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Improved Film Cooling Efficiency of Gas Turbine Blade

SK. Masthan Shareef¹, E.Kiran²

Associate Professor, Dept. of Mechanical Engineering, QIS College of Engineering and Technology, Ongole,
Prakasam (Dst), India¹

M. Tech, Dept. of Mechanical Engineering, QIS College of Engineering and Technology, Ongole,
Prakasam (Dst), India²

ABSTRACT: Gas turbines are extensively used for air craft propulsion, land based power generation and industrial applications. Thermal efficiency of gas turbine improved by increasing turbine rotor inlet temperature. The current rotor inlet temperature in advanced gas turbine 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. Gas turbines are cooled externally and internally. Several methods have been suggested for the cooling of blades and vanes. The techniques that involve to cool the blades and vanes by using cooling methods are external cooling and internal cooling. In this project a turbine blade is designed in CREO parametric software. The gas turbine blades are designed both the cooling methods, the film cooling in external cooling and convection cooling in internal cooling. The turbine blade with convection cooling for 4 holes and 6 holes are modeled. The film cooling air out of the blade through multiple small holes in the structure. CFD analysis to determine the heat transfer rates, heat transfer coefficients of the blade. Thermal analysis to determine the temperature distribution and heat flux, static analysis to determine the deformation, stress and strain for the both blades in ANSYS software. The present used material for blade is chromium steel. In this thesis, it is replaced with ceramic matrix composites, silicon carbide.

I. INTRODUCTION TO TURBINE

The word "**turbine**" was coined in 1822 by the French mining engineer Claude Burdin from the Latin turbo, or vortex, in a memoir, "Des turbines hydrauliques on machines rotatoires à grande vitesse" (Hydraulic turbines or high-speed rotary machines), which he submitted to the Académie royale des sciences in Paris. Benoit Fourneyron, a former student of Claude Burdin, built the first practical water turbine.

A **turbine** is a rotary engine that extracts energy from a fluid flow and converts it into useful work.

The simplest turbines have one moving part, a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades, or the blades react to the flow, so that they move and impart rotational energy to the rotor.

Gas, steam, and water turbines usually have a casing around the blades that contains and controls the working fluid.

Credit for invention of the steam turbine is given both to the British engineer Sir Charles Parsons (1854–1931), for invention of the reaction turbine and to Swedish engineer Gustaf de Laval (1845–1913), for invention of the impulse turbine. Modern steam turbines frequently employ both reaction and impulse in the same unit, typically varying the degree of reaction and impulse from the blade root to its periphery.

A working fluid contains potential energy (pressure head) and kinetic energy (velocity head). The fluid may be compressible or incompressible. Several physical principles are employed by turbines to collect this energy.

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1. TYPES OF TURBINES



Fig: 1.1.1 Steam Turbine

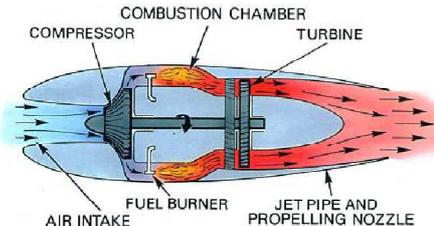


Fig: 1.1.2 Gas Turbine

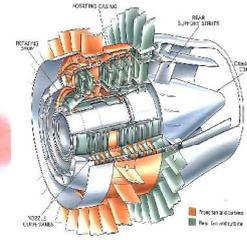


Fig: 1.1.5 Contra Rotating Turbines

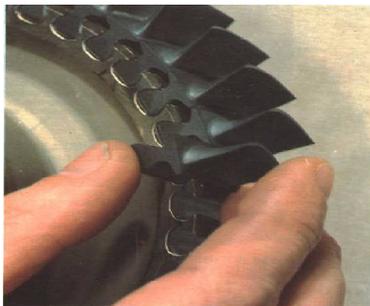


Fig: 1.1.7 Ceramic Turbine

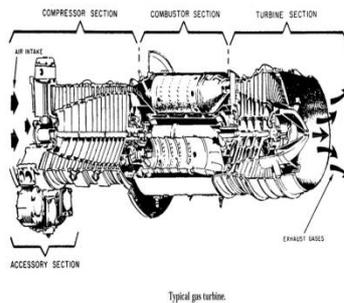


Fig: 1.2 Gas Turbine Engine

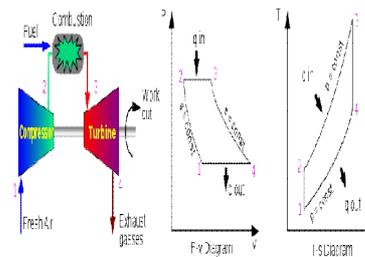


Fig: 1.2.1(a) Working Cycle

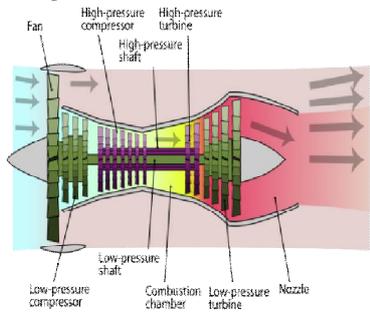


Fig: 1.2.1 (b) Cut section view of a gas turbine engine

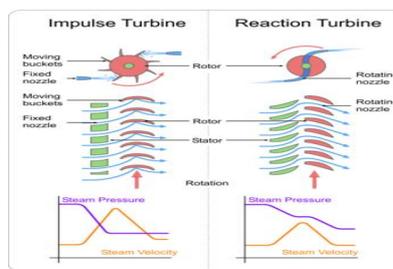


Fig: 1.3 Impulse and reaction Turbines

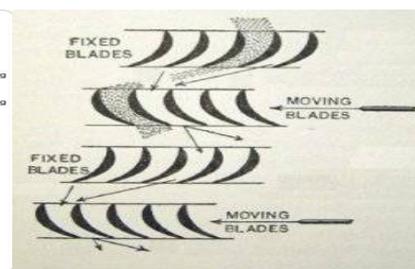


Fig: 1.5.2 Flow in Compressor blades

II. INTRODUCTION TO TURBINE BLADE

A **turbine blade** is the individual component which makes up the turbine section of a gas turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings.

