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ANALYSIS OF COOLING TECHNIQUES OF A GAS TURBINE BLADE

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Abstract - *A gas turbine works on a Brayton cycle. The efficiency of an ideal Brayton cycle depends on the compression ratio which depends on the inlet temperature of the inlet gas entering the turbine. If the inlet temperature of gas increases then the efficiency of the Brayton cycle increases. But the inlet gas temperatures has a limit due to the physical properties of the turbine blades. So, we use many new cooling techniques to cool the turbine blade. By cooling techniques and use of high temperature withstanding materials, this limitation of inlet fluid temperature can be overcome to a great extent. In this paper, various general types of cooling technologies used for cooling the turbine blades are explained. Also new recent types of cooling techniques for gas turbine are explained, different new technology used in gas turbine blade material are explained with case study. In this work three type of blade passages are selected, one model is lattice structures with different spacing and another one is vertical channel model. The thermal load and the aerodynamic load are then obtained from the temperature field and the pressure distribution.*

Key Words: Marine gas turbine blade, failure analysis, Super alloy, and Mechanical analysis etc…

1. INTRODUCTION

Gas turbines play a important role in the today's society, and as the demands for power increase, the power output and thermal efficiency of gas turbines must also increase. Thermal efficiency of the gas turbine can be increased by many different ways. One method of increasing both the power output and thermal efficiency of the engine is to increase the temperature of the gas entering the turbine. But the inlet gas temperatures has a limit due to the physical properties of the turbine blades. In the advanced gas turbines of today, the turbine inlet temperature can be as high as 1500°C; however, this temperature exceeds the melting temperature of the turbine blade metal airfoils. Therefore, it is imperative that the blades and vanes are to be cooled, so they can withstand these extreme high temperatures. Cooling air around 650°C is extracted from the compressor and passes through the turbine blade airfoils. With the hot inlet gases and the cooling air which is sent into the blade, the temperature of the blades can be lowered to approximately 1000°C, which is permissible for reliable operation of the engine. By this cooling effect, we use the same turbine blade at high inlet temperatures which increases the power output and efficiency of the turbine.

1.1 LITERATURE REVIEW

Joshi and Jaiswal (2014), presented the design of Axial flow compressor for a given mass flow rate and required pressure ratio by using mean line method. The parameters include thermodynamic properties of the working fluid, number of rotor and stator blades, tip and hub diameters, stage efficiency, blade dimensions (chord, length and space) for both rotor and stator, flow and blade angles (blade twist), Mach number.

George and Titus (2014), described about gas turbine blades will subject to high tangential, axial and centrifugal forces during their working conditions. While withstanding these forces gas turbine blades may subjected to elongation. Summarizes the design, analysis and modification of the cooling passage in the gas turbine blade design.

Htwe et al (2015), Gas turbines have a vital part in electric power generation. Gas turbine innovation is utilized as a part of an assortment of arrangements for electric power age. Turbine rotor cutting edges are the most critical segments in a gas turbine control plant.

John et al (2012), studied on the design and analysis of Gas turbine blade, CATIA is used for design of solid model and ANSYS software for analysis for F.E.model generated, by applying boundary condition, this paper also includes specific post-processing and life assessment of blade .HOW the program makes effective use of the ANSYS pre-processor to mesh complex turbine blade geometries and apply boundary conditions

1.2 TURBINE BLADE COOLING

Unlike steam turbine blading, gas turbine blading need cooling. The objective of the blade cooling is to keep the metal temperature at a safe level to ensure a long creep life and low oxidation rates. As the blade material melts at a lower temperature than the operating conditions of the turbine, a cooling method must be incorporated into the blade design to ensure the safe and smooth running of the turbine. It is important, while devising a cooling scheme, to have knowledge about the boundary conditions of the blade during turbine operation, so that large gradients can be avoided. This is because large gradients cause thermal stress cutting the component life short significantly Fig. shows the typical temperature contour in a blade. The mean rotor blade temperature is about 3500 c below the prevailing gas temperature after efficient blade cooling.

2. DESIGNING OF TUBINE BLADE PROFILE

The designing of Turbine blade is done by CATIA v5 R20 by running a macro file and the transonic airfoil is generated by joining all the coordinates.

