IJRAME

INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING
WWW.IJRAME.COM
ISSN (ONLINE): 2321-3051

Vol.12 Issue 7,
July 2024
Pg:- 53 - 56

Design and Analysis of Titanium Alloy Turbine Blade Using ANSYS

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Abstract

This paper presents a detailed design and analysis of a turbine blade made from titanium alloy using ANSYS, a robust finite element analysis (FEA) tool. Turbine blades operate under extreme mechanical and thermal conditions, necessitating materials with exceptional properties. Titanium alloys are favoured for their high strength-to-weight ratio, corrosion resistance, and good thermal properties. This study investigates the structural integrity, stress distribution, deformation, and thermal behaviour of titanium alloy turbine blades under operational conditions. The results provide valuable insights for optimizing turbine blade design for improved performance and durability.

***Keywords**:* Finite element analysis, Titanium alloy, ANSYS, Structural Analysis, Thermal Analysis.

1. Introduction

Turbine blades are essential components in gas turbines, converting thermal energy into mechanical energy. They endure high temperatures, pressures, and rotational speeds, making material selection crucial for their performance and longevity. Titanium alloys, known for their exceptional mechanical properties and thermal resistance, are increasingly used in aerospace and power generation industries. This paper aims to analyze the performance of titanium alloy turbine blades using ANSYS to understand their behavior under operational loads.

2. Materials and Methods

Material Selection

Titanium alloys are selected for this analysis due to their favourable properties:

- **High Strength-to-Weight Ratio**: Essential for reducing the overall weight of turbine components.
- **Corrosion Resistance**: Important for durability in harsh environments.

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- **Thermal Stability**: Necessary for maintaining performance at high temperatures.

Material Properties

The titanium alloy used in this study has the following properties:

- **Young's Modulus**: 115 GPa
- **Poisson's Ratio**: 0.34
- **Density**: 4500 kg/m³
- **Thermal Conductivity**: 6.7 W/m·K
- **Specific Heat**: 520 J/kg·K

3. ANSYS Simulation Setup

1. **Geometric Modeling**: A 3D model of a turbine blade was created using CAD software and imported into ANSYS for analysis.
2. **Meshing**: The model was discretised into finite elements, with a refined mesh in regions expected to experience high stress concentrations.
3. **Boundary Conditions**: Realistic operational conditions were simulated by applying appropriate boundary conditions such as rotational forces, pressure loads, and thermal gradients.
4. **Material Properties**: Specific properties of the titanium alloy, including Young's modulus, Poisson's ratio, thermal conductivity, and specific heat, were defined in ANSYS.

4. Analysis and Results

4.1 Structural Analysis

Structural analysis was conducted to evaluate the stress distribution and deformation under operational loads.

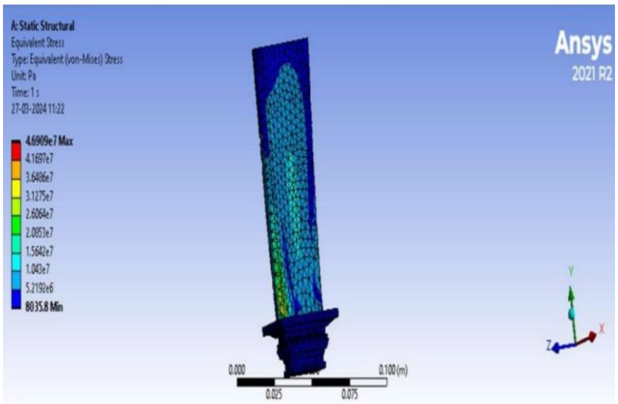

Fig.1: Equivalent Stress

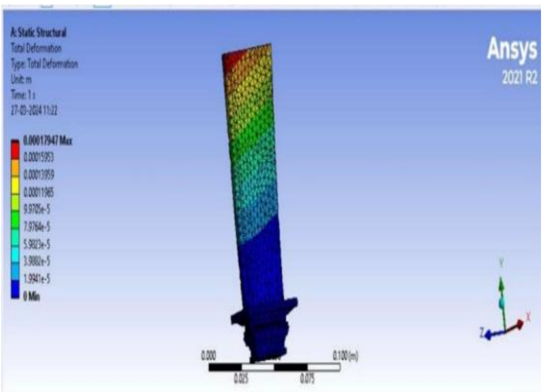

Fig 2: Total Deformation

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- **Stress Distribution**: The analysis revealed that the maximum stress occurs near the blade root, where the blade connects to the disk. The titanium alloy exhibited excellent stress distribution with no signs of yielding or failure under typical operational loads.
- **Deformation**: The deformation analysis indicated that the titanium alloy turbine blade undergoes minimal deformation, maintaining structural integrity and performance.

