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Design and Analysis of Aero Turbine Disc by FEA

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Abstract: The gas turbine obtains its power by utilizing the energy of burnt gases and the air which is at high temperature and pressure by expanding through the several rings of fixed and moving blades. The aero engine works on the phenomena of gas turbine. The deformation and fracture of gas turbine parts like turbine disc which are subjected to high temperature and other mechanical loads, depends mainly on temperature and time and hence due to creep. The objective of this paper is to highlight the stress and deformation distribution to assist in the design of a disc as well as to demonstrate the importance of using finite element (FE) analysis in simulating an actual design case. Then, to present the real model, a three dimensional (3D) axisymmetric model for a non-uniform disc was analyzed using FE analysis. The stresses and deformations developed as a result of the disc operating conditions at high thermal gradients were evaluated using conduction heat transfer modes taking into consideration the material behavior at elevated temperatures. A model is created with the help of software CATIA V5 and transient thermal and structural analysis are performed in ANSYS 16.0 work bench. An attempt is made to suggest best material for a turbine disc to be used as high pressure and low pressure combustion stages by comparing the results obtained for three different materials (Super alloy A286, Inconel 718 and Udimet 720). Based on the plots and results Udimet 720 and Inconel 718 are best suited as high pressure turbine to use at first stage of combustion and gives advantage over Super alloy A286. Results also suggest that Inconel 718 and Super alloy A286 are suitable for turbine disc material to be use at later stages of combustion.
Keywords: Gas Turbine, Turbine Disc, A286, Inconel 718, Udimet720, Thermal analysis, Ansys, Catia, FE analysis, Finite element analysis, fea.

I. INTRODUCTION

The gas turbine works on the principle of Brayton cycle. In an ideal gas turbine, gases undergo four thermodynamic processes: an isentropic compression, an isobaric (constant pressure) combustion, an isentropic expansion and heat rejection. Together, these make up the Brayton cycle. A jet engine operates with an open cycle, which means fresh gas is drawn into the compressor and the working fluid were to be expanded in a turbine, then assuming that there were no losses in either component, the power developed by the turbine can be increased by increasing the volume of working fluid at constant pressure or alternatively increasing the pressure at constant volume. Either of there may be done by adding heat so that the temperature of the working fluid is increased after compression. To get a higher temperature of the working fluid, a combustion chamber is required where combustion of air and fuel takes place giving temperature rise to the working fluid. The turbine escapes energy from the exhaust gas.

Rotating discs are historically of interest to designers in the aerospace industry because of their vast range of uses. A disc belongs undoubtedly among the basic parts of a gas turbine rotor that defines the aero turbine compressor engine's reliability. The main function of turbine discs is to retain the rotating blades and enabling the circumferential force to be transmitted through the central shaft. Each row of blades is retained in the rim of a disk via a root fixing, commonly of fir-tree design.

The structural integrity of turbine disks is very critical to the safety of aero engines. Turbine disk failures occur mainly due to high cycle and low cycle fatigue. Disk failure may also happen due to engine assembly errors, bearing failure, over temperature, over speed and impact due to adjoining component failure.

Turbine disks are subjected severe stresses due to various loads are acting on it. Gas turbine discs are stressed by a combination of centrifugal forces of rotating masses (disc, rotor blades), temperature of working fluid from the combustion chamber affecting the disc and blade surfaces, and the shaft deformation. Its damage during the operation can have fatal consequences, therefore it is important to pay adequate attention to its strength calculation.

In the early days, turbine discs were designed satisfying a maximum over speed requirement. The most important property was tensile strength material cleanliness and defect control weren't major considerations. With continuous development on engines load and temperature requirements became stricter which led to the development of advanced nickel base super alloys. Nowadays, property requirements include sufficient creep strength to withstand the high temperature.

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II. LITERATURE REVIEW

A. Amr Elhefny, Guozhu Liang

This paper presents a two-dimensional (2D) axisymmetric model for a non-uniform disc was analyzed using FE analysis. The stresses and deformations developed as a result of the disc operating conditions at high rotational speeds and thermal gradients were evaluated using two types of heat transfer modes—conduction and convection, taking into consideration the material behavior at elevated temperatures. The greatest stresses in the disc result from the thermal load caused by conduction, and they are located at the center of the disc. In addition, an analytical method was used to evaluate and predict the stresses along the disc, and it gave a good estimate of the stress values compared to the FE model. Based on this estimate, a parametric study was conducted for a range of rotational velocities under high temperature loads for a series of disc radii. Finally, it was found that this method can be used for the preliminary design of different turbines.

B. Theju V, Uday P S , Plv Gopinath Reddy

This paper aims to find out the better material by comparing two material. This paper presents a designed turbine blade with two different materials named as Inconel 718 and Titanium T-6. An attempt has been made to investigate the effect of temperature and induced stresses on the turbine blade. A thermal analysis has been carried out to investigate the direction of the temperature flow which is been develops due to the thermal loading. A structural analysis has been carried out to investigate the stresses, shear stress and displacements of the turbine blade which is been develop due to the coupling effect of thermal and centrifugal loads. An attempt is also made to suggest the best material for a turbine blade by comparing the results obtained for two different materials (Inconel 718 and titanium T6). Based on the plots and results Inconel718 can be consider as the best material which is economical, as well as it has good material properties at higher temperature as compare to that of TitaniumT6.

C. Lakshman Kasina, Raghavan Kotur, Govindaraji Gnanasundaram

The objective of this paper is to design a turbine disk for minimum weight. A numerical investigation is performed to predict stresses and burst margins of turbine disk. A parametric disk model is developed with bore width, bore height, web width and web height parameters. Optimization of turbine disk design is carried out to achieve minimum weight. Sensitivity studies are carried out to understand the geometry parameters influence on the stress and burst margins. The optimization technique was performed to improve the design without compromising on stresses in the disk and burst margin. It was observed that 24% reduction in weight was possible

D. Shailendra Kumar Bohidar, Ravi Dewangan

This paper provides a review about the advanced materials used in different components of gas turbine. Design of Turbo machinery is complex and efficiency is directly related to material performance, material selection is of prime importance. Temperature limitations are the most crucial limiting factors to gas turbine efficiencies. The problems at various components are of different magnitudes. As a result, the materials selection for individual components is based on varying criteria in gas turbines. Also materials and alloys for high temperatures application are very costly. This paper is focused on the study of various materials for their applicability for different components of gas turbine for increasing the performance, reliability and emissions in gas turbines. This paper focus light on above issues and each plays an important role within the Gas Turbine Material literature and ultimately influences on planning and development practices. It is expected that this comprehensive contribution will be very beneficial to everyone involved or interested in Gas Turbines.

E. Dianyin Hu, Rongqiao Wang, Guicang Hou

A new lifetime criterion for withdrawal of turbine components from service is developed in this paper based on finite element (FE) analysis and experimental results. Finite element analysis is used to determine stresses in the turbine component during the imposed cyclic loads and analytically predict a fatigue life. Based on the finite element analysis, the critical section is then subjected to a creep-fatigue test, using three groups of full scale turbine components, attached to an actual turbine disc conducted at 750 C. The experimental data and life prediction results were in good agreement.

F. R.A. Cláudio, C.M. Branco, E.C. Gomes, J. Byrne

In this paper, an FE detailed study of a gas turbine test disc, subjected to similar conditions as in the rim-spinning test, is presented. Finite element analysis were derived from a plain disc (without cracks) and for a geometry with two types of cracks, both at the notch root of the blade insert and located in the corner and in the center (central crack). Using a crack propagation program with appropriate

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fatigue creep crack growth rate data, previously obtained in specimens for the nickel base super alloy IN718 at 600ºC, fatigue life predictions were made. The predicted life results were checked against experimental data obtained in real test discs, and very good agreement was found.

III. SCOPE OF PRESENT WORK

In the present work finite element analysis is carried out using ANSYS 16.0 to determine the thermal stress distribution and deformation and observe the area of critical regions. A test disc which is 3D axisymmetric model has been analyzed by the finite element method, subjected to a condition similar to experimental tests performed by Amr Elhefny, Guozhu Liang [1]. The objective of this study are

A. To develop the 3D Catia model of aero turbine disc using details of turbine disc developed by Amr Elhefny, Guozhu Liang [1]
B. To study the behavior of different material of aero turbine disc working under high temperature environment.
C. To calculate the thermal stress and deformation on turbine disc and analyze the critical region of stress
D. To make comparison between different materials and find out the better material.

IV. METHODOLOGY

A. Description of gas Turbine Geometry

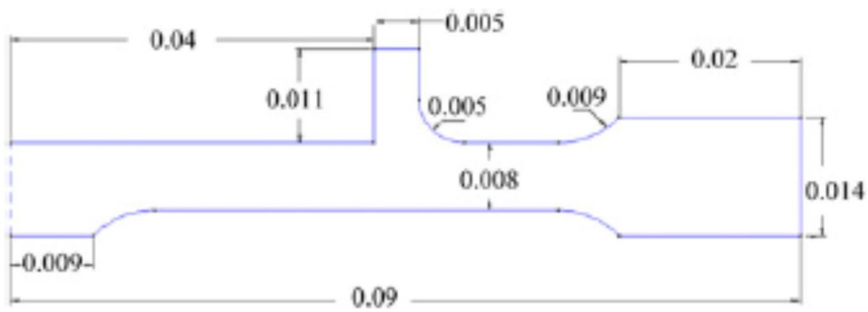

Fig. 1: Detailed dimensions of disc cross section (unit: m).

