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Design and Analysis of Gas Turbine Blade for Optimization of Material

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Abstract: Turbines play a key role in power generation. As the machine is being used, there will be wear and tear of the machine. So, proper maintenance has to be done for the proper functioning of the turbines, or good material have to be used in the manufacture of the turbine blades to attain long run of the turbines. Since the turbine blades are working at high temperature and pressure there are extreme stresses developed on turbine blades. Withstanding of gas turbine blades for the elongations is a major consideration in their design because they are subjected to high tangential, axial, centrifugal forces during their working conditions. The first centrifugal stresses act on the blade due to high angular speeds, and second is thermal stresses that arise due to temperature gradient within the blade material Several methods have been suggested for the better enhancement of the mechanical properties of blades to withstand these extreme conditions. The main objective of the project is to bring out a material used in the manufacture of the turbines which is less in cost, gives a long run and can with stand all the properties required in required condition. Here, different materials are used in the manufacture of turbine blade and performed Static and Thermal analysis on the material in simulation software. All the modelling process is carried out in PROE Software package, and Simulation is done in ANSYS Mechanical Workbench.
Keywords: Gas turbine blade, optimization, Modelling, Static and Thermal Analysis, Proe, Ansys

I. INTRODUCTION

The use of gas turbines for generating electricity dates back to 1939. Today, gas turbines are one of the most widely-used power generating technologies. Gas turbines are a type of internal combustion (IC) engine in which burning of an air-fuel mixture produces hot gases that spin a turbine to produce power. It is the production of hot gas during fuel combustion, not the fuel itself that the gives gas turbines the name. Gas turbines can utilize a variety of fuels, including natural gas, fuel oils, and synthetic fuels. Combustion occurs continuously in gas turbines, as opposed to reciprocating IC engines, in which combustion occurs intermittently.

A turbine blade is the individual component which makes up the turbine section of a gas turbine or steam turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings. Blade fatigue is a major source of failure in steam turbines and gas turbines. Fatigue is caused by the stress induced by vibration and resonance within the operating range of machinery. To protect blades from these high dynamic stresses, friction dampers are used.

Fig1 Turbine Blade

Turbine blades are subjected to very strenuous environments inside a gas turbine. They face high temperatures, high stresses, and a potential environment of high vibration. All three of these factors can lead to blade failures, potentially destroying the engine. Therefore turbine blades are carefully designed to resist these conditions.

Turbine blades are subjected to stress from centrifugal force (turbine stages can rotate at tens of thousands of revolutions per minute (RPM)) and fluid forces that can cause fracture, yielding, or creep failures. Additionally, the first stage (the stage directly following the combustor) of a modern turbine faces temperatures around 2,500 °F (1,370 °C), up from temperatures around 1,500 °F (820 °C) in early gas turbines. Modern military jet engines, like the Snecma M88, can see turbine temperatures of 2,900 °F (1,590 °C). Those high temperatures weaken the blades and make them more susceptible to creep failures. The high temperatures can also make the blades susceptible to corrosion failures. Finally, vibrations from the engine and the turbine itself (see blade pass frequency) can cause fatigue failures.

Proper selection of blade material plays an important role in blade design. The factors that influence the selection of blade materials are

1) Method of manufacture
2) Ease of machining
3) The ability to produce blade sections free from flaws.
4) Ductility both allow of rolling of shapes.
5) The capacity for being welded.
6) Ease of forging easily.
7) Condition of operations.
8) Suitable tensile strength at high temperature.
9) Resistance to creep.
10) Cost.

In this paper we are doing analysis on first stages moving rotor blade of marine Gas turbine. Generally gas turbines work under high pressure, forces and temperature. Turbine blade has to withstand these conditions. So we mainly Concentrated on the turbine blade materials we had selected three materials ,Two of them are nickel based super alloys and one them is titanium alloy. Nickel based alloy are used because they have high resisting capacity and strength, titanium, Aluminum is used because it is light weight, more corrosive resistive and have high strength. So by doing analysis on these three materials we have to find out which material is best suited for marine application. For this first we had designed solid blade model in PROE and then we had imported this PROE file into ANSYS and there we had done fine meshing and then we had applied pressure, centrifugal forces and calculated structural analysis after we had done thermal analysis by applying temperature and heat flux.