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Fig: 2 (a) Turbine Blades

A design is only as efficient as the performance of the selected component materials. The combustor liner and turbine blades are the most critical components in existing high-performance, long-life gas turbines. The extreme conditions of stress, temperature and corrosion make the gas turbine blade a material challenge. Other turbine components present operational problem areas, but to a lesser degree. For this reason, gas turbine blade metallurgy will be discussed for solutions to problem areas. Definition of

2.2 GAS TURBINE BLADE MATERIALS

In the 1980s, IN 738 blades were widely used. IN-738, was the acknowledged corrosion standard for the industry. New alloys, such as GTD-111 possesses about a 35°F (20°C) improvement in rupture strength as compared to IN-738. GTD-111 is also superior to IN-738 in low-cycle fatigue strength.

The design of this alloy was unique in that it utilized phase stability and other predictive techniques to balance the levels of critical elements (Cr, Mo, Co, Al, W and Ta), thereby maintaining the hot corrosion resistance of IN-738 at higher strength levels without compromising phase stability.

A **super alloy**, or **high-performance alloy**, is an alloy that exhibits excellent mechanical strength and creep (tendency for solids to slowly move or deform under stress) resistance at high temperatures, good surface stability, and corrosion and oxidation resistance. Super alloys typically have a matrix with an austenitic face-centered cubic crystal structure. A super alloy's base alloying element is usually nickel, cobalt, or nickel-iron.

Alloy 718 nickel-based alloy. This nickel-based, precipitation hardened alloy is the newest being developed for the next generation of frame type gas turbine machines. This alloy has been used for wheels in aircraft turbines for more than 20 years. Alloy 718 contains a high concentration of alloying elements and is therefore difficult to produce in the very large ingot sizes needed for the large frame type turbine wheel and spacer forgings. This effort required close cooperation between the manufacturer, and its super alloy metals and large forging suppliers to conduct the solidification and forging flow studies that are necessary to bring into production a new wheel material for large wheels. This development effort has resulted in the production of the largest ingots ever made and forged into high-quality qualification turbine wheel and spacer forgings.

2.3 TURBINE BLADE COATING

Blade coatings were originally developed by aircraft engine industry for aircraft gas turbines. Metal temperatures in heavy-duty gas turbines are lower than those in aircraft engines. However, heavy-duty gas turbines generally subjected to excessive contamination or accelerated attack known as hot corrosion.

The PT-Al coating is a precious metal applied by uniformly electroplating a thin layer (0.00025 inch) of platinum onto the bucket at the airfoil surface, followed by pack-diffusion steps to deposit a layer of aluminum and chromium. The resulting coating has an outer skin of an extremely corrosion resistant, platinum-aluminum inter-metallic composition. As seen in figure no. test was conducted for comparative corrosion on coated and uncoated IN-738 blades. The blades were run side-by-side in the same machine under severe corrosive conditions. The two blades were removed from interim evaluation after 11,300 service hours (289 starts). The unit burnt sour natural gas

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containing about 3.5% ppm sulfur and was located in a region where the soil surrounding the site contains up to 3% sodium.

The uncoated blade showed an 0.005 inch corrosion attack over 50% of the airfoil concave face, with about 0.010 inch penetration at the base of the airfoil. Examination of the coated blade revealed no visual evidence of attack, except for one small roughened spot on the leading edge about 1 inch up from platform, and a second spot in the middle of the convex side about 1 inch down from the tip.

Metallographic examination of other areas revealed similar degrees of corrosion on the two blades. At no point on the coated blade had the corrosion penetrated to the base metal, although in the two areas on the coated blade about 0.002 inch of the original 0.003 inch coating has been oxidized.

Experience with uncoated IN-738 blades in this very hostile environment indicates about 25,000 hours blade life can be attained. The coated blade life, based on this interim evaluation, should add an additional 20,000 hours of life.

Experience has shown that the lives both uncoated and coated blades depend to a large degree on the amount of fuel and air contamination. This effect is shown in fig which illustrates the effect of sodium, a common contaminant, on blade life at 1600° F (871° C). The presence of increased level of contaminants give rise to an accelerated form of attack called hot corrosion.

