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Comparative CFD Analysis of Forced Convection Cooling of a Gas Turbine Blade of Different Materials with Several Staggered holes

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Abstract

For gas turbines, the energy of the fluid can be expressed in terms of the enthalpy change, which is almost directly related to the turbine temperature. The performance of the gas turbine can be improved by continuously improving the temperature and compression ratio. In this article, for the cooling of blades, making several radial holes has been suggested to pass high cooling air at high velocity along the span of blade. CFD analysis has been used to analyse the effect of heat transfer of a gas turbine with six different models which has 6,7,8,9,10,11,12 inline one row of holes and are further compared with each other. Three different materials has been considered and heat transfer in each material has been examined and then compared. After evaluation it has been concluded that the blade with 12 staggered holes in Titanium had the minimum temperature rise. All other performances were also best in Titanium comparative to other two materials.

Keywords: Gas turbine, staggered holes, CFD analysis.

1. Introduction

A machine called turbine is that which converts the rotational energy of a fluid pumped by a rotor into work or energy. The machine does this and generates electricity through conduction or electrical induction. For gas turbines, the energy of the fluid can be expressed in terms of the enthalpy change, which is almost directly related to the turbine temperature. The working fluid in the gas turbine is burnt fuel mixed with air. Most gas turbine engines have at least one compressor, combustion chamber and turbine. They are usually built as a unit and run entirely as generators; this is called an open circuit; remove the air from the air and release the combustion product and leave it where it is. Since the success of the cycle depends on the integration of all parts, not only the turbine but also the internal generator needs to be considered.

2. Problem Identification and Methodology

The efficiency and power output of a gas turbine plant depend on the maximum temperature reached in the cycle. Advanced gas turbine engines operate at high temperatures (1200-1500°C) to maximize thermal efficiency and power output. As the oil temperature increases, the heat transfer to the blade will increase and this will cause thermal failure of the blade. Film cooling is one of the process used to reduce temperature of blades. Cold film is formed by blowing cold air onto the teeth through small holes in the teeth. This air creates a thin layer of cooling air on the surface of the blade, protecting the blade from hot oil. In this study, CFD analysis was used to analyse the temperature change of a gas turbine with a 6 to 13 row hole structure and a comparison was made for three different materials. Estimation is done with CFD software using FLUENT. The following steps are followed to carry out the work-

1. Firstly the CAD model of turbine blade has been created.
2. Afterwards three suitable material were selected for the designing.
3. Ansys Fluent was used for CFD analysis to get the results.
4. On the basis of the analysed result graphs to be plotted for comparison.
5. Validating the results.

3. Dimensions of Turbine blade

Dimensions of Turbine blade taken for modeling purpose were-
Diameter of shaft, D = 1400 mm,
Speed of turbine in RPM, N = 3500 rpm,
Length of blade, L = 100 mm,
Diameter of cooling air passage, d = 2.5 mm

3.1 Geometric Modeling of blade

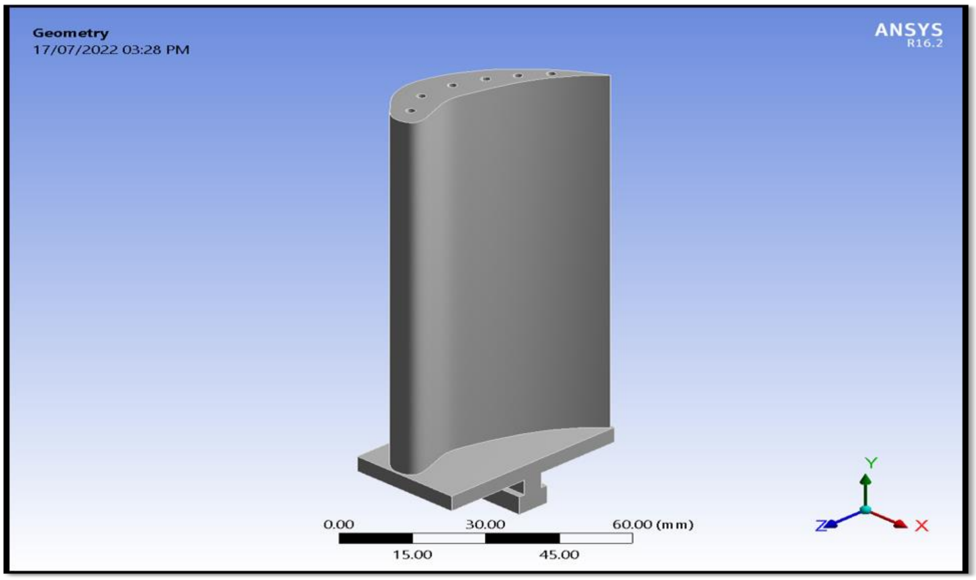

Fig 1 Geometry of a Gas Turbine blade model with 6 holes.