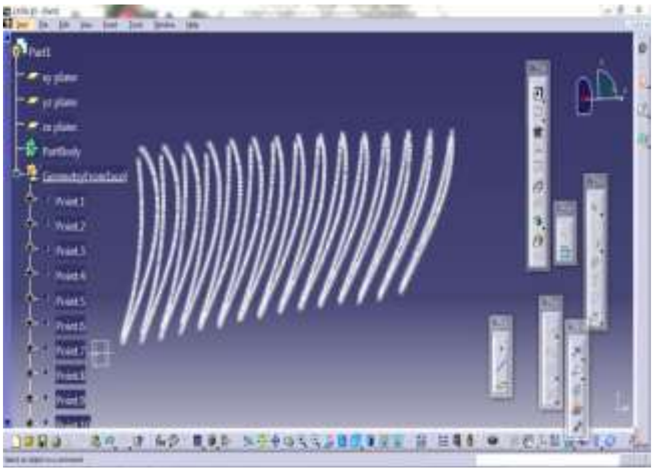

Fig -1: Multiple section of gas turbine blade

Using multi section surface concept, all curves are joined and formed as surface as shown as below. Surface is filled using close surface option in CATIA and hub modeling was done with thickness of 20 mm, length 149 mm and width 35 mm. Final images can be shown as below.

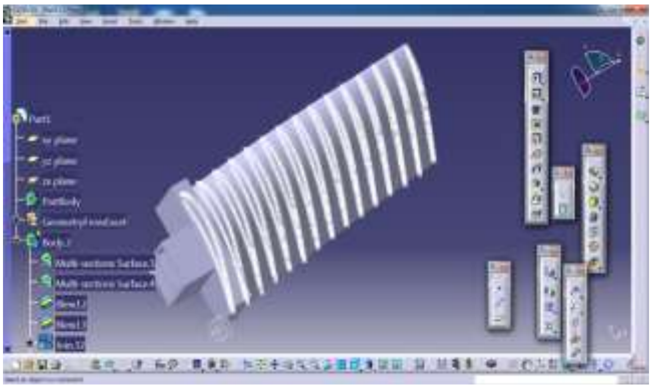

Fig -2: Solid model of Gas Turbine

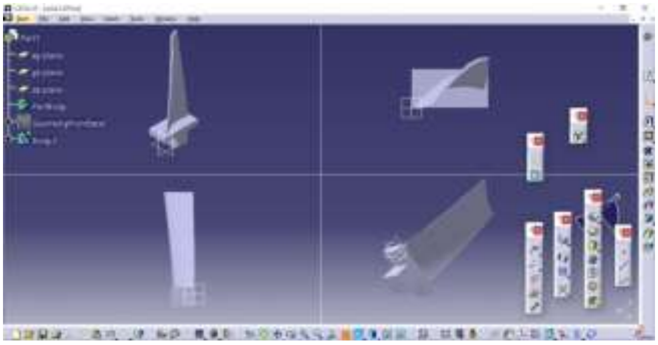

Fig -3: Views of gas turbine blade

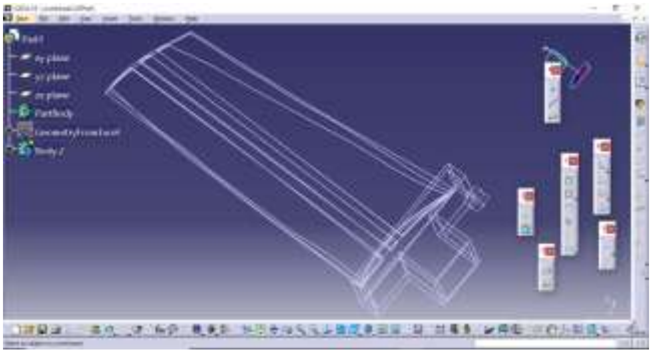

Fig -4: Wireframe model of Vertical channel

Fig -5: Wireframe model of lattice structure

In the above figures, the wireframe model of vertical channel is shown. It clearly shows the vertical slots created in the blade through which the cooling fluid passes. And below figure shows the wireframe models of the blade with number of lattice channels though which the cooling fluid passes inside the blade to have a better cooling effect.