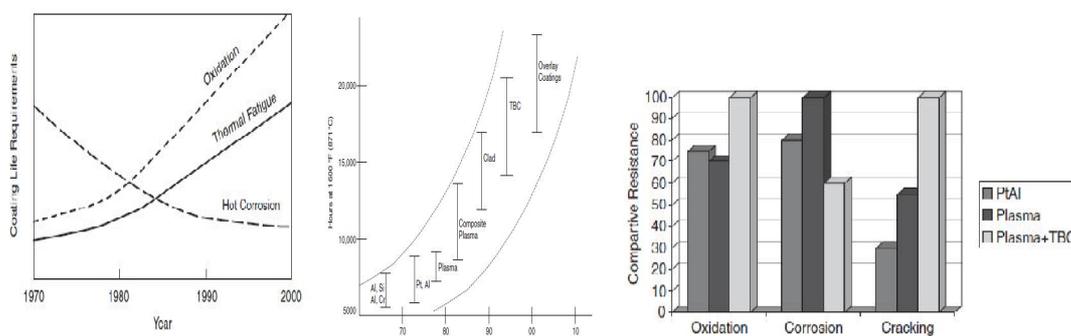


Fig: 2.3(a) Blade coating Evolution Fig: 2.3 (b) Developments of coatings Fig: 2.3 (c) Comparative resistances in various types of coatings

2.4 THERMAL BARRIER COATINGS

Thermal barrier coatings are highly advanced material systems usually applied to metallic surfaces, such as gas turbine or aero-engine parts, operating at elevated temperatures, as a form of exhaust heat management. These coatings serve to insulate components from large and prolonged heat loads by utilizing thermally insulating materials which can sustain an appreciable temperature difference between the load-bearing alloys and the coating surface. In doing so, these coatings can allow for higher operating temperatures while limiting the thermal exposure of structural components, extending part life by reducing oxidation and thermal fatigue.



Fig: 2.4 thermal barrier coated blade

2.5 TURBINE BLADE COOLING

Another strategy to improving turbine blades and increasing their operating temperature, aside from better materials, is to cool the blades. There are three main types of cooling used in gas turbine blades; convection, film, and transpiration cooling. While all three methods have their differences, they all work by using cooler air (often bled from the compressor) to remove heat from the turbine blades

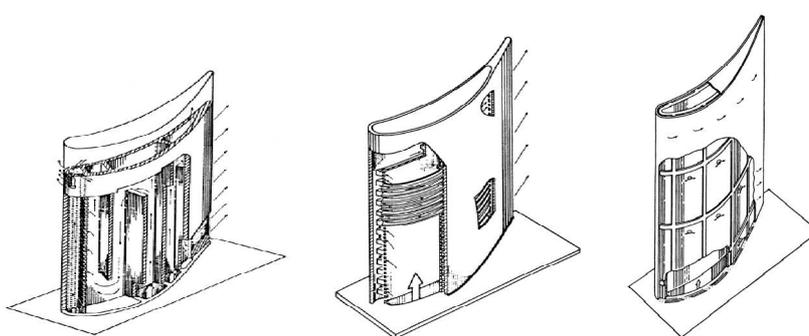


Fig: 2.5(a) Turbine cooling Fig: 2.5(b) Film and Convection cooled Fig: 2.5(c) Impingement cooling Fig: 2.5(d) Transpiration cooling

III. INTRODUCTION TO CAD AND CREO

Computer-aided design (CAD) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. The term **CADD** (for Computer Aided Design and Drafting) is also used

PTC CREO, formerly known as Pro/ENGINEER, is 3D modeling software used in mechanical engineering, design, manufacturing, and in CAD drafting service firms. It was one of the first 3D CAD modeling applications that used a rule-based parametric system. Using parameters, dimensions and features to capture the behavior of the product, it can optimize the development product as well as the design itself.

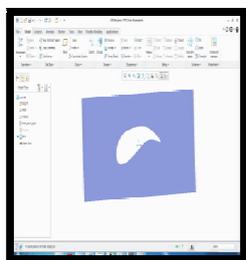


Fig 3a

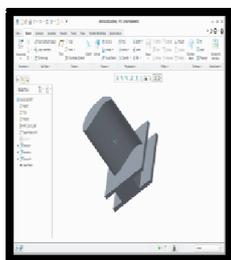


Fig3b

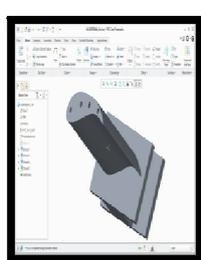


Fig 3c

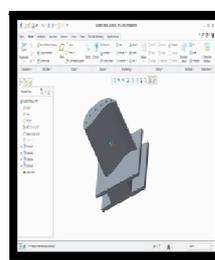


Fig 3d

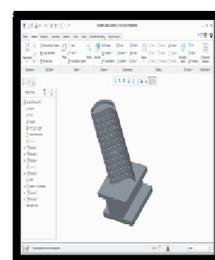


Fig 3e

Fig 3 (a) 2D MODEL OF GAS TURBINE BLADE Fig 3 (b) WITHOUT HOLES GAS TURBINE MODEL Fig: 3 (c) WITH 4 HOLES (CONVECTION COOLING) GAS TURBINE MODEL Fig: 3 (d) WITH 6 HOLES (CONVECTION COOLING) GAS TURBINE MODEL 3.2 (e) WITH HOLES (FILM COOLING) GAS TURBINE MODEL

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IV. INTRODUCTION TO FEA

Finite element analysis is a method of solving, usually approximately, certain problems in engineering and science. It is used mainly for problems for which no exact solution, expressible in some mathematical form, is available. As such, it is a numerical rather than an analytical method. Methods of this type are needed because analytical methods cannot cope with the real, complicated problems that are met with in engineering. For example, engineering strength of materials or the mathematical theory of elasticity can be used to calculate analytically the stresses and strains in a bent beam, but neither will be very successful in finding out what is happening in part of a car suspension system during cornering.

