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Static Structural Analysis of Gas Turbine Blade

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Abstract—*Turbine blades are considered to be heart of turbine and play a vital role in extracting energy from high temperature and high pressure gases. Withstanding of gas turbine blade at high temperature for better efficiency and work output is a major consideration in their design. In spite of high temperature it is also subjected to high tangential, axial and centrifugal forces during their working conditions. To survive in this difficult environment, turbine blades are often made from exotic materials. A key limiting factor in gas turbine engine is the performances of material available for the hot section of engine especially the gas turbine blades. Here, we took three materials such as Nimonic alloy 80A, super alloy X, Inconel 625 that are used to manufacture turbine blades and performed static structural analysis at three different speeds. All the modeling process is carried out in SOLIDWORKS and simulation is done in ANSYS Mechanical Workbench. Based on the result of comparative study, it is concluded that Inconel 625 can be a suitable material for the manufacturing of gas turbine blades.*

Keywords*: Gas turbine blade, SOLIDWORKS, ANSYS Workbench, Static Structural analysis.*

1. INTRODUCTION

Gas turbine is a machine delivering mechanical power using a gaseous working fluid based on Brayton cycle. It is an internal combustion engine like the reciprocating Otto and Diesel engine with the major difference that the working fluid flows through the gas turbine continuously not intermittently. The continuous flow of working fluid requires the compression, heat input, and expansion to take place in separate components. For that reason gas turbine consists of several components working together and synchronized in order to achieve production of mechanical power, in case of industrial applications, or thrust for aeronautical purposes. Expansion of working fluid may occur entirely within the turbine, in case of industrial gas turbine or partially in the turbine and remaining in the jet nozzle, which is the case of aero engine. First successful design of an industrial gas turbine is attributed to Aegidius Elling (1923) whereas the first aero engine to power an Aircraft (He 178, 1939) has been designed by Hans Joachim Pabst. Since then Gas turbine technology is characterized by a history of tremendous advances in power output and efficiency, where a key role has been played by the turbine inlet temperature. It plays a vital role in aviation, land based power generation, and marine application due to their high power to weight ratios and compactness. But low thermal efficiency is a limiting factor in their application. Thermal efficiency can be increased by using high mean temperature of heat addition. It requires the material with high thermal stability. Researches are going on to invent the material having high thermal stability. It results in increasing thermal efficiency day by day.

Blade failures can be caused by a number of mechanisms under the turbine operating conditions of high rotational speed at elevated temperature. In general, blade failures can be grouped into two categories: (a) High cycle fatigue (HCF), low cycle fatigue (LCF) and (b) creep rupture. Blade fatigue failures are often related to anomalies in mechanical behavior and manufacturing defects. To identify the causes of the blade fatigue failures, a complete investigation has to be carried out, integrating both the mechanical analyses and metallurgical examination. Metallurgical examination can be very effective in determining whether the failure is related to material defects, machining marks, poor surface finish, initial flaws or heat treatment. Mechanical analysis includes stress analysis and vibration analysis. It is observed that 42% of turbine failure occurs due to blade failure. Turbine blades are mainly affected due to static load at elevated temperature and vibrational forces. For this reason structural, thermal, and modal analysis is carried out. Here in this paper only static structural analysis is carried out.

2. MATERIALS USED IN GAS TURBINE BLADES

Proper selection of blade material plays an important role in blade design. Factors that influences the selection of blade materials are:- (1) Ease of machining (2) Ability to produce blade section free from flaws (3) Weld ability (4) Resistance to fatigue & creep (5) Cost etc. Super alloy were developed since the second quarter of 20th century as material in order to satisfy all physical and chemical properties. It can be divided into three groups namely: - (a) Nickel base (b) Cobalt base (c) Iron base, super alloy. Gas turbine blades are principally made of nickel base and cobalt base super alloy. Properties of material used in the analysis are given below:-

