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Design And Analysis of Axial Flow Turbine Rotar Blades Made with Forged Alloys of Ss, H30 Steel and Titanium for Different Turbine Conditions

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***Abstract*:**

The design of an axial flow gas turbine differs from that of a regular turbine. Material rotor blades must endure not only high temperatures, but also thrust generated in an axial direction. Therefore, the rotor blades must be specially designed to handle the thrust as well as the heat. They must be able to withstand the thrust as well as the high temperatures, and must also be able to withstand the vibrations of the turbine. Thermal degradation and tangential thrust degradation can both be found in axial turbines. The rotor blades must be able to withstand both the thermal and thrust forces, as well as the vibrations of the turbine. This means that they must be made from materials with high thermal and thrust resistance as well as high strength and stiffness. Additionally, the rotor blades must be able to withstand corrosion and wear and tear from the rotor shaft. It is necessary to analyze the degradation of turbine rotor blades for different materials in order to avoid this major problem. The current work focuses on high strength forged alloys made from Steel**,** H30 and titanium analyzed for degradation using Ansys software. Various temperatures and pressure conditions were examined in the present work for transient thermal analysis with CFD flow. Analysis of axial flow gas turbines is based on temperatures of 1000 and 1200^{0}C, and pressures of 28 and 30 MPa.

Key words*: Gas Turbine Blade, study state Thermal analysis, Transient Thermal analysis*

1.0 Introduction

Gas turbines are the primary generators of energy in each of these experiments. Due to the high efficiency of gas turbines, they were chosen as the best option for this application. Three major components make up a simple gas-turbine: compressor, combustor, and turbine. Fuel and compressed air are combined and burned in a gas turbine that runs on the Brayton cycle principle. In order to generate power, the hot gas is expanded by turning a turbine. Gas turbine engines convert the chemical energy of the fuel into mechanical energy, which can be expressed as shaft power or kinetic energy. Power production gas turbines are gas turbines specifically designed to produce electricity. The gas turbines on an airplane transform the fuel's potential energy into motion. Several parts of the engine collaborate to convert the energy stored in the fuel into the shaft power or propulsion force that moves the engine.

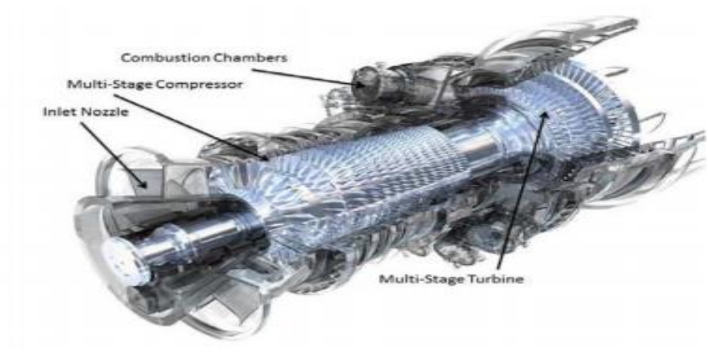

Figure 1: gas turbine

Gas turbines convert combustion energy into heat by compressing the working gas (air). The working gas is subjected to rising temperatures and pressures. Working gas energy is converted into rotating blade energy by means of gas-blade interaction in the engine. Both types of gas turbines can be shown in the diagram below. There is an open cycle (which is internal) and a closed cycle (external type). The combustor and the turbine are the most crucial components of both compressors.

GTurbine blades in gas turbines or steam turbines are made up of many smaller parts. The blades are what actually collect energy from the superheated, super pressed gas that the combustor produces. In order to function reliably in such extreme conditions, gas turbines frequently require exotic materials like superalloys and a wide variety of cooling technologies. These may be broken down into internal and external cooling, as well as thermal barrier coatings on the blades individually. For both steam and gas turbines, blade fatigue is a common cause of failure. Vibration and resonance within the operational range of machinery are known stressors that contribute to fatigue. Blades are safeguarded from these extreme dynamic loads by using friction dampers.

Objectives:

- To study the gas turbine blade geometry
- A three-axis CNC machine was used to optimize the turbine blade, and different tools were used to manufacture it dimensionally.
- The Gas turbine blade design in done by using NX 12.0 and Analysis is done by ANSYS 2020R1(Inconel 625)
- To the gas turbine blade analyze with ANSYS 2022R1 (study state and transient thermal)

2. Literature Review

Akira Murata et al. (2013) In their investigation of the centrifugal buoyancy effect, they used large eddy simulations, and the results showed that the buoyancy decreased the pressure loss coefficient during a sharp turn, while increasing and decreasing the straight pass' pressure loss coefficient during the first and second straight passes, respectively. Deepu et al (2012) Learning while on location A gas turbine is a device that converts the thermal energy of fuel into mechanical work, such as the rotation of a shaft. The blades of the turbines of a gas turbine power plant are the most important parts of the entire facility. Evans, A. G., Mumm (2001) Gas turbines are primarily protected by TBC systems from the corrosive effects of high temperature erosive chemicals. Thermal cycling and mechanical stresses can cause wear, cracks, and TC delamination, which affects their performance. Garcia and Grandt, (2005). A fatigued component's fatigue life is severely shortened when it comes into contact with another component while under contact stress due to micro-slip at the contacting interface. George and Titus (2014), In their study to significant centrifugal forces throughout their operational conditions. Gas turbine blades may experience elongation if they must tolerate these stresses. Analyzes and summarizes the changes made to the gas turbine blade cooling route design. Gongnan Xie et al. (2013) Several quantitative studies were conducted to find the optimal arrangement of downstream half-size ribs for heat transfer and pressure drop. It was determined that six distinct ribbed channels could be compared.

GongnanXie et al. (2014) used a variety of truncated rib designs to study turbulent heat transport quantitatively. The effects of truncation ratios (truncated length to passage width) on pressure drop and heat transfer enhancement under constant total length conditions were investigated by engineers who designed rib topologies with varying truncation ratios. Heeyoon Chung et al. (2015) Experiments were conducted to determine how well a rib-roughened channel with an intersecting rib transfers heat and mass. Two different rib configurations and channel sizes were evaluated. The test findings showed that the ribs with the most intersections and angles performed the best. Htwe et al (2015), Gas turbines are crucial to the production of electricity. Many different types of electrical generating plants utilize gas turbine technology. The cutting edges on the turbine rotor are the most important component of a gas turbine's control system. Static loads have the greatest impact on the cutting edges of turbines. The cutting edges of the gas turbine rotor are particularly sensitive to temperature changes. Jaroslav Pokluda (2010) An insulated ceramic top coat, a corrosion-resistant layer, and a bond coat are the standard components of thermal barrier coatings. The TBC spalls when a thermally produced oxide layer, initially 2-3 m thick between the bond coat and top coat, expands to 8-10 m due to excessive heating. When heated, the interfaces between the coating and the gas channel and the coating and the substrate degrade. Jiang and Yang (2010),gas turbine reliability and machineability are improved by study into life prediction and damage control In gas turbines, creep and fatigue are the most typical modes of failure.

3. Research Methodology

The aerospace engines have been the driving force behind the majority of the advancements in gas turbine technology.

A turbine is a device used to generate fluid flow, and its turbine rotor is turned by an agent that generates heat, typically an exhaust gas stream, gaseous byproducts of chemical reactions, or compressed gas. Based on the working agent's mass flow intensities, this available work determines how much power the turbine can generate and use to run various pieces of machinery. The axial flux and the radial fluid systems are classed for the flow path of the exhaust gas. Each turbine consists of two main components which make up the stage of the turbine.