Structural Analysis

ANSYS Autodyne is computer simulation tool for simulating the response of materials to short duration severe loadings from impact, high pressure or explosions

ANSYS Mechanical

ANSYS Mechanical is a finite element analysis tool for structural analysis, including linear, nonlinear and dynamic studies. This computer simulation product provides finite elements to model behavior, and supports material models and equation solvers for a wide range of mechanical design problems. ANSYS Mechanical also includes thermal analysis and coupled-physics capabilities involving acoustics, piezoelectric, thermal-structural and thermo-electric analysis.

V. DESIGN AND ANALYSIS OF GAS TURBINE BLADE

5.1 CFD ANALYSIS OF GAS TURBINE BLADE

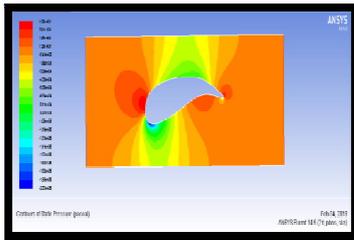


Fig 5.1(a) PRESSURE

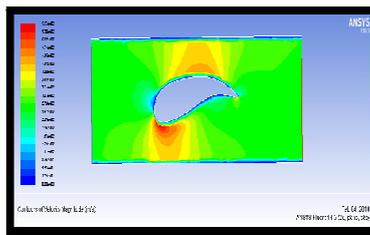


Fig 5.1(b) VELOCITY

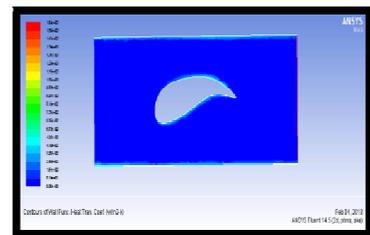


Fig 5.1(c) HEAT TRANSFER

COEFFICIENT

Mass Flow Rate	(kg/s)
inlet	81.468056
interior_trm_srf	-122.299993
outlet	-81.446236
wall_trm_srf	0
Net	0.021820068

Fig 5.1(d) MASS FLOW RATE

Total Heat Transfer Rate	(w)
inlet	48690096
outlet	-48677832
wall_trm_srf	0
Net	13064

Fig 5.1(e) HEAT TRANSFER RATE

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5.2 STATIC ANALYSIS OF GAS TURBINE BLADE WITHOUT HOLES MATERIAL - CHROMIUM STEEL

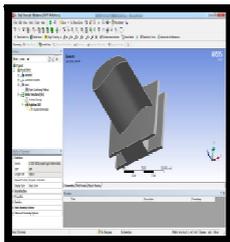


Fig5.2 a

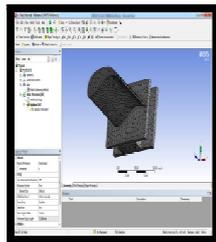


Fig 5.2b

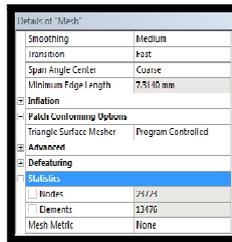


Fig 5.2 c

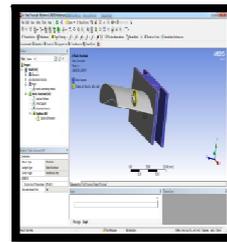


Fig 5.2 d

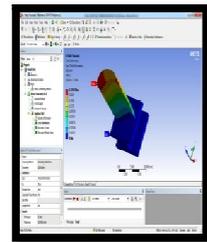


Fig5.2 e

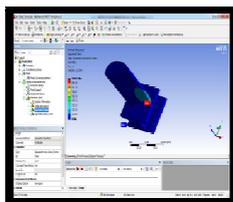


Fig 5.2f

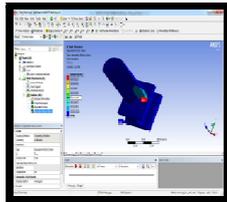


Fig 5.2 g

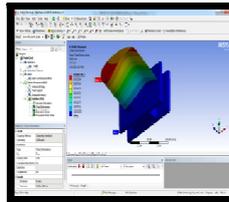


Fig 5.2 h

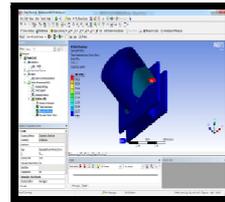


Fig 5.2 i

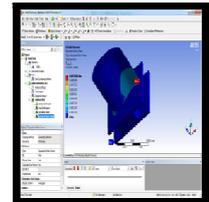


Fig 5.2 j

(WITH 4 HOLES (convection cooling) MATERIAL - CHROMIUM STEEL)

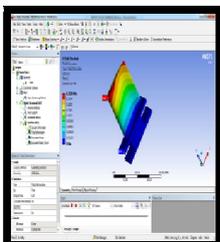


Fig 5.2 j

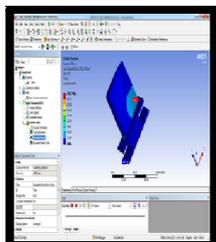


Fig 5.2 k

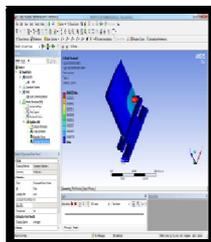


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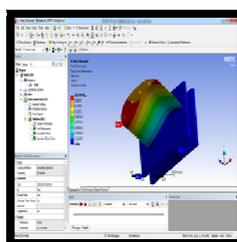