Materials	Super Alloy X	Nimonic 80A	Inconel 625
Young's Modulus(Gpa)	210	222	208

Density (kg/m3)	7780	8190	8440
Poisson's Ratio	0.3	0.35	0.29
Thermal conductivity(w/m k)	22	11.2	21.3
Thermal expansion(°c)	10E-6	12.7E-6	13.1E-6
Yield strength(M pa)	1175	1144	1150
Melting temperature(°c)	1370	1340	1350

The ability to run at increasingly high gas temperature has resulted from a combination of material improvement and the development of more sophisticated arrangements for internal and external cooling; nowadays high pressure turbine blades receive compressed air bled from the compressor and it is injected to the turbine blades through small holes drilled on them, with the purpose to establish a protection layer on the edge of the blades and guaranty that hot flue gases could not affect directly them. The most difficult and challenging point is the the turbine inlet because there are several difficulties associated to it like, extreme temperature (1400°c-1500°c), high pressure, high rotational speed, vibration, small circulation area, and so on. Severity of different surface related problems for gas turbine application are shown below:-

	Oxidation	**Hot corrosion**	**Inter diffusion**	**Thermal Fatigue**
Aircraft	Severe	Moderate	Severe	Severe
Land Power Generator	Moderate	Severe	Moderate	Light
Marine Engines	Moderate	Severe	Light	Moderate

3. MODELLING & ANALYSIS OF TURBINE BLADE

Modelling of turbine blade is done on giving 145° bend to standard profile of NACA 6409 using SOLIDWORKS. Key profile is generated by using given XYZ coordinates and checking the joining of end point by zooming. Now it is extruded and bent through 145° using "Flex Feature" to get the desired shape and height of blade. It is exported to ANSYS WORKBENCH in IGS format for analysis.

Following parameter has been taken for calculation of forces applying on the blade:-

Blade height (H) = 0.12m
Rotor diameter (D) = 0.51m
Mean diameter (Dm) = 0.63m
Speed (N) = 20000, 40000, 60000 rpm
Temperature (T) = 1000K
No. of blade=120

For max diagram efficiency nozzle angle (α) should be as small as possible. Due to manufacturing constraint it is taken as 14° Velocity of blade $(Vb) = \frac{\pi DmN}{60} = 659.7344m/s$

since $\frac{Vb}{V1} = \frac{cos\alpha}{2} \Rightarrow Absolute\ velocity(V1) = 1359.8625m/s.$

Inlet blade angle

$$(tan\beta 1) = (V1\ sin\alpha 1)/(V1\ cos\alpha 1 - Vb) = 0.4986 \Rightarrow \beta 1 = 26.5034° = \beta 2(for\ impulse\ turbine)$$

