade temperature is shown in fig.while surrounding holes the temperature value is low because of cooling effect.
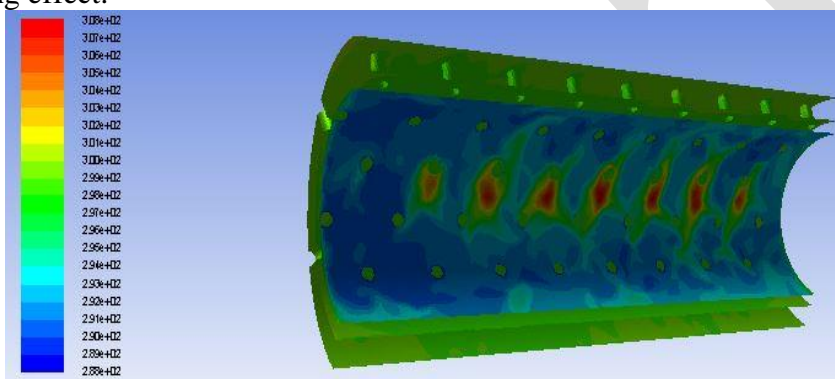

Fig.6.5 Pressure distributions inner surface

Like temperature distribution the pressure distribution is occur in the inner wall of the blade. While at the holes the pressure is less as compare to the other space of the inner blade.

RESULTS AND DISCUSSIONS
6.1 STEEL BLADE ANALYSIS
The initial step is that to analyzed the graph between the experimental and the computational for steel blade of non-dimensional temperature and the non-dimensional length of blade.
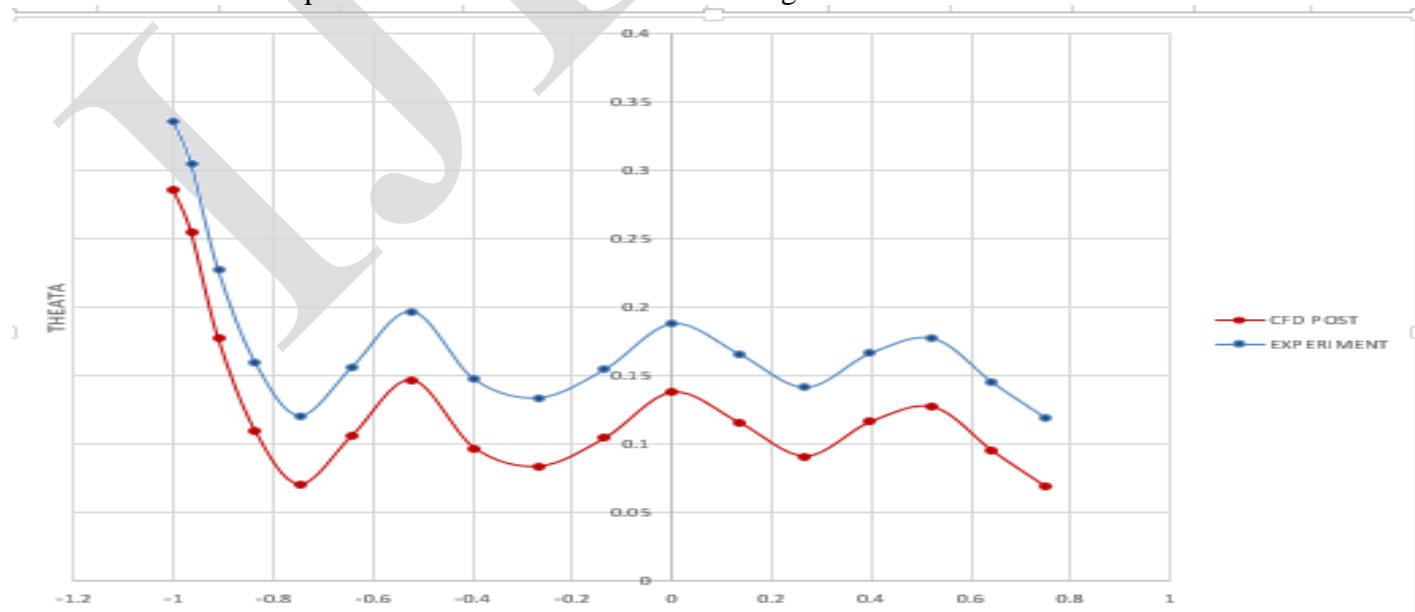