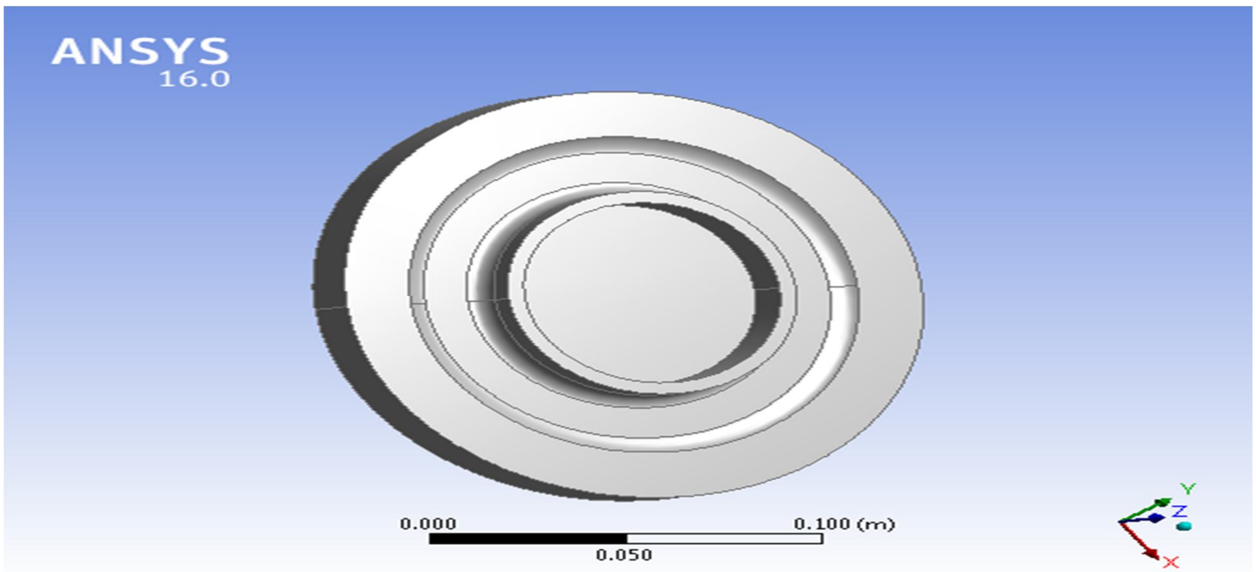

Fig. 2: 3D CATIA model of turbine disc

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B. Material

Advancements made in the field of materials have contributed in a major way in building gas turbine engines with higher power ratings and efficiency levels. Improvements in design of the gas turbine engines over the years have importantly been due to development of materials with enhanced performance levels. The materials developed at the first instance for gas turbine engine applications had high temperature tensile strength as the prime requirement. This requirement quickly changed as operating temperatures rose. Stress rupture life and then creep properties became important. In the subsequent years of development, low cycle fatigue (LCF) life became another important parameter. Many of the components in the aero engines are subjected to fatigue- and /or creep-loading, and the choice of material is then based on the capability of the material to withstand such loads. A286, an austenitic iron-base alloy has been used for years in aircraft engine applications (Schilke, 2004). Inconel 718 has been used for manufacture of discs in aircraft engines for more than 25 years (Schilke, 2004). Both these alloys have been produced through the conventional ingot metallurgy route. Powder Metallurgy (PM) processing is being extensively used in production of super alloy components for gas turbines. PM processing is essentially used for Nickel-based super alloys. It is primarily used for production of high strength alloys used for disc manufacture such as IN100 or Rene95 which are difficult or impractical to forge by conventional methods. Some of super alloy can produce by both conventional ingot metallurgy route and Powder Metallurgy although the powder metallurgy prove to have grater advantages over conventional ingot metallurgy route. This paper makes the comparison of three material – Inconel 718, Udimet 720 and Super alloy A286 under high temperature operating condition and plot the stress distribution and deformation to suggest better material.

C. Material Properties

The material properties are taken from the reference [8], [9], [10], [11], [12] at reference temperature 600˚C.

Material	**Chemical Composition**	**Remark**
Super alloy A286	Fe15Cr25Ni1.2Mo2Ti0.3Al0.25V 0.08C 0.006B	Iron-base super alloy, ingot metallurgy route
Inconel 718	Ni19Cr18.5Fe3Mo0.9Ti0.5Al5.1Cb 0.03C	Nickel-iron-base super alloy, ingot metallurgy route
Udimet 720	55Ni18Cr14.8Co3Mo1.25W5Ti2.5Al0.035C 0.033B0.03Zr	Nickel-base super alloy, ingot metallurgy / powder metallurgy route

Material / Properties	Super Alloy A286	Inconel 718	Udimet 720
Density (kg/m^3)	7940	8220.9	8082.5
Coefficient of thermal expansion (C^{-1})	0.000017	0.000014	0.00001224
Young's modulus (GPa)	157 (600˚C) 200 (22˚C)	166.8 (600˚C) 200 (22˚C)	170.27 (600˚C) 226 (22˚C)
Poison's ratio	0.335	0.276	0.286
Tensile yield strength(MPa)	621	1034.2	1128
Ultimate tensile strength (MPa)	841	1275.5	1455
Thermal conductivity (w/m k)	23.8 (600˚C) 12.7 (22˚C)	20.593 (600˚C) 11.39 (22˚C)	25 (600˚C) 9.4 (22˚C)
Specific heat (J/kg C)	419	435	460

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D. Operating Condition

The thermal effect that originated from the attached hot blades was represented by an abrupt high temperature of 600˚C at the outer boundary surface of the disc. Because of thermal conduction, heat was transferred from the outer boundary surface to the center of the disc for the subsequent 100 s, representing one operational life cycle of the turbine. The heat transfer from outer surface of the turbine disc to center of turbine disc is considered only conduction process.

It is assumed that ambient temperature to be 0˚C to predict the behavior of stress under cold environment condition as greater the temperature difference between environment and working conditions greater will the stresses generated.

It is to be noted that the same analysis can be performed assuming ambient temperature - 22˚C.

V. ANALYSIS OF TURBINE DISC

A. Material – Super alloy A286

Temperature distribution in Super alloy A286

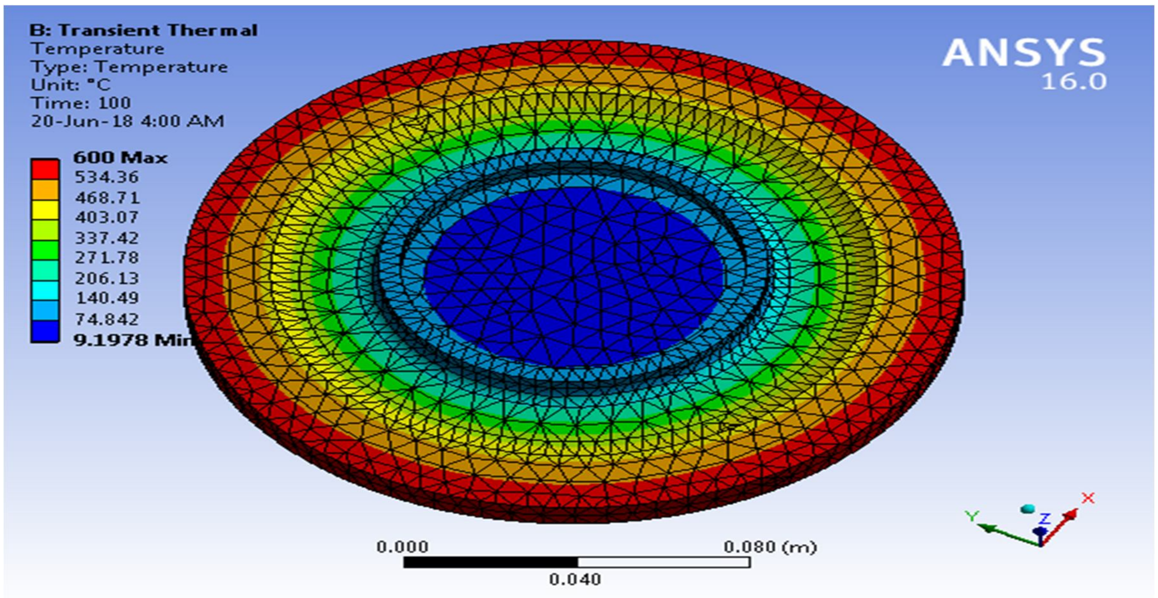
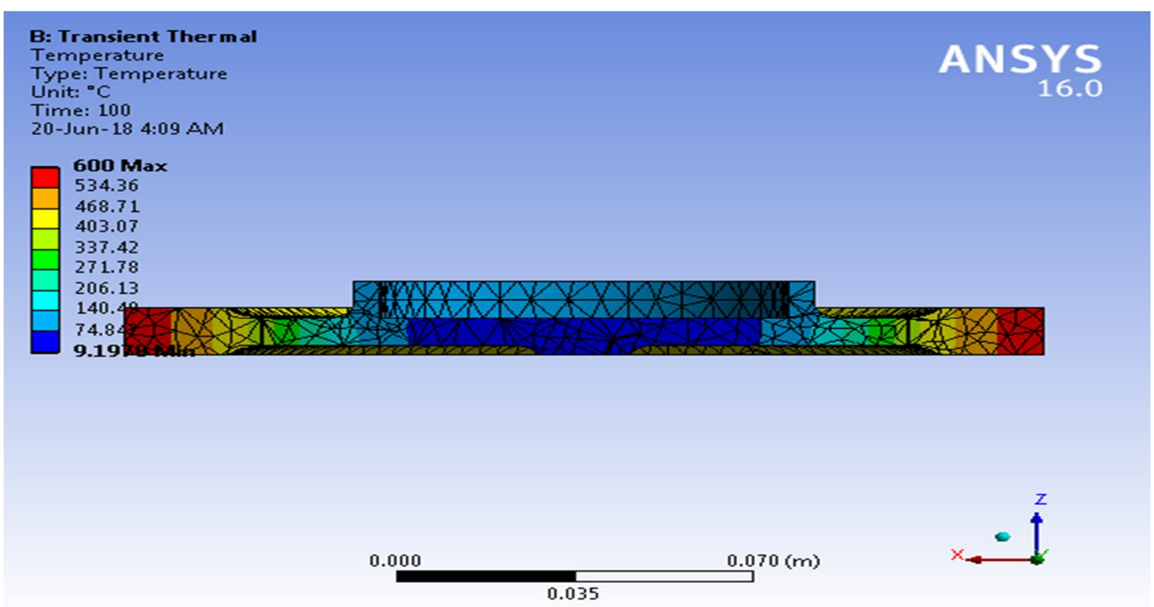


Fig. 3: Temperature distribution in Super alloy A286.