Materials Selected

a) Nimonic 80A
b) Super alloy grade X
c) Titanium Aluminum alloy

Table 1 Material Properties

MATERIALS	NIMONIC 80A	SUPER ALLOY GRADE X	TITANIUM ALLUMINIUM
Young's Modulus (GPa)	222	160	110
Density (kg/m3)	8190	9000	4810
Poisson's ratio (m)	0.35	0.3	0.3
Thermal conductivity (w/mk)	24.5	22	8.4
Thermal expansion (c)	16.2e-6	10e-6	9.4e-6
Centrifugal force	17869N	19599.5N	8174.87N

II. MODELING OF TURBINE ABLDE

Pro/ENGINEER was the industry's first rule based constraint (sometimes called "parametric" or "variational") 3D CAD modelling system. The parametric modelling approach uses parameters, dimensions, features, and relationships to capture intended product behaviour and create a recipe which enables design automation and the optimization of design and product development processes. This design approach is used by companies whose product strategy is family based or platform driven, where a prescriptive design strategy is fundamental to the success of the design process by embedding engineering constraints and relationships to quickly optimize the design, or where the resulting geometry may be complex or based upon equations. Creo Elements/Pro provides a complete set of design, analysis and manufacturing capabilities on one, integral, scalable platform. These required capabilities include Solid Modelling, Surfacing, Rendering, Data Interoperability, Routed Systems Design, Simulation, Tolerance Analysis, and NC and Tooling Design.

A. Steps for modeling turbine blade

1) Open the PROE and select file from the menu bar, then choose modeling as part and solid, then enter our modeling part name and select ok. Then choose mm part dimensions, and next enter into the modeling sheet.
2) Select the front plane and click on sketch.
3) Select the point command and indicate the points as per the co-ordinate values.
4) Join all the points plotted according to the co-ordinates (Xi,,Yi) by using spline command.

Where, i is co-ordinate number for point.

a) Xi is X co-ordinate of ith point.
b) Yi is Y co-ordinate of ith point.

5) Join the co-ordinate points by using spline curve command. Then click on tick mark.
6) Extrude the drawn figure by using extrude command.
7) Select the drawn sketch which has to be extruded.
8) Then extrude the section sketch upto required dimension.
9) After extruding, then click on tick mark for completion.
10) Change the view into AB standard view.
11) The standard isometric view displays the turbine blade model.
12) Change the figure wire frame drawing into solid model.