$$Vr1 = Vr2 = V1 - V = 700.1281m/s$$

$$V2 = Vr2 + Vb = \frac{1359.8625m}{s}$$

$$\frac{V2}{sin\beta 2} = \frac{Vr2}{sin\delta} \Rightarrow \delta = 13.2825°$$

$$Vw1 = V1\ cos\alpha 1 = \frac{1319.4687m}{s}$$

/

$$Vw2 = V2\cos(180 - \delta) = -\frac{1323.4849m}{s}$$

$$Va1 = V1\ sin\alpha 1 = \frac{328.9805m}{s}$$

$$Va2 = V2\sin(180 - \delta) = 312.4317m/s$$

Tangential Force (Ft) =$\dot{M} \times \Delta Vw = 83517.33376N$

Ft/blade=695.97N

Axial force (Fa) =$\dot{M} \times \Delta Va = 522.94208N$

Fa/blade=4.35785N

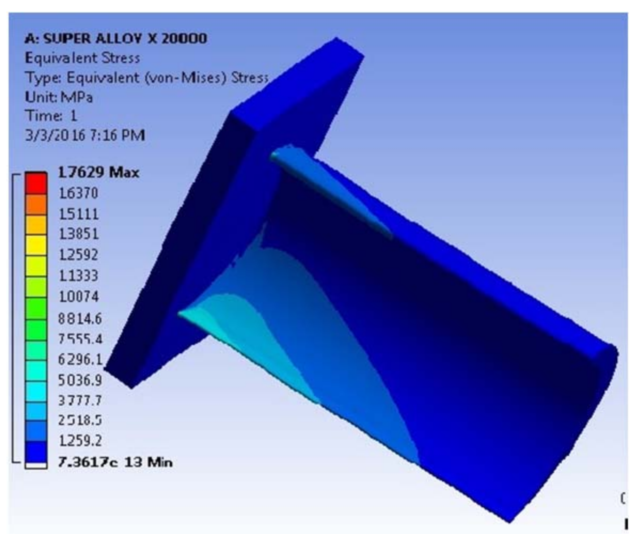
Power generated=$\dot{M}$ (Vw1+Vw2) U=55.09MW

Centrifugal Force (Fc) =$\rho A\omega^2(\frac{R2^2 - R1^2}{2})$

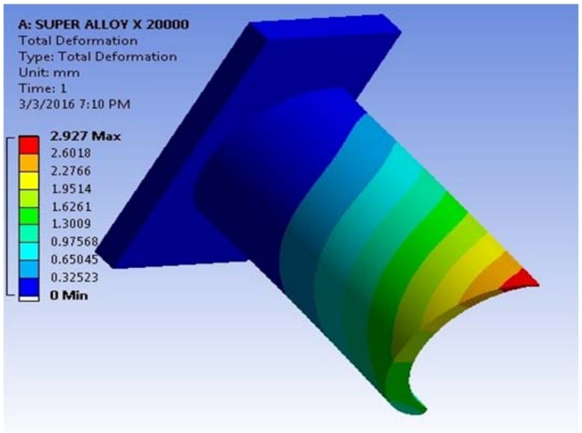
Centrifugal Force Acting on Turbine Blade at Various Speeds

Material	**Centrifugal Force at different speeds, Fc in N**		
	20000RPM	**40000RPM**	**60000RPM**
Super alloy X	798196.132	3192784.53	7183765.19
Nimonic 80A	840260.421	3361041.68	7562344.07
Inconel 625	865909.396	3463637.58	7793184.86

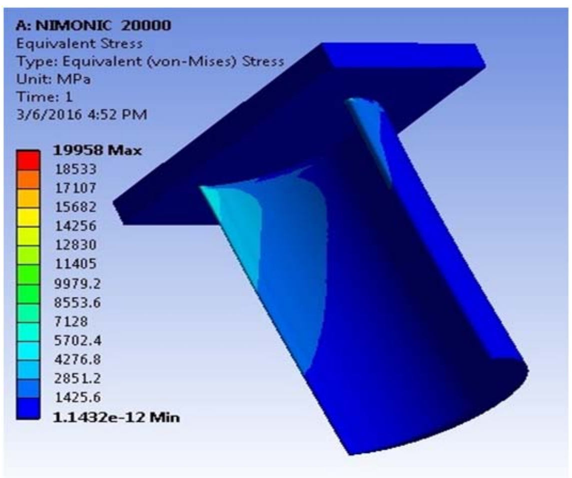
Stress on Super Alloy X Turbine Blade at 20000RPM



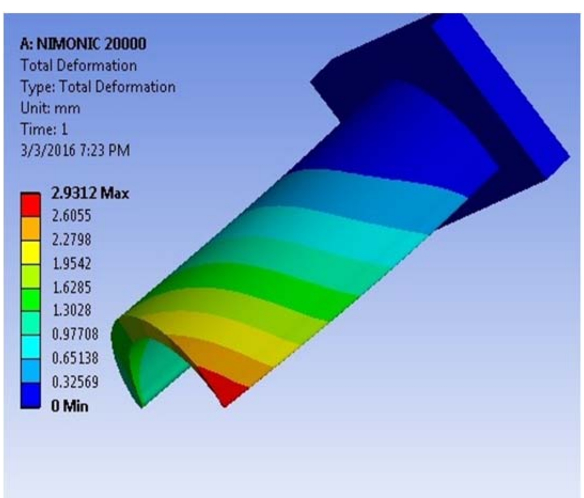
Deformation on Super Alloy X Blade at 20000 RPM