Fig. 4: Sectional view of temperature distribution in Super alloy A286.



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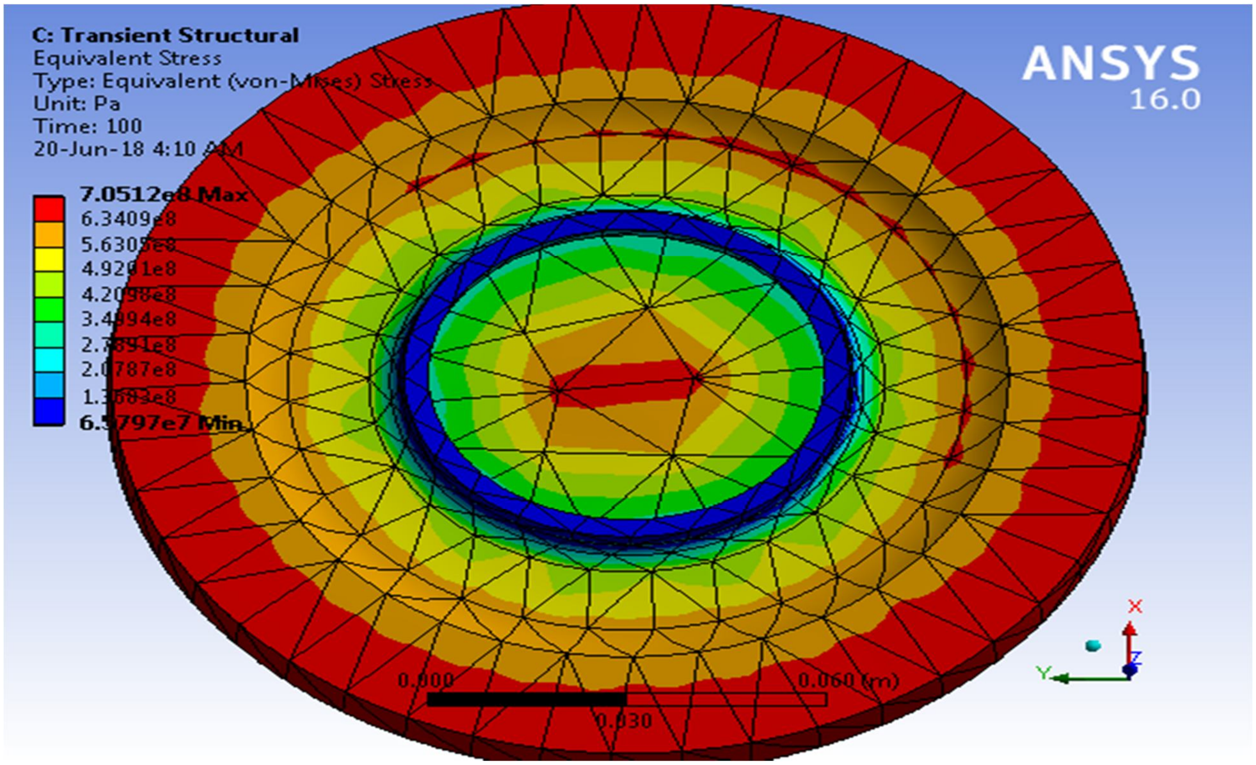

Fig. 5: Stress distribution in Super alloy A286

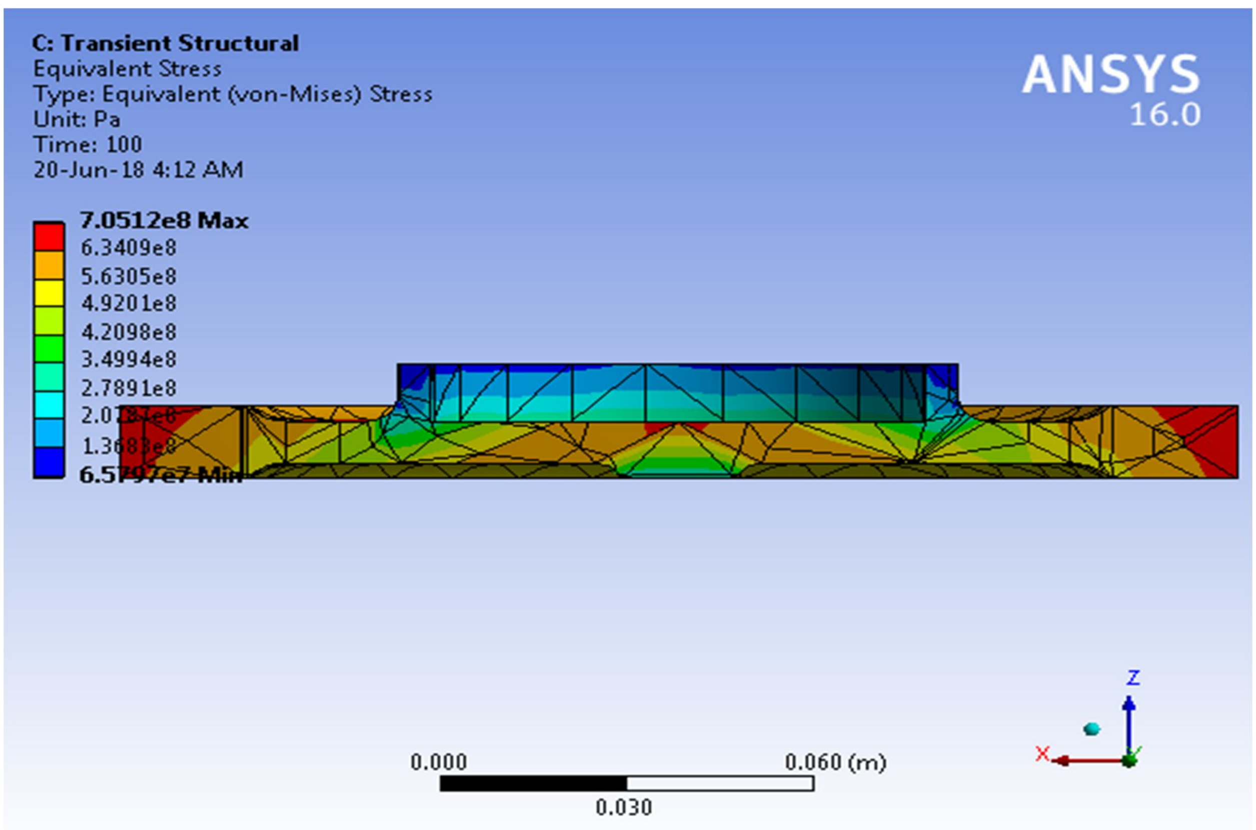

Fig. 6: Sectional view of Stress distribution in Super Alloy A286

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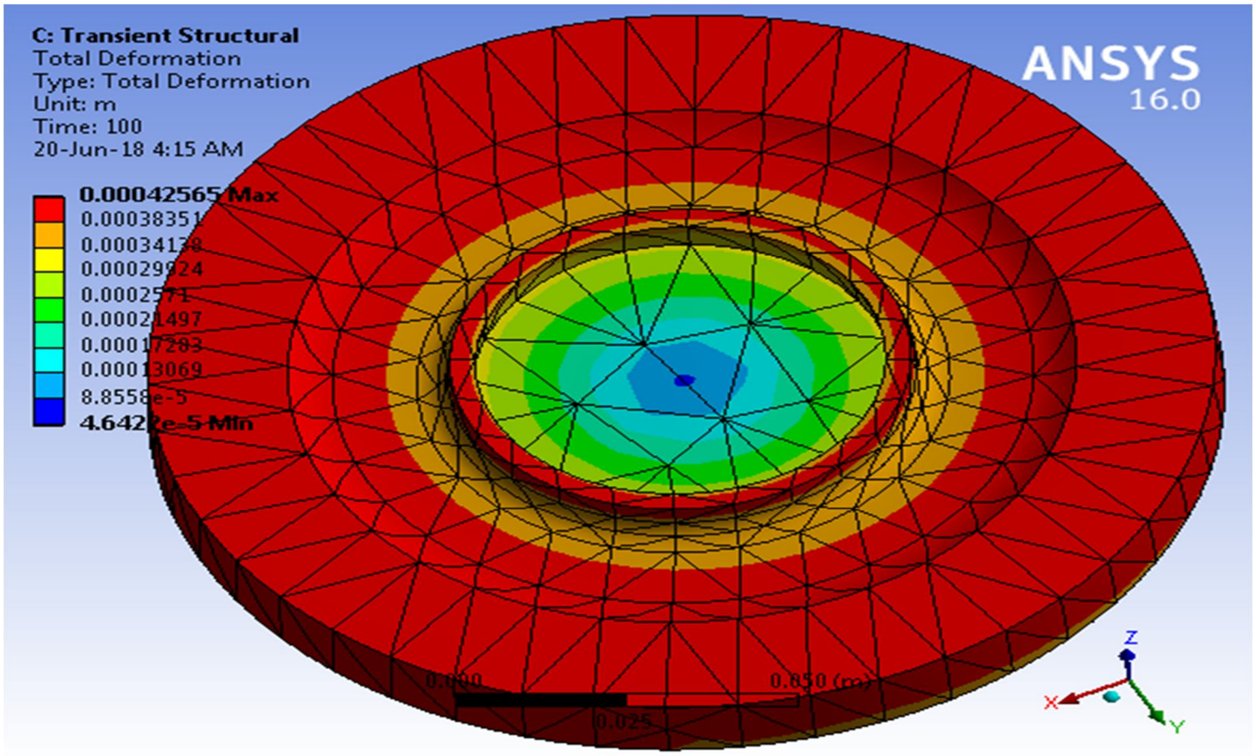