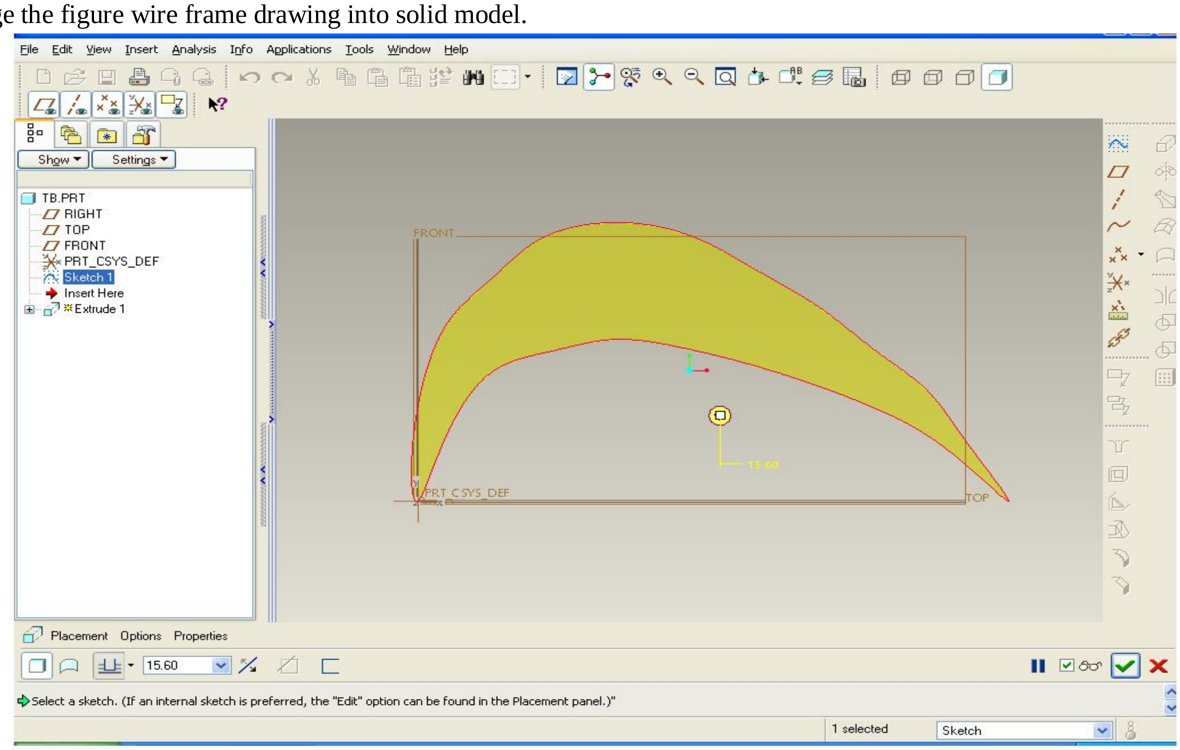

Fig 2 Cross-section of Aerofoil blade sketch

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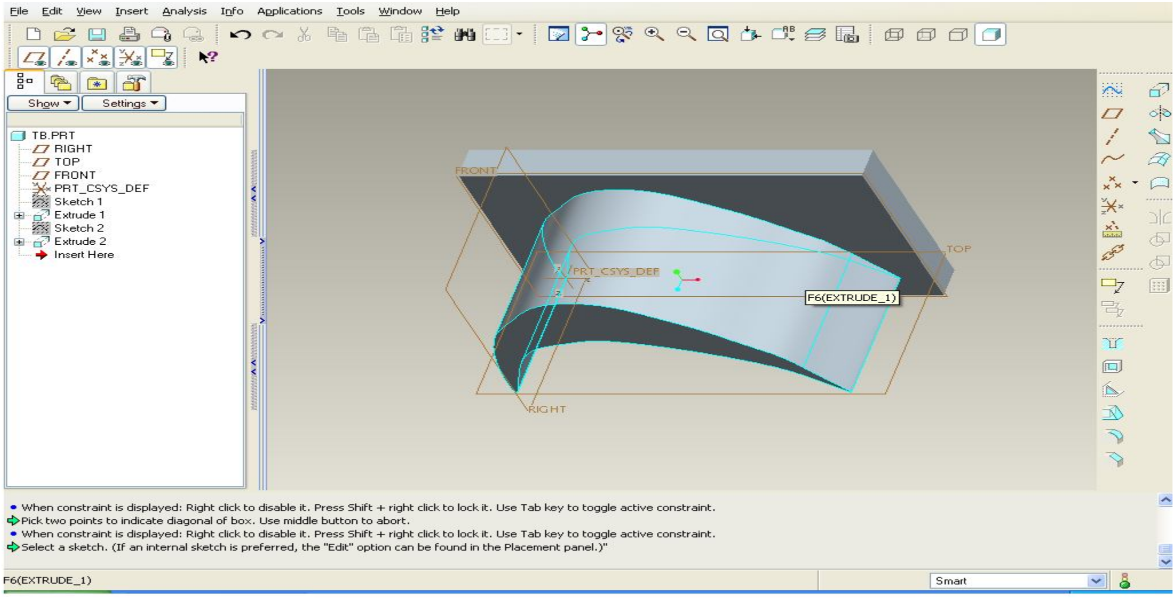

Fig 3 Solid Model of Turbine Blade

13) Reselect the front plane and draw the rectangular box by selecting the rectangular command.
14) Extrude the rectangle box 6mm by using extrude command.
15) Attach the rectangle to the blade profile.
16) Change the diagram from wire frame model to the solid model and standard orientation.
17) Finally save the diagram in IGES format for further analysis.