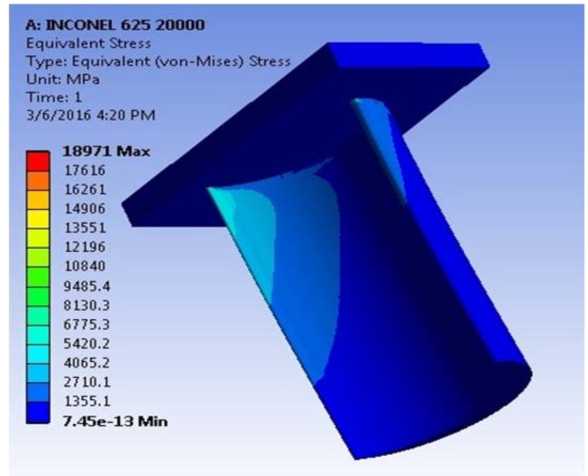
Stress on Nimonic 80A Blade at 20000 RPM



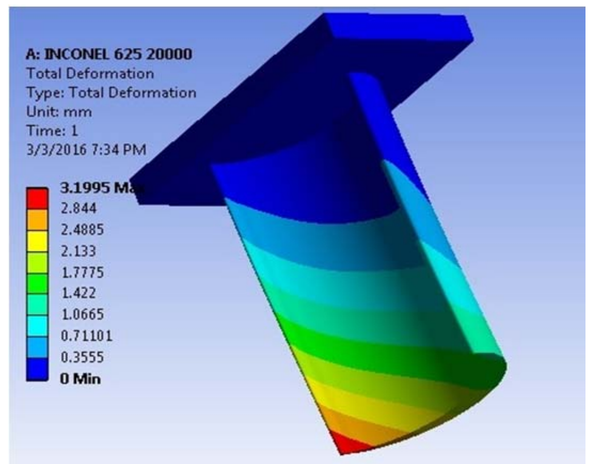
Deformation on Nimonic 80A Blade at 20000 RPM



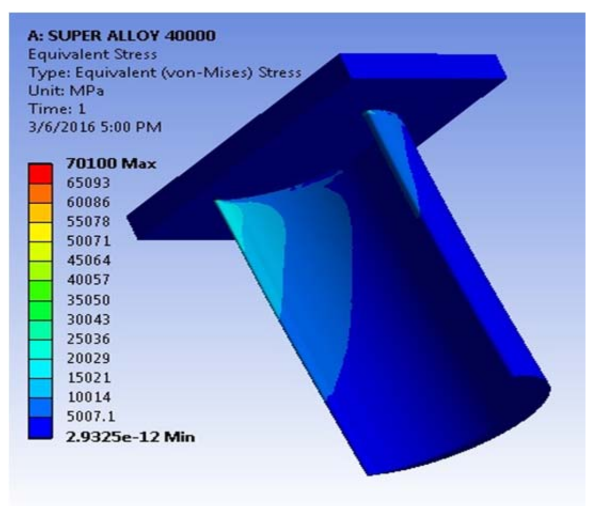
Stress on Inconel 625 Blade at 20000 RPM



