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FLOW ANALYSIS OF GAS TURBINE BLADE WITH THERMAL BARRIER COATING

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ABSTRACT

The hot gases coming from the combustion chamber of gas turbine engine is about 1800K to 2000K and it will cause the oxidation and hot corrosion of turbine blades. Design of the coating thickness is a multi objective optimization problem facing by the manufacturing industries to withstand the blade erosion, corrosion and thermal stress to improve the blade efficiency. Thermal barrier coatings (TBCs) are widely applied in protecting metallic components, which are used in aero- and land-based gas turbines. The aim of this study is to find the suitable materials for thermal barrier coating of turbine blades and to analyse the thermal protection provided by TBC while compare with the temperature resistance of turbine blade material. CFM 56-7B series turbofan engine(B737) is considered for the study ,which consists of a four stage low pressure turbine and a single stage high pressure turbine. The **ANSYS WORKBENCH** is used to do the static structural & steady state thermal analysis of the gas turbine blades and **CATIA** is used to develop the model of the turbine blade.

Keywords*: Thermal barrier coating, Turbine blade cooling, Ceramic materials, Intermetallic compounds, high temperature hot gas.*

1. INTRODUCTION

The high temperature hot gases coming after combustion can damage the turbine blades and will cause the decrement of its life & efficiency. So we have to reduce the thermal stress which affects the turbine blade to a great extend. Gas turbine engines may be affected in a number of ways, including: increased deterioration of seals and bearings, increased operation under low load conditions giving rise to the risk of blade flutter and fatigue damage, increasing amounts of fatigue damage due to more frequent starts, load fluctuations etc. For this purpose many researches are going on about the turbine blade materials and they have developed the thermal barrier coatings for turbine blades . Researches shows that the TBC provides protection against the oxidation and hot corrosion from high temperature gases. Some of the benefits of thermal barrier coating are: reduction of maintenance costs, increase of the working temperature, reduction of thermal loads, resistance increase to erosion and corrosion and reduction of the high temperature oxidation. TBC are highly advanced materials applied to metallic surfaces, which operating at elevated temperatures and can allow higher operating temperatures & limits the thermal exposure of structural components and thus extends the parts life. In advanced aero engines , thermal barrier coating technology is listed as one of the three key technologies for advanced aero-engine turbine blades with high temperature structural materials and high efficiency air cooling. It utilizes ceramic materials with high temperature resistance and low thermal conductivity to be combined with metal ,which can effectively reduced the surface temperature of the metal in a high temperature environment, thereby greatly extending the working life of metal parts. This paper is the computational study of turbine blade with different TBC coating materials.

1.1 CFM 56 7-B SERIES TURBOFAN ENGINES

The number of turbine stages varies in different types of engines, with high-bypass-ratio engines tending to have the most turbine stages. The number of turbine stages can have a great effect on how the turbine blades are designed for each stage. CFM 56-7B engine has twin spool compressor and turbine. A three stage low pressure compressor is driven by a four stage low pressure turbine & a nine stage high pressure compressor is driven by a single stage high pressure turbine. HPT is provided by a thermal barrier coating (ceramic coating) due to the high temperature gases formed after combustion. The blade material is the alloy of titanium and ceramic coating is applied to the blades as TBC. The turbine blade configuration of these type of engine is dove tail design, the blade head is inserted into the slot of the hub. Each dovetail includes at least a pair of blade tangs including blade relief faces . The dovetail assembly also includes a rotor disk including a plurality of dovetail slots , each sized to receive a dovetail.

2. METHODOLOGY

The model of gas turbine blade is generated in the CATIA and analysis is done in ANSYS WORKBENCH . The meshing can be done by default mode with 2mm to 22mm sizing in ANSYS workbench. The mesh size 15 mm for blade without coating & 3mm for the coating surface is selected after the mesh study done with five design points. The convex surface of turbine blade is high pressure side and there we will apply a force of 980N and the bottom face is a fixed one. It shows the support between the blade root & slot of the hub. The mode of heat transfer in the gas turbine is forced convection and the heat transfer coefficient is 200W/(m2K). We know that the exhaust temperature coming after combustion ranges between 1200°C to 1500°C and the ambient temperature is taken as 1500°C. Deformation, stress & heat flux are the results got from the static structural analysis and steady state thermal analysis done in ANSYS workbench

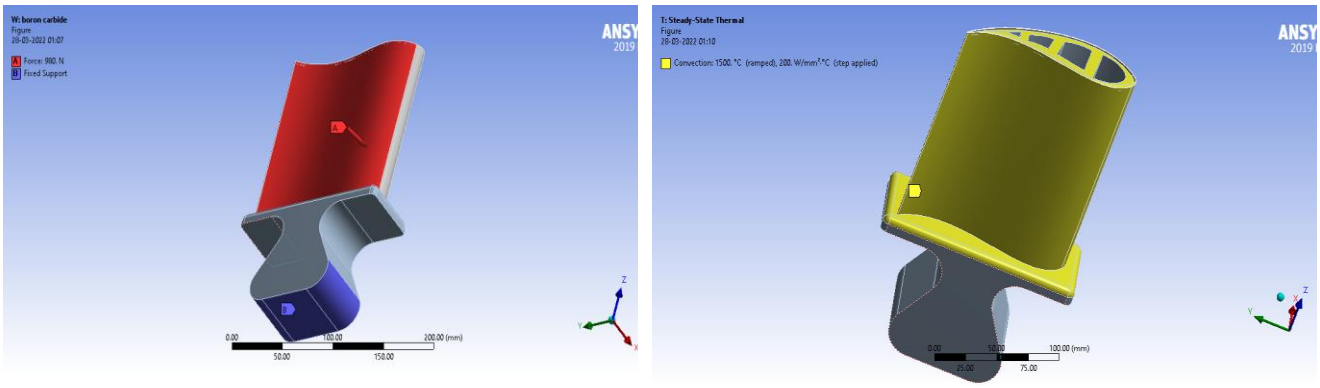


Fig 1 a)Force & Support **b) Forced convection in turbine blades**

2.1 TURBINE BLADE ANALYSIS WITHOUT THERMAL BARRIER COATING

Ti6Al4v & INCONEL 625 are the two materials selected as turbine blade materials, which are the alloys of Titanium and Nickel. These materials offers high temperature resistance , better structural strength and now a days these are the alloys chosen by the manufactures in the components which require protection from the excessive heat problems especially in aerospace and automobile industry. The thermal conductivity of Ti6Al4v and INCONEL 625 are 7.1 W/m-K and 9.8 W/m-K respectively.