III.ANALYSIS OF TURBINE BLADE

The ANSYS Work bench platform is the frame work upon the industry's broadcast and deepest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user through even complex metaphysics analyses with drag and drop simplicity. With bi-directional CAD connectivity, powerful highly automated meshing, a project level update mechanism, pervasive parameter management and integrated optimization tools, the ANSYS Work bench platform delivers unprecedented productivity, enabling simulation The Work bench environment allows you to solve much more complex analyses, including (as of ANSYS16.0):

1) Multi-part assemblies.
2) 3-D solid elements, shell elements, and shell-solid assemblies.
3) Non-linear contact with or without friction.
4) Small displacement and large displacement static analyses.
5) Modal, harmonic, and Eigen value bucking analyses.
6) Steady state thermal analysis, including temperature Dependent material properties and thermal contact.

A. Procedure For Analysis In Ansys Workbench:

1) Open ANSYS work bench analysis version16.0 ANSYS work bench environment will be seen. Then assembled part in CATIA is imported in (IGES) format to ANSYS by going through this step.
2) Static structural geometry import ANSYS work bench environment will be seen like this. Select the static structural analysis type from top menu bar by clicking new analysis tab as shown below.
3) The next step will be assignment of material properties to the solid model. Default material will be structural steel in ANSYS, materials applying on the element whose analysis is to be done will be changed by varying its mechanical properties like young's modulus, density, Poisson ratio,etc.
4) At the left side of the page, click MODEL EDIT then mechanical window will open. Select mesh on left side of the screen and select sizing at the bottom of the page then you can select the relevance center of mesh you are desired.

5) Right click to static structural on left side of the page and then click to INSERT option and provide then click FORCE and these forces are provided in all 3directions.
6) Select the points where forces are to be applied and its magnitude with its direction. Click to apply on bottom left portion of the page.
7) Similarly click STATIC STRUCTURAL INSERT fixed supports (constraints).
8) Select the points where constraints are to be applied.
9) Right click to solution option on top left portion of the page and then select what are outputs to be obtained in this present project of the page and then select what are outputs to be obtained in this present Project we required Deformation and Equivalent Stress (Von-misses).
10) Click on SOLVE icon on Top menu as shown below.
11) ANSYS reports are generated.
12) Click to report preview and print preview.
13) You can get the reports in the word format by using the SEND TO button on the pallet.