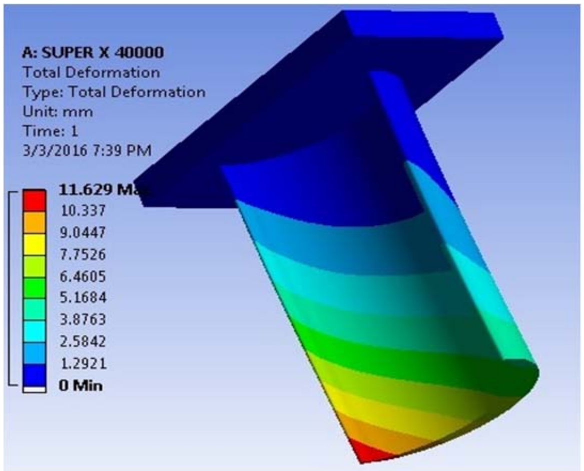
Deformation on Inconel 625 Blade at 20000 RPM



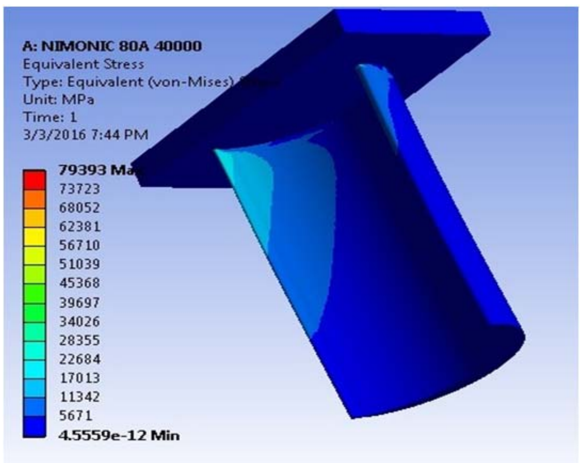
Stress on Super Alloy X Blade at 40000 RPM



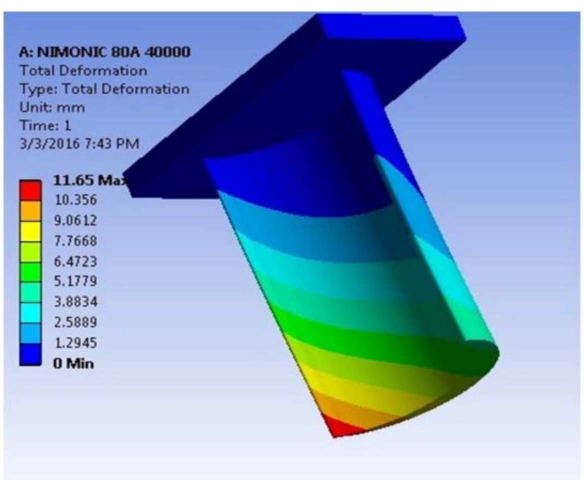
Deformation on Super Alloy X Blade at 40000 RPM



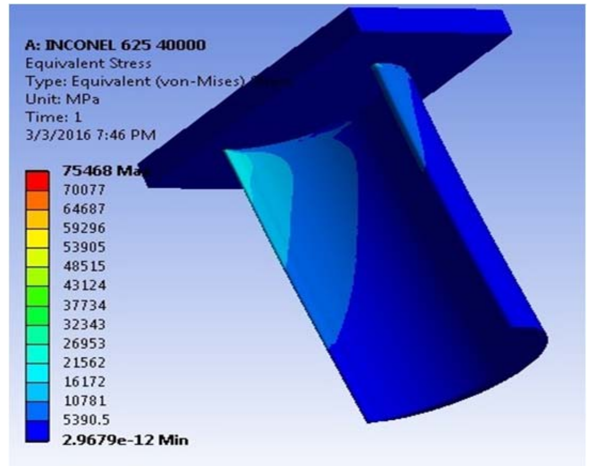
Stress on Nimonic 80A Blade at 40000 RPM