3. ANALYSIS OF TURBINE BLADE

The turbine blade is analyzed for its thermal and structural performance. The structural and thermal analysis of a gas turbine is carried out using ANSYS 14.0 software. Single blade is taken into consideration for analysis as turbine blades are mounted on the periphery of hub symmetrically along the axis of rotation of the blade. The cross section of the blade is in the X-Y plane and the length of the blade is along the Z axis. Centrifugal forces generated during service by rotation of the disc were calculated by applying an angular velocity to the turbine blade. A gas pressure was also applied over the aerofoil. The temperatures of the blade and disc were non-uniform, inducing thermal stresses by differential thermal expansion.

Static analysis was carried out to determine the mechanical stresses, strains and elongation experienced by the gas turbine rotor blade. In this analysis, the gas forces are assumed to be distributed evenly, the tangential and axial forces act through the centroid of the blade. The centrifugal force also acts through the centroid of the blade in the radial direction.

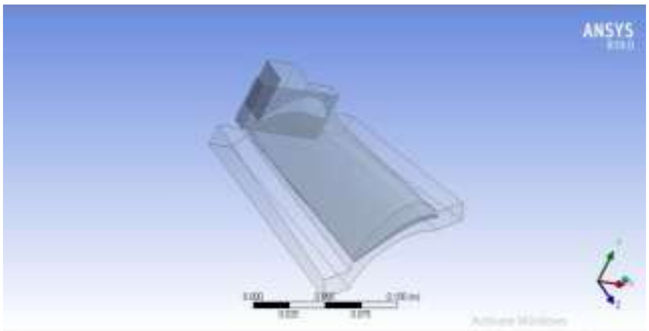

Fig -6: Fluid domain created in ANSYS

A fluid domain is created in ANSYS software to which the the inlet fluid can be sent with required velocity. The input and output of the inlet fluid can be fixed at the stage.

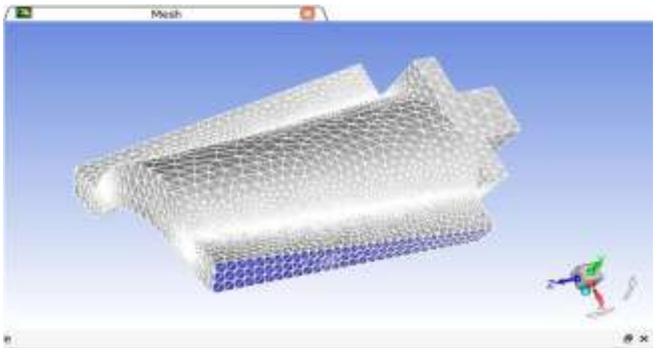

Fig -7: Finite element mesh created in ANSYS

The above image shows the finite element model of gas domain and turbine blade. Here tetra hadrons element is used to mesh the domain and blade.

Table -1: Boundary conditions

Gas temp	960K
Inlet Gas Velocity	1090 m/sec
Air coolant velocity	28.3e-3 kg/sec
Coolant Air temperature	450K

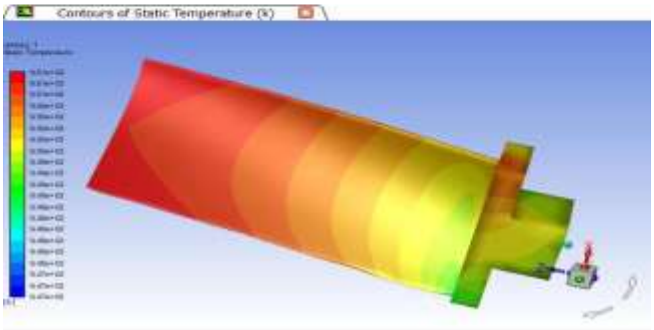

Fig -8: Temperature contour on blade (solid).

The above fig shows the total temperature distribution on gas turbine blade after gas passes over blade profile. Thermal analysis was carried out to determine the thermal stresses such as the temperature distribution of the gas turbine rotor blade. Maximum temperature occurs at the tip of blade. Minimum temperature appears at the hub of blade and we can clearly able to see in the above image. All together maximum temperature is 951K.