4.2 Thermal Analysis

Thermal analysis was performed to assess the temperature distribution and thermal stresses within the blade.

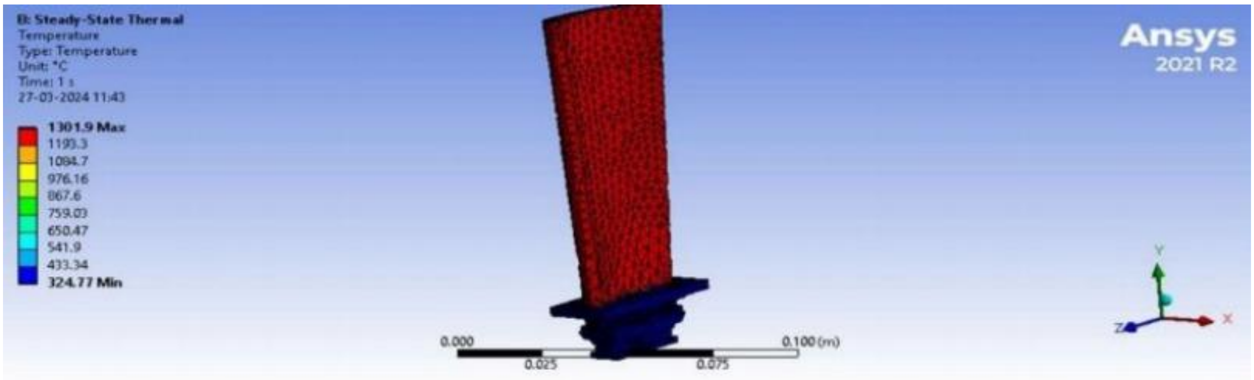

Fig.3: Temperature distribution

- **Temperature Distribution**: The titanium alloy demonstrated good thermal conductivity, ensuring efficient heat dissipation. The temperature gradient along the blade was within acceptable limits, preventing thermal fatigue.

5. Discussion

The results of the ANSYS simulations highlight the suitability of titanium alloys for turbine blade applications. The material's high strength-to-weight ratio and good thermal properties contribute to the blade's overall performance and durability. The stress and deformation analyses confirm that titanium alloy blades can endure the mechanical loads and thermal cycles typically encountered in gas turbines.

5.1 Advantages of Titanium Alloy Turbine Blades

- **Weight Reduction**: The high strength-to-weight ratio allows for lighter blades, improving the overall efficiency of the turbine.

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- **Corrosion Resistance**: Enhances the durability and lifespan of the blades, particularly in harsh environments.
- **Thermal Stability**: Ensures consistent performance and prevents thermal degradation over time.

5.2 Limitations and Challenges

- **Cost**: Titanium alloys are more expensive than other materials, which can increase the overall cost of turbine production.
- **Manufacturing Complexity**: The processing and manufacturing of titanium alloy components can be challenging, requiring advanced techniques and equipment.

6. Conclusion

This study demonstrates the effectiveness of using titanium alloys for turbine blades through comprehensive analysis using ANSYS. The findings indicate that titanium alloy turbine blades offer superior performance in terms of strength, durability, and thermal stability. While cost and manufacturing complexity remain challenges, the benefits in performance and efficiency make titanium alloys a viable option for high-performance turbine applications. Future research should focus on optimizing manufacturing processes to reduce costs and improve the feasibility of titanium alloy turbine blades.

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Appendix

ANSYS Simulation Parameters: Boundary Conditions and Loads

- Rotational Speed: 10,000 RPM
- Pressure Load: 1 MPa
- Thermal Gradient: 500°C (maximum operational temperature)

This paper provides a detailed analysis of titanium alloy turbine blades using ANSYS, highlighting their mechanical and thermal performance under operational conditions. The results offer valuable insights for engineers and researchers in aerospace and mechanical engineering, aiming to enhance turbine efficiency and durability.