DESIGN AND ANALYSIS OF GAS TURBINE BLADE PROFILE USING DIFFERENT MATERIALS

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ABSTRACT:

Gas turbines are currently one of the most efficient turbo machinery sources. This technology has applications in numerous sectors, including manufacturing, aerospace, household, and small-scale enterprises. Gas turbine engines present many challenges when choosing blade profiles, selecting materials, and controlling turbine rotor blade vibration. The influence of these factors on structural performance and stress deformation is significant. The total heat flux, the directional distortions of the turbine blades, and the thermal error resulting from the interaction between the heat and centrifugal loads have all been analyzed. In addition, the temperature flow is a result of thermal loading. The results for three materials (Inconel 718, titanium T6, and SS316) are compared to choose the optimum material for a turbine blade.

Key words: Gas Turbine Blade, NX 12.0, Transient Thermal analysis

1.0 INTRODUCTION

Gas turbines convert thermal energy obtained from the combustion of fuel in pressure gas and high temperatures into mechanical energy to drive electric generators **[1]** The engine of a gas turbine consists of three main parts, namely compressor, combustion system, and turbine **[2]** Components in the combustion system have a significant role in ensuring reliable operation in various air/fuel ratios and loads. Conditions of hot section components such as nozzles, burners, and blades exposed to hot gas coming out of the combustion system are very vulnerable to failure **[3].** The first stage blades in the turbine are considered very critical in hot gas path inspection. The most common failure mechanism modes in the nozzle and blade are fatigue, creep, erosion, and corrosion **[4]**. The first stage blade in a gas turbine function as a guide of hot gas supplied from the combustion chamber towards the turbine blade so that the blade experiences high heat pressure **[5]** Blades in turbines are usually made of nickel superalloys, coated with a thermal barrier **[6]** Gas turbines are the primary generators of energy in each of these experiments. Due to the high efficiency of gas turbines, they were chosen as the best option for this application.

Gas turbine:

Gas turbine engines convert the chemical energy of the fuel into mechanical energy, which can be expressed as shaft power or kinetic energy. Power production gas turbines are gas turbines specifically designed to produce electricity. The gas turbines on an airplane transform the fuel's potential energy into motion. Several parts of the engine collaborate to convert the energy stored in the fuel into the shaft power or propulsion force that moves the engine.

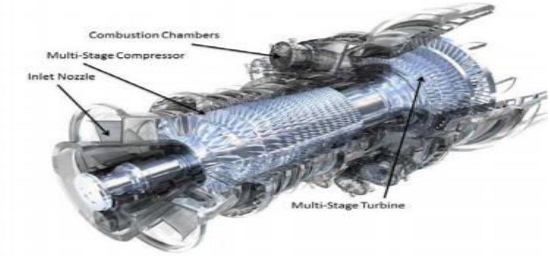


Fig 1: Gas turbine

Gas turbines convert combustion energy into heat by compressing the working gas (air). The working gas is subjected to rising temperatures and pressures. Working gas energy is converted into rotating blade energy by means of gas-blade interaction in the engine. Both types of gas turbines can be shown in the diagram below. There is an open cycle (which is internal) and a closed cycle (external type). The combustor and the turbine are the most crucial components of both compressors.

Gas turbine blade:

Turbine blades in gas turbines or steam turbines are made up of many smaller parts. The blades are what actually collect energy from the superheated, super pressed gas that the combustor produces. In order to function reliably in such extreme conditions, gas turbines frequently require exotic materials like superalloys and a wide variety of cooling technologies. These may be broken down into internal and external cooling, as well as thermal barrier coatings on the blades individually. For both steam and gas turbines, blade fatigue is a common cause of failure.

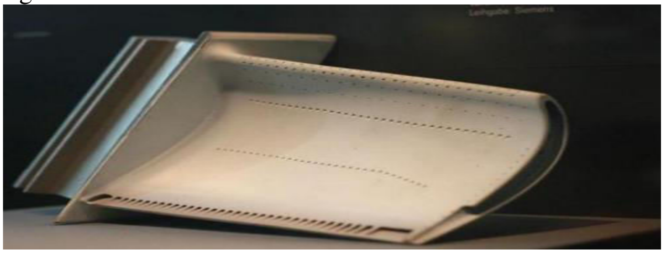


Fig 2: Turbine Blade

Objectives:

- To study the gas turbine blade geometry
- A three-axis CNC machine was used to optimize the turbine blade, and different tools were used to manufacture it dimensionally.
- The Gas turbine blade design in done by using NX 12.0 and Analysis is done by ANSYS 2024 R1
- To analyze the gas turbine blade using with ANSYS 2024R1 (transient thermal Analysis)

2.0 LITERATURE REVIEW

L.Umamaheswararao et al **[7]** have investigated the stress distribution and temperature distribution on gas turbine blade and have stated in paper titled “Design and analysis of a gas turbine blade by using FEM”. In this paper the first stage rotor blade of a gas turbine has been analyzed for structural, thermal analysis using ANSYS (Finite Element Analysis Software). The material used for the blade was specified as INCONEL 718. P.V. Krishnakanth et al. **[8]** have summarized the design and analysis of Gas turbine blade in paper titled “Structural & Thermal Analysis of Gas Turbine Blade by Using F.E.M” in which CATIA V5 is used for design of solid model of the turbine blade with the help of the spline and extrudes options, ANSYS 11.0 software is used analysis of F.E. Barhm Abdullah Mohamad et al. **[9]** have worked on paper with title “Failure analysis of gas turbine blade using finite element analysis” related to failure analysis of the turbine blade of a gas turbine engine 9E GE type, installed in a certain type of simple systems consisting of the gas turbine driving an electrical power generator. Murali. K et al **[10]** have worked on the first stage rotor blade of the gas turbine in the paper titled with “Design and Fatigue Analysis of Turbine Rotor Blade by Using F.E.M”. The first stage rotor blade of the gas turbine is Analysed for the static and thermal stresses resulting from the tangential, axial and centrifugal forces. Sindhu N L, Dr. N Chikkanna **[11]** In the present work the first stage rotor blade of a two-stage gas turbine has been Analyzed for static structural, steady state thermal, modal and high cycle fatigue using ANSYS 17. An attempt has been made to investigate the effect of temperature and induced stresses on the turbine blade.

3.0 RESEARCH METHODOLOGY

The aerospace engines have been the driving force behind the majority of the advancements in gas turbine technology. These engines were developed with a focus on maximizing reliability, performance, number of starts, and flexibility across the whole flight envelope. The utilization of high aspect ratio compressor blades and the optimization of pressure ratio and turbine firing temperature to produce maximum work output per unit flow have traditionally been regarded as standards for aircraft engine performance. The industrial gas turbine has historically prioritized durability over other factors, resulting in a design that is less than optimal in terms of performance under stress. Industrial gas turbines can operate in low-temperature, high-pressure environments.