Fig 5.2 m

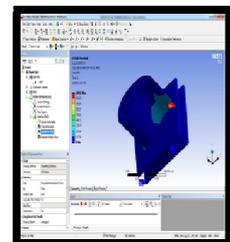


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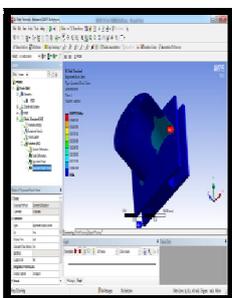


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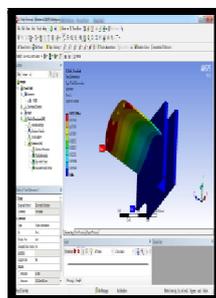


Fig 5.2 p

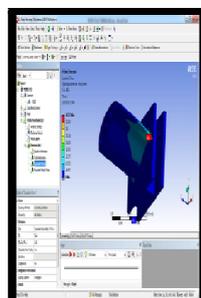


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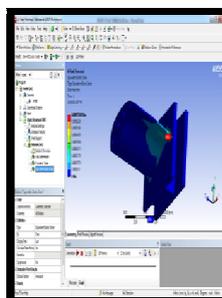


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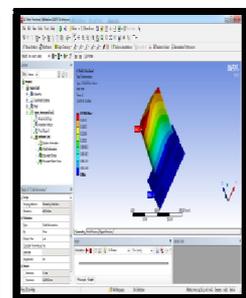


Fig 5.2 s

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WITH 6 HOLES (convection cooling) MATERIAL - CHROMIUM STEEL

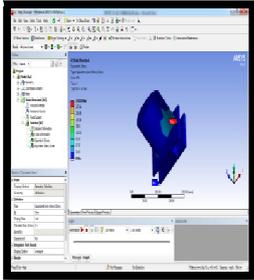


Fig 5.2 t

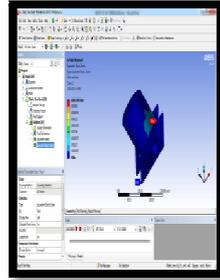


Fig 5.2 u

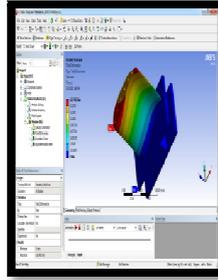


Fig 5.2 v

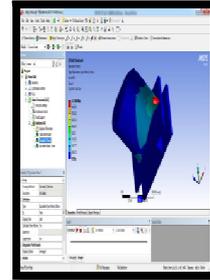


Fig 5.2 w

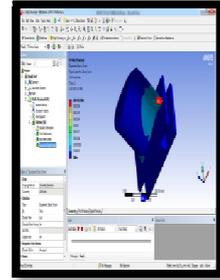


Fig 5.2 x

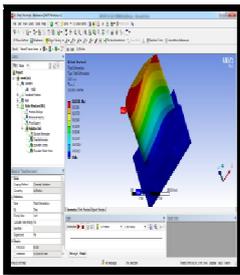


Fig 5.2 y

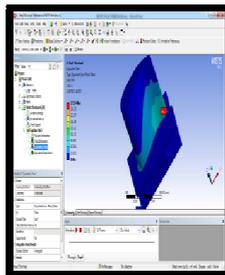


Fig 5.2 z

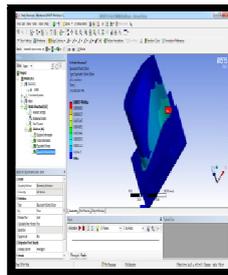


Fig 5.2(a1)

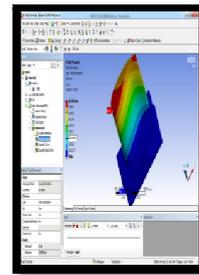


Fig 5.2(b1)

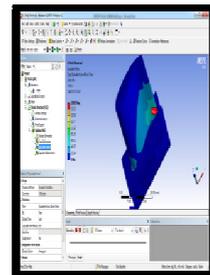


Fig 5.2(c1)

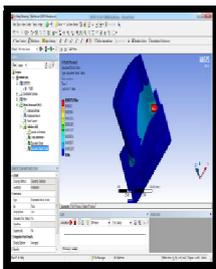


Fig 5.2(d1)

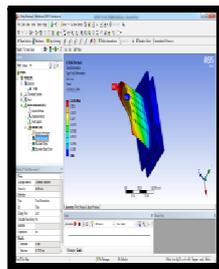


Fig 5.2(e1)

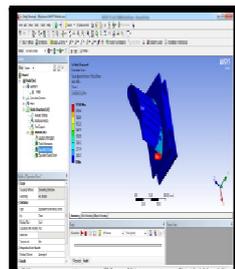


Fig 5.2(f1)

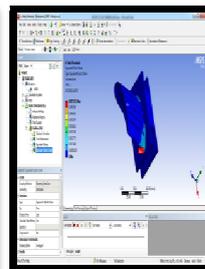


Fig 5.2(g1)

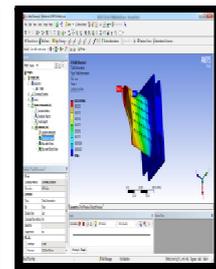


Fig 5.2(h1)

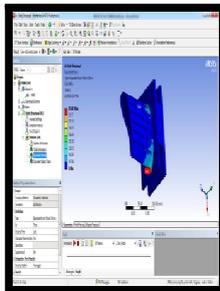


Fig 5.2(i1)

