Comparative Stress and Deformation Analysis of Rigid Flange Couplings with Various Materials

R. Sridevi[1], Mrs. P. Gayathri[2], Mr. T. Harish[3]

[1]M. Tech Student,Department of Mechanical Engineering, Pragati Engineering college (A), Surampalem, reddisridevi14@gmail.com

[2,3] Assistant Professor,Department of Mechanical Engineering Pragati Engineering College (A), Surampalem. gayathri.p@pragati.ac.in, harish.t@pragati.ac.in

Abstract: Rigid flange couplings are important mechanical components used to connect rotating shafts in power transmission systems. Their performance and reliability mainly depend on their ability to withstand applied loads, resist stress, and minimize deformation during operation. This study focuses on the design and static structural analysis of a rigid flange coupling using different materials, namely Structural Steel, Cast Iron, Aluminum Alloy, and Titanium Alloy. A brief review of coupling types is included to highlight the importance of rigid flange couplings in mechanical systems. The rigid flange coupling is modeled using SolidWorks 2026, and the static structural analysis is carried out in ANSYS 2025 R2. The analysis is performed by applying a pressure of 80 MPa and a load of 1000 N on the coupling. The selected materials are evaluated to study their influence on the structural performance of the coupling. The results are validated by comparing total deformation, equivalent stress, and strain distribution under the given loading conditions. The study provides useful insights for selecting suitable materials in the design of strong, reliable, and durable rigid flange couplings for industrial applications.

Keywords: Rigid flange coupling, SolidWorks 2026, Ansys 2025 R2.

1. Introduction

Coupling is a device used to connect the shafts together for the purpose such as power and torque transmitting. Generally, couplings are used for connection of shafts that are manufactured separately. Some of the examples are motor, generator; electric motor and centrifugal pump etc. Inconvenience in transportation of shaft of greater length and limitations of manufacturing results in the reason of joining of two or more shafts by means of coupling. The shafts that are connected by coupling are simple enough to assemble and disassemble for the purpose of repair and alterations. The unadorned failure due to shearing of bolts head, key head, nuts and other projecting parts may cause accidents. So, it should be covered by fencing the flanges or by providing guards. The shaft connected by the coupling may have collinear axes, intercepting axes or a parallel axis with a small distance in between them. They are further classified into two types; Rigid and Flexible Coupling. Rigid flange coupling consists of two separate grey cast iron flanges. One keyed to the driving shaft and the other to the driven shaft by means of nuts and bolts arranged on a circle concentric with the axes of the shafts. There are two types of rigid flange couplings; Protected and Unprotected rigid flange coupling. A protected rigid flange coupling has a protective circumferential rim that covers the nut and bolt head. So in any case of failure of bolts during operation, broken piece of bolt will dash against this rim and eventually fall down, protecting the operator from any possible injuries. In unprotected rigid flange coupling there is no protective circumferential rim. So, in any case of failure of bolts, it may cause severe injuries to the operator.

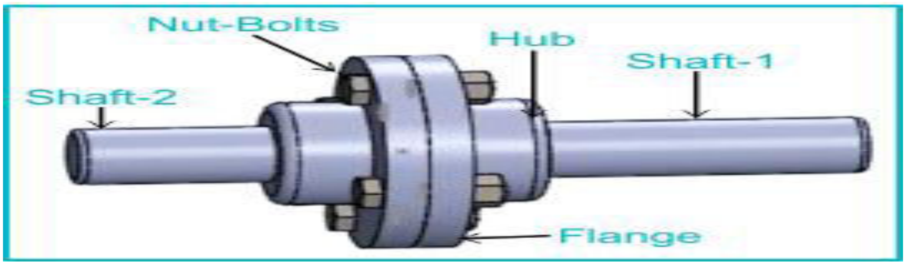

Figure 1: Rigid flange coupling

Rigid Flange Coupling

A Rigid Flange Coupling is a type of coupling used to connect two shafts rigidly, ensuring that they rotate together without any relative movement. It consists of two flanges that are rigidly bolted together, providing a solid connection between the shafts.

- **Heavy Machinery:** Used in heavy industrial machines such as compressors, pumps, blowers, and conveyors where shafts need a strong and secure connection.
- **Power Transmission Systems:** Ideal for transmitting power in mechanical drives where shafts are precisely aligned and do not require flexibility.
- **Marine Engines:** Sometimes used in marine propulsion systems where shaft alignment is maintained, providing reliable torque transmission.
- **Machine Tools:** Applied in machine tools like lathes and milling machines where precision and rigid connection between shafts is critical.

Problem Statement

Many mechanical failures in rotating machinery originate from coupling failure due to excessive stress or deformation. These failures are often linked to inappropriate material selection or poor understanding of how different materials behave under load. While rigid flange couplings are designed for strength and rigidity, their performance is directly influenced by the material from which they are made. Understanding how different materials respond to similar loading conditions can aid in optimizing design and extending service life.