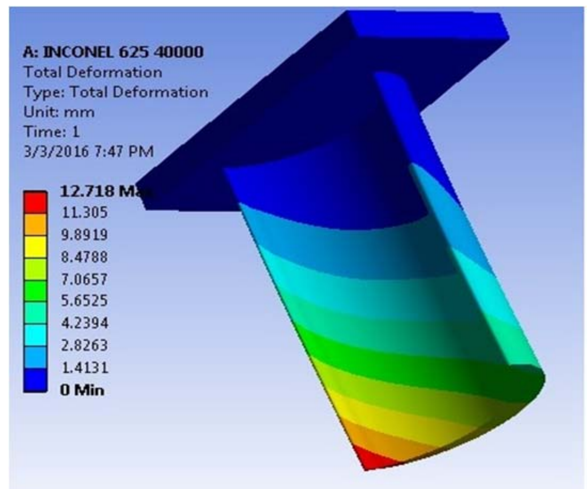
Deformation on Nimonic 80A Blade at 40000 RPM



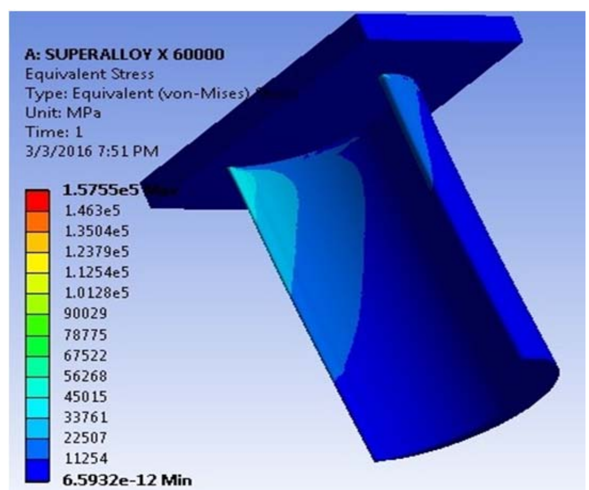
Stress on Inconel 625 Blade at 40000 RPM



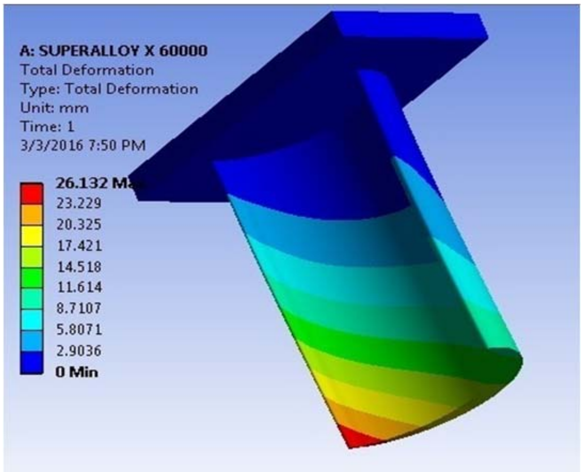
Deformation on Inconel 625 Blade at 40000 RPM



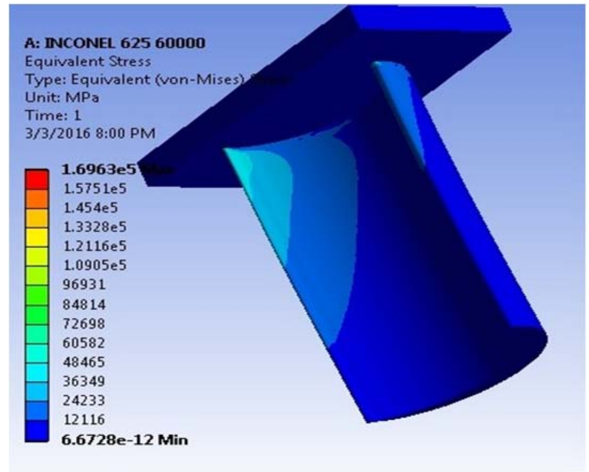
Stress on Super Alloy X Blade at 60000 RPM