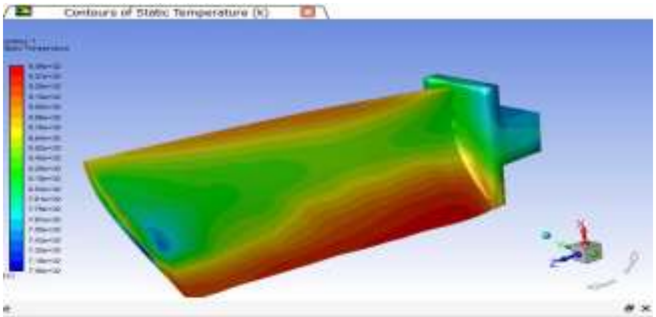

Fig -9: Temperature contour on blade (Vertical).

The above fig shows the total temperature distribution on gas turbine blade with vertical channels. All together maximum temperature is 949K.

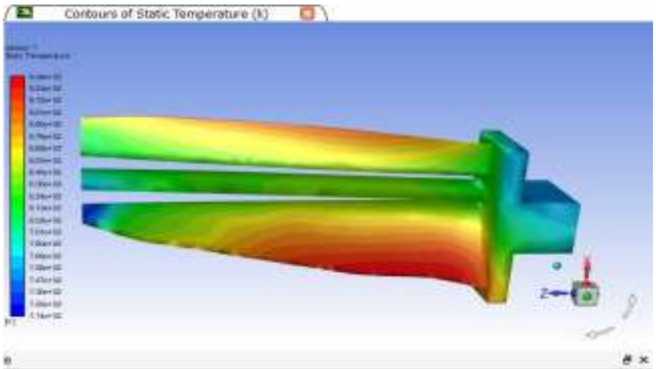

Fig -10: Temperature contour of coolant (Vertical).

In the above fig shows the total temperature distribution on coolant which is passing through the vertical channels after inlet gas passes over blade profile All together maximum temperature is 706K.

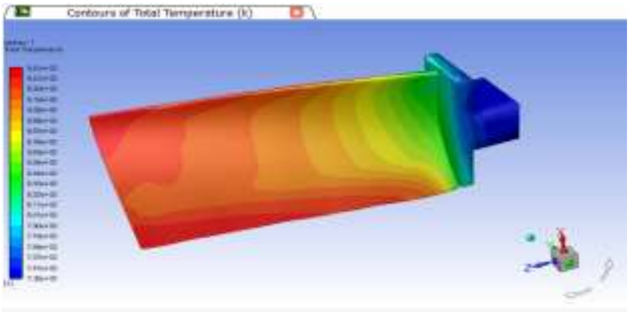

Fig -11: Temperature contour with lattice

In the above fig shows the total temperature distribution on coolant which is passing through the channels after inlet gas passes over blade profile All together maximum temperature is 951K.

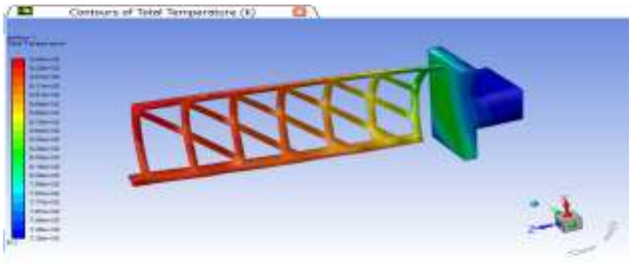

Fig -12: Temperature contour inlet with lattice structure

In the above fig shows the total temperature distribution on coolant which is passing through the channels after inlet gas passes over blade profile All together maximum temperature is 942K.

4. STATIC STRUCTURAL ANALYSIS

In real time, the position where we place the hub of blade in its exact location, likewise in ANSYS software same location we applied the boundary condition Dynamic pressure Load applied on front face of blade. The final post processing result such as deformation and stresses are placed below.