- The stator, a stationary rim with profiled vanes fixed either co-axially (in axial-flow turbines) or in parallel (in radial-flow turbines).

- Turbine blades consist of a revolving disk with a stationary rim (or many stationary rims) with profiled blades mounted either around the disk's periphery (in axial flow turbines) or on its face surface (in radial-flow turbines).

- Turbines are separated into action (impulse) turbines and reheat (steam) turbines based on how the incoming energy of exhaust gases is distributed among the fundamental subassemblies. Exhaust gases in reaction turbines are decompressed not only by the directing vanes (stator vanes) at the nozzle's tip, but also by the vanes in the turbine's rotor.

- The energy produced is split between running the compressor in industrial turbines and generating power for the power receivers. Gas turbines are integral components of aeronautical engines like turbojets, turboprops, and helicopter engines. Increases in engine drive (power) can be achieved by optimizing turbine performance, which in turn influences motor efficiency.

This effectiveness is quite sensitive to the exhaust temperature at the turbine inlet. Increasing this temperature by more than 450 K over the past few years has greatly improved turbine overall performance and resulted in an even better unit power coefficient. To Specialized techniques are employed to renew the cabs and blades, guaranteeing consistent service even when subjected to extreme temperatures and mechanical stress.:

Figure 2: Adaptive CNC blending of repaired air foil tip

The CAD software consists of the computer programs to implement computer graphics on the system plus applications programs to facilitate the engineering functions of the user company. CAD/CAM software uses CAD drawing tools to describe geometries used by the CAM portion of the program to define a tool path that will direct the motion of a machine tool to machine the exact shape that was drawn. CAM uses Computer systems to plan, manage, and control the operations of a manufacturing plan through either direct to indirect computer interface with the plant's production resources. Figure represents the mockup of the milling process using the GUI Interface. NX 12 delivers a number of feature editing and creation enhancements that drive productivity improvements. For example, you can now see the feature section direction when creating, editing, or replacing features. You now have the option to retain or delete child features when deleting features.

3.1 Design for Additive Manufacturing:

Additive manufacturing is more important than ever in product design. NX 12 gives you the tools to design lightweight parts by filling a volume with a lattice structure, helping you optimize your design for additive manufacturing, reduce material use and meet weight requirements without compromising the strength or robustness of your design.

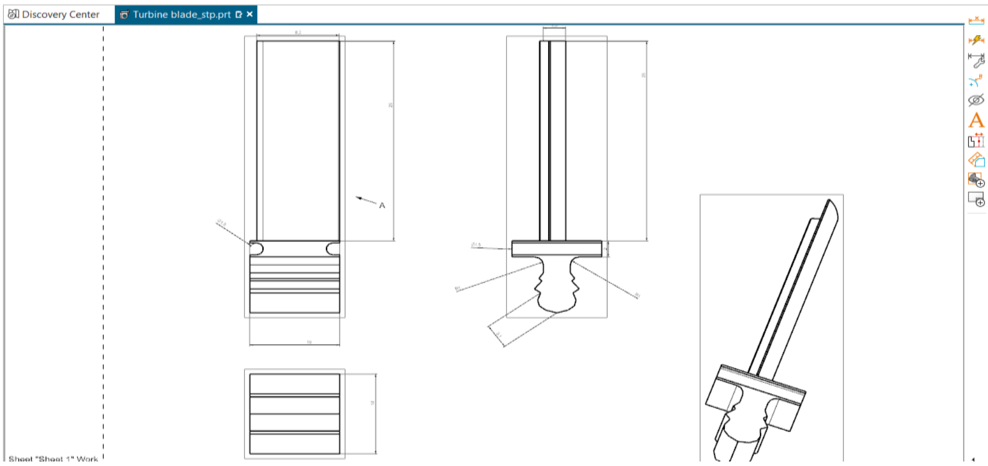

Figure 3: Geometric view

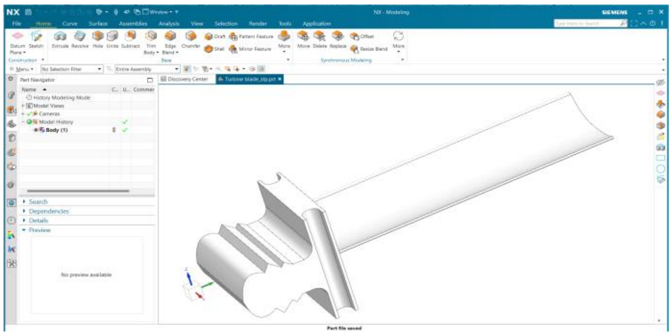

Figure 4: Gas turbine blade

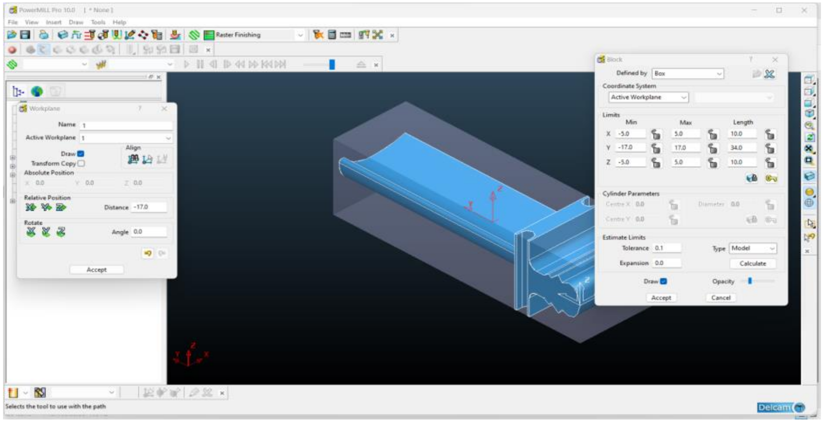

Figure 5: Imported model in CAD CAM Software

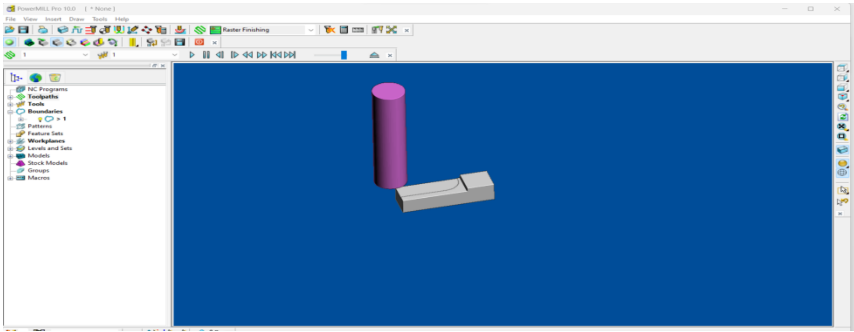

Figure 6: turbine blade tool Analyzation with Inconel material

Tuijin Jishu/Journal of Propulsion Technology
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Vol. 45 No. 1 (2024)

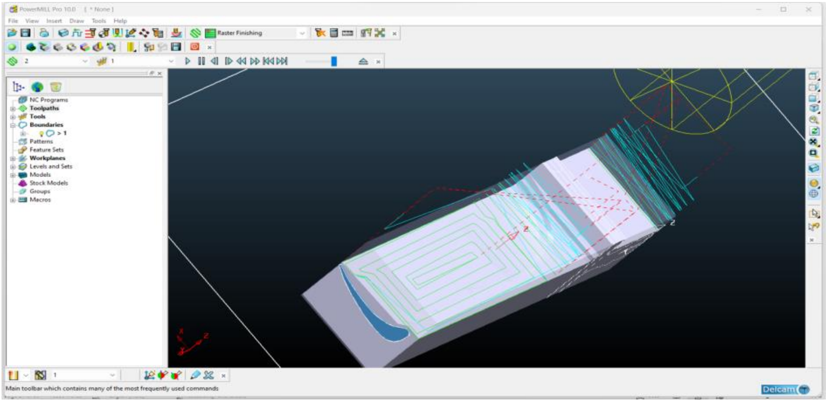

Figure 7: Turbine blade optimization process with INCONEL 718 Material

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It can be used to analyze either small or large-scale deflection under loading or applied displacement. It can analyze elastic deformation, or "permanently bent out of shape" plastic deformation.