Fig. 7: Deformation in Super alloy A286

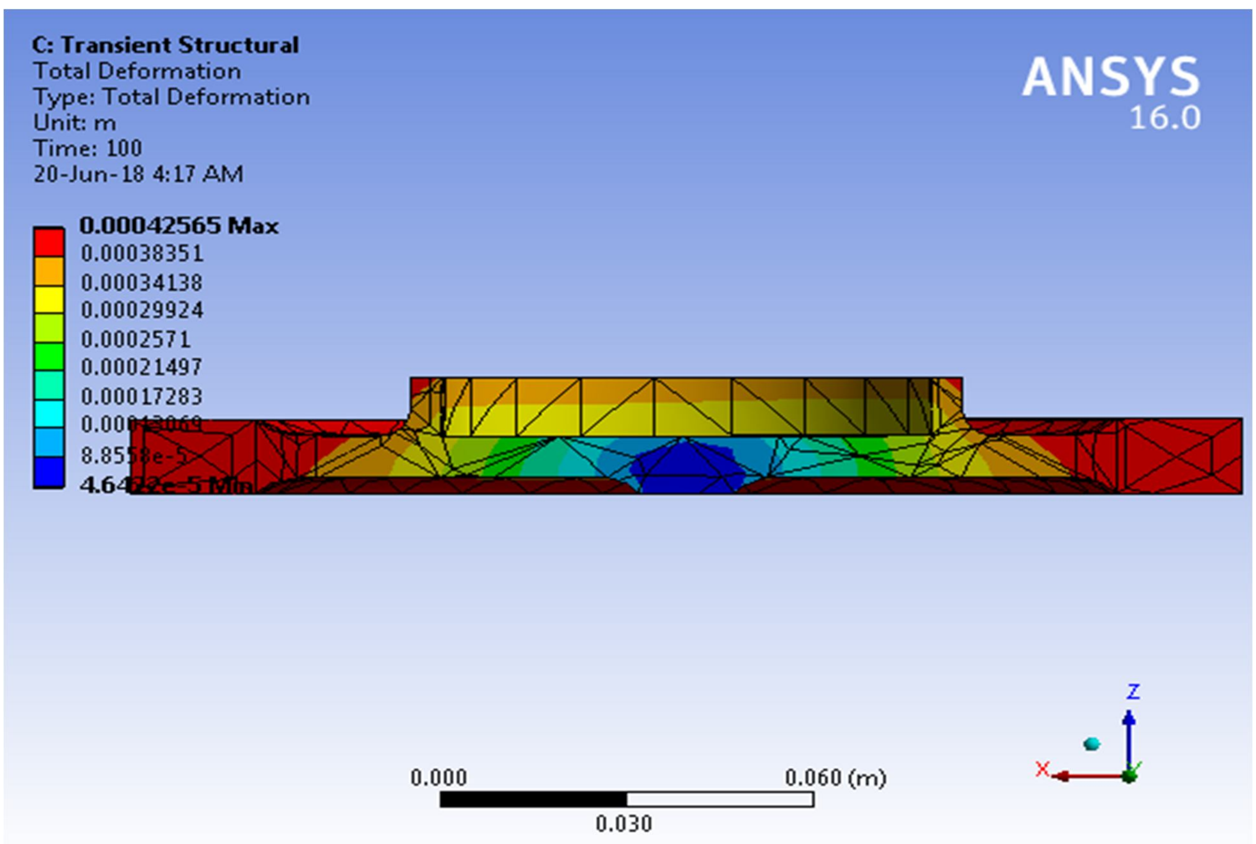

Fig. 8: Sectional view of deformation in Super alloy A286

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B. Material – Inconel 718

Temperature distribution in Inconel 718-

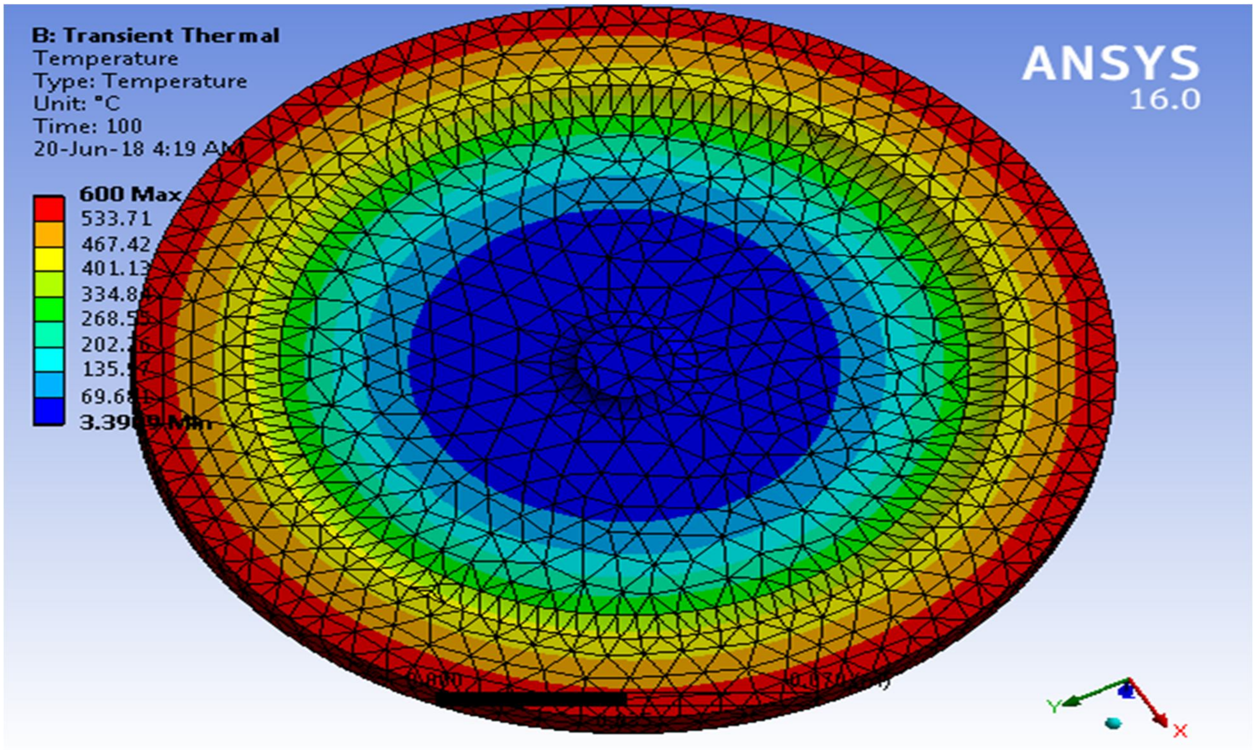

Fig. 9: Temperature distribution in Inconel 718

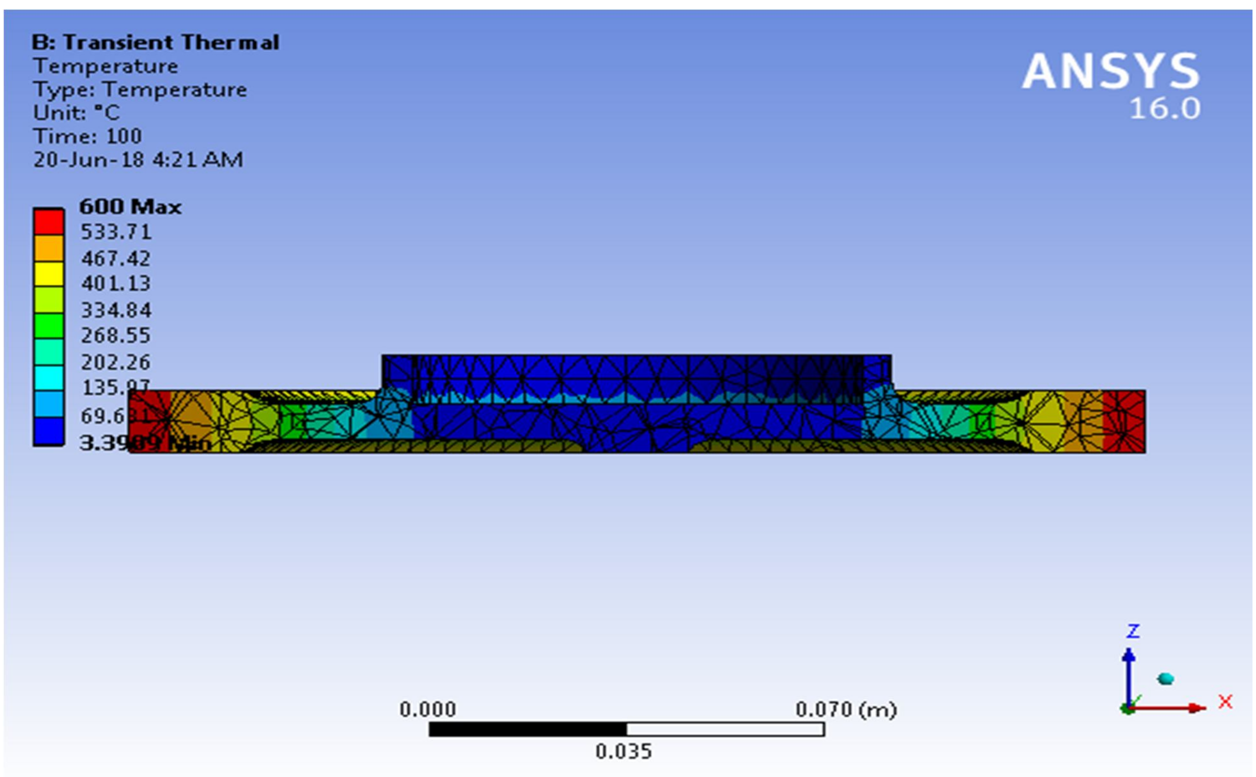

Fig. 10: Sectional view of temperature distribution in Inconel 718

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Stress Distribution and Deformation in Inconel 718-