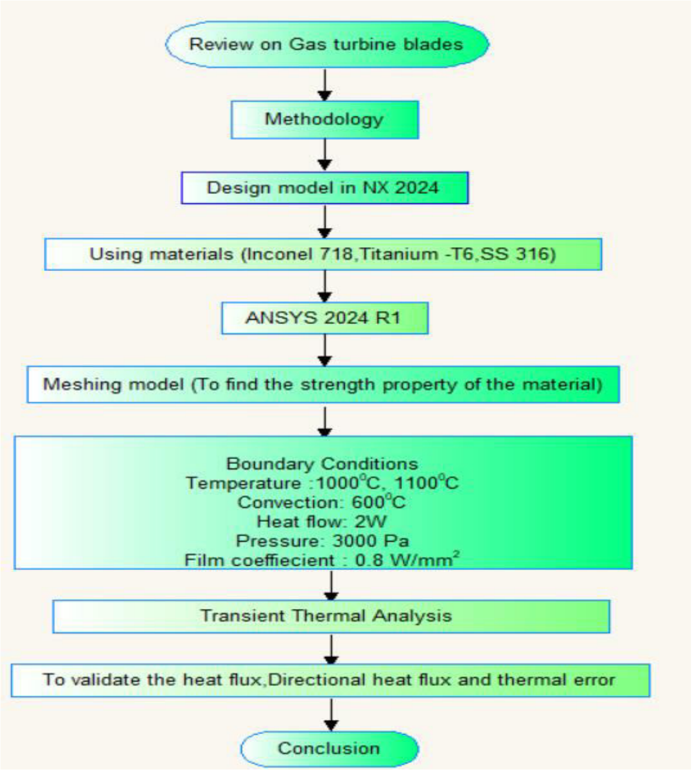


Fig 3: Design flow chart

Using materials:

The most important requirement for the gas turbine blade is to have high creep resistance at a higher temperature using different types blade materials in those analysis

Table 1: Gas turbine blade using different Material properties

Engineering Properties	Inconel 718	Titanium -T6	SS 316
Density (g/cc)	8.19	4.5	7.98
Thermal expansion coefficient (µm/m.°C)	13	7.14	17.2
Melting temperature (°C)	1350	1725	1100
Young's modulus (Gpa)	204	100	190
Ultimate tensile strength (MPa)	965	1070	480
Poisson's ratio	0.29	0.36	0.3

INTRODUCTION TO NX 12.0

Solid works delivers a number of feature editing and creation enhancements that drive productivity improvements. For example, you can now see the feature section direction when creating, editing, or replacing features. You now have the option to retain or delete child features when deleting features. This gives you more control over how your features is linked, and makes it easier to change or update your model.

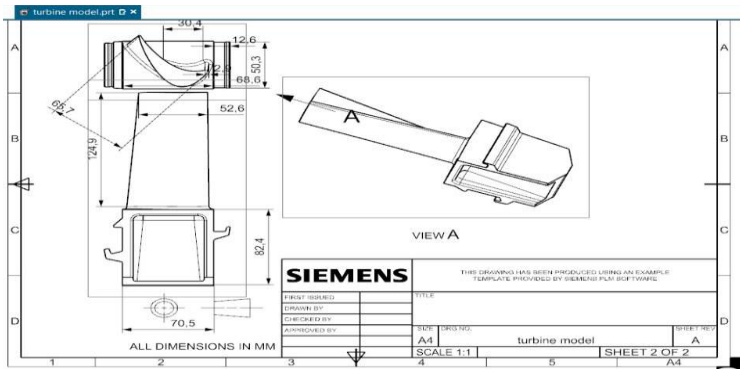
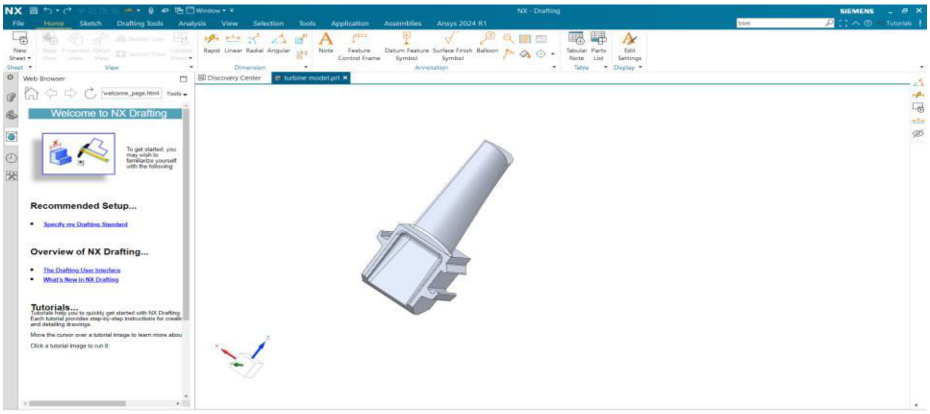


Fig 4: Geometric view



Welcome to NX Drafting

To get started, you may wish to familiarize yourself with the following

Recommended Setup...

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Overview of NX Drafting...

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Click a tutorial image to run it.

Fig 5: Gas turbine blade

Turbine blades

There are many methods of inspection of turbine blades, each of which may be used until all is inspected to a certain extent.

TBC Processing Methods

TBCs and EBCs are both types of coating materials frequently used as defense mechanisms for CMCs on components found in aerospace vehicles. CMCs are lighter and are able to endure higher temperatures than metallic materials do at 200 C. In dry air surfaces, protective silica forms which provide stability for long-term situations with temperatures of up to 1300 ˚C. However, the layer silica on the surface responds violently to surface recession in combustion conditions where moisture is present For CMC to work effectively in a hard and complex aircraft operating environments, a security system is therefore very important

VISUAL INSPECTION

As the name suggests, this type of check is a visually conducted preliminary examination, whether by inspection or by sight.

1. Bore scope: An engine component, such as turbine blades, can be examined using this equipment. With a flexible bore scope, the optical tube is adjustable so that it may be adjusted in various directions to find the component being inspected.

2. Magnifying glass: The blade may be examined with a loupe after disassembly, to see whether the blades are deformed and cracked.

Liquid Penetrating Testing

This approach includes the application of a fluorescent dye to the region to be investigated, and then highlights the points that are damaged or flawed. Until the paint or penetration can be applied on the turbine blade, all pollutants which can obstruct or fill the cracks on the blades' Depending on their size and composition, cracks and damaged regions may require more or less time for the penetrator to make its way inside. The next step is to remove the surplus dye from the blade.

Magnetic Particle Testing

It uses an induced magnetic force to reveal the defective areas on the blade surface. Indirect and direct magnetization of the component can be carried out. As the stream is applied through the blade, a magnetic field is created around it and a magnetic field is then applied from the outside to the blade. After any flaw in the blade has been magnetised, the magnetic flux will be released. The iron particles are applied to the surface, and then the leakage is attracted. Any aggregation of iron particles in some areas indicates the defect in this position and necessary steps can be taken to repair this defect.

Eddy Current Inspection

Eddy current testing is a type of electromagnetic testing that employs electromagnetic induction to locate flaws in conductors. By passing an alternating current, the driver sets off the fields, the magnitude of which grows and shrinks as the current changes from maximum to minimum.

Laser Cutting Turbine Blade Different Operations:

Gas turbines are the rare synthesis of traditional heavy engine architecture and state-of-the-art development technology. Not only the entire turbine but also each blade is a technological marvel that blends high accuracy and efficiency. The shape of blades in a gas turbine varies and each undergoes extremely high operating stress. At 1,400 ° C,

Fig 6: Turbine blade during laser drilling

The Laser systems for these deep penetration boxes (up to 25 mm) with pulse length are worked in the 1 mm range for these cylindrical holes at 15–90 ° C on curved blade surfaces. Moreover, most of the exit holes are created so as to allow the film to cool down.