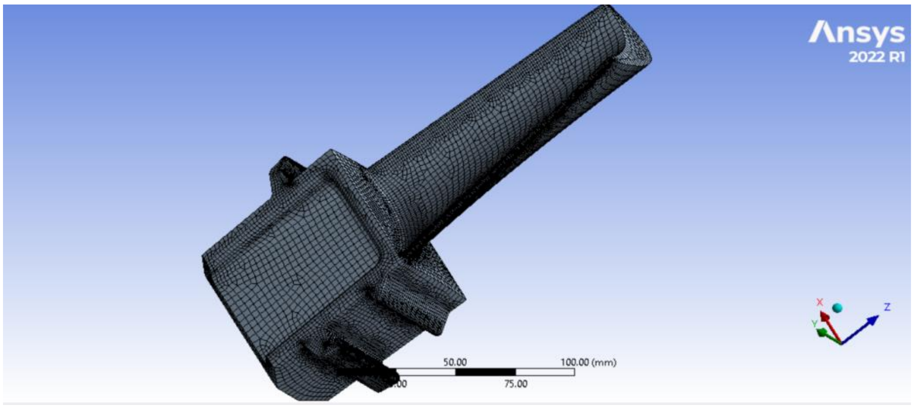

Figure 8: Meshed view

Titanium T6: Grade 4 titanium is the strongest pure grade titanium, but it is also the least moldable. Still, it has a good cold formability, and it has many medical and industrial uses because of its great strength, durability and weldability

Density	4.62e-06 kg/mm³
Structural	
Isotropic Elasticity	
Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	96000 MPa
Poisson's Ratio	0.36
Bulk Modulus	1.1429e+05 MPa
Shear Modulus	35294 MPa
Isotropic Secant Coefficient of Thermal Expansion	9.4e-06 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	930 MPa
Tensile Ultimate Strength	1070 MPa
Tensile Yield Strength	930 MPa
Thermal	
Isotropic Thermal Conductivity	0.0219 W/mm·°C
Specific Heat Constant Pressure	5.22e+05 mJ/kg·°C

Structural Steel Material properties:

Structural Steel is a chromium-nickel based steel that possesses increased levels of resistance against several substances, due to the addition of molybdenum in its composition

Properties of Outline Row 4: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Thermal Conductivity	60.5	W m^-1 C^-1
5	Specific Heat Constant Pressure, C_p	434	J kg^-1 C^-1

Properties- H30		
Tensile strength	892～017	σb/MPa
Yield Strength	060	σ 0.2 ≥/MPa
Elongation	79	δ5≥(%)
Density	800	kg/m3
Thermal conductivity	35-74	W/m.K
Specific heat	450-460	J/kg.K
Resistivity	0.50-0.60	Ohm.mm2/m

4. Results And Discussions

- Transient thermal analysis involves assessing the equilibrium state of a system subject to constant heat loads and environmental conditions.
- The simplest form of static structural analysis A static structural analysis determines the effect of steady (or static) loading conditions on a structure, while omitting inertia and damping effects, such as those caused by time varying loads.