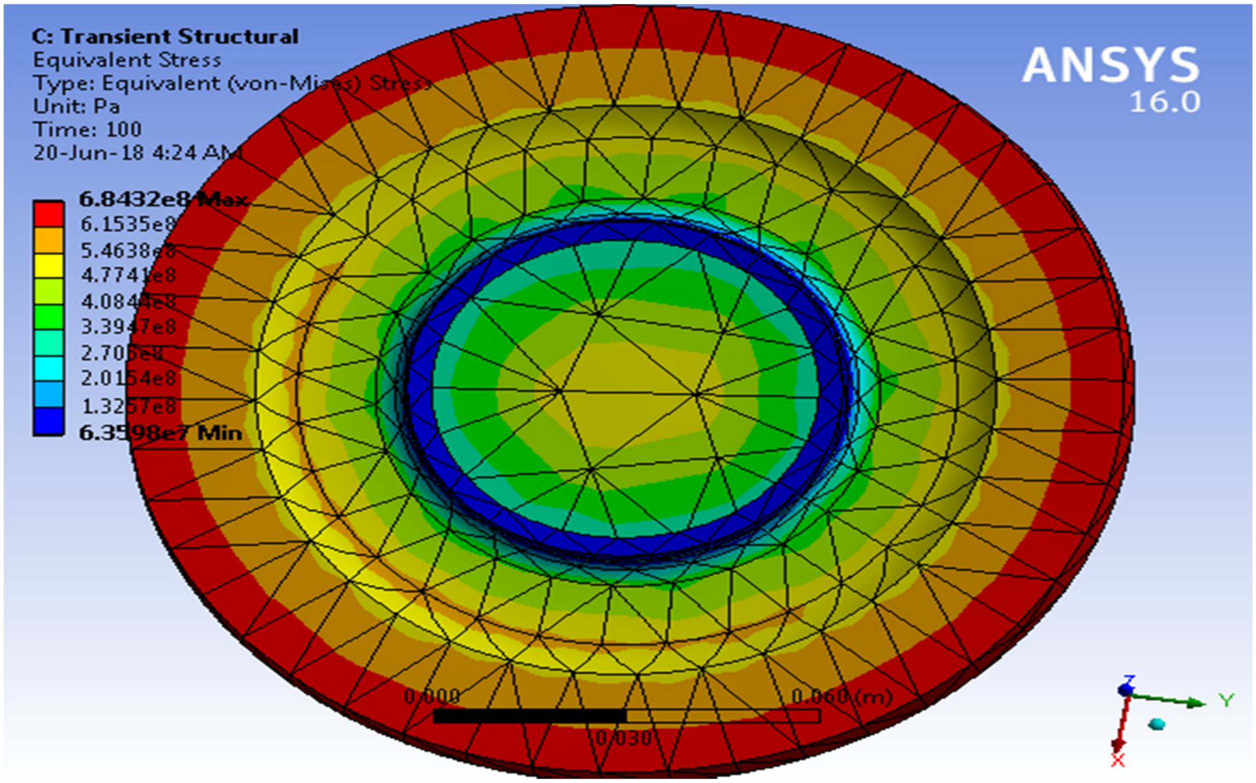

Fig. 11: Stress distribution in Inconel 718

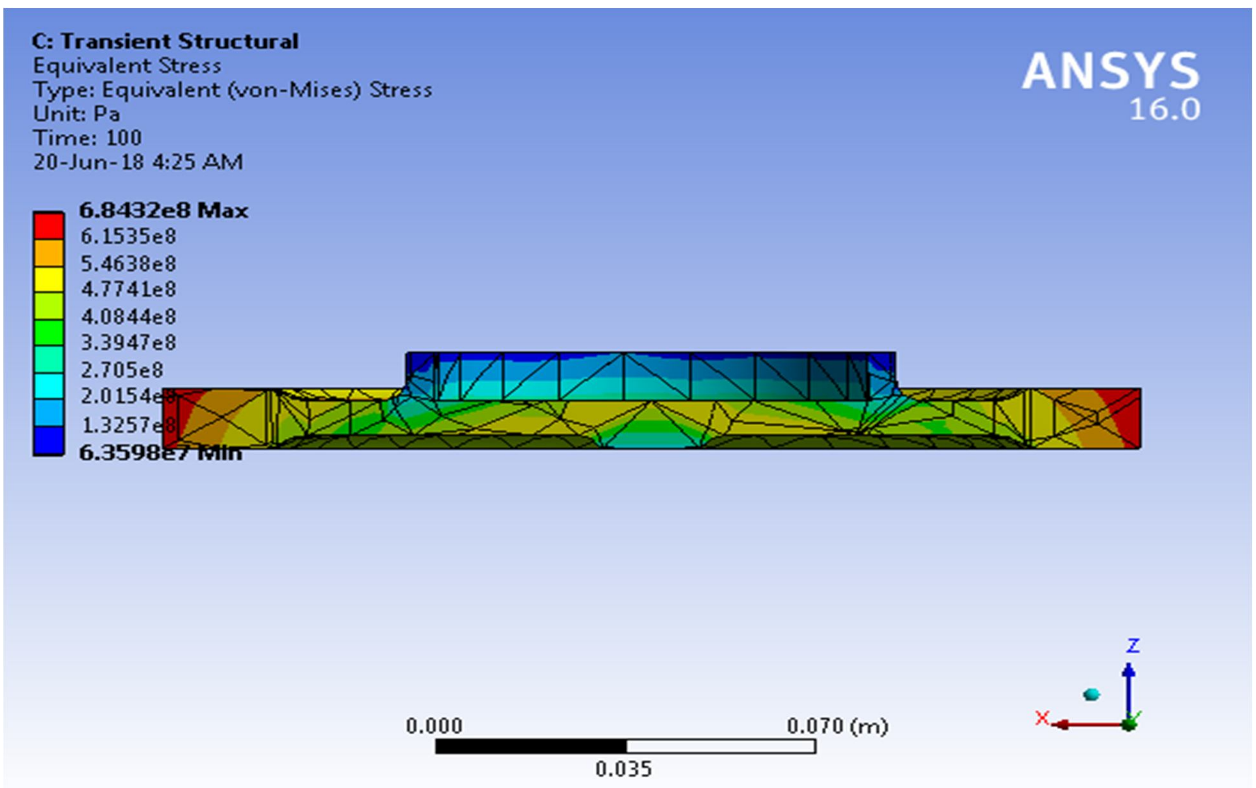

Fig. 12: Sectional view of Stress distribution in Inconel 718

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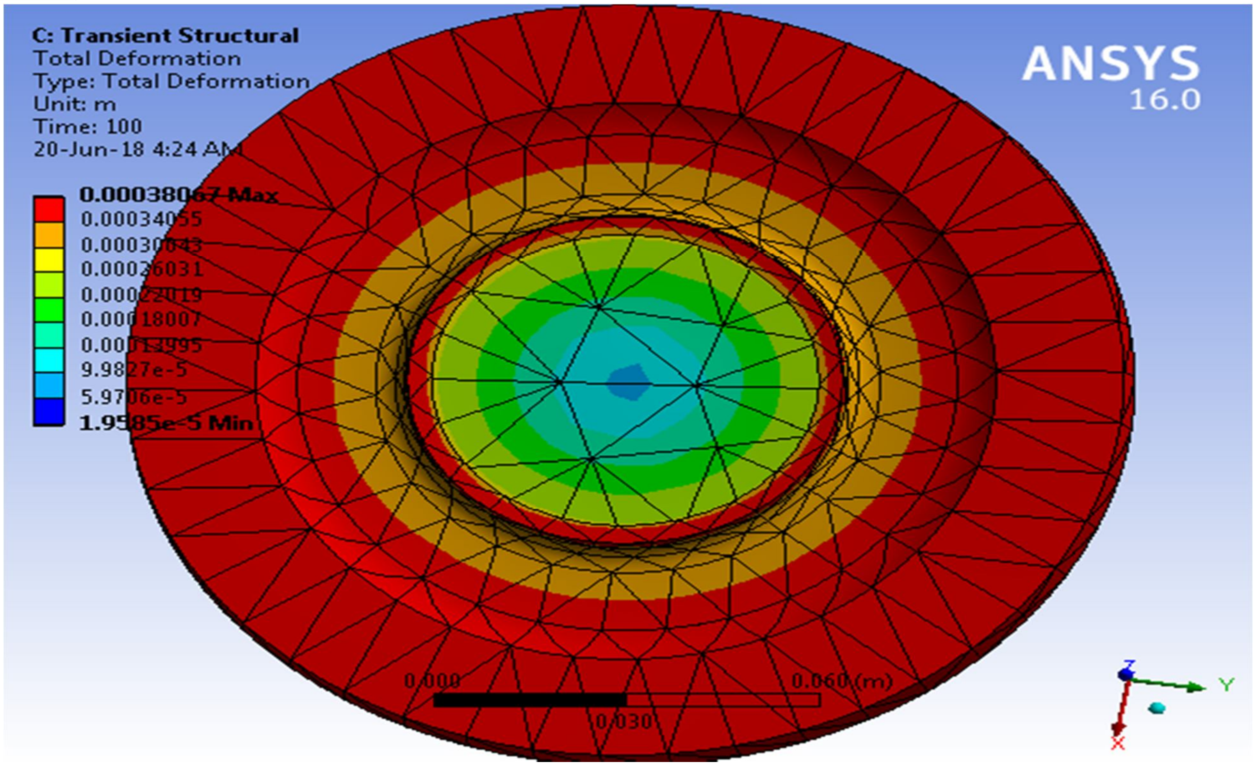