Laser Drilling:

The number of cooling holes in turbine motors has risen considerably with the increased developments in laser process and control technology. Laser piercing enables the machining in a wide variety of materials in both very small and precise hole sizes and directions. These holes may be tapered or formed to improve the quantity, direction and cooling properties of the blade. One element with one setup can drill hundreds or thousands of cooling holes.

Fig 7: Laser drilling turbine blade

Cylindrical holes:

Melting and vaporising the material because of the absorption of energy from a concentrated laser beam is how most laser drillers of 0,8 mm diameter 0.0 hole in a 5 mm gap in turbine engine components work. Laser boiling pulse systems, the pulse length of which is determined by the system's overall parameters and is typically milliseconds for boiling turbine blades.

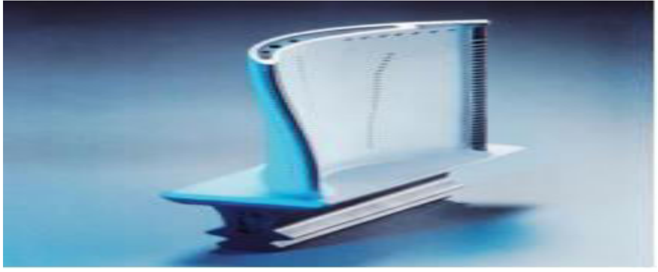


Fig 8: Gas turbine blade with about cooling holes, half of which have shaped exit holes.

Tip finish and blend machining:

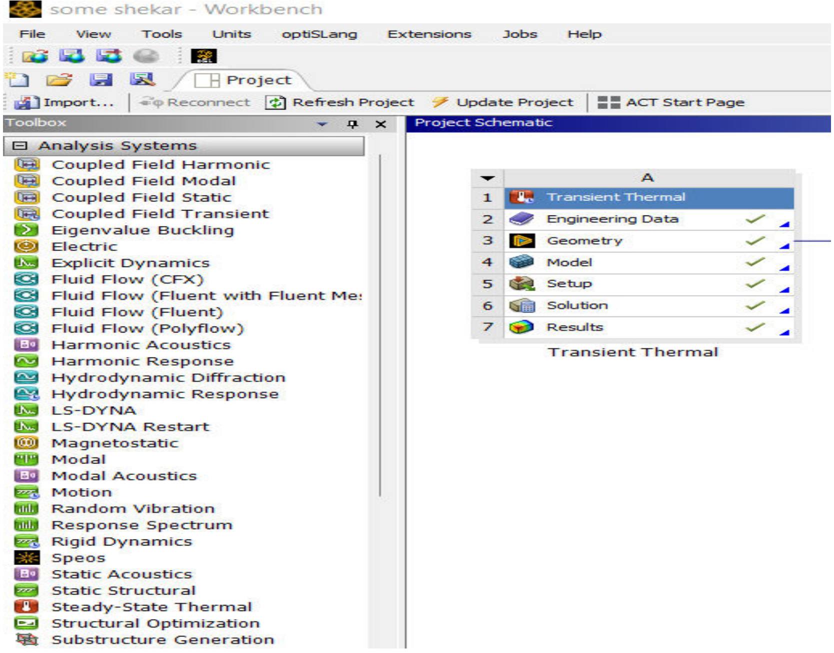
The advice proved flexible. The titanium thin-size wall geometry was CNC finished and blended using power MILL machining, which involved a highly cautious 500-1,500 mm/min feed speed with a spindle vessel of 2,000 rpm, and was performed without coolant or robust fixation utilizing the ball's nose cutting system. The milling exhibited short fills from the laser cladding (where not enough material was stored), but it helped resurface and return the blade to its desired form and tolerance otherwise.

Fig 9: Adaptive CNC blending of repaired air foil tip

The inspection capability was originally envisaged as the final inspection phase at multiple points in the processing phases. Early trials gave an insight into the effects of each move in terms of the component accuracy.

4.0 RESULTS AND DISCUSSIONS

- Steady-state thermal analysis involves assessing the equilibrium state of a system subject to constant heat loads and environmental conditions.
- The simplest form of steady-state analysis is linear steady-state thermal analysis in which input parameters, such as material properties, are prescribed independent variables.



	A	
1	Transient Thermal	
2	Engineering Data	✓
3	Geometry	✓
4	Model	✓
5	Setup	✓
6	Solution	✓
7	Results	✓

Transient Thermal

Fig 10: ANSYS Layout

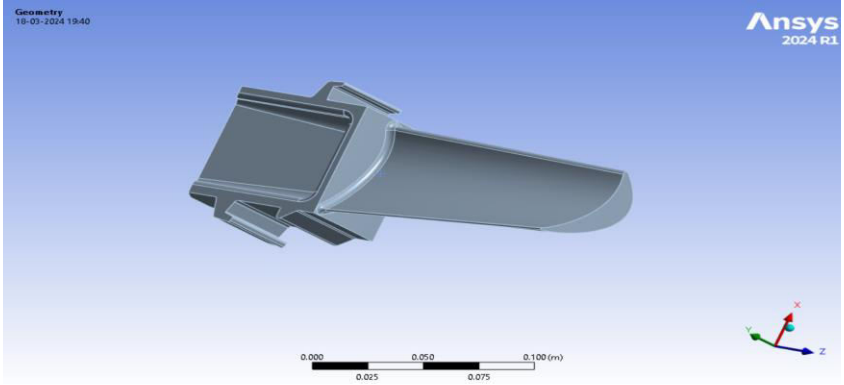


Fig 11: Imported model

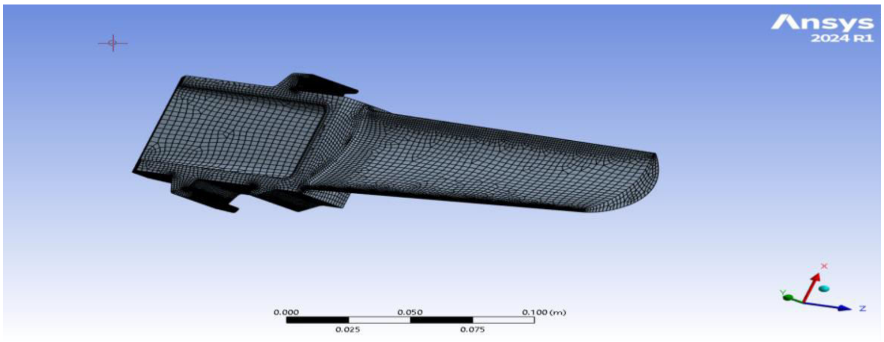
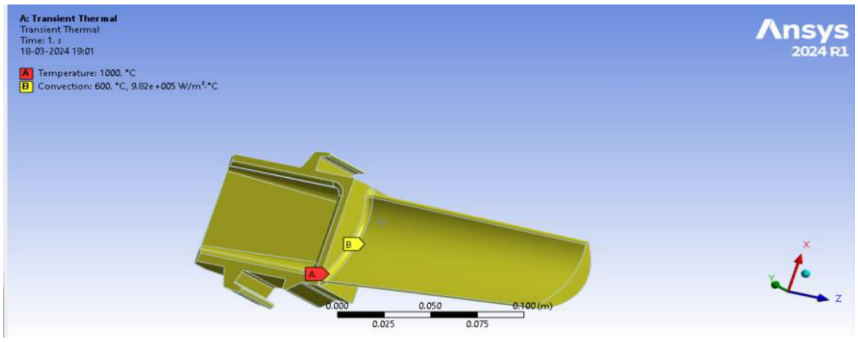