Fig.6.1 Non dimensional temperature versus non-dimensional blade length

Non-dimensional temperature nothing but a temperature ratio of difference between wall temperature and coolant temperature to the difference between mainstream temperature and coolant temperature .wall temperature is determine from the computationally and main stream temperature and coolant temperature is given as the reference paper[4]

From above graph the experiment values and computational values of graphs are match to each other as compare experimental and computational values the difference is 0.06.

If we want instead of determining non dimensional temperature otherwise we can determine the temperature from computationally and compare with experimental values. From fig (6.2) we can see that the difference is found that only 1k.so almost the values from experimental and computational fluid dynamics values and graphs are matches to each other.
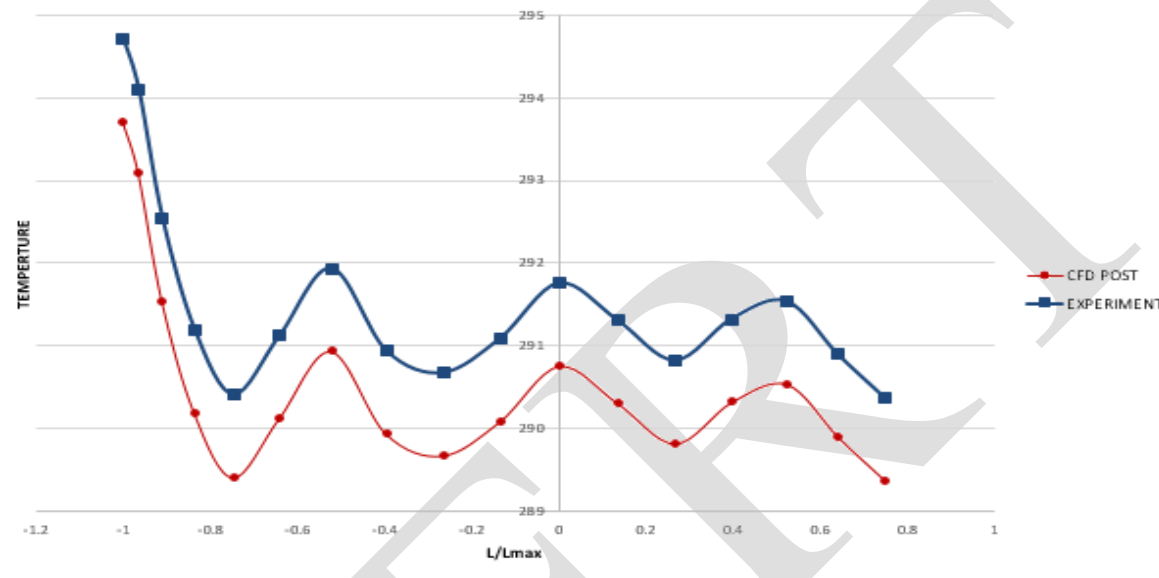

Fig.6.2 Temperature versus the non-dimensional blade length

The heat transfer coefficient or film effectiveness is used to calculating the heat transfer typically by phase transition between fluid and solid.in my project the fluid is the coolant air and solid is the blade.