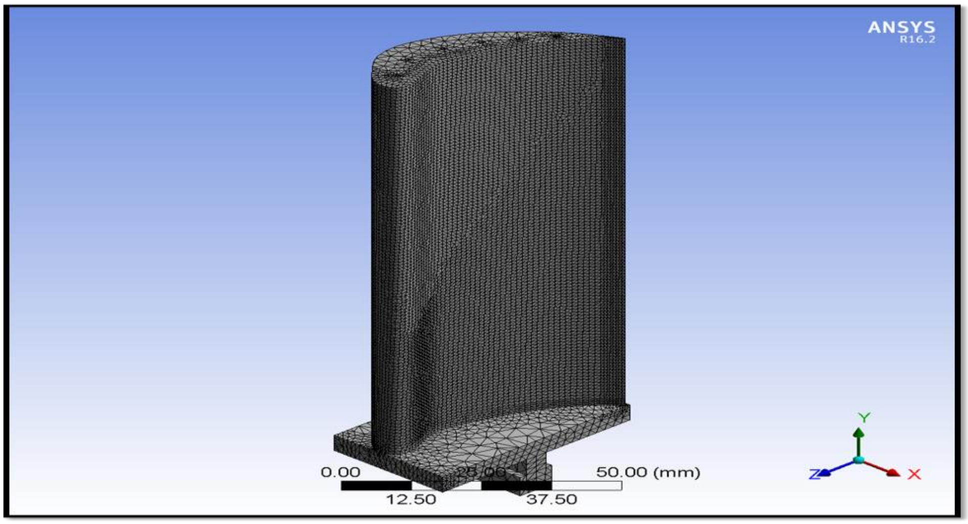

Fig 2 Meshing of model using Tetrahedron Element

4. Simulation and Analysis

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Analysis started primarily with the selection of materials. Different materials are considered and for different numbers of hole, the analysis has been done.

First Material: Copper; Annealed.

Table 1 Properties of copper

Poisson's Ratio	0.343
Heat of Fusion	204.8 J/g
Heat of Vaporization	5234 J/g
CTE, linear	20.2 µm/m-°C
Specific Heat Capacity	0.385 J/g-°C
Thermal Conductivity	10500 W/m-K
Melting Point	1083.2 - 1083.6 °C
Boiling Point	2562 °C

Second Material: Nickel, Ni

Table 2 Properties of Nickel

Poisson's Ratio	0.31
Heat of Fusion	305.6 J/g
Heat of Vaporization	5862 J/g
CTE, linear	13.1 µm/m-°C
Specific Heat Capacity	0.460 J/g-°C
Thermal Conductivity	60.7 W/m-K
Melting Point	1455 °C
Boiling Point	2913 °C

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Third Material: Titanium, Ti

Table 3 Properties of Nickel

Poisson's Ratio	0.34
Heat of Fusion	435.4 J/g
CTE, linear	8.90 µm/m-°C
Specific Heat Capacity	0.528 J/g-°C
Thermal Conductivity	17.0 W/m-K
Melting Point	1650 - 1670 °C
Boiling Point	3287 °C

The values obtained for temperature variations for the blade without and with 6 holes are shown in fig 3 and fig 4 respectively. Similarly, the effect of heat flux has also been analysed and is shown in fig 5 and 6 respectively for the surface of blade without hole and with 6 holes. A similar simulation has been carried out for other number of holes made in blade viz 7, 8, 9, 10, 11, 12 and 13 holes. The figure shown below is for the copper and for other materials the values obtained are depicted and compared through graphs.