Fig 12: Meshed model

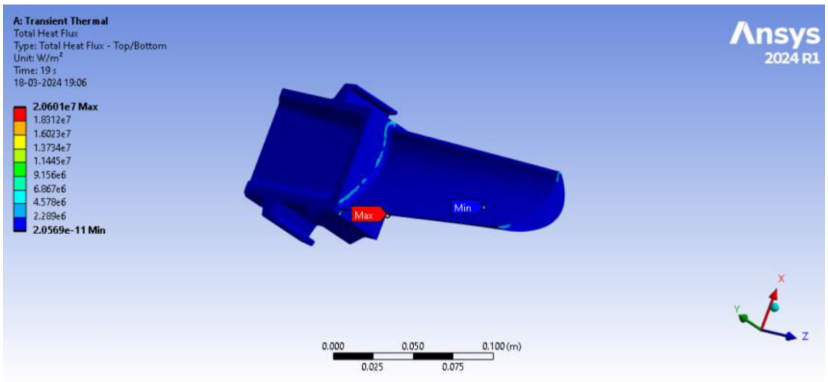


A: Transient Thermal
Transient Thermal
Time: 1. s
18-03-2024 19:01

A Temperature: 1000. °C
B Convection: 600. °C, 9.82e+005 W/m²·°C

Fig 13: Properties Assignment

Transient thermal analysis of Inconel 718 gas turbine blade at 1000^{0}C



A: Transient Thermal
Total Heat Flux
Type: Total Heat Flux - Top/Bottom
Unit: W/m²
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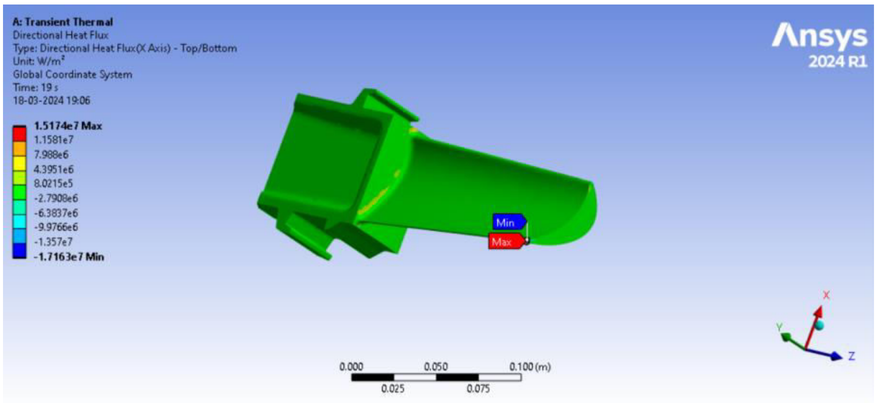
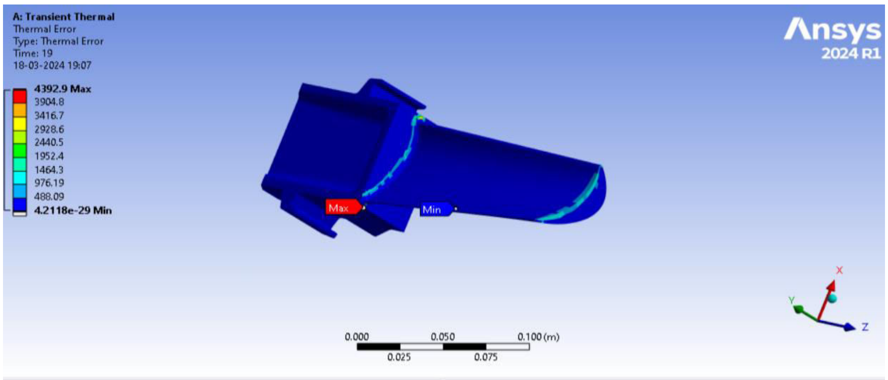
Fig 14: Total heat flux



A: Transient Thermal
Directional Heat Flux
Type: Directional Heat Flux(X Axis) - Top/Bottom
Unit: W/m²
Global Coordinate System
Time: 19 s
18-03-2024 19:06

Fig 15: Directional heat flux



A: Transient Thermal
Thermal Error
Type: Thermal Error
Time: 19
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Fig 16: Thermal error