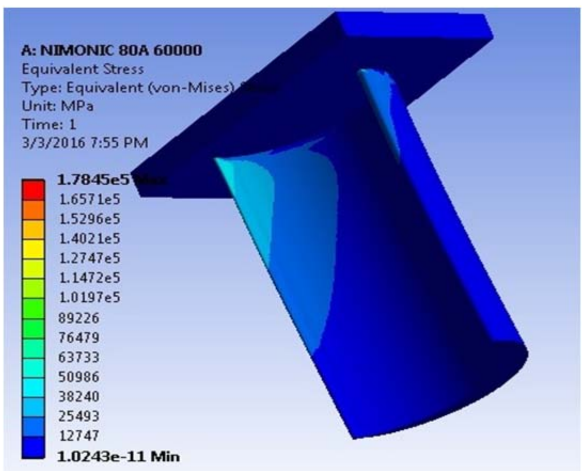
Deformation on Super Alloy X Blade at 60000 RPM



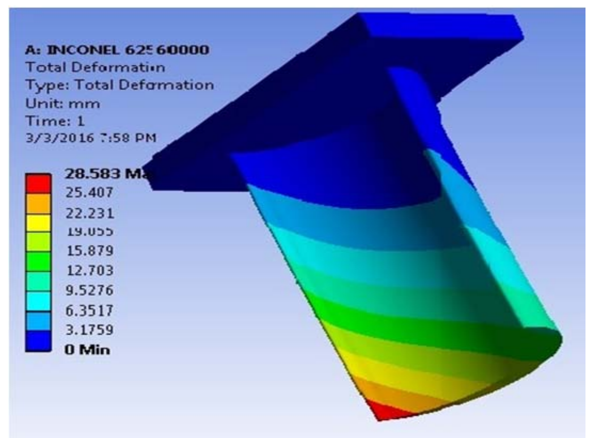
Stress on Nimonic 80A Blade at 60000 RPM

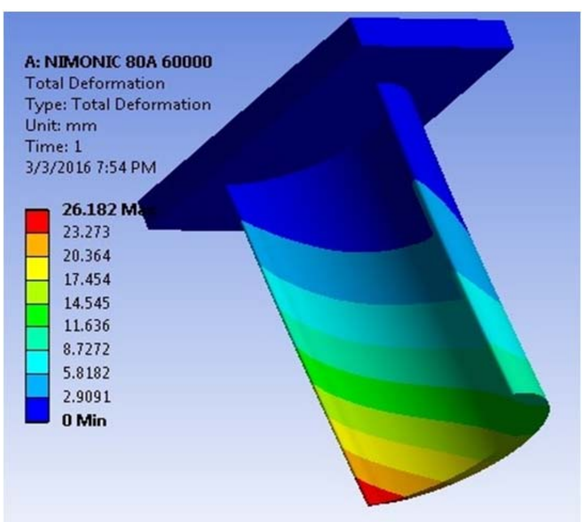


Deformation on Inconel 625 Blade at 60000 RPM



Deformation on Nimonic 80A Blade at 60000 RPM





Stress on Inconel 625 Blade at 60000 RPM

4. RESULT & DISCUSSION

Max. Stress/Max Deformation			
Speed	**Super Alloy X**	**Nimonic 80A**	**Inconel 625**
20000	6022.89	6808.81	5929.36
40000	6028.03	6814.84	5933.95
60000	6029.00	6815.75	5934.64

From the above analysis it is conclude that Inconel 625 should be used as a turbine blade material for varying speed condition as stress/deformation ratio is minimum at all speed.

Percentage Increase in Force(N)/Volume(mm3)			
Speed	**Super Alloy X**	**Nimonic 80A**	**Inconel 625**
20000to40000	8.53E-2	8.85E-2	7.74E-2
40000to60000	1.60E-2	1.33E-2	1.16E-2

From the above table it can also be concluded that for Inconel 625 there is minimum percentage increase in force per volume with increase in speed. Percentage increase in force per unit volume is less for change in speed from 40000 to 6000 rpm than that of 20000 to 40000 rpm. Von misses stresses for the blade are maximum at the joint portion where profile is attached to root. Total deformation is maximum at tip portion of the blade profile.

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