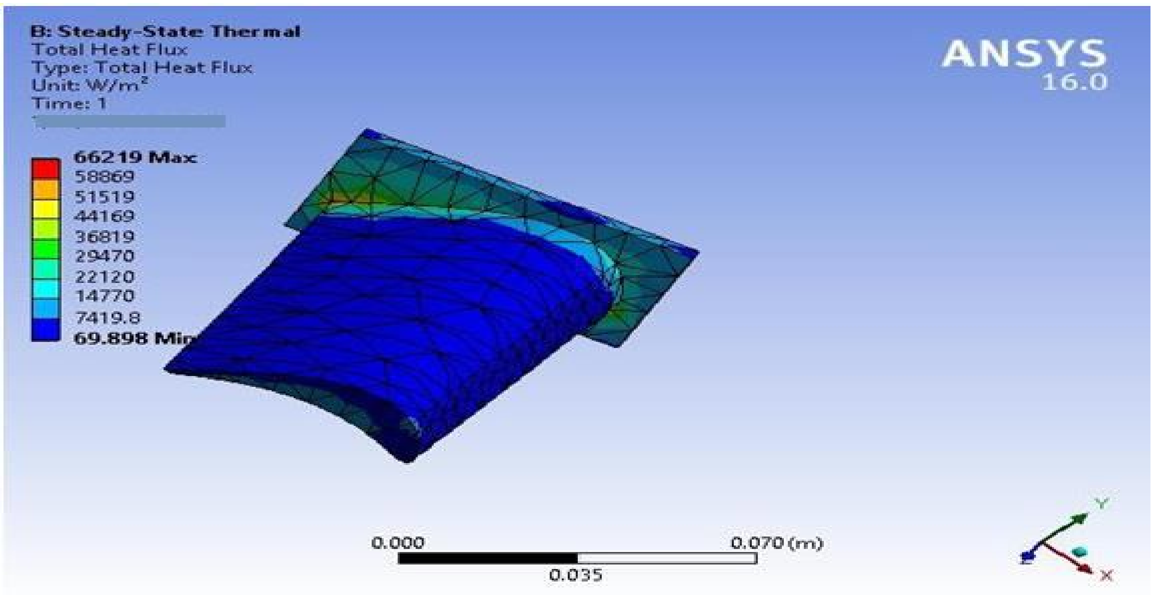

Fig. 4 Total Heat flux of Turbine Blade with NIMONIC 80A material

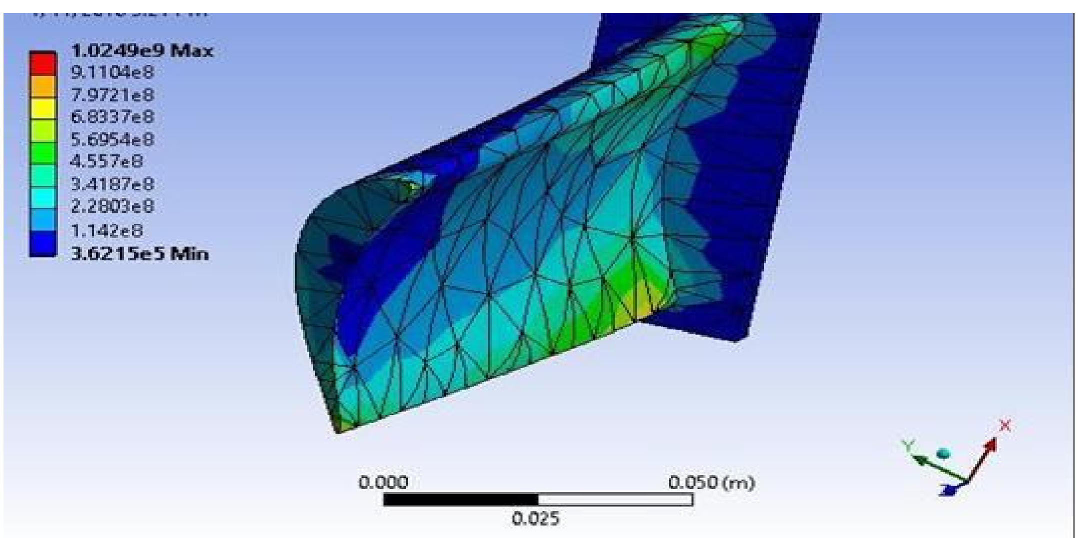

Fig 5 Equivalent stress of turbine blade with NIMONIC 80A material

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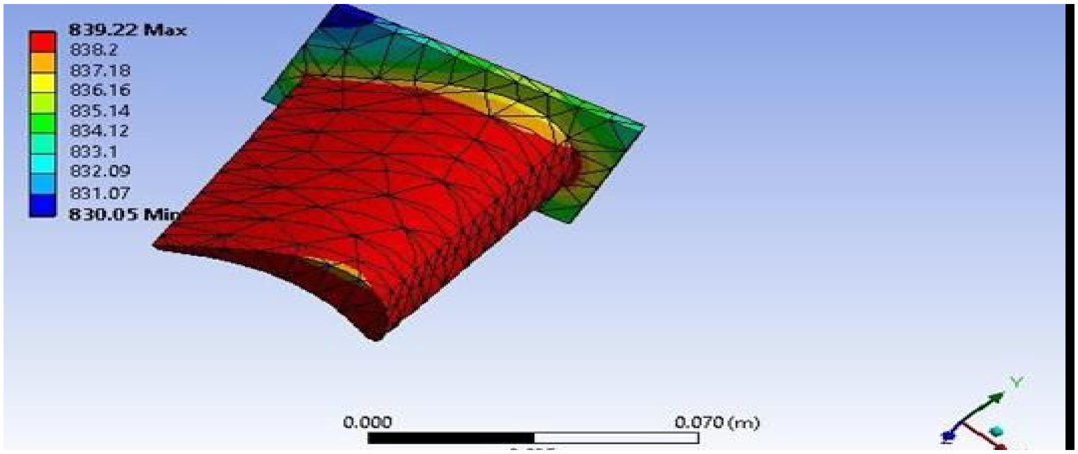