2.2 TOTAL DEFORMATION AND DIRECTIONAL DEFORMATION

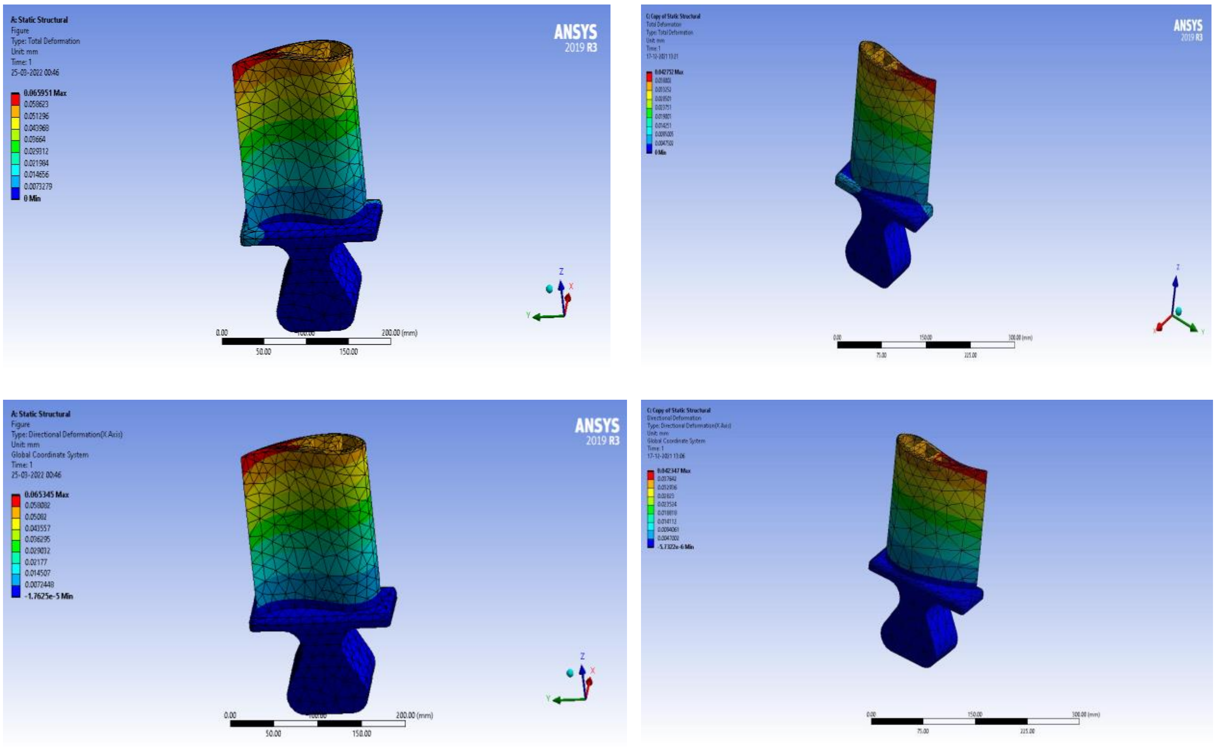


Fig 2 a) Ti6Al4v **b) INCONEL 625**

2.3 EQUIVALENT STRESS (VON-MISES STRESS) & MAJOR PRINCIPAL STRESS

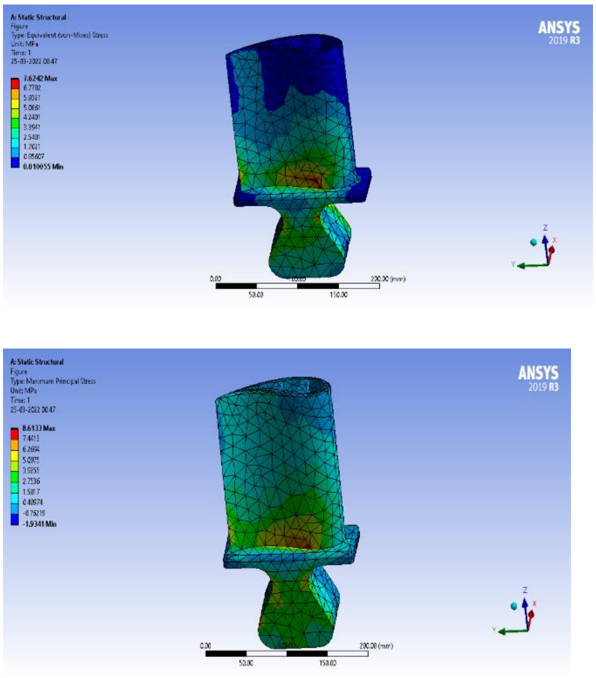
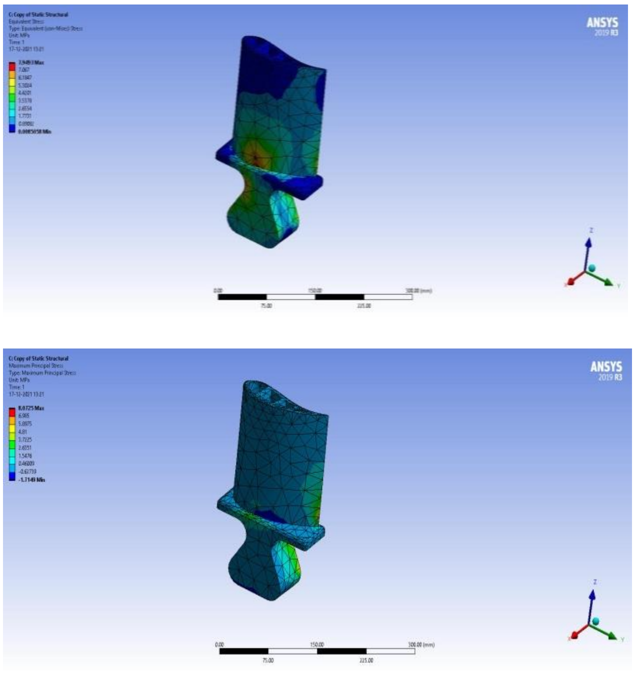