4.1 Static Structural Analysis at 28 MPa Pressure using Structural steel:

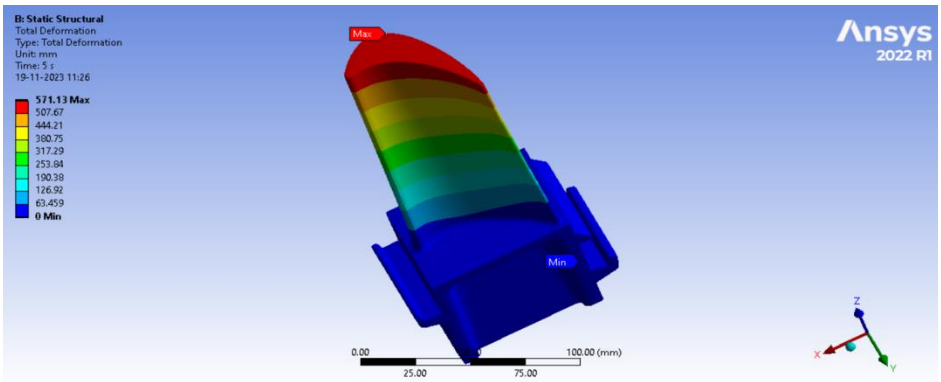

Figure 9: Total deformation

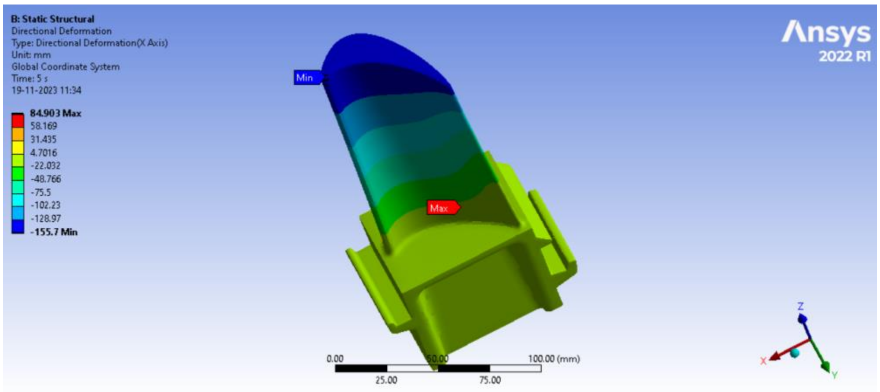

Figure 10: directional deformation

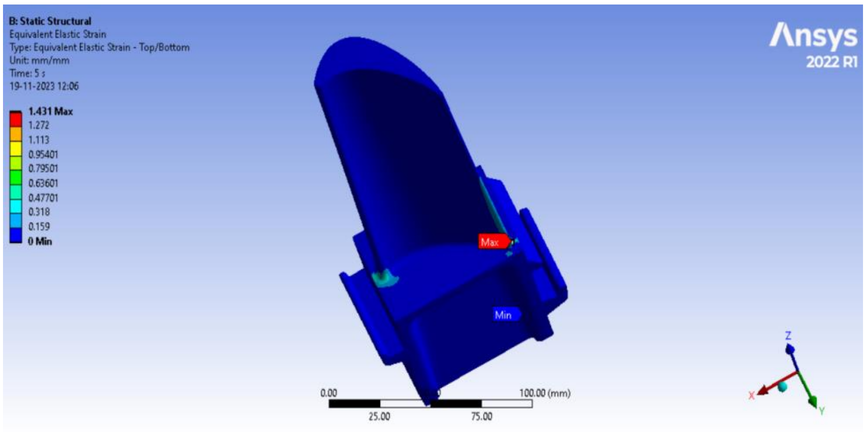

Figure 11: Equivalent elastic strain

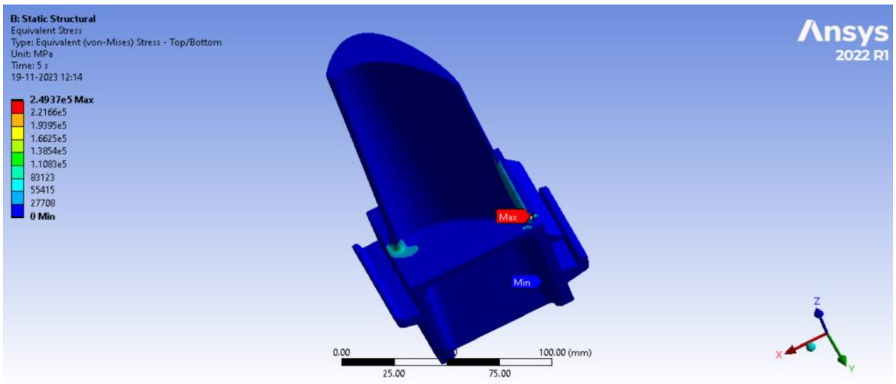

Figure 12: Equivalent Stress

4.2 Static Structural Analysis at 28 MPa Pressure using Titanium alloy:

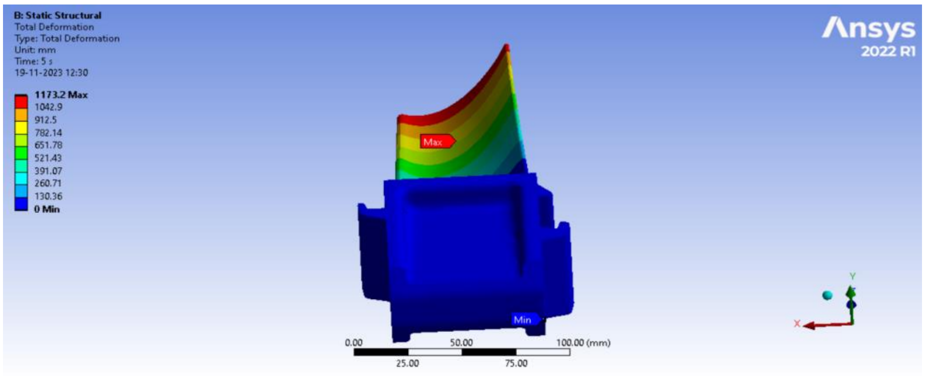

Figure 13: Total deformation

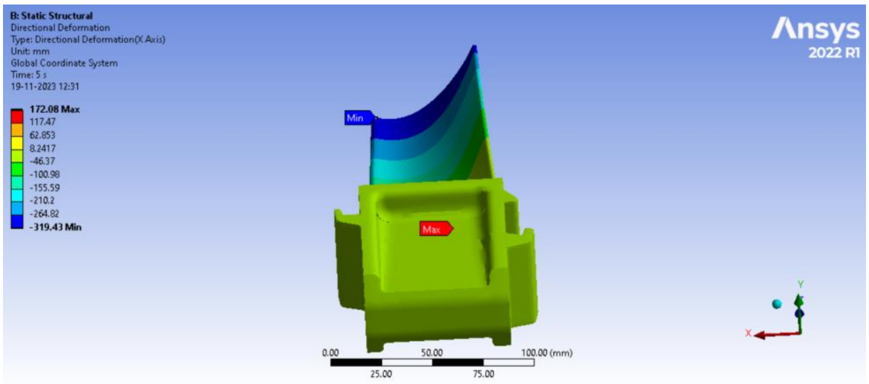

Figure 13: directional deformation

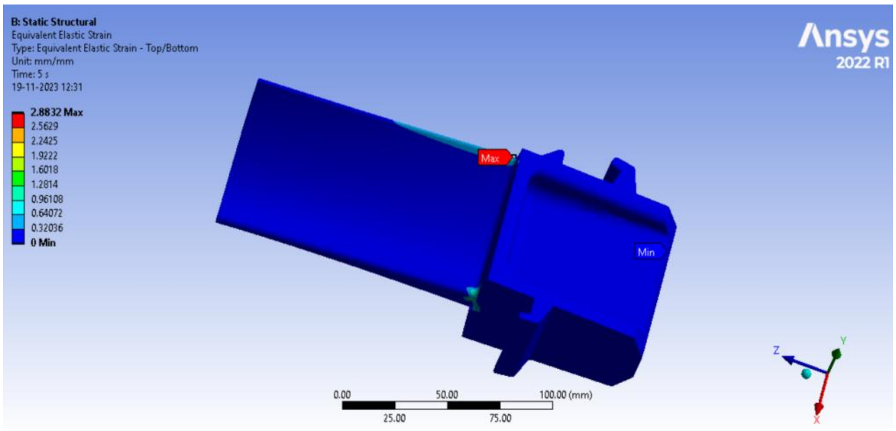

Figure 14: Equivalent elastic strain

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 1 (2024)

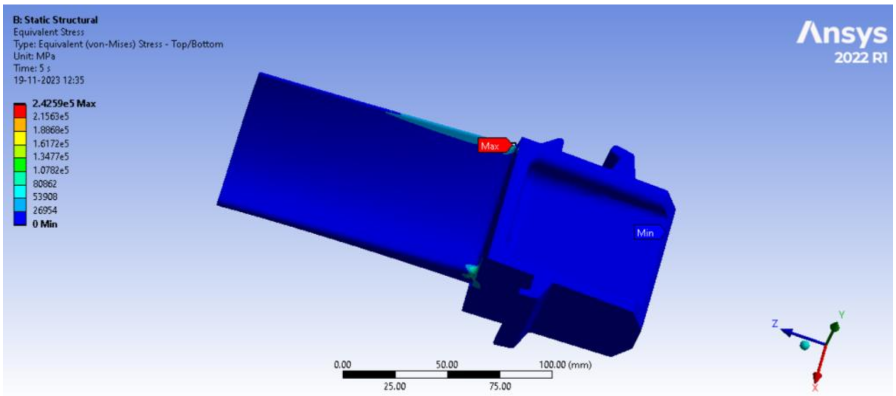

Figure 15: Equivalent Stress

Static Structural Analysis at 28 MPa Pressure using H30:

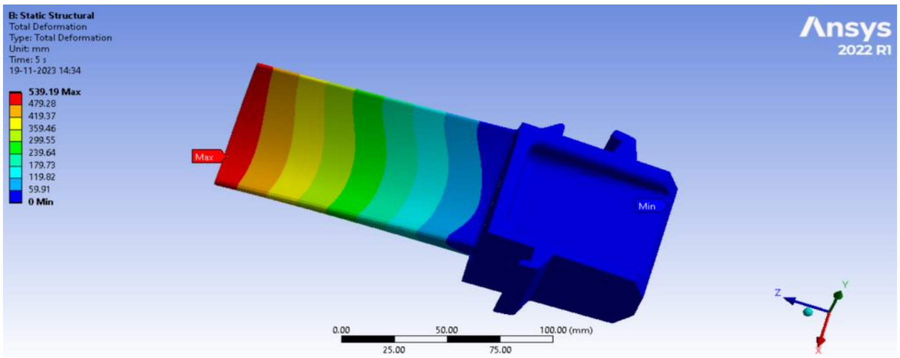

Figure 16: Total deformation

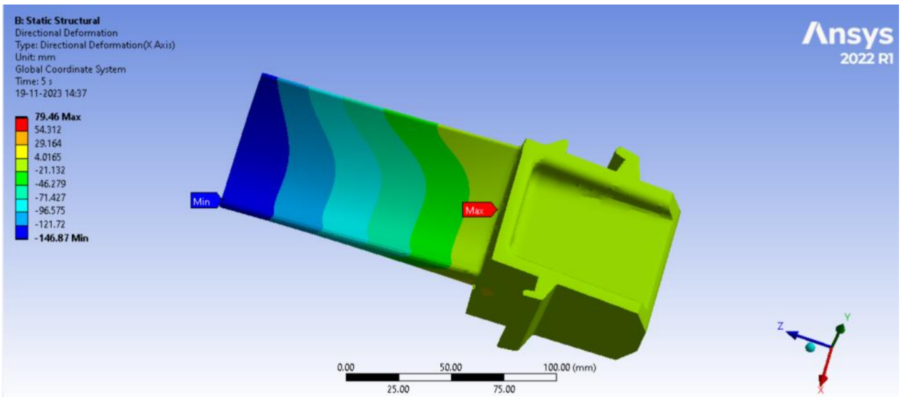

Figure 17: directional deformation

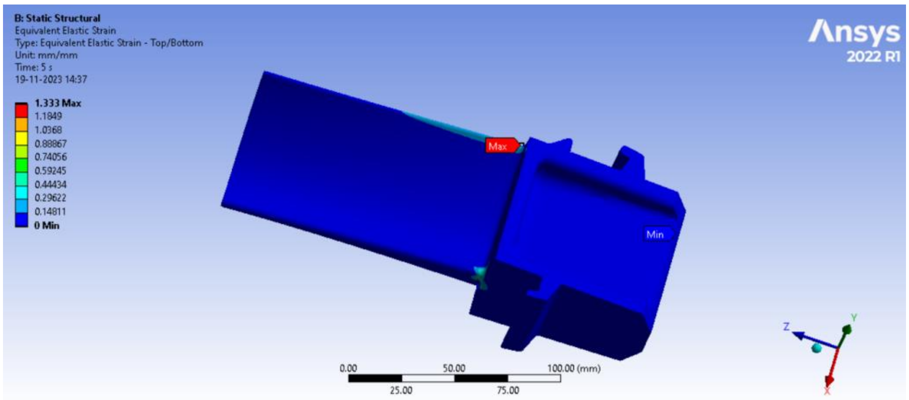

Figure 18: Equivalent elastic strain

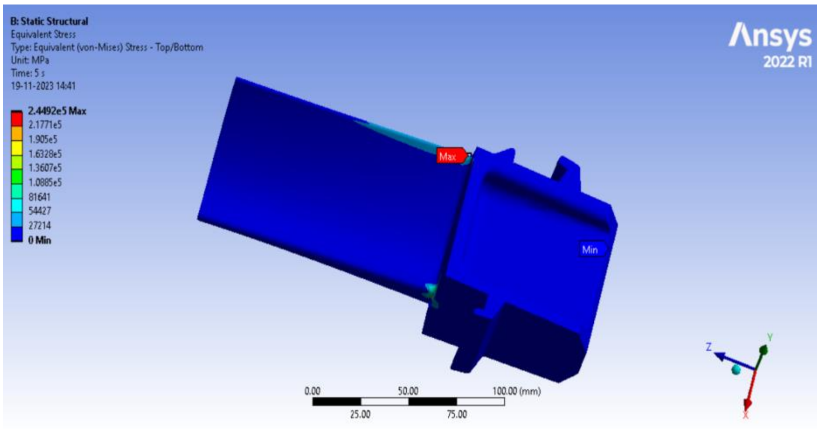

Figure 19: Equivalent Stress

4.3 Static Structural Analysis at 30 MPa Pressure using Structural steel:

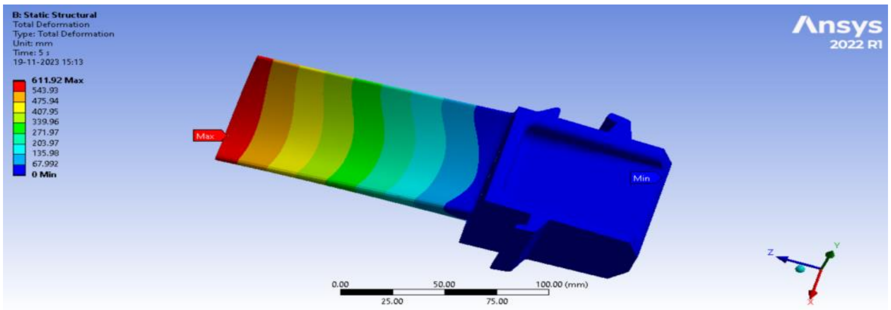

Figure 20: Total deformation

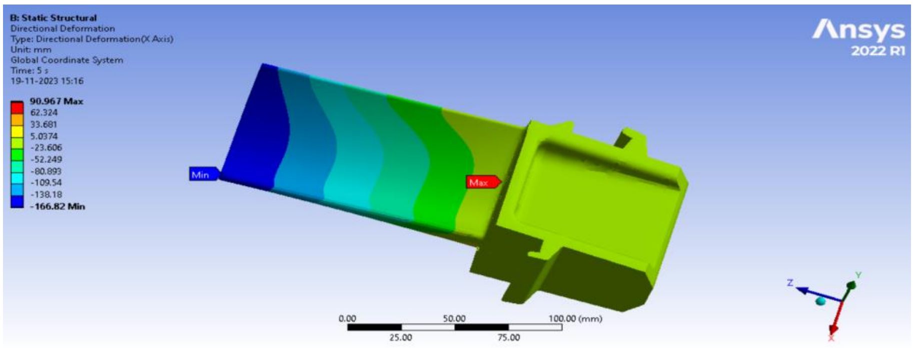

Figure 21: directional deformation

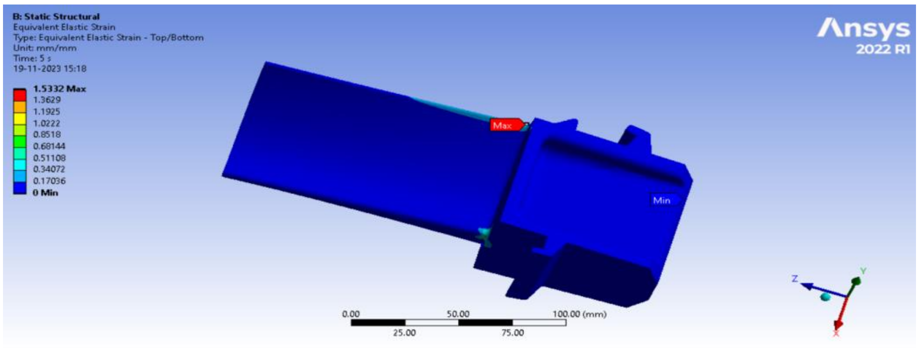

Figure 22: Equivalent elastic strain