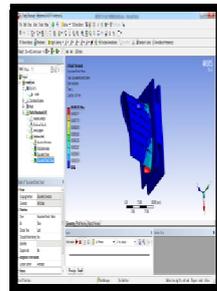


Fig 5.2(j1)

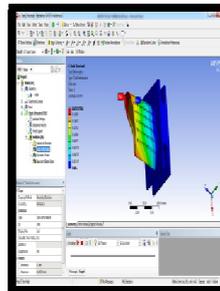


Fig 5.2(k1)

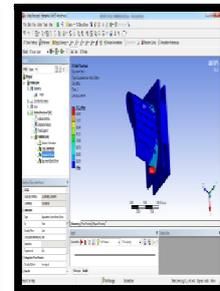


Fig 5.2(l1)

Fig 5.2(a) IMPORTED MODEL, Fig 5.2(b) MESHED MODEL, Fig 5.2(c) BOUNDARY CONDITIONS, Fig 5.2(d) DEFORMATION Fig 5.2 (e) STRESS, Fig 5.2(f) STRAIN, Fig 5.2 (g) DEFORMATION (MATERIAL -

SILICON CARBIDE), Fig 5.2(h) STRESS, Fig 5.2(i) STRAIN, Fig 5.2(j) DEFORMATION (MATERIAL - CERAMIC MATRIX COMPOSITES), Fig 5.2(j) STRESS, Fig 5.2(k) STRAIN, Fig 5.2(l) DEFORMATION (WITH 4 HOLES (convection cooling) MATERIAL - CHROMIUM STEEL)
 Fig 5.2 (m) STRESS, Fig 5.2(n) STRAIN, Fig 5.2(o) DEFORMATION (MATERIAL - SILICON CARBIDE), Fig 5.2(p) STRESS, Fig 5.2(q) STRAIN, Fig 5.2 (r) DEFORMATION (MATERIAL - CERAMIC MATRIX COMPOSITES), Fig 5.2 (s) STRESS, Fig 5.2(t) STRAIN, Fig 5.2(u) DEFORMATION WITH 6 HOLES (convection cooling) MATERIAL - CHROMIUM STEEL
 Fig 5.2(v) STRESS, Fig 5.2(w) STRAIN, Fig 5.2(x) DEFORMATION (MATERIAL - SILICON CARBIDE), Fig 5.2(y) STRESS, Fig 5.2(z) STRAIN, Fig 5.2(a1) DEFORMATION (MATERIAL - CERAMIC MATRIX COMPOSITES), Fig 5.2(b1) STRESS, Fig 5.2(c1) STRAIN, Fig 5.2(d1) DEFORMATION (FILM COOLING GAS TURBINE BLADE MATERIAL - CHROMIUM STEEL), Fig 5.2(e1) STRESS, Fig 5.2(f1) STRAIN, Fig 5.2(g1) DEFORMATION (MATERIAL - SILICON CARBIDE), Fig 5.2(h1) STRESS, Fig 5.2(i1) STRAIN, Fig 5.2(j1) DEFORMATION (MATERIAL - CERAMIC MATRIX COMPOSITES), Fig 5.2(k1) STRESS, Fig 5.2(l1) STRAIN

5.3 THERMAL ANALYSIS OF GAS TURBINE BLADE WITHOUT HOLES MATERIAL - CHROMIUM STEEL

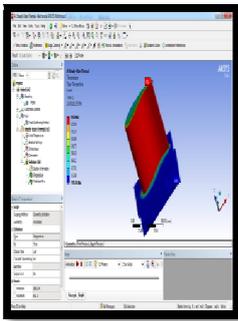


Fig 5.3 (a)

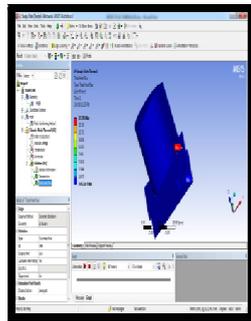


Fig 5.3(b)

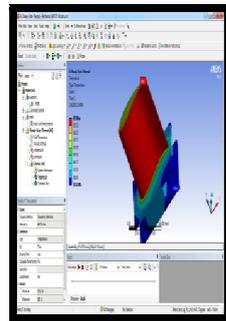


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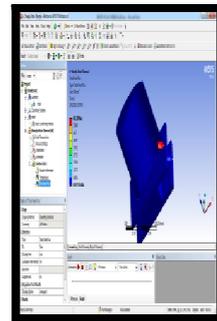


Fig 5.3(d)

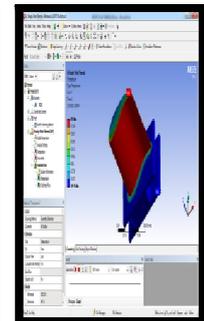


Fig 5.3(e)

WITH 4 HOLES (convection cooling) MATERIAL - CHROMIUM STEEL

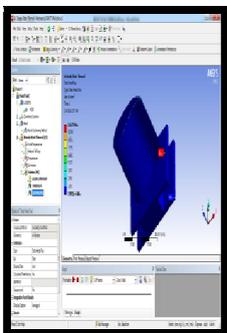


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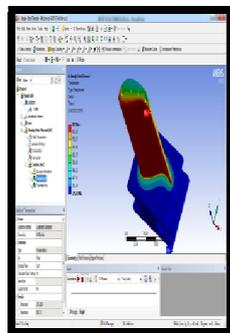