Fig 3 a) Ti6Al4v



b) INCONEL 625

2.4 TOTAL HEAT FLUX & DIRECTIONAL HEAT FLUX

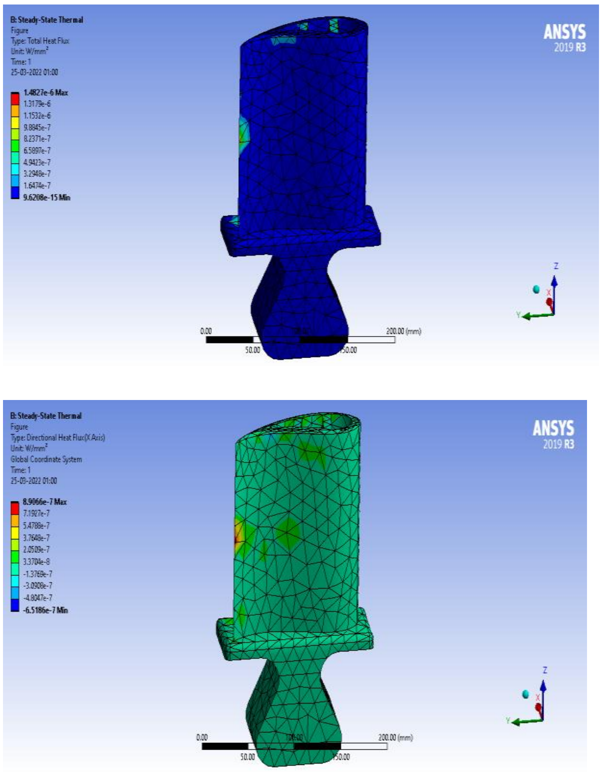
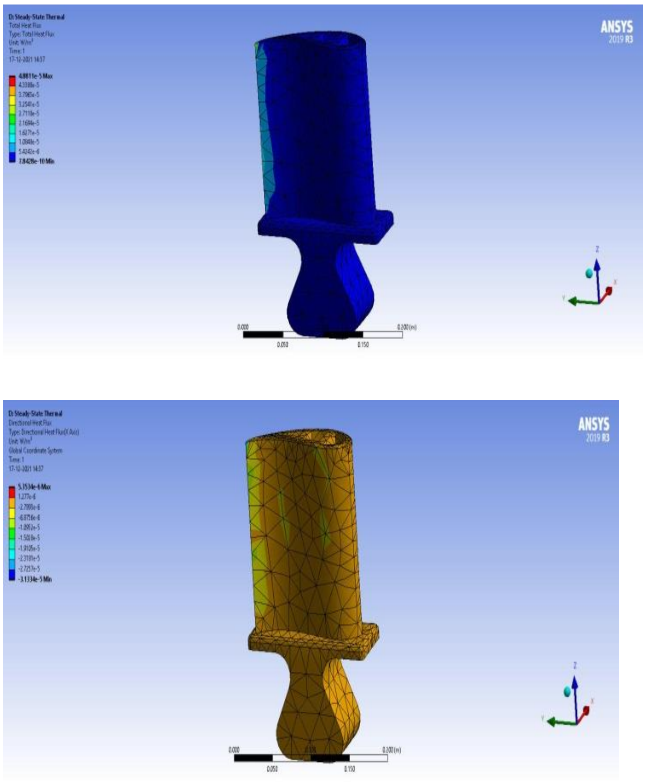


Fig 4 a) Ti6Al4v



b) INCONEL 625

2.5 DISADVANTAGES OF GENERAL BLADE COOLING AND BENEFITS OF COOLING WITH TBC

Blockage of blade cooling systems leading to turbine failure, damage to blade coatings, blockage of instruments and/or control bleed air posts, jamming of variable guide vanes and/or stator vanes. Due to this problems the cooling provide by thermal barrier coating is a big advantage. The thickness ranges from 0.4mm to 2mm can give the efficient temperature resistance and the thickness is provided to the blades by considering the material properties .In this case the thickness of TBC is taken as 0.5mm. Barrier coatings are typically applied on metals and ceramics when they are unable to withstand very harsh operating conditions. Many industrial processes occur at very high temperatures under the flow of harsh, corrosive gases. Due to this metals often can corrode, which can lead to catastrophic failure during operation.

2.6 BLADE ANALYSIS WITH THERMAL BARRIER COATING

The materials opted as TBC materials are zirconium oxide, zirconium silicate, silicon carbide and nickel aluminide , the blade materials are Ti6Al4v and INCONEL 625. Nickel aluminide is an intermetallic compound and others are ceramic coatings. Maximum allowable temperature of these materials ranges between 1650°C to 2000°C. So these can withstand high temperatures.