From above graph(fig.6.3) we can concluded that from the computational fluid dynamics the heat transfer on a blade to the particular holes(L/Lmax) is merge from the obtain graph from the experimental.
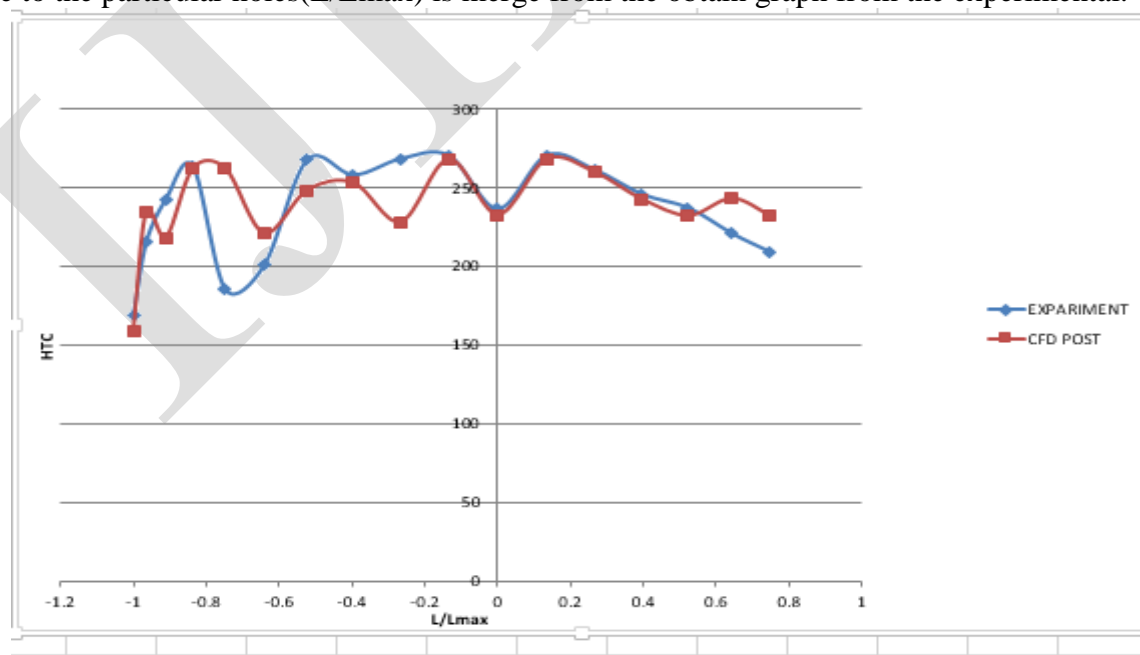

Fig.6.3 Heat transfer coefficient versus non-dimensional length
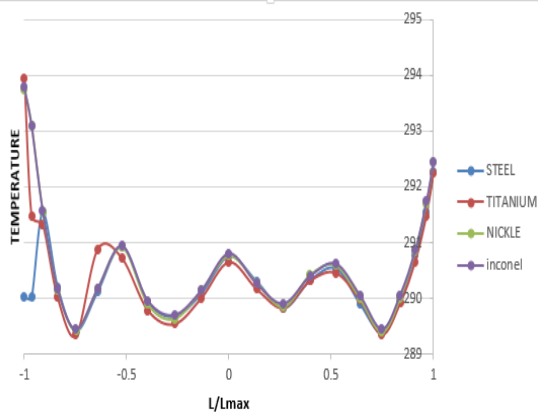
6.2 COMPARISON OF LOW TEMPERATURE MATERIALS

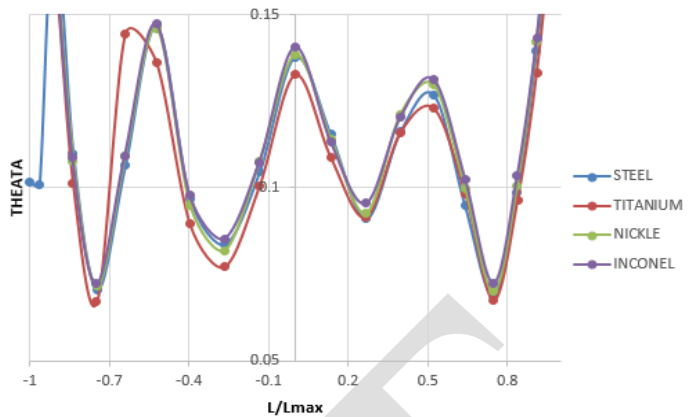**Fig.6.2.1 Non-dimensional temperature to the Non-dimensional length**