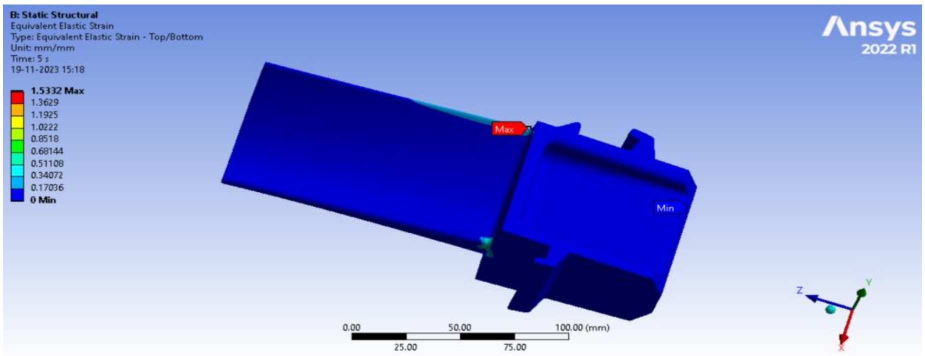

Figure 23: Equivalent Stress

Static Structural Analysis at 30 MPa Pressure using Titanium alloy:

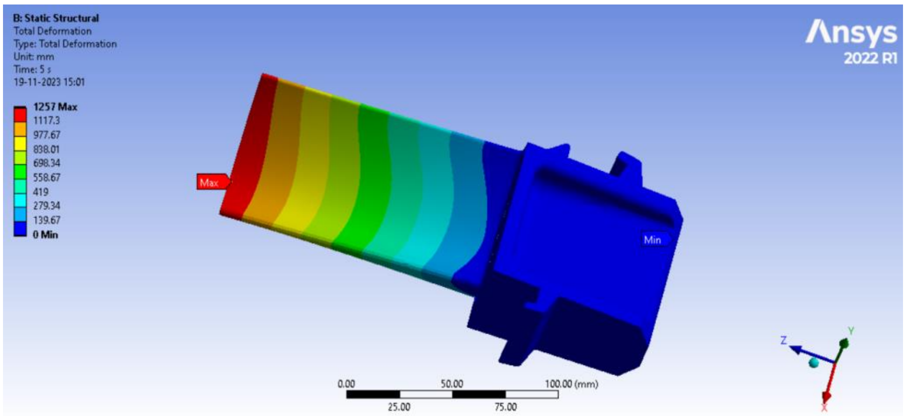

Figure 24: Total deformation

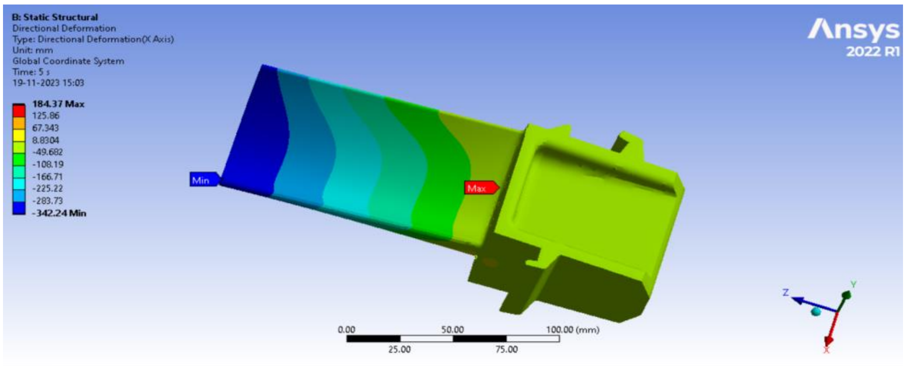

Figure 25: directional deformation

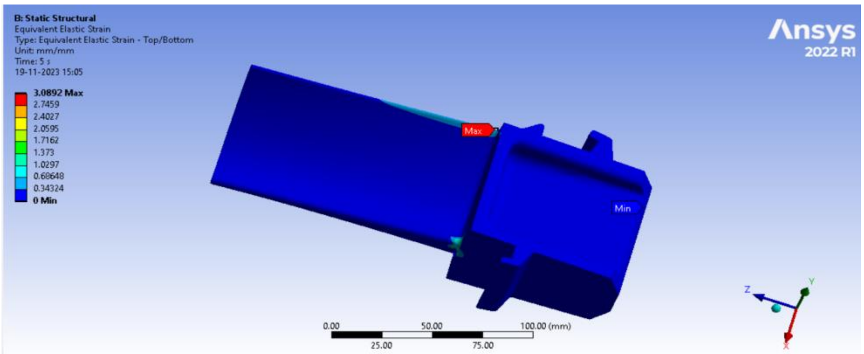

Figure 26: Equivalent elastic strain

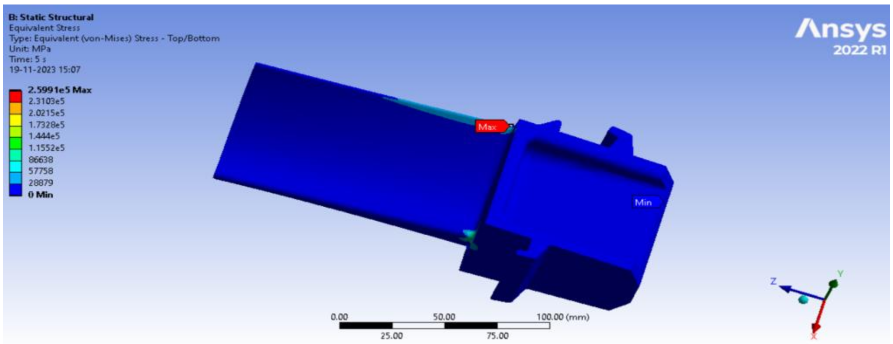

Figure 27: Equivalent Stress

Static Structural Analysis at 30 MPa Pressure using H30:

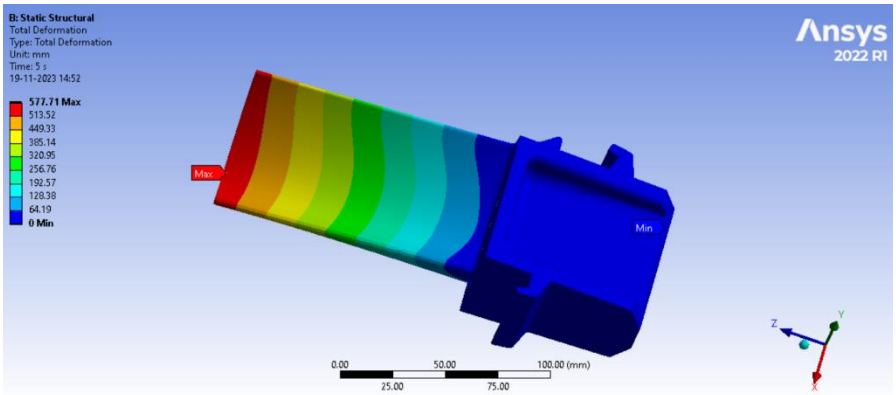

Figure 28: Total deformation

Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 1 (2024)