Fig 5.3(g)

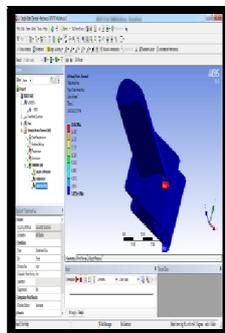


Fig 5.3(h)

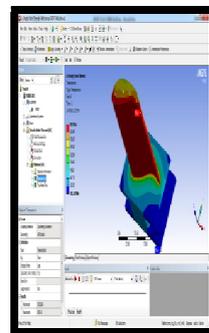


Fig 5.3(i)

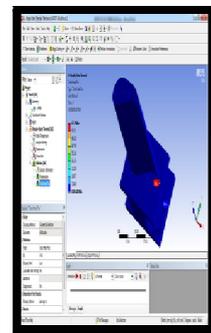


Fig 5.3(j)

WITH 6 HOLES (convection cooling) MATERIAL - CHROMIUM STEEL

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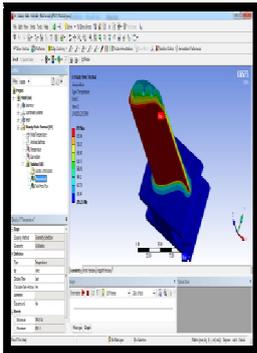


Fig 5.3(k)

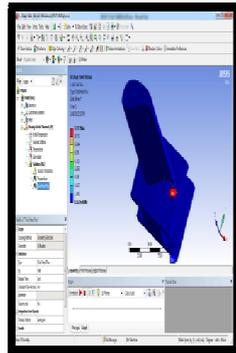


Fig 5.3(l)

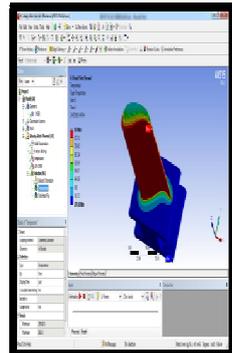


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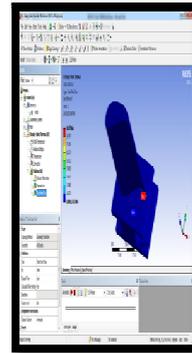


Fig 5.3 (n)

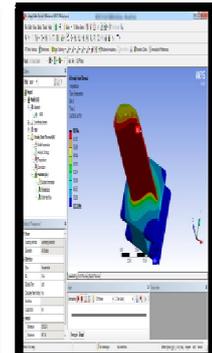


Fig 5.3 (o)

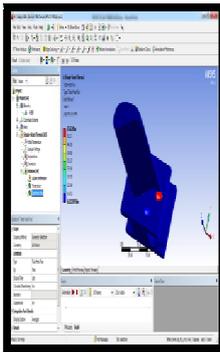


Fig 5.3(p)

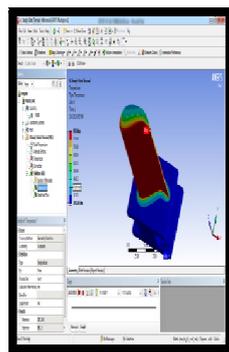


Fig 5.3(q)

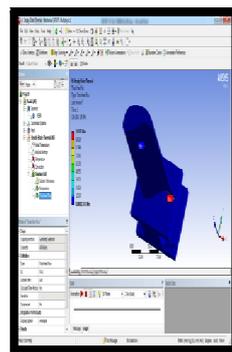


Fig 5.3(r)

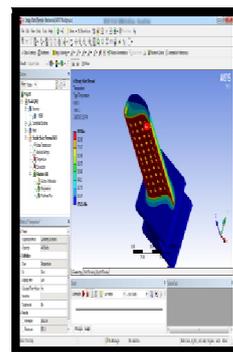


Fig 5.3(s)

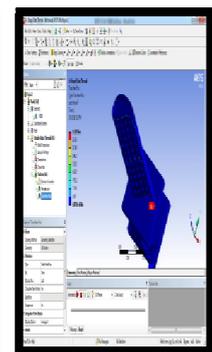


Fig 5.3(t)

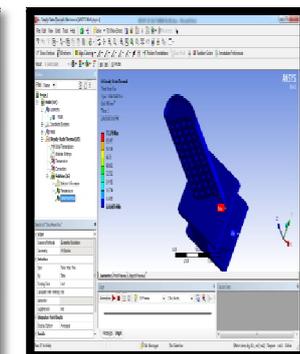
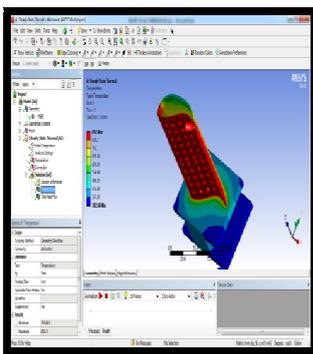


Fig 5.3(u)

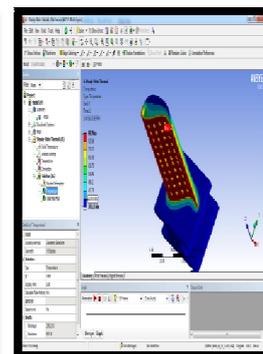


Fig 5.3(v)