Table -2 : Blade material properties

Parameter	Units	Ni alloy X
Youngs Modulus	GPa	210
Density	Kg/m^3	7780
Poission ratio		0.33
Thermal conductivity	w/mK	22
Thermal expansion	10e-6/0C	16

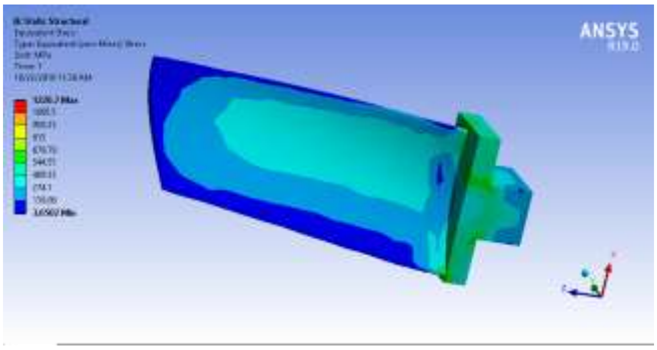

Fig -13: Stresses on solid model

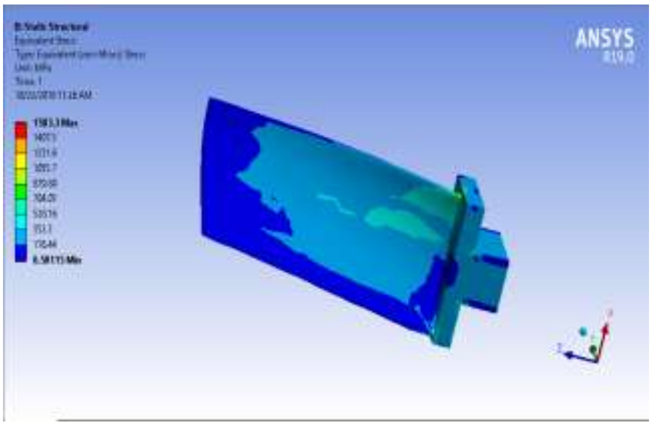

Fig -14: Stresses on vertical channel model

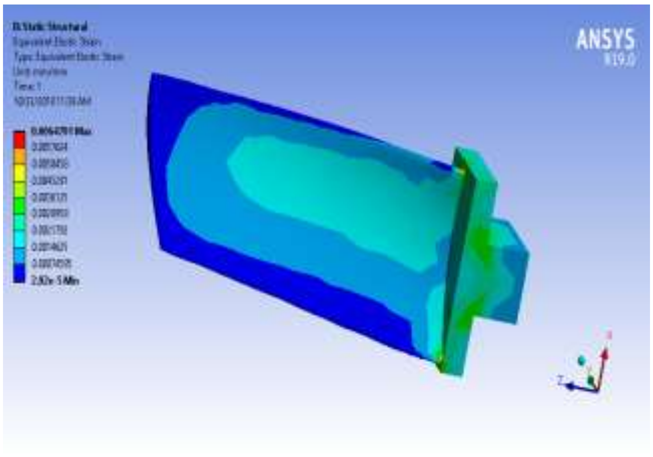

Fig -15: Strain on solid model

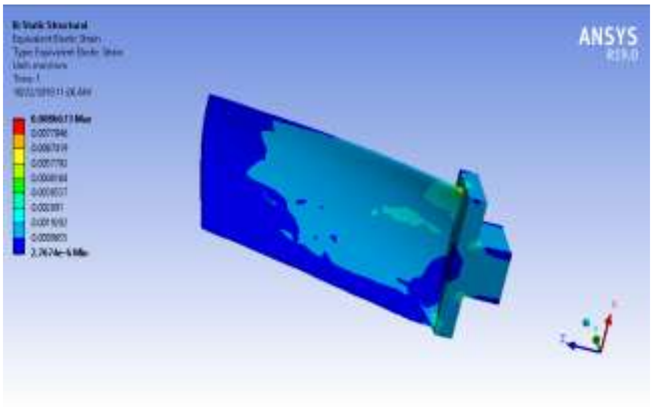

Fig -16: Strain on vertical channel model

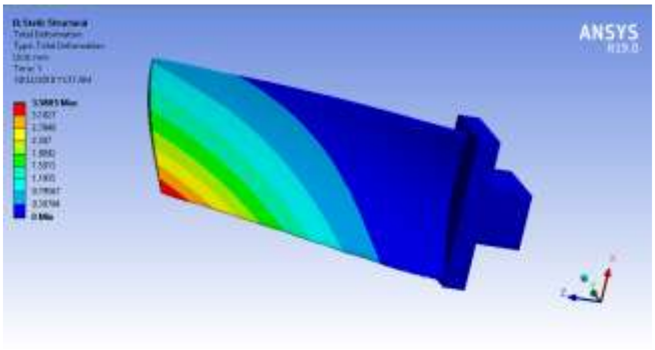

Fig -17: Deformation of solid model

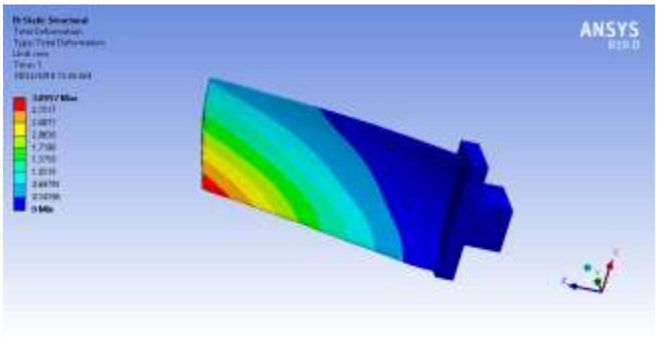

Fig -18: Deformation of vertical channel model

In the above image shows the total deformation of Deformation of solid model 1after dynamic pressure load applied on face of blade and the red indicate the maximum deformation and blue indicates minimum deformation. Maximum deformation occurs at the tip of blade because there is no support at tip, so there is a high chance of the blade to get bent. Minimum deformation appears at the hub of the propeller and we can clearly able to see in the above image. All together maximum deformation is 3.58 mm for solid model and maximum deformation is 3.09 mm for blade with vertical channels

6. RESULTS AND DISCUSSION