Fig. 13: Deformation in Inconel 718

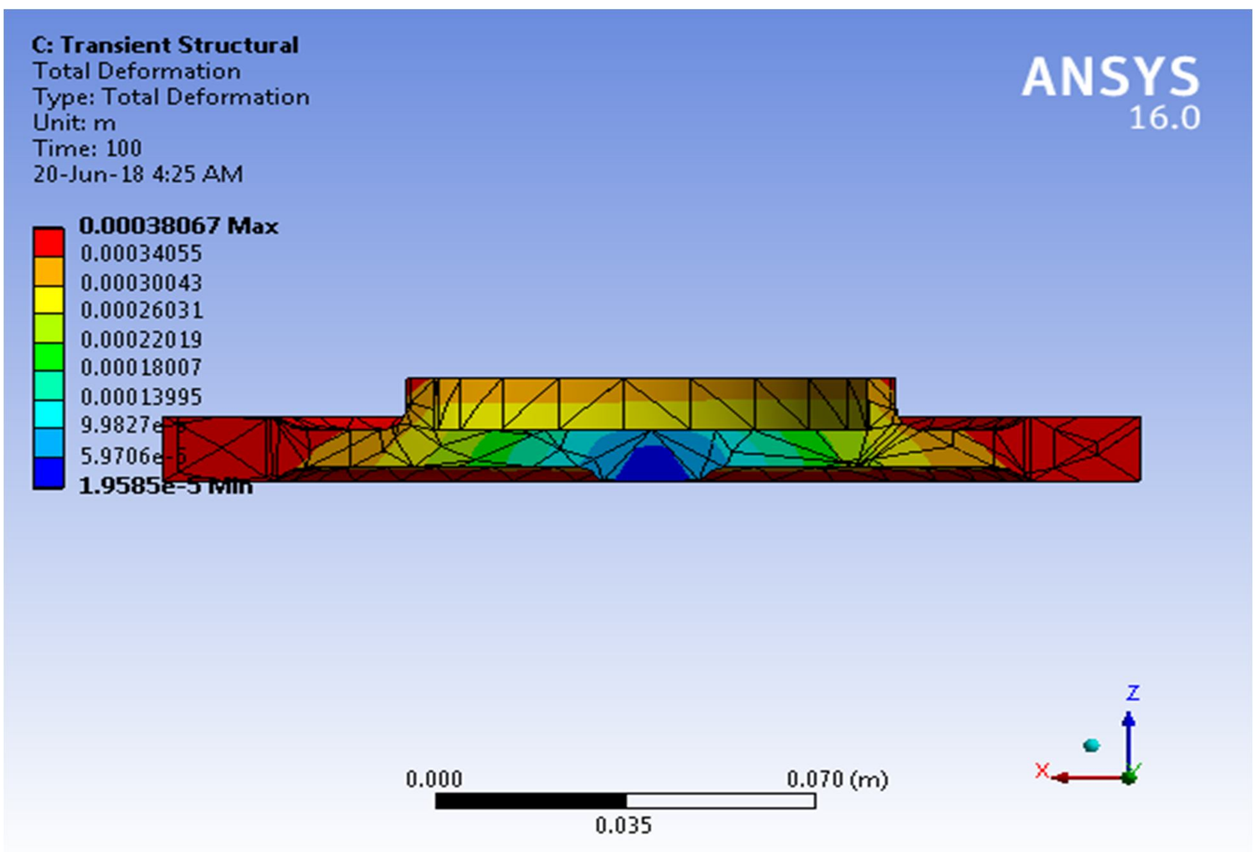

Fig. 14: Sectional view of deformation in Inconel 718

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C. Material – Udimet 720

Temperature distribution in Udimet 720.-

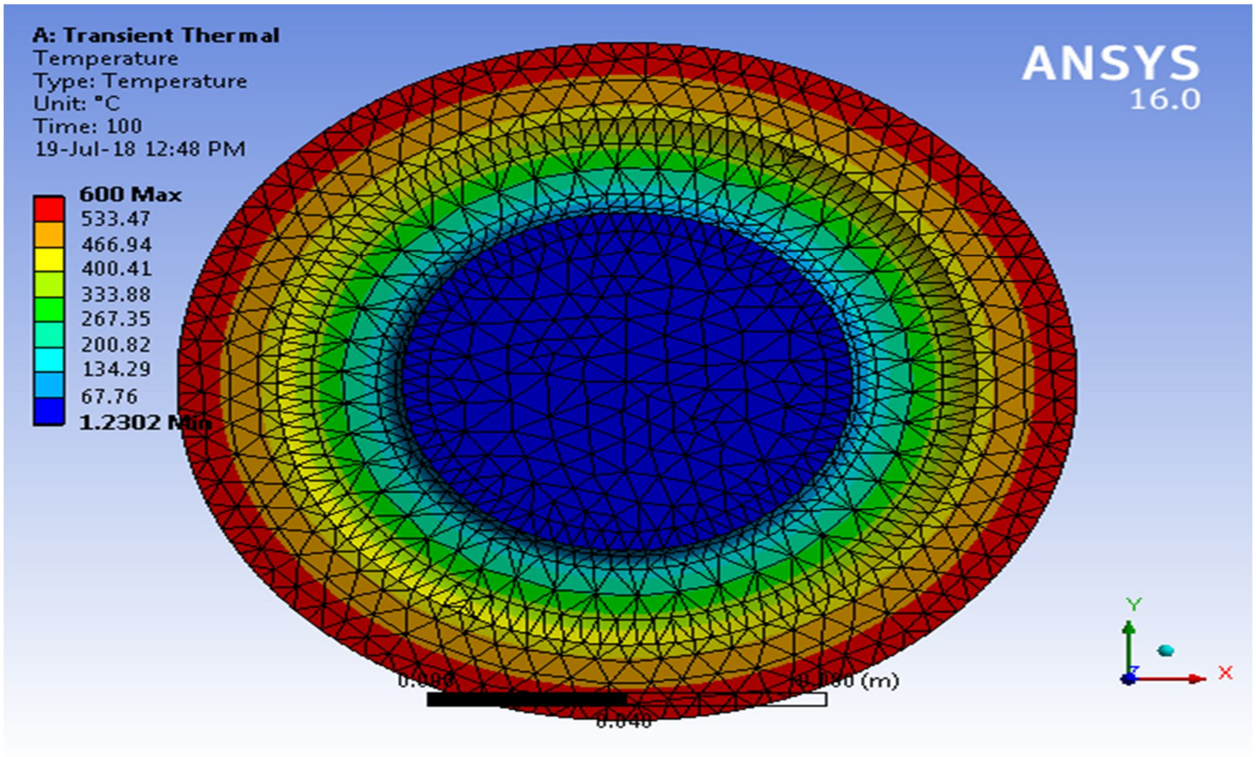

Fig. 15: Temperature distribution in Udimet 720

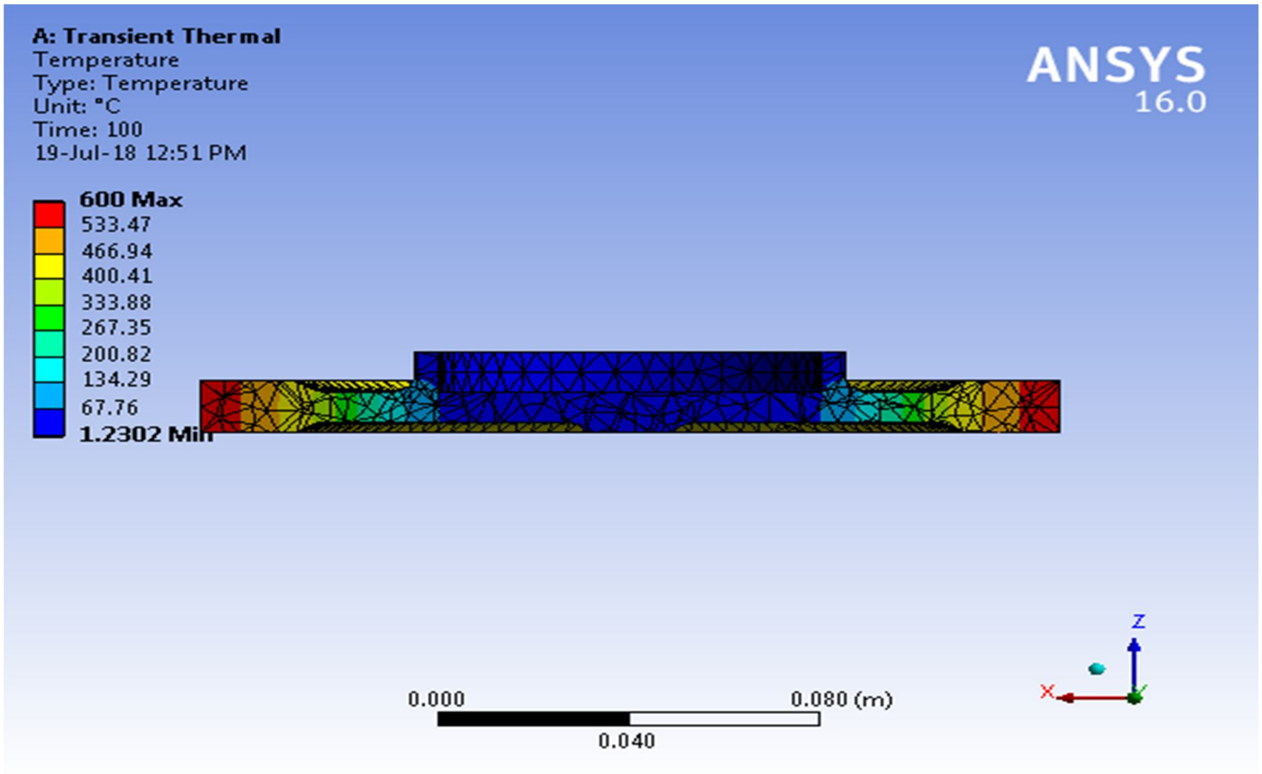

Fig. 16: Sectional view of temperature distribution in Udimet 720

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Stress Distribution and Deformation in Udimet 720-