Transient thermal analysis of Inconel 718 gas turbine blade at 1100^{0}C

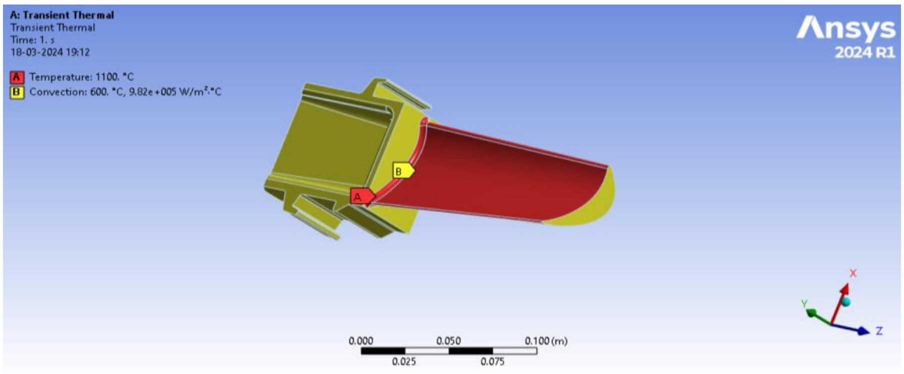


Fig 17: Properties Assignment

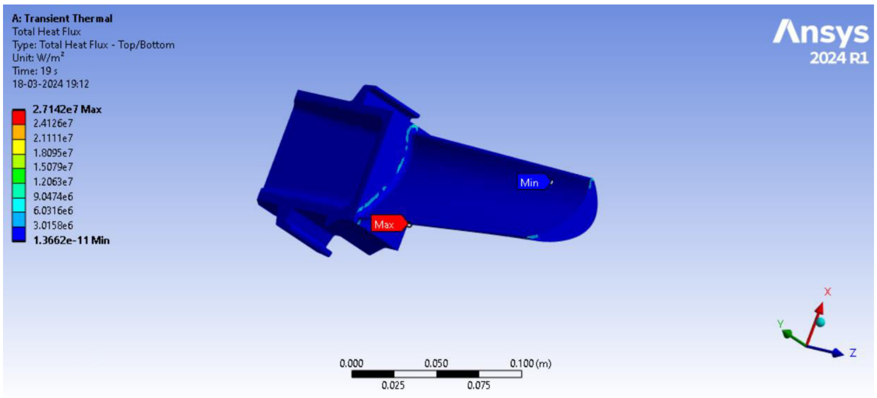


Fig 18: Total heat flux

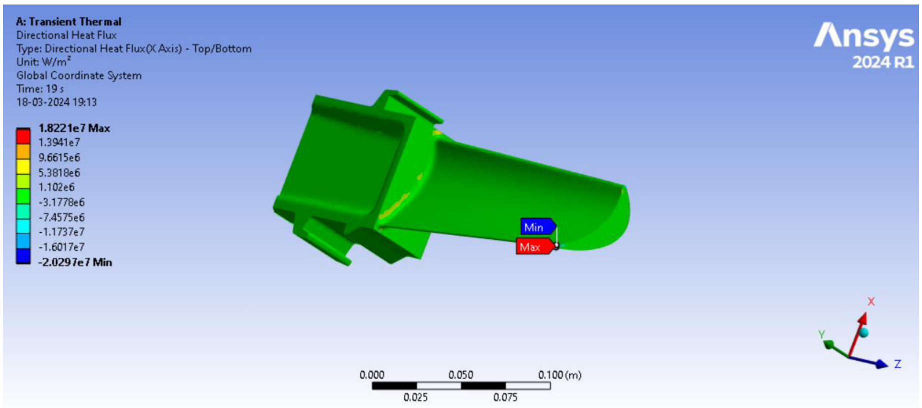


Fig 19: Directional heat flux

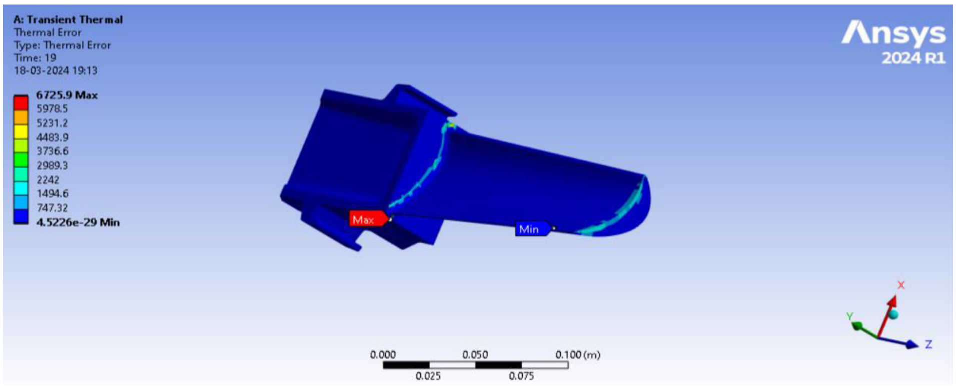


Fig 20: Thermal error

Transient thermal analysis of Titanium -T6 gas Turbine blade at 1000^{0}C

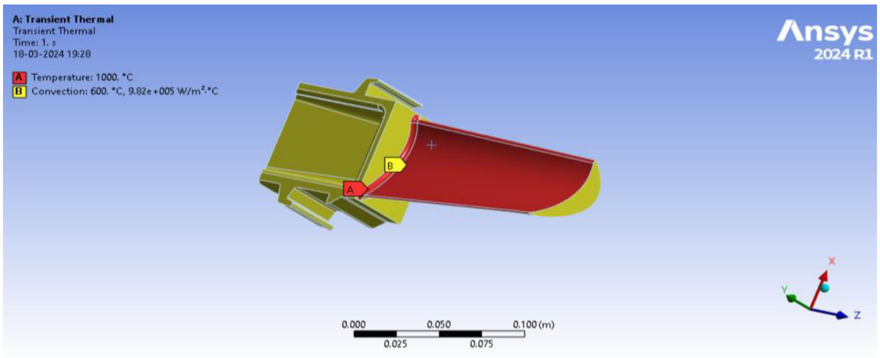


Fig 21: Properties assignment

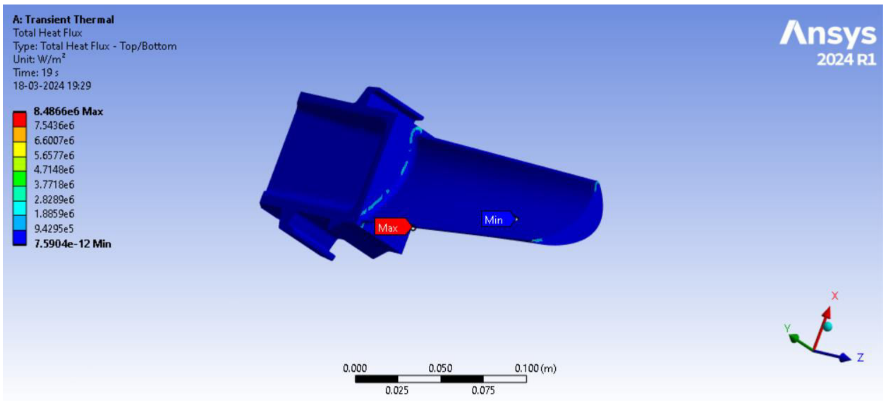


Fig 22: Total heat flux

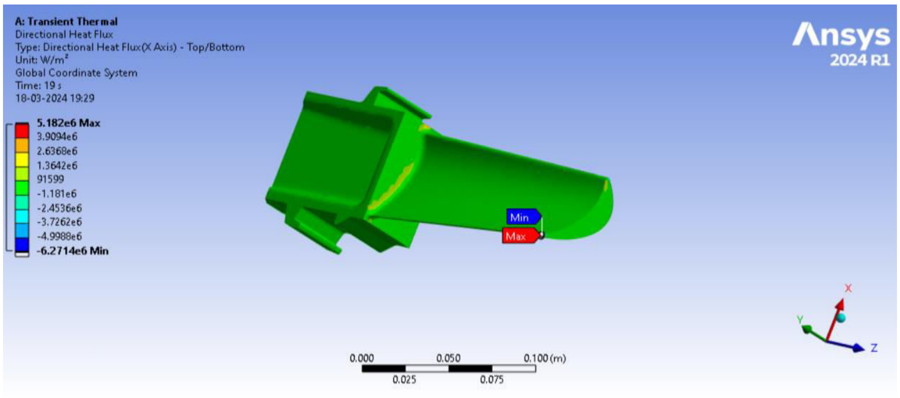


Fig 23: Directional heat flux

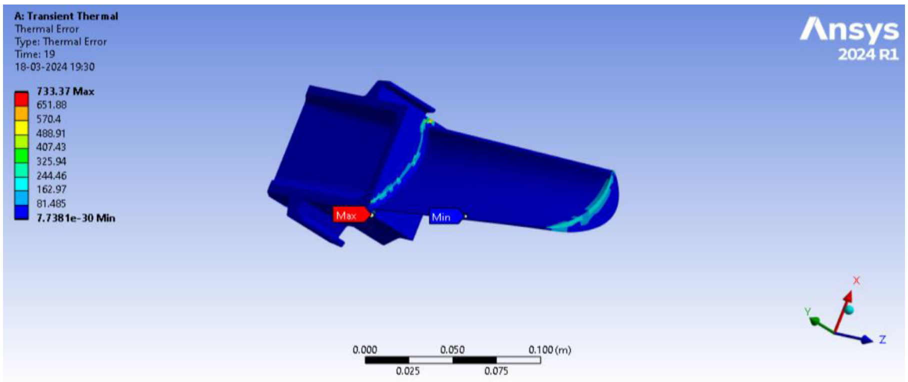
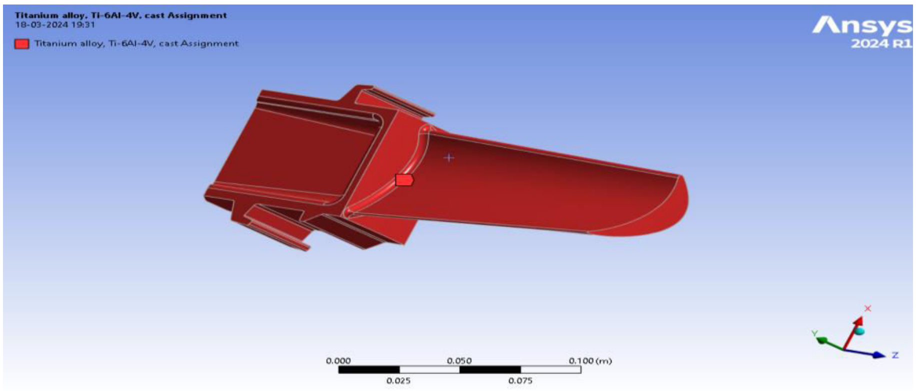