2.7 TOTAL DEFORMATION

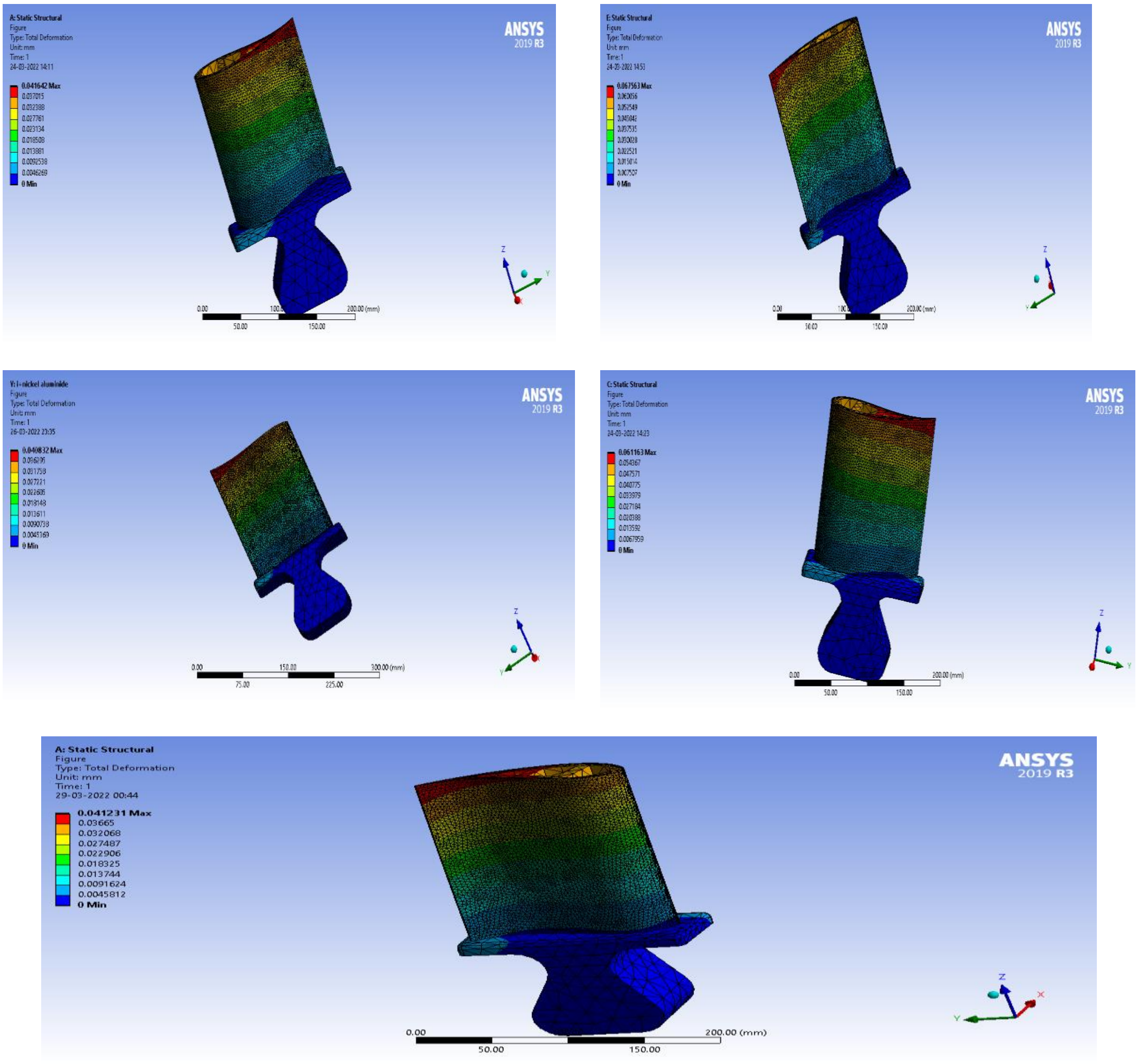


Fig 5 a) Inconel 625+ Zirconium oxide b) Ti6Al4v + Silicon carbide c) Inconel 625+Nickel Aluminide d) Ti6Al4v + Zirconium oxide e) Inconel 625+Zirconium silicate