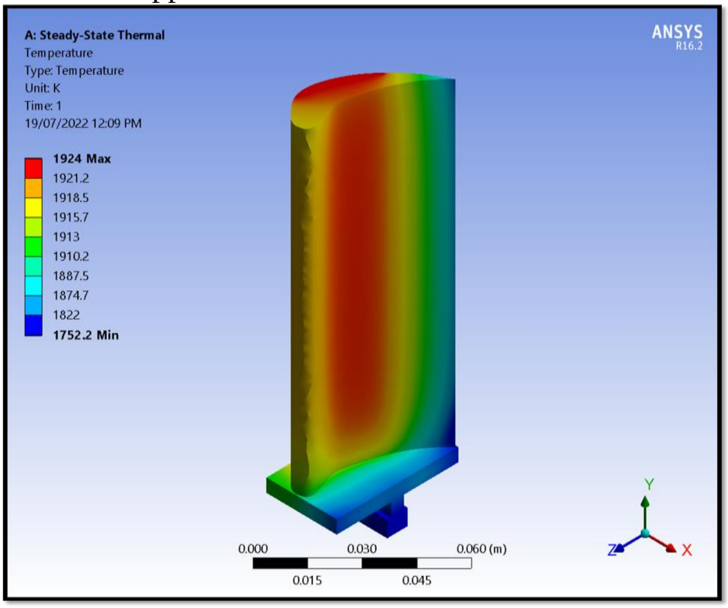

Fig 3 Temperature Variation over the surface of blade without holes

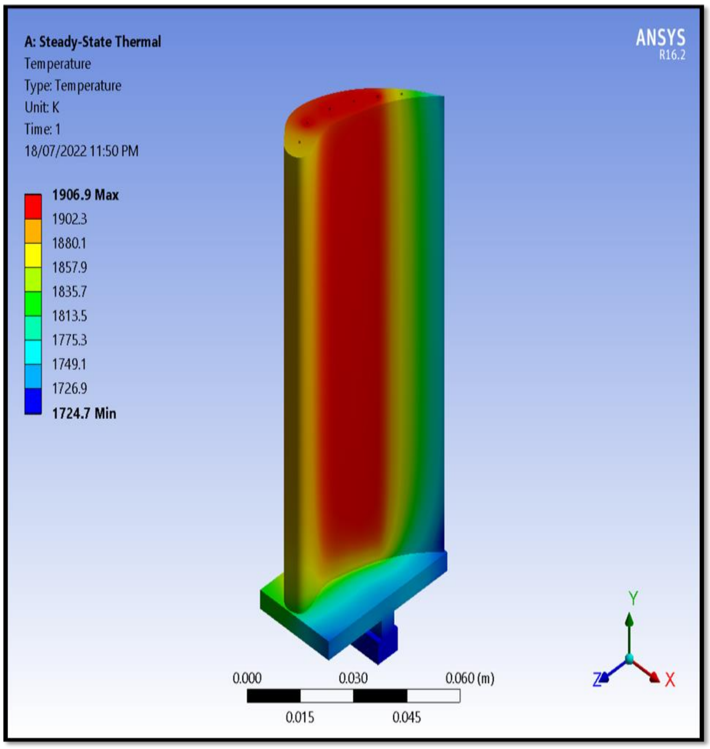

Fig 4 Temperature Variation over the surface of Turbine blade with 6 holes

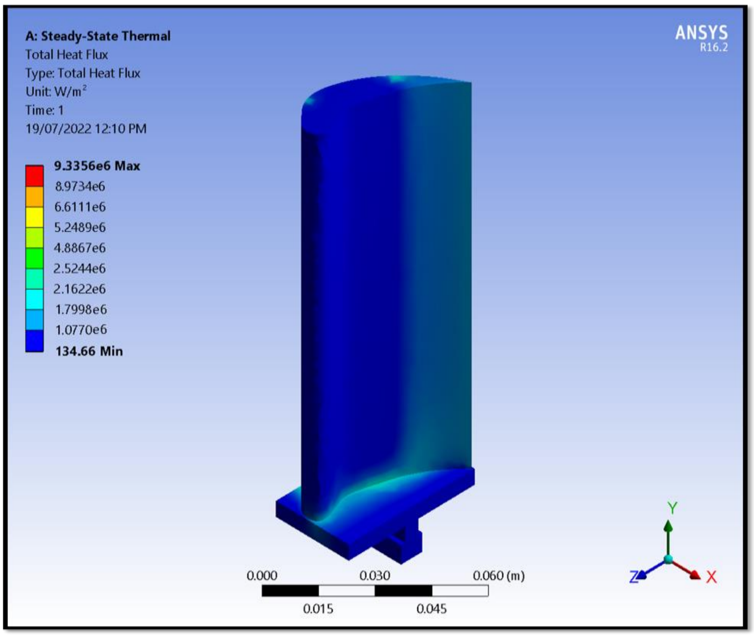

Fig 5 Total Heat Flux in Turbine blade without holes

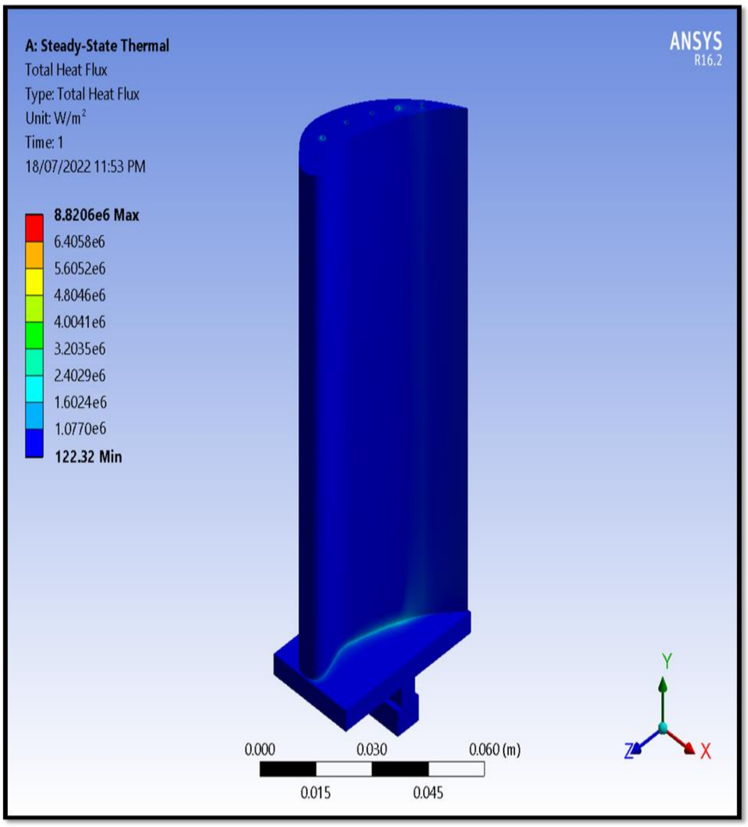

Fig 6 Total Heat Flux in Turbine blade with 6 holes.

5. Results

The results of various effect of temperature on varying numbers of holes are plotted and values tabulated for each materials. Further a comparison has been made to find out the suitability of materials.

Table 4 Comparison of temperature developed in turbine blade with and without hole

Material	Temperature (in °C)	
	without hole	with holes
Cu	1924	1906.9
Nk	1993.7	1988.1
Ti	2019.1	2008.6