Fig.6.2.1 Temperature to the non-dimensional length Non-dimensional length

6.3 COMPARISON OF HIGH TEMPERATURE MATERIALS

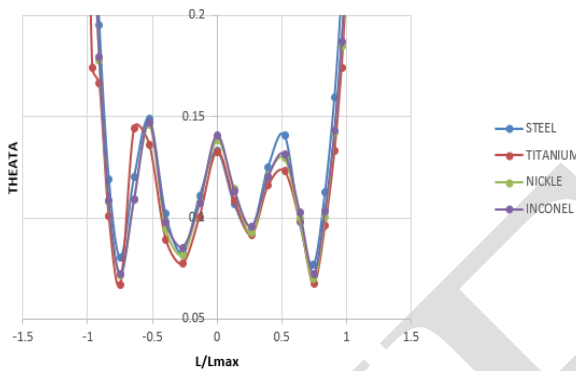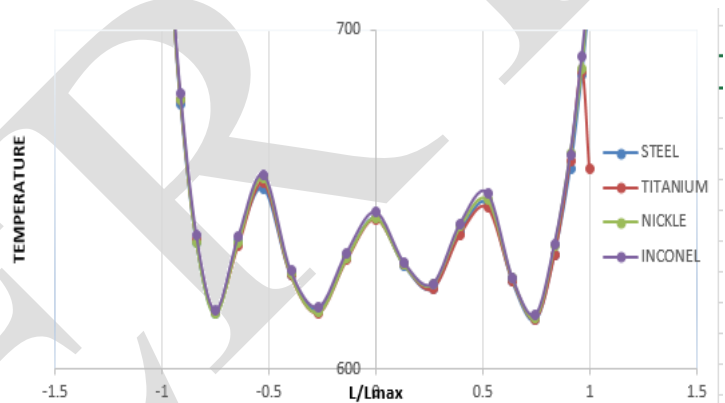**Fig.6.2.3 Non-dimensional temperature to the Non-dimensional length**

Fig.6.2.4 Temperature to the non-dimensional length Non-dimensional length

CONCLUSIONS

We observer that the temperature distribution of the inner surface of jet impingement and outer surface of the film surface also stagnation region at the leading edge along with the pressure distribution on pressure surface and section surface. Model dimension is same for all four materials (Steel, Titanium, Nickel and Inconel).

The same condition is apply to all the materials.

    (i)   for low materials: jet velocity is 25.5m/s, main steam velocity is 30m/s and main steam temperature is 308k and the impingement jet temperature is 288k.

    (ii)   for high temperature materials: jet velocity is 30m/mainstream velocity is 265m/s and main stream temperature is 1112.22k and impingement jet temperature is 573k

Finally the conclusion of CHT analysis of jet impingement and film cooling on leading edge of gas turbine blade are:

    (i)   The computational studies carried out to realistic NGV leading edge with effusion holes and multiple jet with staggered arrangement for conjugate boundary conditions.Analisis the non-dimensional temperature with the non-dimensional blade length and non-dimensional temperature to no dimensional blade length.

    (ii)   For the steel blade the experiment and computational post the temperature difference is 1k while for non-dimensional temperature is 0.06 also the heat transfer coefficient also matches experimental to computational post.

(iii)   Compare to the thermal analysis for steel, Inconel, Nickel and Titanium materials. The thermal flux is more for Inconel than above given materials. Also the strength of Inconel is better than other materials. However its limitation is weight science its density is more than other materials.

(iv)   For the low temperature materials that means by introducing the low temperature of jet and analysis it from mentation above graphs the peak and valley appearance due to the staggered arrangement of jet holes also in the high temperature materials.

(v)   The effect of the blowing ratio (M) is different to section side and pressure side. The blowing ratio is increases because of the coolant tend to distributed more towards the pressure side.

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