Fig 24: Thermal error

Transient thermal analysis of Titanium -T6 gas Turbine blade at 1100^{0}C



Titanium alloy, Ti-6Al-4V, cast Assignment
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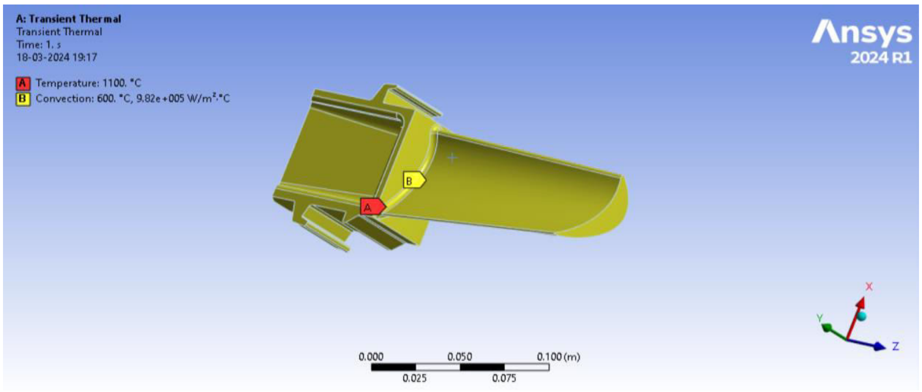
🟥 Titanium alloy, Ti-6Al-4V, cast Assignment

Fig 25: Material assignment



A: Transient Thermal
Transient Thermal
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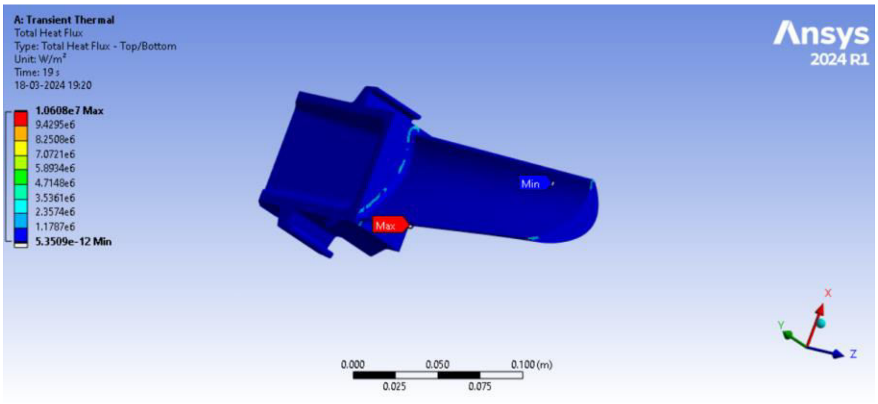
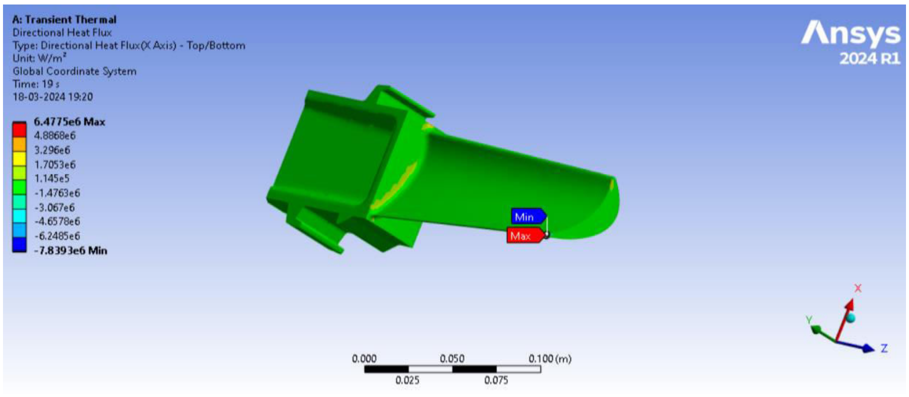
A Temperature: 1100. °C
B Convection: 600. °C, 9.82e+005 W/m²·°C

Fig 26: Properties assignment



A: Transient Thermal
Total Heat Flux
Type: Total Heat Flux - Top/Bottom
Unit: W/m²
Time: 19 s
18-03-2024 19:20

Fig 27: Total heat flux



A: Transient Thermal
Directional Heat Flux
Type: Directional Heat Flux(X Axis) - Top/Bottom
Unit: W/m²
Global Coordinate System
Time: 19 s
18-03-2024 19:20