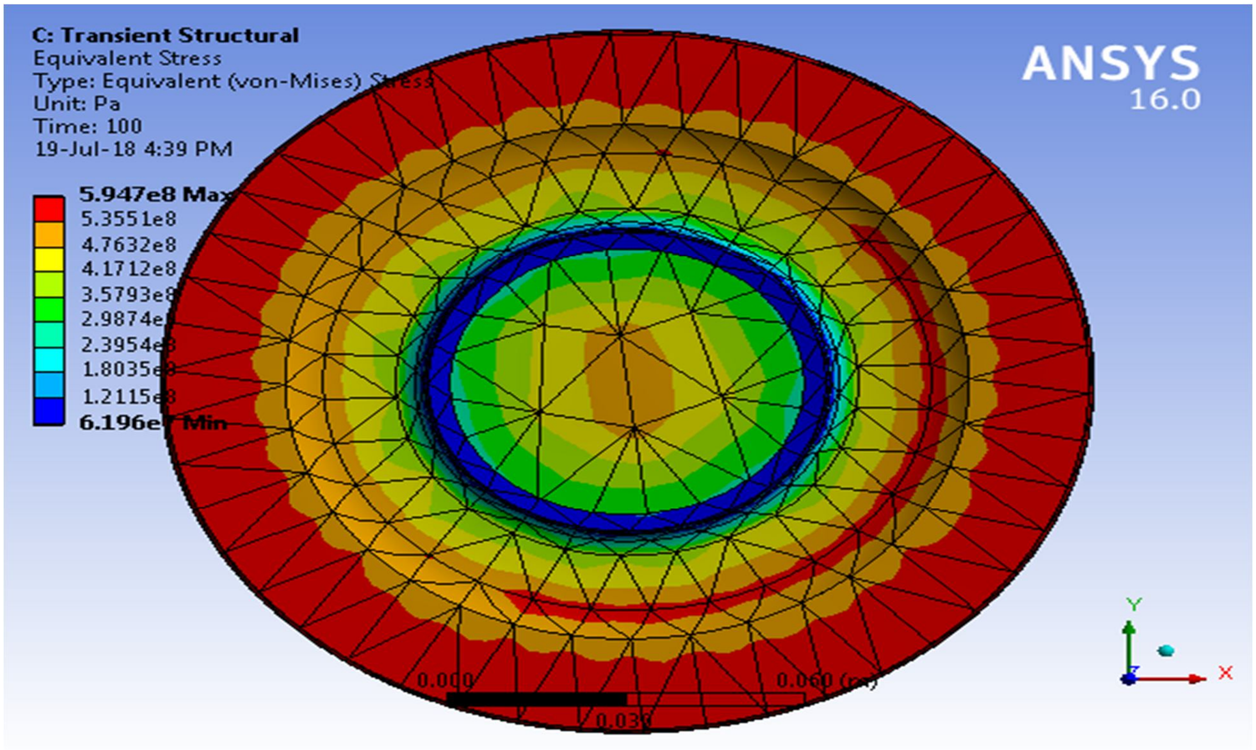

Fig. 17: Stress distribution in Udimet 720

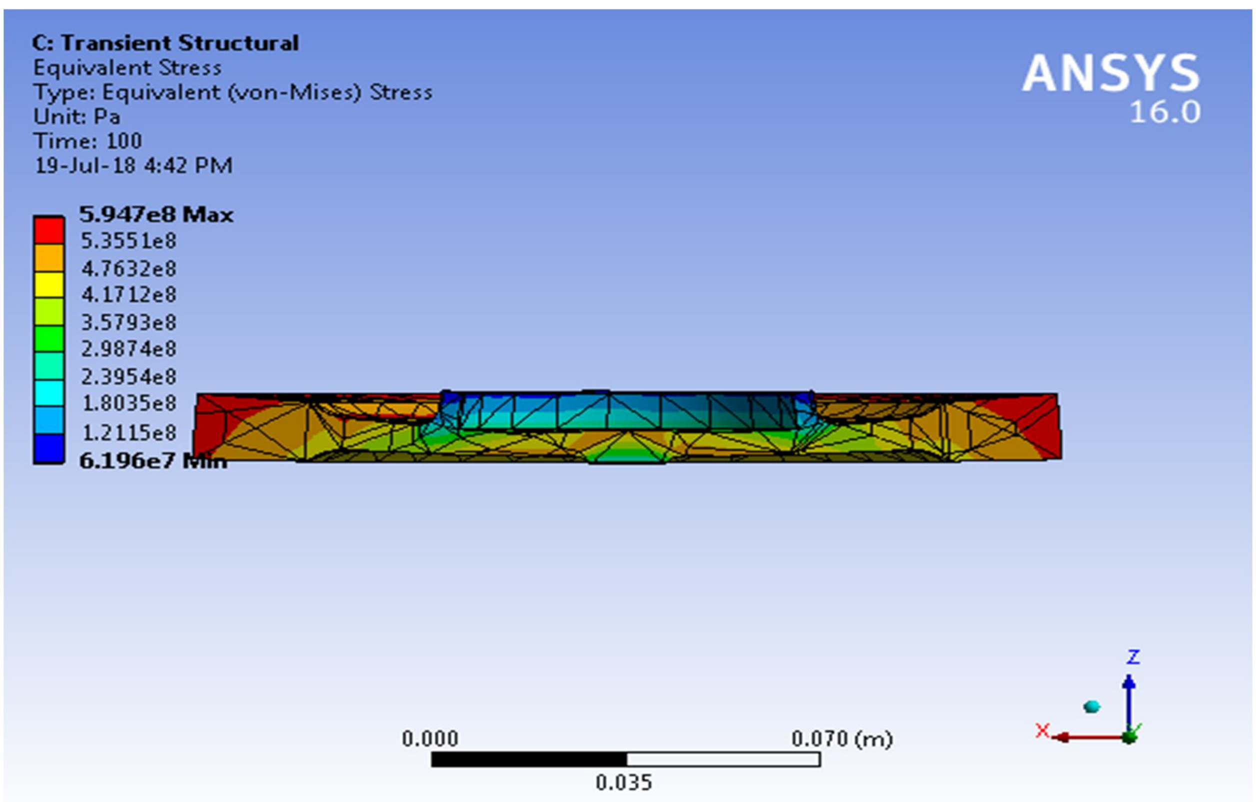

Fig. 18: Sectional view of Stress distribution in Udimet 720

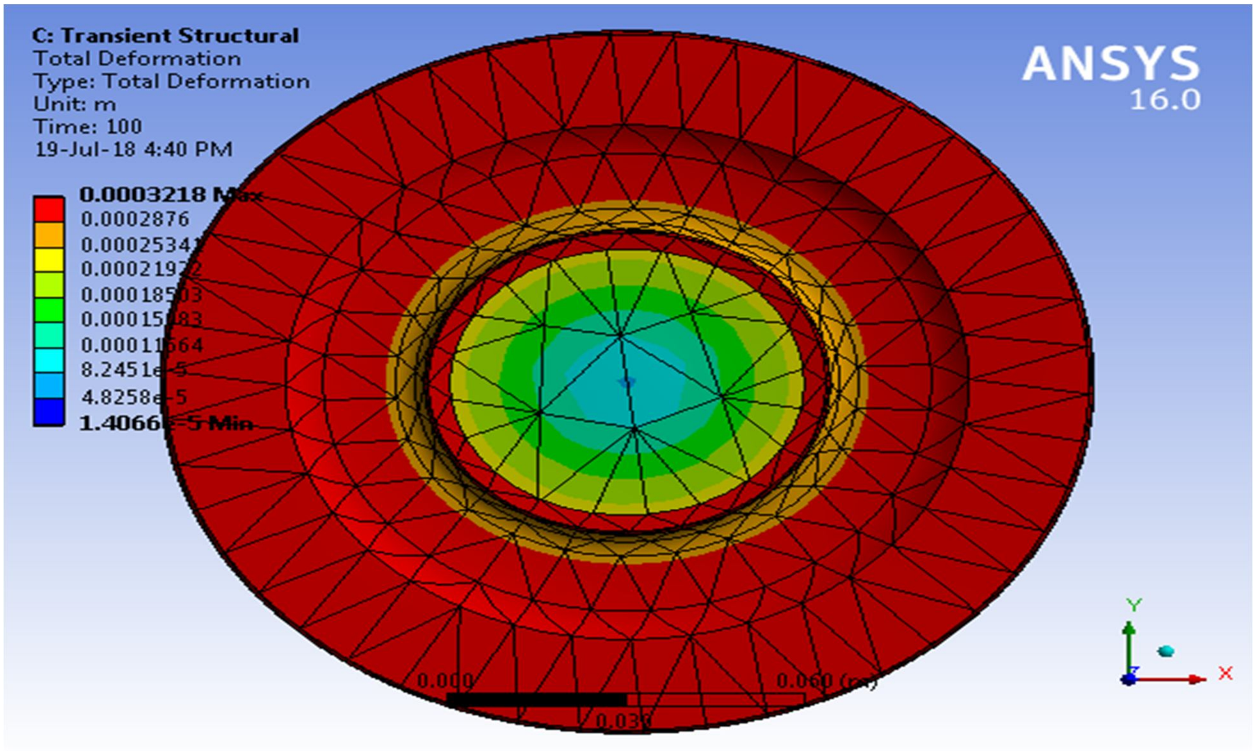

Fig. 19: Deformation in Udimet 720

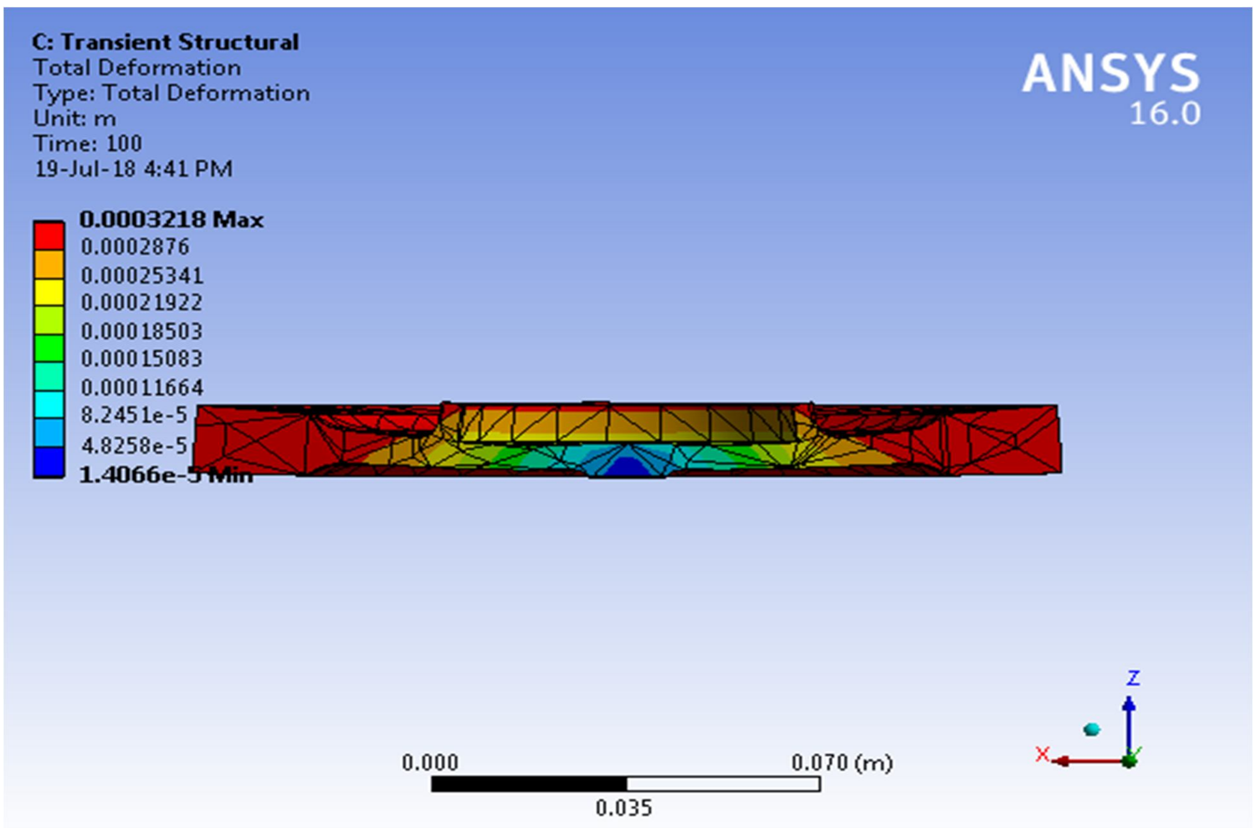

Fig. 20: Sectional view of deformation in Udimet 720

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VI. RESULTS

Properties / Material	Temperature (˚C)		Stress distribution (MPa)		Max Deformation (m)
	Min	Max	Min	Max	
Super alloy A286	9.19˚C	600˚C	65.79	705.12	4.25 e (-04)
Inconel 718	3.39˚C	600˚C	63.59	684.32	3.80 e (-04)
Udimet 720	1.23˚C	600˚C	61.96	594.7	3.21 e (-04)

VIII. CONCLUSION