Fig 6 Temperature analysis of turbine blade with NIMONIC 80A material

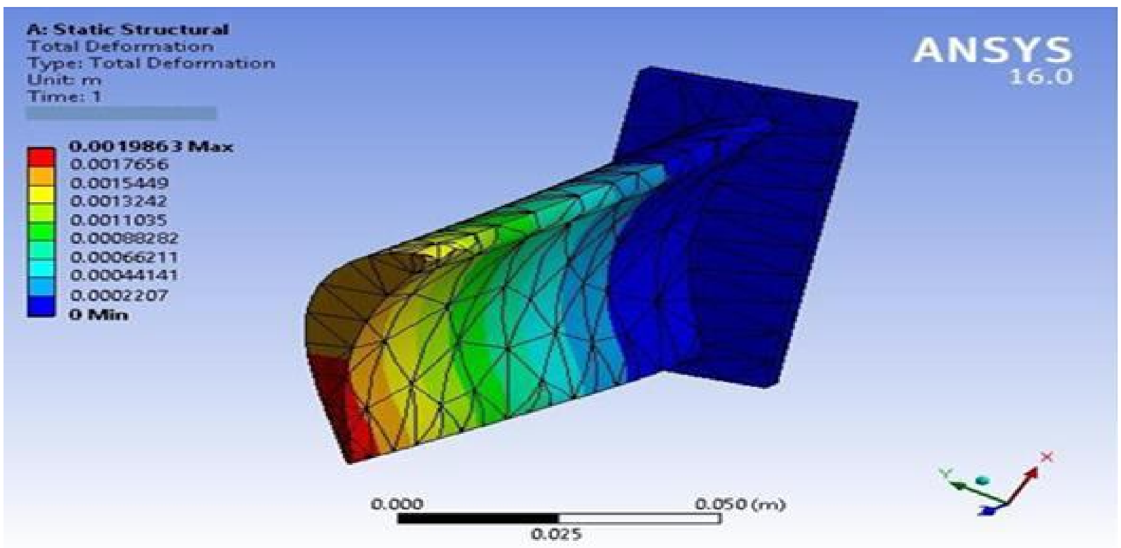

Fig 7 Total deformation of turbine blade with NIMONIC 80A material

IV. RESULTS AND DISCUSSIONS

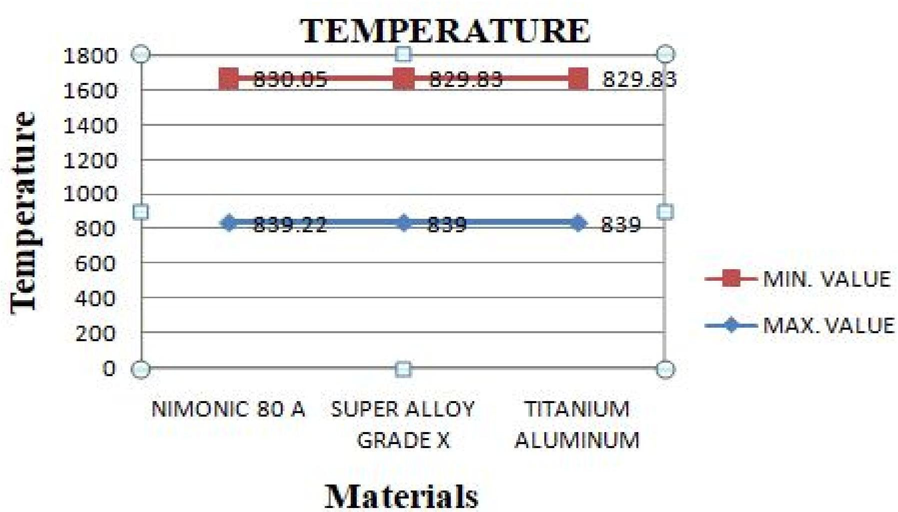

Fig 8 Temperatue distribution of turbine blade for different Materials

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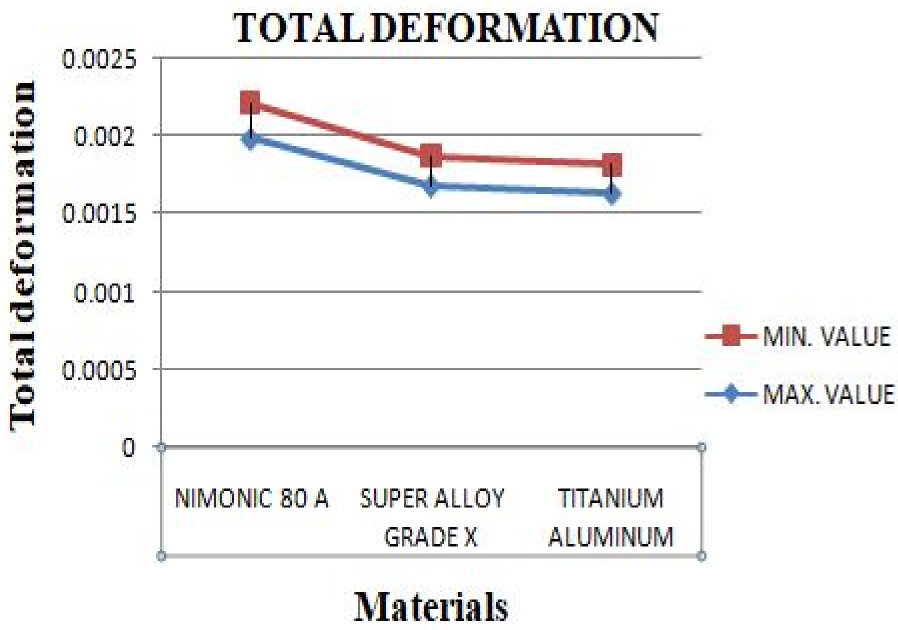

Figure 4.4 Total deformation of turbine blade for different Materials

From the drawn graphs we observe that,

1) The figure 4.1 represents stress values of the materials. The NIMONIC 80A having highest stress values than the other two materials. i.e. 1.0249E9 is maximum and 3.625E5 is minimum.
2) The super Alloy Grade X having the stress values of 5.5621E8 is maximum, and 2.077E5 is minimum.
3) The Titanium aluminum having the stress values of 4.99E8 is maximum, and 1.545E5 isminimum
4) From the results the Titanium aluminum material is having less stress values than compare to two materials. So, the titanium aluminum is best material for turbine blade application.
5) The figure 4.2 represents temperature values of the materials. The NIMONIC 80A, Super Alloy Grade X, Titanium Aluminum having the minimum temperature values of 830.05, 829.83, 829.83 and maximum temperature values of 839.22, 839,839 respectively.
6) From the results the three materials are having same values approximately, so, any material can be taken for turbine blade application as per the temperature results.
7) The figure 4.3 represents the total deformation values of the materials. The NIMONIC 80A having the deformation value of 0.0016341 is maximum and 0.00018157 is minimum.
8) The super Alloy Grade X having the deformation value of 0.0016833 is maximum, and 0.000187is minimum.
9) The Titanium aluminum having the deformation values of 0.0016341 is maximum, and 0.00018157 is minimum.
10) From the results the Titanium aluminum material is having less deformation values than compare to two materials. So, the titanium aluminum is best material for turbine blade application

V. CONCLUSION

Three materials Nimonic 80A, Super alloy grade X, Titanium Aluminum used for manufacturing of turbine blades of a gas turbine engine are meant for marine applications and power generating applications, and they have been selected. The turbine blade model profile is generated by using PROE 4.0 software. The turbine blade is analyzed for its structural and thermal performance for the loading conditions in ANSYS16.0. From the above results Nimonic 80A is having high thermal and stress withstanding capacity hence it can be used for high thermal and stress applications. Although Titanium aluminum is having best properties such as less weight and corrosive resistance, we can use it for turbine blade application. Super alloy grade X is having medium stress compare to Nimonic 80A and Titanium aluminum. But Titanium aluminum is having less stresses than Nimonic 80A and Super Grade X. Hence, we conclude that Titanium Aluminum is best suited for turbine blade applications because of high thermal withstanding capacity and minimum deformation. And it is easy available material in market with low cost.

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