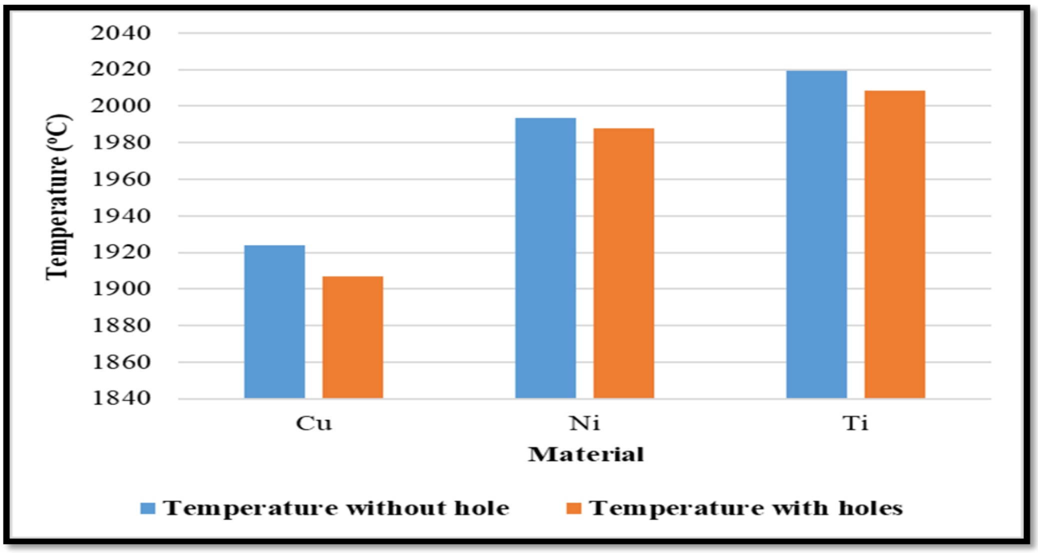

Fig 7 Variation of temperature development in turbine blade with and without hole consideration

Table 5 Comparison of heat flux development in turbine blade with and without hole

Material	Heat Flux (W/m^2)	
	without hole	with holes
Cu	9.34E+06	8.82E+06
Nk	4.68E+06	4.18E+06
Ti	1.53E+06	1.41E+06