Fig 28: Directional heat flux

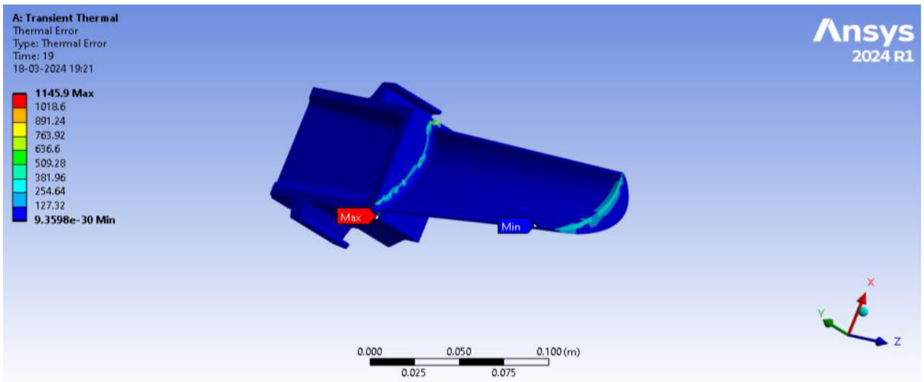


Fig 29: Thermal error

Transient thermal analysis of SS316 gas turbine blade at 1000^{0}C

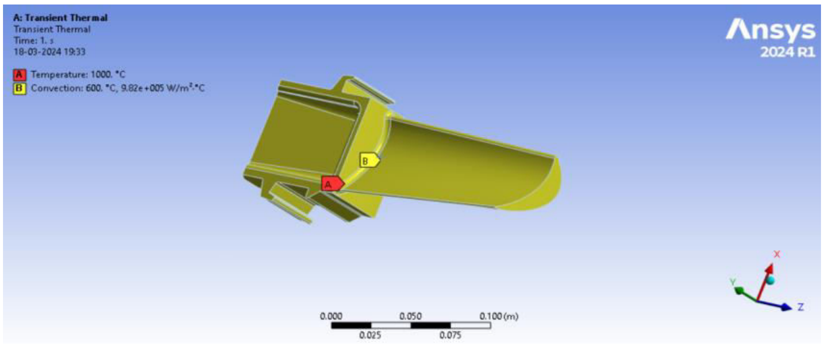


Fig 30: Properties assignment

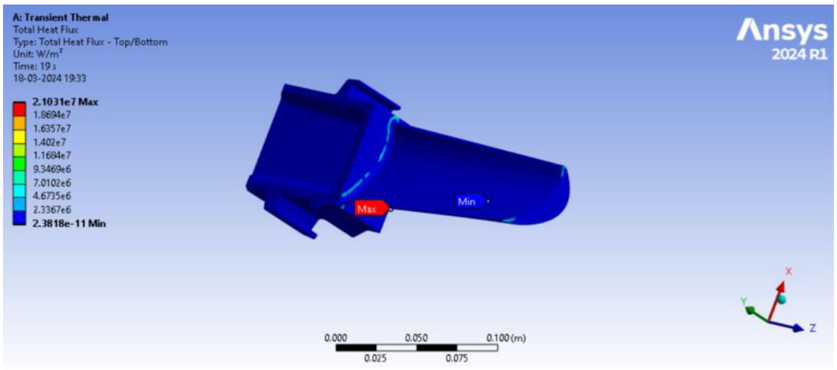


Fig 31: Total heat flux

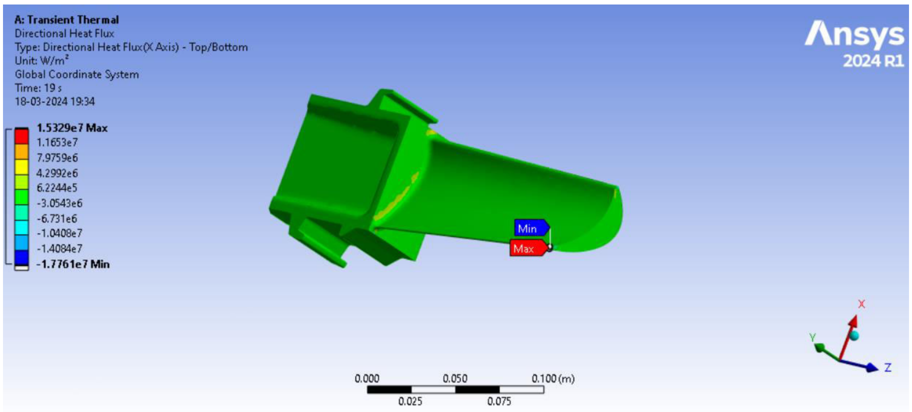


Fig 32: Directional heat flux

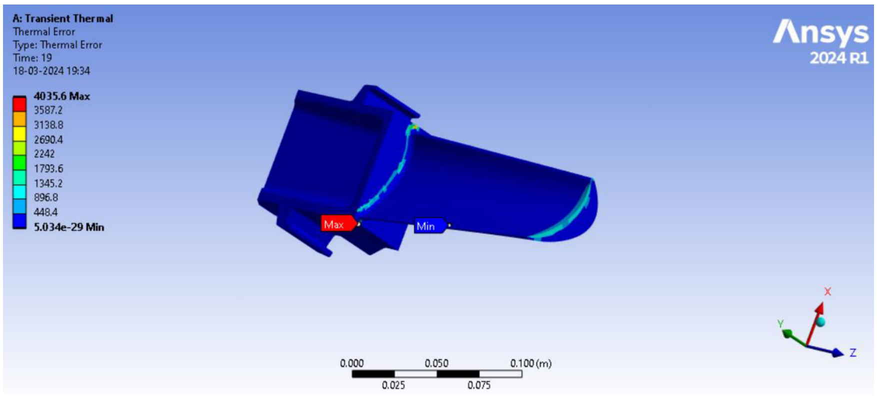


Fig 33: Thermal error

Transient thermal analysis of SS316 gas turbine blade at 1100^0C

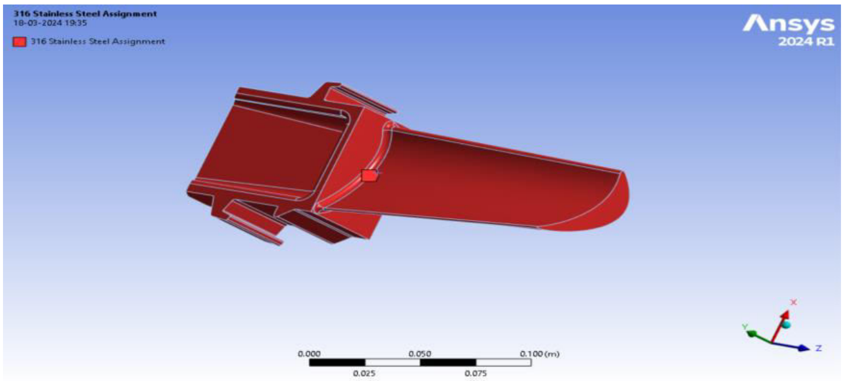


Fig 34: Material Assignment

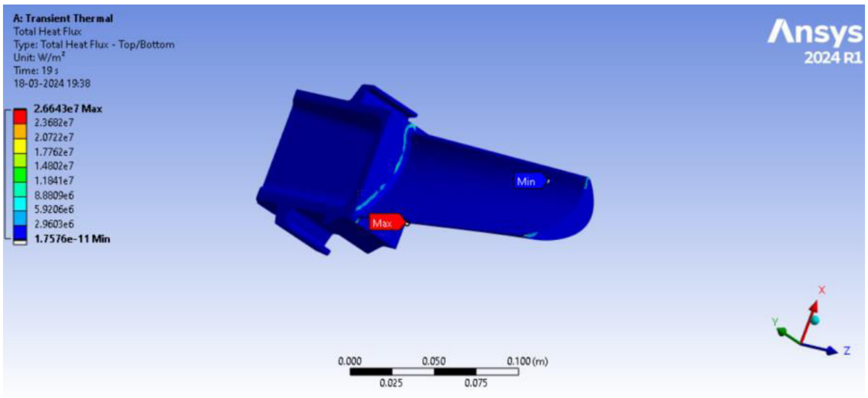


Fig 35: Total heat flux

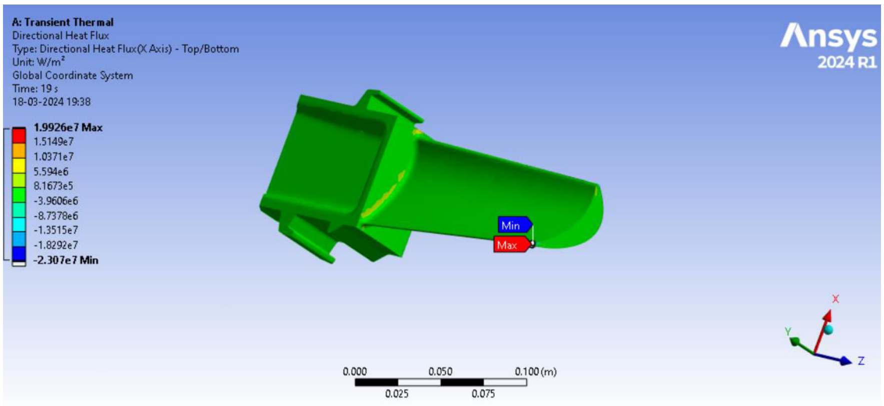


Fig 36: Directional heat flux

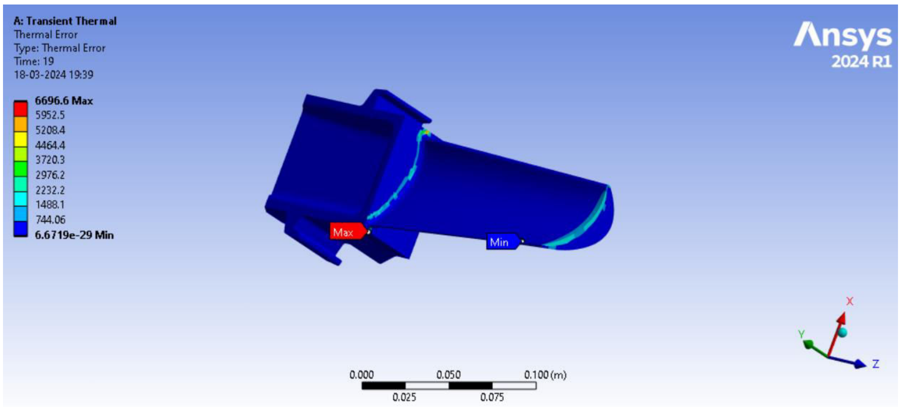


Fig 37: Thermal error

Table 1: Transient thermal analysis of gas turbine blade total heat flux(w/mm^2) using different materials

S. No	**Materials**	**Temperature At 1000^0C**	**Temperature At 1100^0C**
1	Inconel 718	2.06	2.71
2	Titanium -T6	8.48	1.06
3	SS316	2.10	2.66

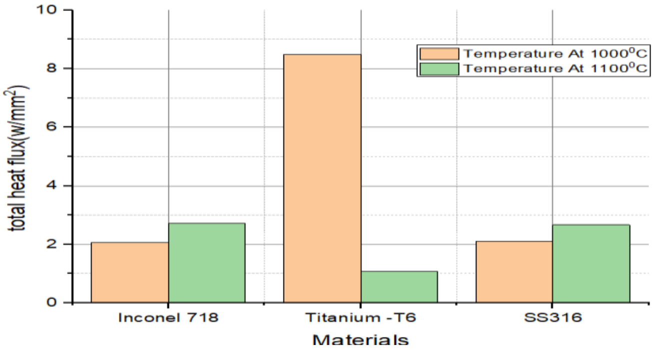


Fig 38: Validation of gas turbine blade using different materials at total heat flux(w/mm^2)

Table 2: Transient thermal analysis of gas turbine blade using different materials at Directional heat flux (w/mm^2)

S. No	**Materials**	**Temperature At 1000^0C**	**Temperature At 1100^0C**
1	Inconel 718	1.51	1.822
2	Titanium -T6	5.18	6.477
3	SS316	1.53	1.99

- The dataset represents temperatures of three different materials, namely Inconel 718, Titanium-T6, and SS316, at 10,000C and 11,000C. The temperatures vary between materials and temperatures, with Titanium-T6 recording the highest in both cases.
- Inconel 718 and SS316 show similar behavior at both 10,000C and 11,000C, with temperatures being on the lower spectrum. This could indicate similar heat resistance capacities for these materials.
- Titanium-T6 exhibits significantly higher temperatures at both 10,000C and 11,000C compared to Inconel 718 and SS316. This suggests that Titanium-T6 may possess superior thermal properties.

- There is an overall increment in the temperatures from 10,000C to 11,000C for each material. This pattern indicates that the materials may allow for temperature escalations with increasing conditions.

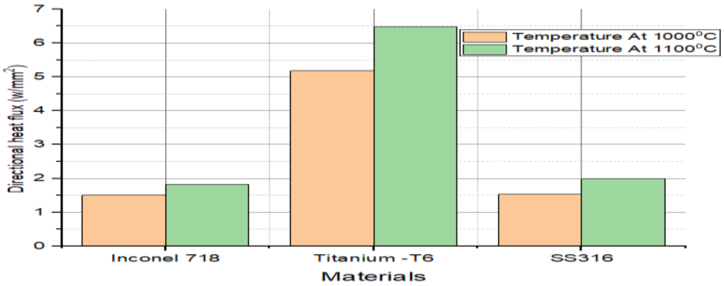


Fig 39: Validation of gas turbine blade using different materials at directional heat flux (w/mm^2)

- The average temperature for the material Inconel 718 is lowest at both 1000^0C and 1100^0C, hinting it may be more heat resistant than the others.