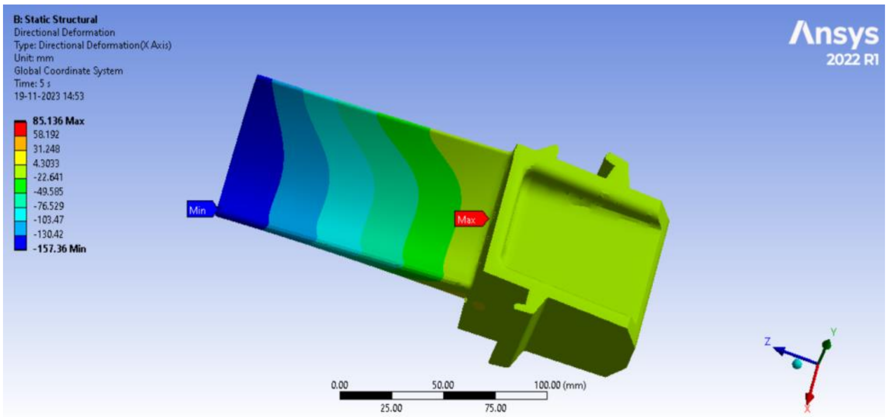

Figure 29: directional deformation

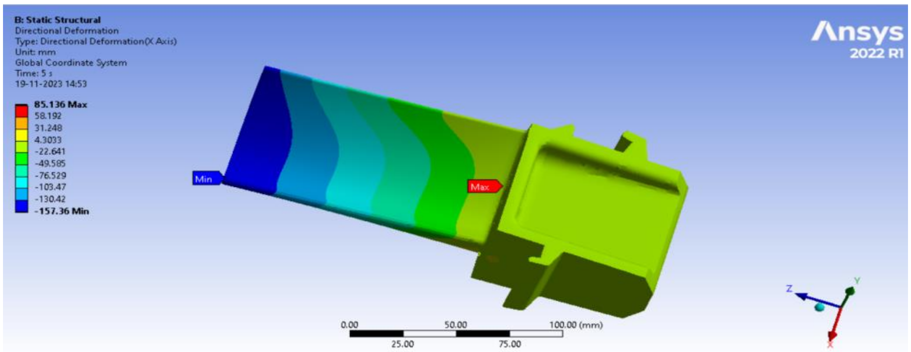

Figure 30: Equivalent elastic strain

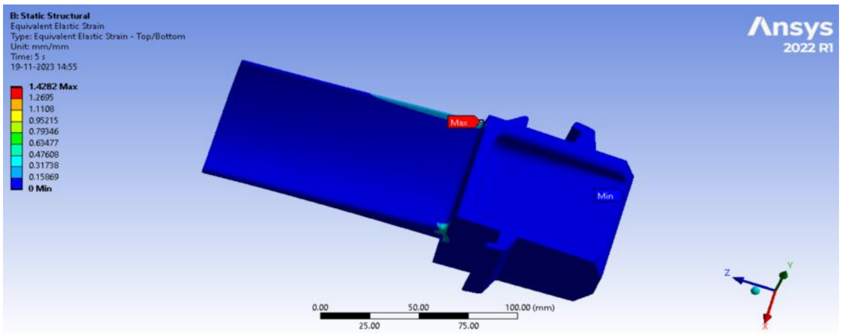

Figure 31: Equivalent Stress

Table: Static Structural Analysis of rotor blade using different materials at 28 MPa Pressure

Materials	Total deformation (mm)	Directional deformation (mm)	Equivalent elastic strain	Equivalent Stress (Mpa)
Structural steel	571.13	84.903	1.431	2.493
Titanium alloy	1173.2	172.03	2.88	2.425
H30	539.19	79.46	1.33	2.449