2.8 DIRECTIONAL DEFORMATION

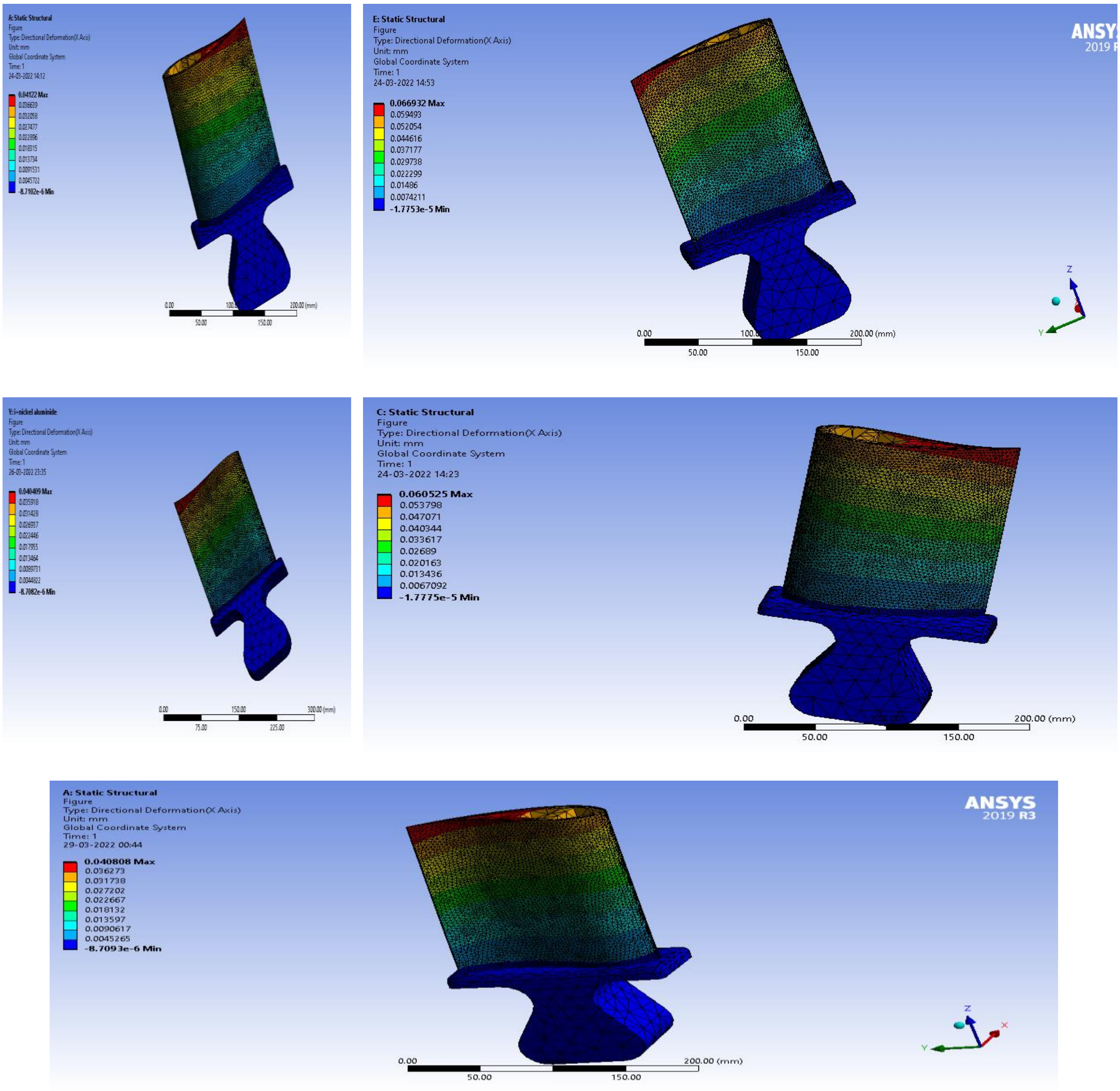


Fig 6 a) Inconel 625+ Zirconium oxide b) Ti6Al4v + Silicon carbide c) Inconel 625+Nickel Aluminide d) Ti6Al4v + Zirconium oxide e) Inconel 625+Zirconium silicate

2.9 EQUIVALENT STRESS (VON-MISES STRESS)

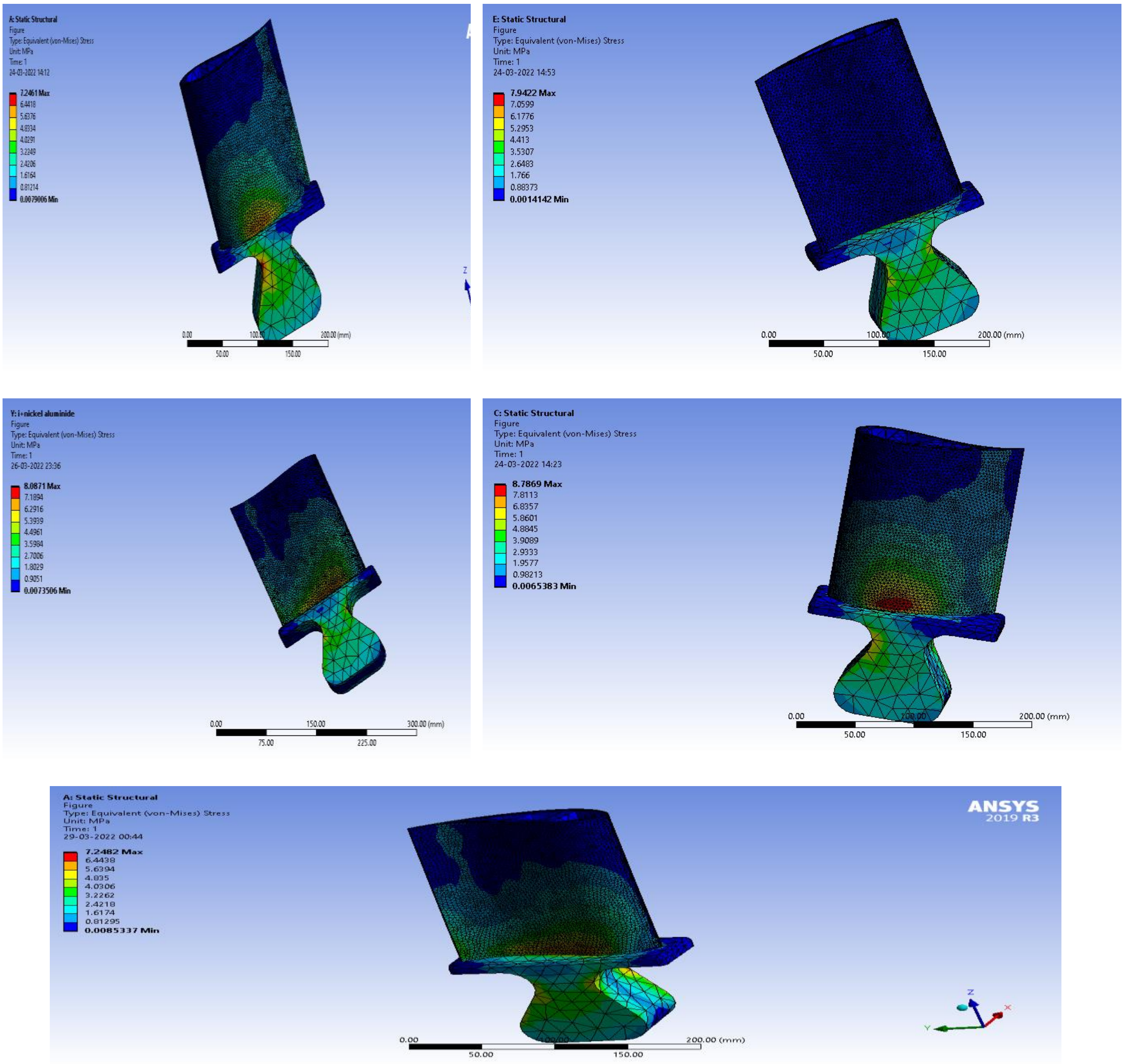


Fig 7 a) Inconel 625+ Zirconium oxide b) Ti6Al4v + Silicon carbide c) Inconel 625+Nickel Aluminide d) Ti6Al4v + Zirconium oxide e) Inconel 625+Zirconium silicate