- The temperatures for Titanium -T6 are the highest among all materials, suggesting it might handle heat less efficiently.
- The range of temperatures for 1100^0C (4.655) is higher than that of 1000^0C (3.67), implying more variation in material performance at higher temperatures.

Table 3: Transient thermal analysis of gas turbine blade Thermal error using different materials

S. No	**Materials**	**Temperature At 1000^0C**	**Temperature At 1100^0C**
1	Inconel 718	4392.9	6725.9
2	Titanium -T6	733.37	1145.9
3	SS316	4035.6	6696.9

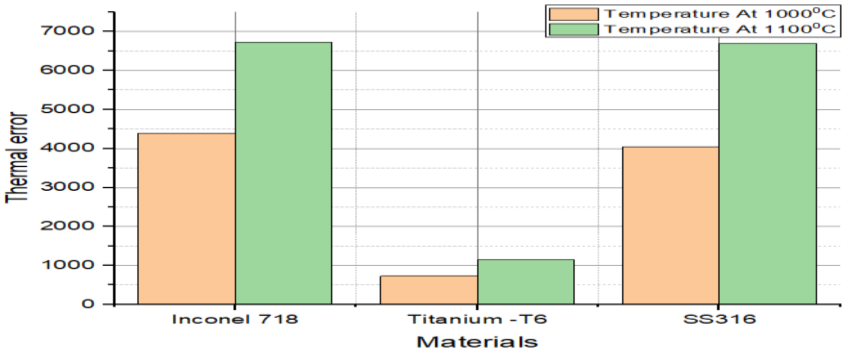


Fig 40: Validation of gas turbine blade using different materials at thermal error

- The maximum temperature was achieved with Inconel 718 at 1100^0C, edging towards a fiery 6725.9, hinting at its superior heat tolerance.
- Among analysed materials, Titanium T-6 showed the lowest average temperature at both 1000^0C and 1100^0C, indicating it may not be suitable for high-temperature applications
- The temperature variance is greater at 1100^0C. This may suggest that different materials perform quite diversely under extreme heat stresses

Conclusions:

Turbine blades are one of the most important components of a gas turbine engine. Blade materials under environmental conditions are hampered by high temperatures, high pressures, and large centrifugal forces. The total heat flux variation in steady state is very less, but in transient thermal at pressure 3000 Pa, the heat flux is increasing rapidly with increasing temperature as shown in graph Finally In the simulation, it is observed that minor damage is occurrence up to Inconel 718. But at the same time, it will have higher value of elastic strength, higher values of yield strength which will induce lesser value of the stress on the blade It is also seen Inconel 718 have good material properties at higher temperature has compare to that of the titanium T6 and SS316.By observing simulation results, the coating is needed to be increased without affecting profile geometry is suggestable for future endorsement. A variant model analysis has been done by varying the input pressure of the hot gas; most of the temperature contours founded at the leaving edge and heat fluxes are observed in concave profiles. Model analysis stating that the results of blade analysis may vary with pressure conditions with vector directions, it can analyze as a future improvement. A satisfactory edge with the limitation of this research to deposit thickness and process parameters of coating can be helpful for further studies.

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