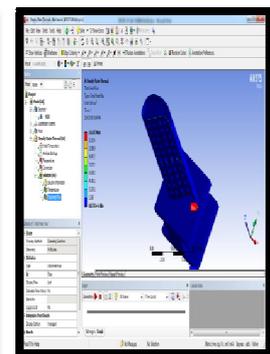


Fig 5.3(w) Fig 5.3(x)

**Fig 5.3 (a) TEMPERATURE DISTRIBUTION, Fig 5.3(b) HEAT FLUX, Fig 5.3(c) TEMPERATURE DISTRIBUTION (MATERIAL - SILICON CARBIDE), Fig 5.3(d) HEAT FLUX, Fig 5.3(e) TEMPERATURE DISTRIBUTION (MATERIAL - CERAMIC MATRIX COMPOSITES), Fig 5.3(f) HEAT FLUX WITH 4 HOLES (convection cooling) MATERIAL - CHROMIUM STEEL
Fig 5.3(g) TEMPERATURE DISTRIBUTION, Fig 5.3(h) HEAT FLUX, Fig 5.3(i) TEMPERATURE DISTRIBUTION (MATERIAL - SILICON CARBIDE), Fig 5.3(j) HEAT FLUX, Fig 5.3(k) TEMPERATURE DISTRIBUTION (MATERIAL - CERAMIC MATRIX COMPOSITES), Fig 5.3(l) HEAT FLUX WITH 6 HOLES (convection cooling) MATERIAL - CHROMIUM STEEL**

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Fig 5.3 (m) TEMPERATURE DISTRIBUTION, Fig 5.3 (n) HEAT FLUX, Fig 5.3 (o) TEMPERATURE DISTRIBUTION (MATERIAL - SILICON CARBIDE), Fig 5.3(p) HEAT FLUX, Fig 5.3(q) TEMPERATURE DISTRIBUTION (MATERIAL - CERAMIC MATRIX COMPOSITES), Fig 5.3(r) HEAT FLUX, Fig 5.3(s) TEMPERATURE DISTRIBUTION (MATERIAL - SILICON CARBIDE), Fig 5.3(t) HEAT FLUX, Fig 5.3(u) TEMPERATURE DISTRIBUTION (MATERIAL - CERAMIC MATRIX COMPOSITES), Fig 5.3(v) HEAT FLUX, Fig 5.3(w) TEMPERATURE DISTRIBUTION (MATERIAL - SILICON CARBIDE), Fig 5.3(x) HEAT FLUX

VI. RESULTS AND DISCUSSION

Table 6.1: CFD ANALYSIS RESULTS

Fluid	Pressure(Pa)	Velocity (m/s)	Heat transfer coefficient (w/m ² -k)	Mass flow rate(kg/s)	Heat transfer rate(W)
Air	4.50e+04	5.57e+02	1.64e+03	0.021820068	13064

Table 6.2: STATIC ANALYSIS RESULTS TABLE

	Material	Deformation (mm)	Stress (MPa)	Strain
Without holes	Chromium steel	0.17633	1059.1	0.0058425
	Silicon carbide	0.03551	389.45	0.00099684
With 4 holes	Ceramic matrix composite	0.19208	294.27	0.006551
	Chromium steel	0.17479	1004.2	0.0055528
	Silicon carbide	0.035138	367.72	0.00097018
With 6 holes	Ceramic matrix composite	0.19048	278.82	0.0061785
	Chromium steel	0.17492	727.86	0.004302
	Silicon carbide	0.035201	272.54	0.00077494
Film cooling	Ceramic matrix composite	0.19058	200.55	0.0047553
	Chromium steel	0.17505	979.83	0.0053321
	Silicon carbide	0.035193	354.04	0.00093051
	Ceramic matrix composite	0.19073	272.21	0.0059353

Table 6.3: THERMAL ANALYSIS OF RESULTS TABLE

	Material	Temperature (°C)		Heat flux (w/mm ²)
		Max.	Min.	
Without holes	Chromium steel	892	295.18	17.705
	Silicon carbide	892	302.6	60.128
With 4 holes	Ceramic matrix composite	892	295.15	11.637
	Chromium steel	892	295.15	12.117
	Silicon carbide	892	302.36	63.29
With 6 holes	Ceramic matrix composite	892	295.18	18.482
	Chromium steel	892	295.43	16.85
	Silicon carbide	892	315.52	57.62
Film cooling	Ceramic matrix composite	892	295.19	11.037
	Chromium steel	892	295.15	14.103
	Silicon carbide	892	302.48	73.176
	Ceramic matrix composite	892	295.15	14.103

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VII. CONCLUSION

Gas turbines are cooled externally and internally. Several methods have been suggested for the cooling of blades and vanes. The techniques that involve to cool the blades and vanes by using cooling methods are external cooling and internal cooling.

In this project a turbine blade is designed in CREO parametric software. The gas turbine blades are designed both the cooling methods, the film cooling in external cooling and convection cooling in internal cooling . The turbine blade with convection cooling for 4 holes and 6 holes are modeled. The film cooling air out of the blade through multiple small holes in the structure. The present used material for blade is chromium steel. In this thesis, it is replaced with ceramic matrix composites, silicon carbide.

By observing the static analysis results, stress values are less for ceramic matrix composite material, and compared to the turbine blade models convection cooling 6 holes blade has less stress compared with external cooling gas turbine blade.

By observing the thermal analysis results the heat flux values are more for silicon carbide and temperature distribution is more for 6 holes gas turbine blade.

So it can be concluded the ceramic matrix composites material and internal convection cooling 6 holes gas turbine blade is better model and material.

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