2.10 MAJOR PRINCIPAL STRESS

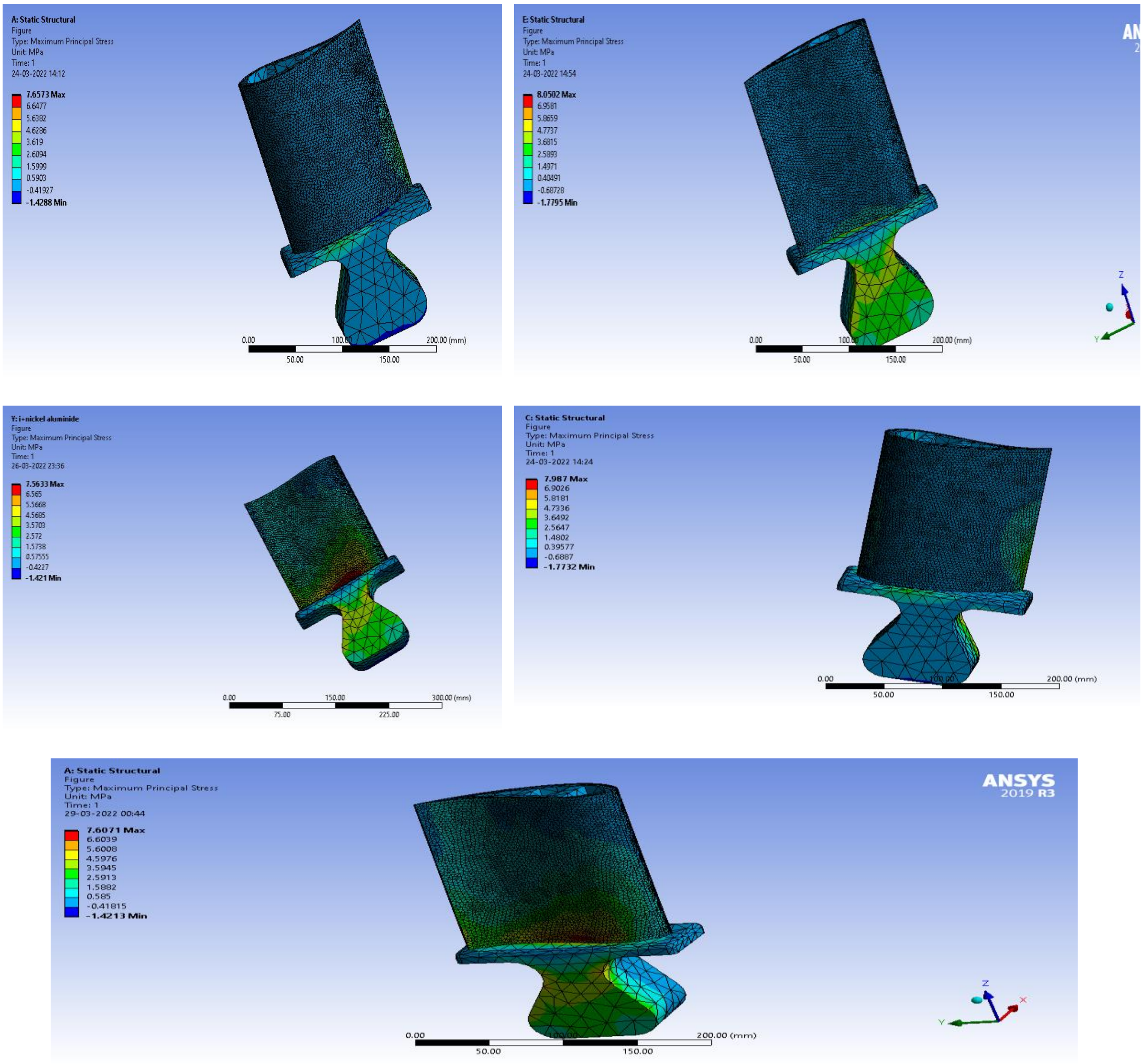


Fig 8 a) Inconel 625+ Zirconium oxide b) Ti6Al4v + Silicon carbide c) Inconel 625+Nickel Aluminide d) Ti6Al4v + Zirconium oxide e) Inconel 625+Zirconium silicate