Blade failures can be caused by a number of mechanisms under the turbine operating conditions of high rotational speed at elevated temperature in corrosive environments. To identify the causes of the blade failures, a complete investigation has to be carried out, integrating both the metallurgical examination and mechanical analyses. This work focuses on failure analysis of gas turbine blades found in gas turbine engines meant for marine propulsion through mechanical analysis. This research work deals with the modeling and analysis of gas turbine blades. The thermal-structural finite element analysis was performed on the turbine blades using ANSYS 14.0 software and results were discussed. Total Gas turbine with coolant passages models are created as single component in CATIA software. And model was imported into ANSYS software. Fluent analysis is performed to find out the temperature and hydro dynamic pressure. Dynamic hydraulic pressure loading is considered. In static structural analysis, the results are shown below.

Table -3: Temperature on Gas turbine blade.

TEMPERATURE ON TURBINE BLADE (K)	Solid	Vertical channel	Lattice structure
Max temp (K)	951	949	902
Min temp(K)	947	706	680
Avg temp(K)	949	827.5	791

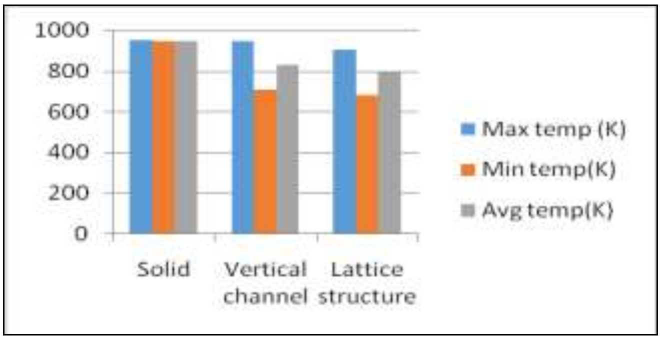

Chart -1: Temperature on Gas turbine blade

The above graph shows the temperature on Gas turbine blade. The X-axis shows the Temperatures in different. The Y-axis denotes for the Temperatures of blade surface. The maximum temperature induced in the solid model of turbine blade is 949 K, while in blade having cooling hole along the length, it is nearly 827.5.K and the blade with lattice channel the temperature is nearly 791K

Table -4: Stress of Gas turbine blade models.