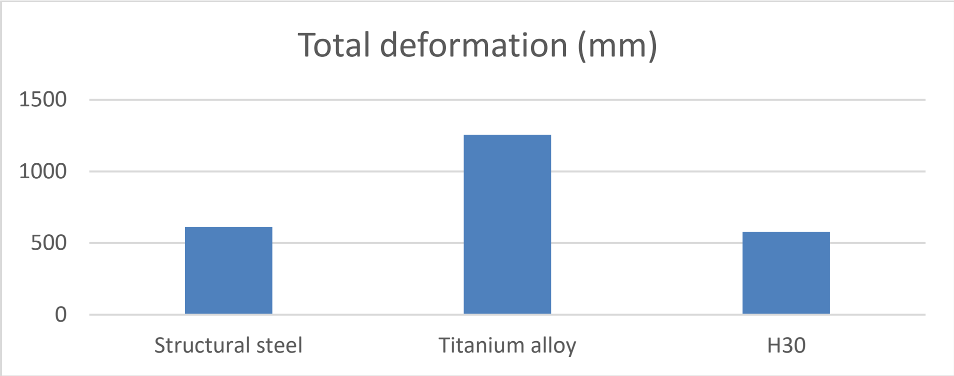

Figure 32: Variation of Total deformation at 28 MPa Pressure

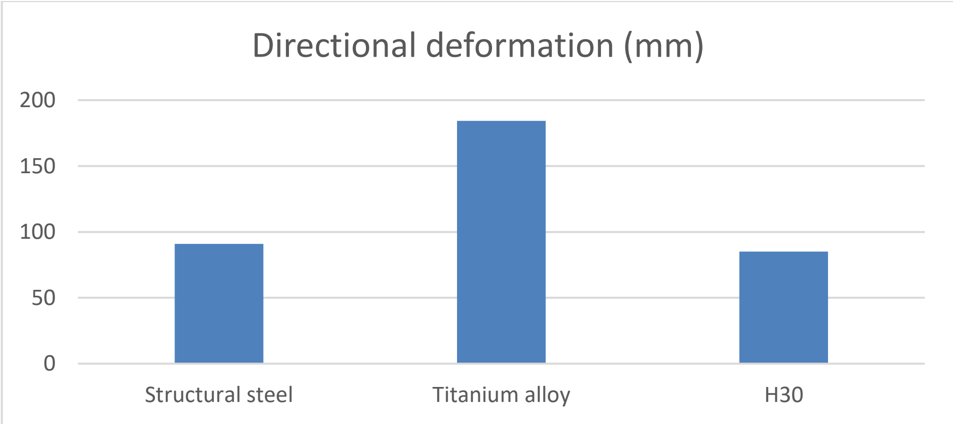

Figure 33: Variation of Directional Deformation

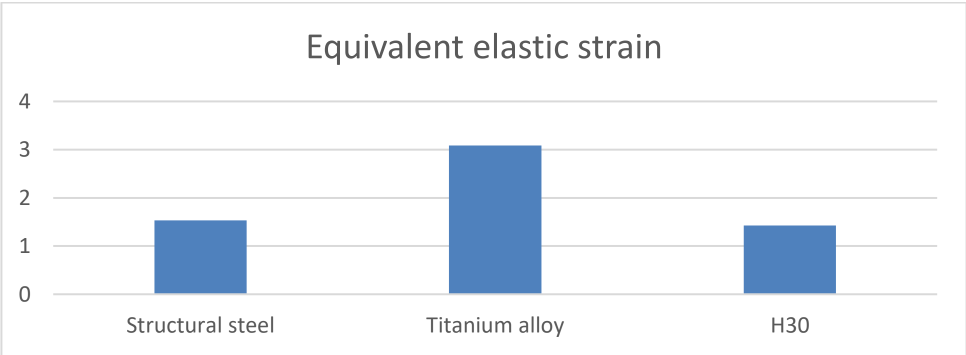

Figure 34: Variation of Equivalent elastic strain

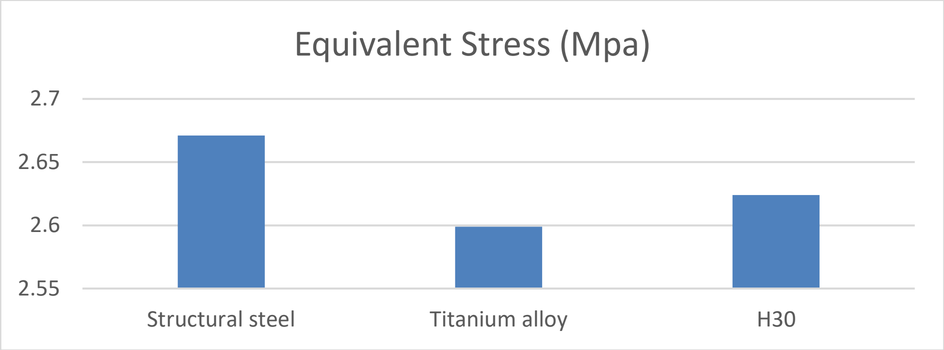

Figure 35: Variation of Equivalent stress

Table: Static Structural Analysis of rotor blade using different materials at 30 MPa Pressure

Materials	Total deformation (mm)	Directional deformation (mm)	Equivalent elastic strain	Equivalent Stress (Mpa)
Structural steel	611.92	90.967	1.5332	2.671
Titanium alloy	1257	184.37	3.089	2.599
H30	577.71	85.136	1.4282	2.624

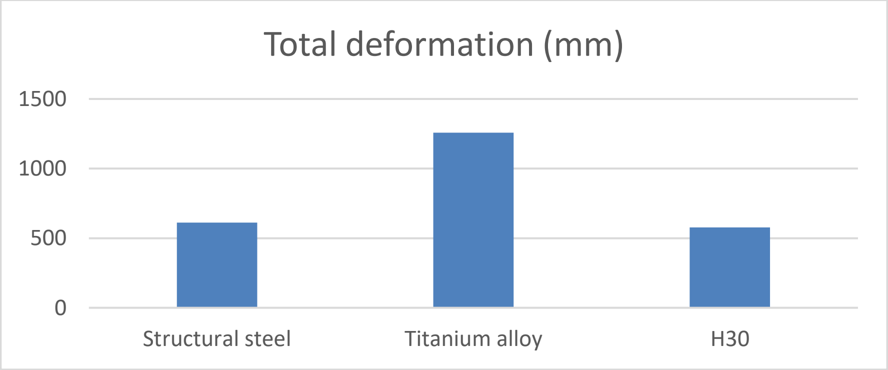

Figure 36: Variation of Total deformation at 28 MPa Pressure

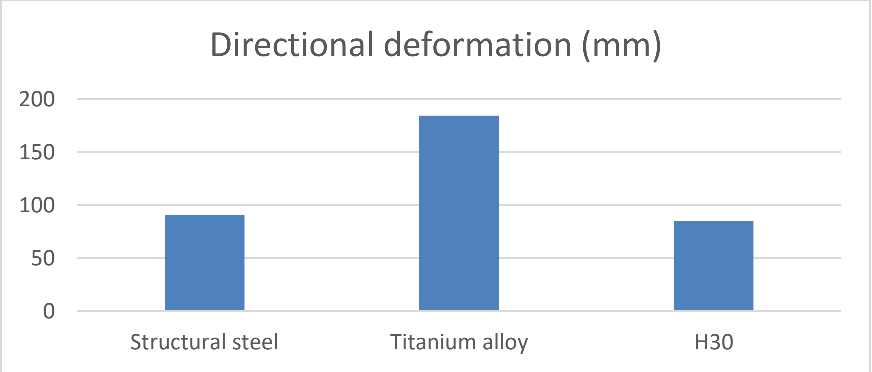

Figure 37: Variation of Directional Deformation

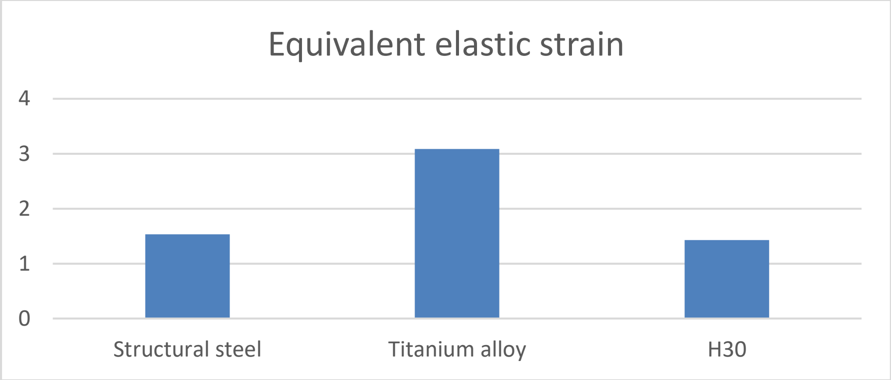

Figure 38: Variation of Equivalent elastic strain

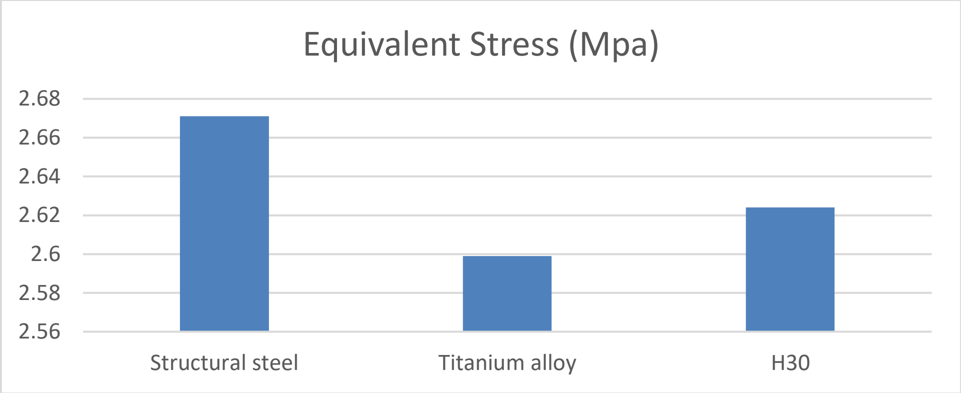

Figure 39: Variation of Equivalent stress

5. Conclusions:

The material with the highest total deformation is Titanium alloy, with a value of 1173.2, significantly above the average of 761.17. This could mean it's more prone to changes in shape. despite its high deformation, Titanium alloy has the lowest equivalent stress at 2.425, under the average of 2.456. This suggests it might be more resistant to stress. The structural steel, despite its lower total deformation than Titanium alloy, has the highest equivalent stress at 2.493. This could indicate it is less stress resistant. Structural steel shows significantly lower total deformation and directional deformation compared to titanium alloy, suggesting higher stability. Perhaps it could be a preferred material for applications requiring high dimensional stability. H30 displays both the lowest total deformation and the lowest equivalent elastic strain, indicating it may be the most resistant material to deformation in the given data set. Despite variations in material types and deformation measurements, equivalent stress averages out to 2.63 with a minimal range, implying a similar level of stress for all materials. This could highlight a standard stress level required across different materials.

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