2.11 TOTAL HEAT FLUX

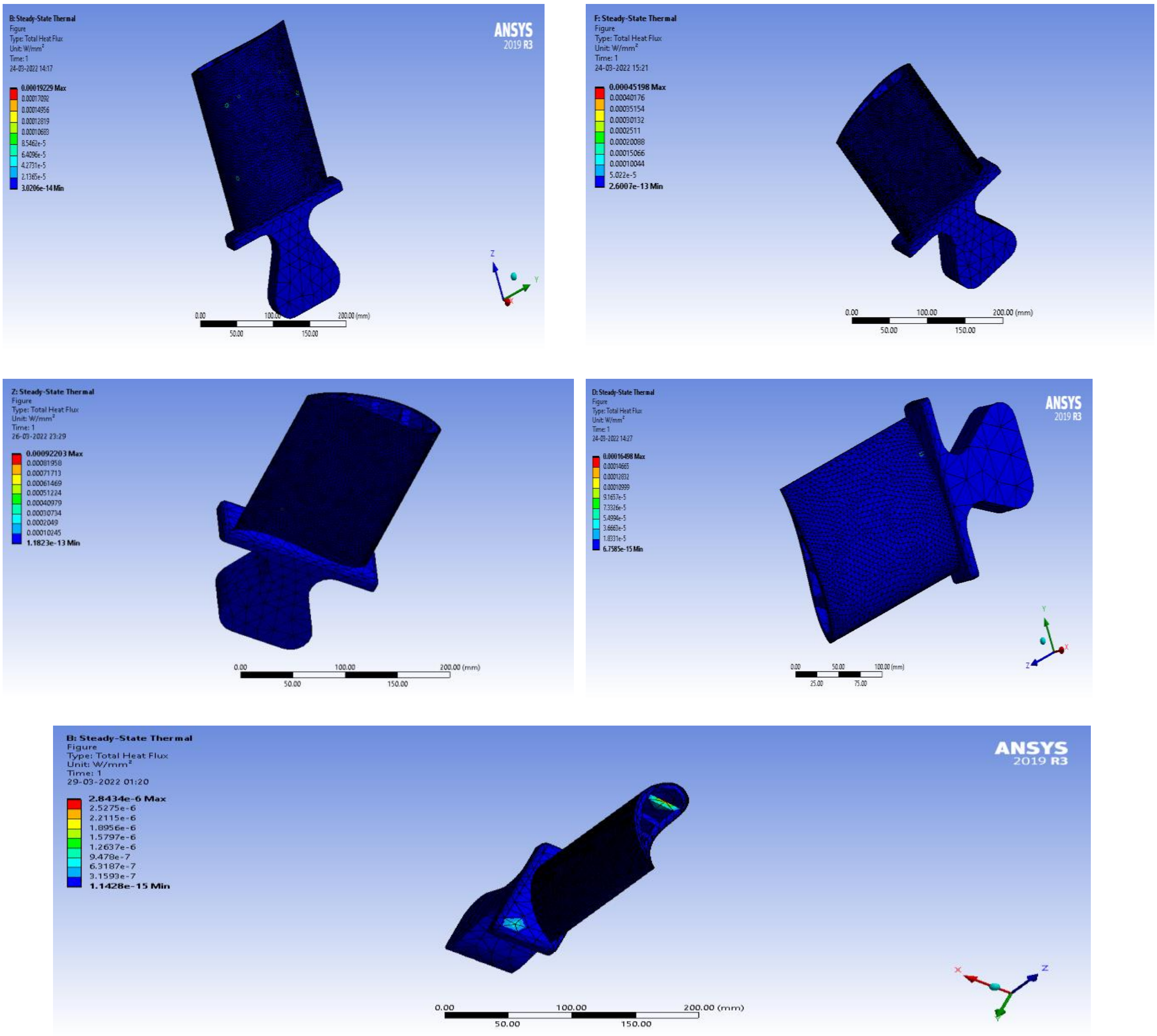
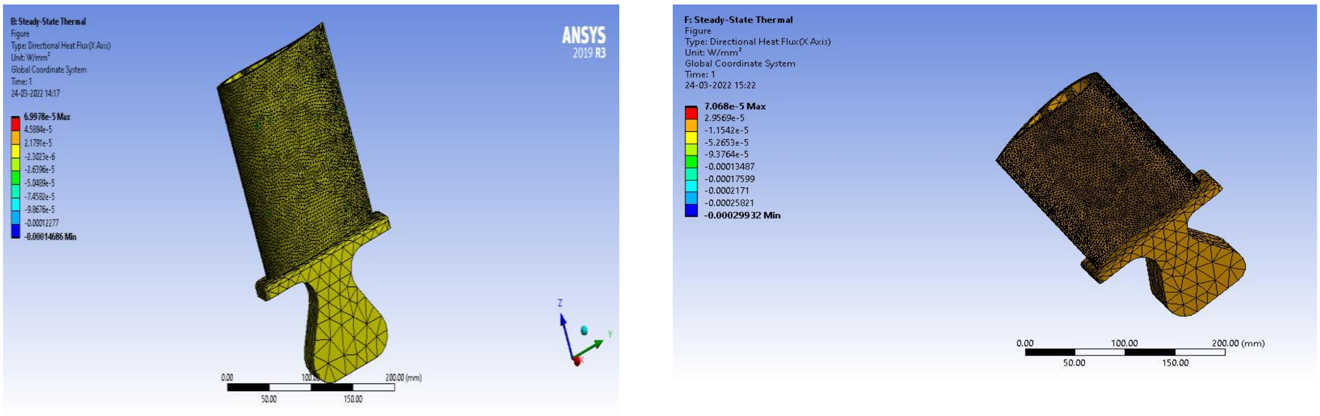


Fig 9 a) Inconel 625+ Zirconium oxide b) Ti6Al4v + Silicon carbide c) Inconel 625+Nickel Aluminide d) Ti6Al4v + Zirconium oxide e) Inconel 625+Zirconium silicate