As it is evident form the results that under similar turbine disc design and similar operation conditions the Udimet 720 achieves better temperature distribution and better distribution of stress as compared to other two material. Also, the deformation in case of Udimet 720 is lower when compared with Inconel 718 and Super alloy 286. Udimet 720 proves to be a better material in high pressure turbine disc to use at first stage of combustion and Inconel 718 and Super alloy A286 to be used at later stages of combustion process. Also on comparing Inconel 718 with Super alloy A286, Inconel 718 gives better result and thus, can be used as turbine disc material in preceding stages of combustion together with Super alloy A286 if needed.

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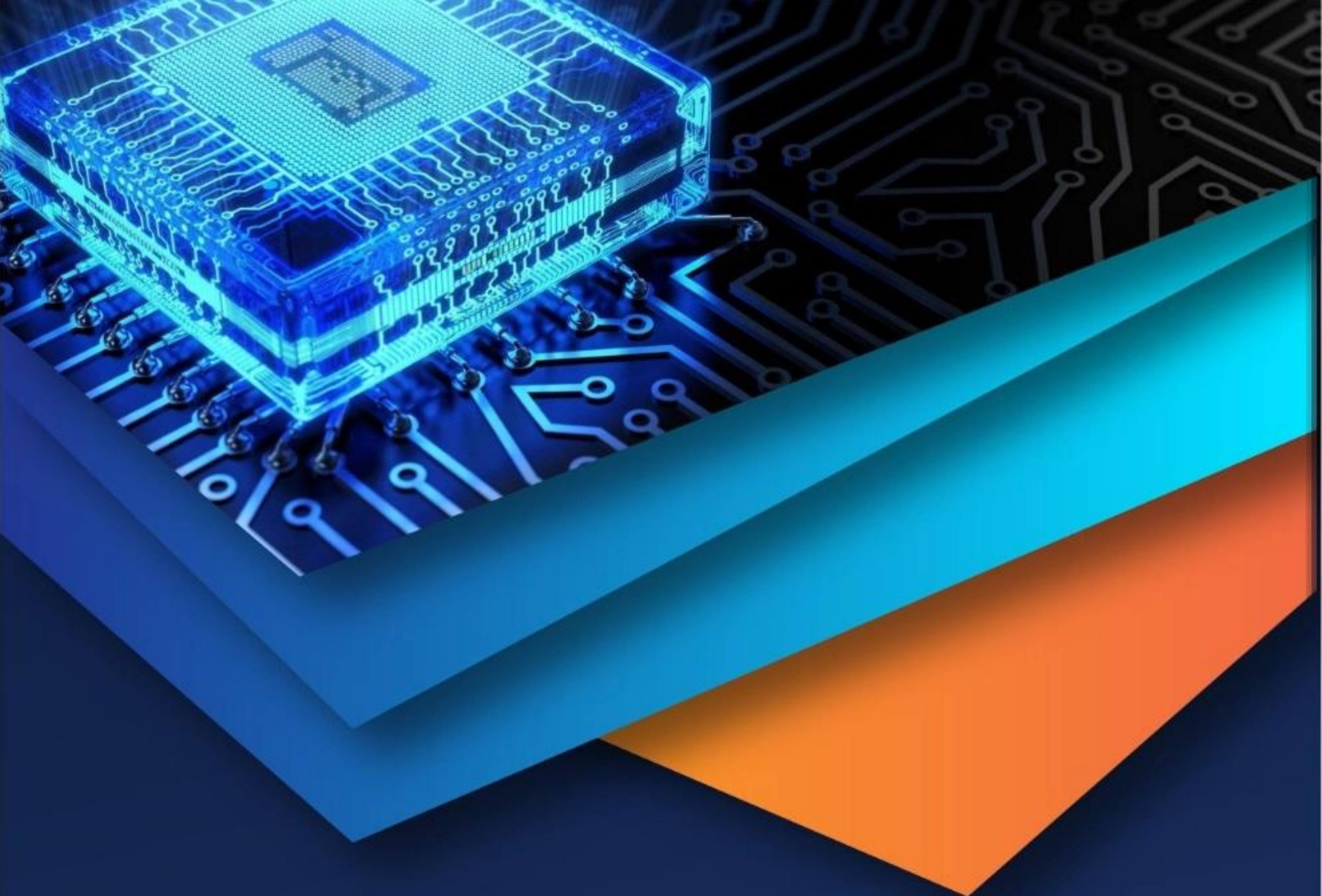

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