STRESS (MPa)	Solid	Vertical channels	Lattice structure
SUPER ALLOY X	1220	1583	795

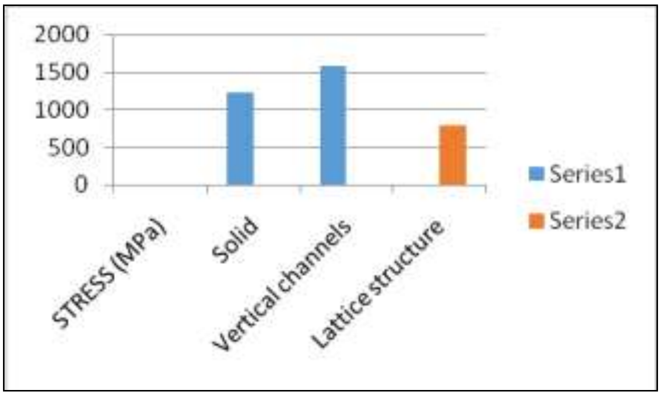

Chart -2: Stress of Gas turbine blade models

The above graph shows the stresses of Gas turbine models for different structures. The X-axis shows different turbine blades with the solid model, vertical channel and with lattice channels. The Y-axis denotes for the stress of turbine blade surface. For solid blade, in the material Super alloy X shows the stress occurs nearly at 1220 M.Pa, while the for the blade with vertical cooling, the stress occurs nearly at 1583 M.Pa and for the blade with lattice channel the stress occurs at 795 M.Pa.

Table -5: Strain of Gas turbine blade models.

Strain	Solid	Vertical channels	Lattice structure
SUPER ALLOY X	0.0064	0.0086	0.0044

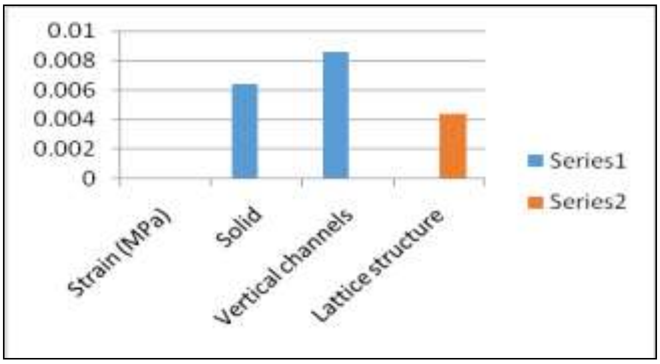

Chart -3: Strain of Gas turbine blade models

The above graph shows the Strain of Gas turbine models for different material. The X-axis shows the Model designs such as solid, vertical channel, The Y-axis denotes for the Strain of blade surface.

Table -6: Deformation of Gas turbine blade models.

Deformation (mm)	Solid	Vertical channels	Lattice structure
SUPER ALLOY X	3.58	3.09	2.34

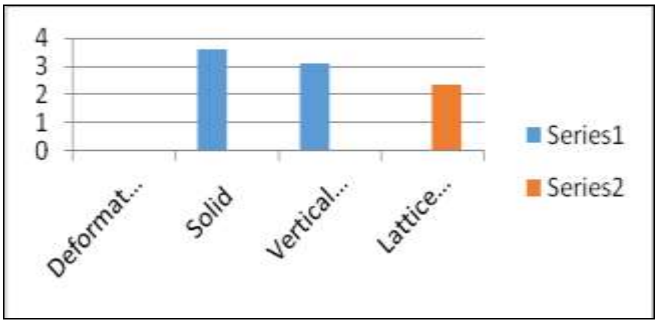

Chart -4: Deformation of Gas turbine blade models

The above graph shows the Strain of Gas turbine models for different material. The X-axis shows the Model designs such as solid, vertical channel. The Y-axis denotes for the deformation of blade surface.

7. CONCLUSION

1) The main aim of the project has been to select the best cooling techniques for better running life of gas turbine blade
2) The maximum von mises stress induced in the gas turbine blades of all models under consideration are lesser than the yield strength
3) Fluid structure interface analysis revealed that stress induced is less in turbine blade with the lattice structure compared to other models under analysis.
4) Minimum deformation has been observed in turbine blade with the lattice structure compared to other two blade models.
5) Fluid structure interface analysis revealed that less strain is observed in turbine blade with the lattice structure compared to other models under analysis.
6) From the analysis, also observed that the maximum temperature induced in the turbine blade with the lattice structure is 902^{0}C, which is comparably less than the temperature induced in other two gas turbine blade models.
7) It can be finally concluded that the lattice structure in turbine blade provide the effective cooling which may rises the life of a turbine blade.

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