2.12 DIRECTIONAL HEAT FLUX



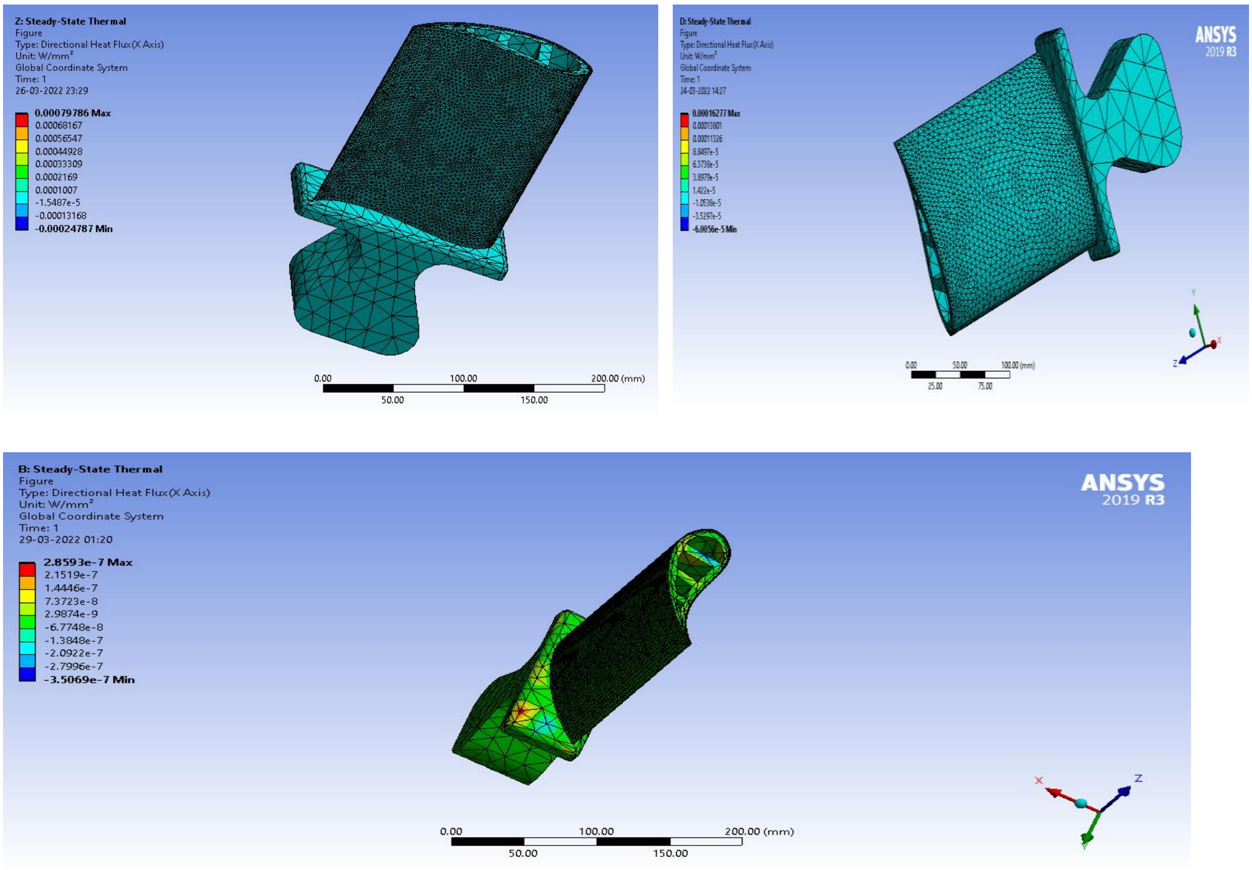


Fig 10 a) Inconel 625+ Zirconium oxide b) Ti6Al4v + Silicon carbide c) Inconel 625+Nickel Aluminide d) Ti6Al4v + Zirconium oxide e) Inconel 625+Zirconium silicate

3. RESULTS

3.1 STATIC STRUCTURAL & STEADY STATE THERMAL ANALYSIS OF TURBINE BLADE WITHOUT COATING

Table 1 Results of blade without coating

Materials	Total deformation (mm)	Directional deformation (mm)	Equivalent Stress(MPa)	Maximum Principal Stress(MPa)	Total heat flux(w/mm2)	Directional heat flux (w/mm2)
Ti6Al4v	0.06591	0.065345	7.6242	8.6133	1.4827e-6	8.9066e-7
Inconel 625	0.04275	0.04234	7.949	8.0725	4.8811e-5	5.3534e-6

3.2 STATIC STRUCTURAL & STEADY STATE THERMAL ANALYSIS OF TURBINE BLADE WITH COATING

Table 2 Results of blade with coating

Materials	Total deformation (mm)	Directional Deformation (mm)	Equivalent Stress (MPa)	Maximum Principal Stress(MPa)	Total heat flux(w/mm2)	Directional heat flux (w/mm2)
Ti6Al4v + zirconium oxide[TBC]	0.061163	0.060525	8.7869	7.987	0.00016498	0.00016277
Inconel 625 +Zirconium silicate[TBC]	0.041231	0.040808	7.2482	7.6071	2.8434e-6	2.8593e-7
Ti6Al4v + silicon carbide[TBC]	0.067563	0.066932	7.9422	8.0502	0.00045198	7.068e-5
Inconel 625 + zirconium oxide [TBC]	0.041642	0.04122	7.2461	7.6573	0.00019229	6.9978e-5
Inconel 625 + Nickel aluminide[TBC]	0.040832	0.040409	8.0871	7.5633	0.00092203	0.00079786

4. CONCLUSION

While analysing the turbine blade with and without coating it is strictly concluded that the structural strength and thermal resistance of the turbine blade will increase by providing the coating. The usage of ceramic & intermetallic coating materials as the TBC's shows the strong reduction in deformation, stress and heat fluxes induced in the blades at high exhaust gas temperature. We know that the hot gas from the combustion chamber has temperature of about 1500°C and it is very difficult to withstand that temperature up to a long time by the turbine blade is a critical task. . The blade materials taken for analysis are **Ti6Al4v & Inconel 625** ,and have done the static structural and steady state thermal analysis . After evaluating its results the coating materials such as **Silicon carbide, Nickel aluminide, Zirconium oxide, Zirconium silicate** is added along with the blade materials such as Inconel 625& Ti6Al4v and did static structural & steady state thermal analysis. The results have proven that the application of coating materials reduced the deformation, stresses & heat fluxes forms in turbine blades. So from the conducted study it is concluded that the application of thermal barrier coatings can reduce the excess temperature problems and can increase the structural strength.

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