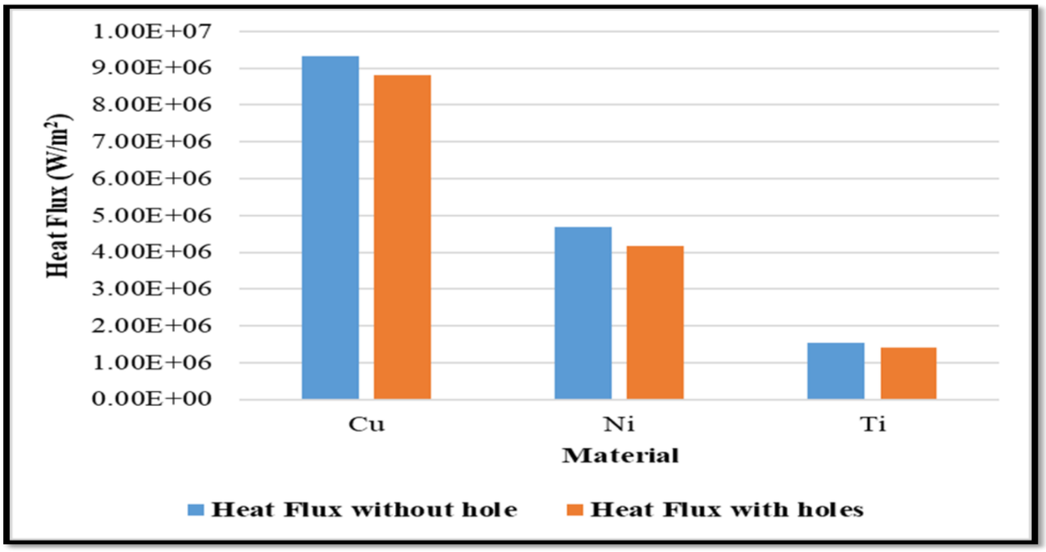

Fig 8 Variation of heat flux development in turbine blade with and without hole

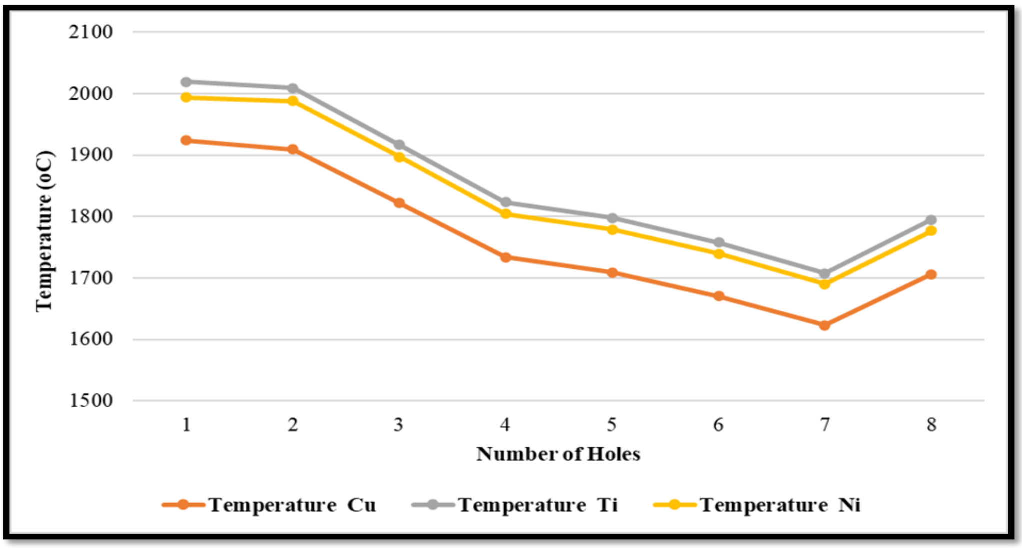

Fig 9 Variation of temperature development in turbine blade for different number of holes

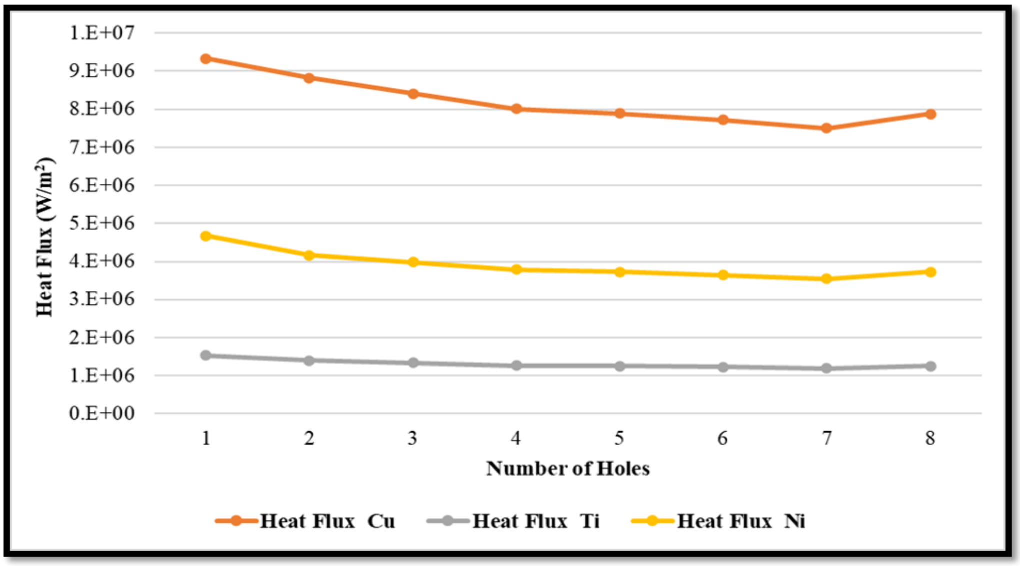

Fig 10 Variation of heat flux development in turbine blade for different number of hole

In figure number 9 and 10, the number of holes along x axis is shown from 1 to 8 which represents actual number of holes as from 6 to 13.

6. Conclusions

Gas turbine blade cooling of three different materials was investigated. Titanium (Ti) has been shown to have better thermal performance due to lower tooth temperature and less thermal stress. It has been found that giving cold air to the teeth can reduce the problem of heat and cold. By analysing models with different numbers of holes, it was determined that the 12 hole model was the most suitable.

6.1 Further scope of the work

Further the alloy of various materials can also be analysed and the results may be obtained for different holes.

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A Brief Author Biography

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Alok Sharma – has completed Bachelor of Mechanical Engineering from Government Engineering College, Raipur and M.E. in Production from Bhilai Institute of Technology, Durg. He has currently submitted his PhD thesis in CSVTU, Bhilai. He has a teaching experience of 23 years and is working as Head of Department & Associate Professor in SSTC, Bhilai. He also has an online teaching experience of

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Vikky Kumhar- has completed his BE in Mechanical Engineering from CSVTU Bhilai. He also completed his M Tech in Mechanical Engineering specialization in CAD/CAM Robotics from CSVTU Bhilai. He is currently working as Assistant Professor in Department of Mechanical Engineering, SSTC Bhilai. He holds the more than 10 years' experience in teaching as well as industry. He had published more than 40 international papers and more than 15 papers in conference. His research interests are in bio mechanical and materials, computer aided conceptual design, 3D modelling and optimization, hybrid composites, additive manufacturing etc.