Objectives

The primary goal of this study is to evaluate and compare the mechanical performance of a rigid flange coupling when fabricated from various engineering materials under identical loading conditions. The specific objectives are as follows:

- To design the model done by using SW 2026 Analysis was using Ansys 2025 R2
- To compare the stress and deformation responses when different materials are used.
- To recommend the most efficient material based on strength, deformation, and weight-to-performance ratio.

2. Literature Review

A review on the design and analysis of rigid flange couplings are iterative processes involving theoretical calculations and advanced simulation tools like FEA. Material selection is paramount, with engineers balancing performance requirements (strength, fatigue, damping) against manufacturing feasibility and cost. Somvir Singh Bharat Bhushan [1] To decrease the weight of flange coupling. For this, composite material aluminium silicon carbide is used for the flange which is light in weight and good thermal and mechanical properties. In the project we used Finite Element Analysis method to optimize the flange coupling design. D. B. Shah et al. [2] performed parametric modelling and drawing automation for flange coupling using excel spreadsheet. In the work he integrated commercially available packages Autodesk Inventor with Microsoft excel spreadsheet for creation of modelling and manufacturing drawing. I. J. Jadeja et al. [3] developed GUI based design software in VB Environment to Integrate with CREO for design and modelling using case study of coupling. They reviewed the procedural steps involved in the design of couplings and the development of the software package using visual basic as a tool for the design. R. T. Salunkhe et al. [4] designed and carried out analysis of coupling using ANSYS. The project presented the concept of reducing maximum shear stresses by adding a new material between shaft and hub. The modelling of rigid flange coupling was done in CREO 2.0 and analysis of rigid flange coupling was carried out with the

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help of ANSYS 15 Software for calculated torque. Vijay Tayade Minal etc. al. [5] In this project, a three-dimensional finite element analysis (FEA) of bolted flange joints has been carried out by taking experimentally obtained loading and unloading characteristics of the gaskets. Analysis shows that the distribution of contact stress has a more dominant effect on sealing performance than the limit on flange rotation specified by ASME. Jaiswal Ritick etc. al. [6] This study compare the theoretical and analytical values and proceeds to find out the optimized value of grade of materials for the rigid flange Coupling (carbon steel for shaft, keys and bolts, and grey cast iron for flange) on the criteria of appropriate dimensions for the components and appropriate value of factor of safety. Basha C.Subhahan etc. al. [7] The main objective of this study is to verify the safe design of flange coupling to transmit power of 25 kW by comparing theoretical and analytical result both. UG-NX10.0 software is used to create the model of flange coupling. Maurya Ramprakash etc. al. [8] This study Compare the theoretical and analytical calculation of rigid flange coupling. The material from which coupling is manufacture is EN8 as it has better properties than most of the material from which coupling is manufactured like mild steel, cast iron. Taji Dr. Santosh etc. al [9] The impact on modal parameters of rigid flange coupling having fixed support at the two ends is studied with the aid of various the diameter, material and power to the shaft. Analytical evaluation has been carried out referring the wellknown method of layout and vibration. Mendi VenkannaBabu etc. al. [10] The present study of this paper is to reduce the maximum shear stress by selecting a suitable material for flange coupling. For this purpose, modeling of the rigid-flange coupling is carried out in Uni-graphics and analysed in ANSYS Workbench.

3. Methodology

This chapter details the methodological steps undertaken for the design and structural analysis of a rigid flange coupling. The primary objective is to develop a robust design that can efficiently transmit torque and power between co-axial shafts, while ensuring that all components operate within safe stress limits.

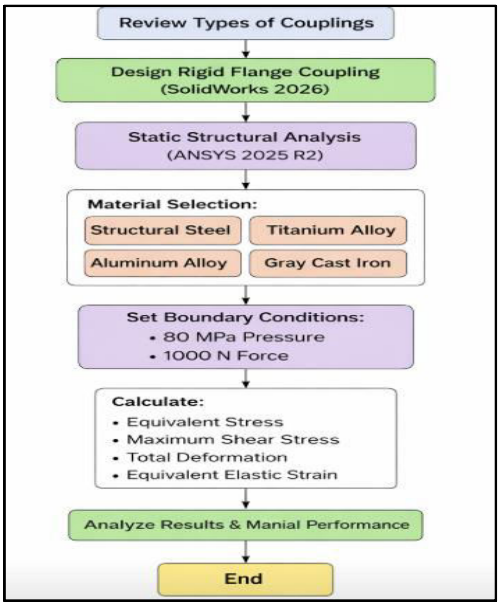

Figure 2: Design flow chart

Rigid Flange Coupling Working Procedure

A rigid flange coupling is a type of mechanical coupling used to connect two shafts so they rotate together as a single unit. It is commonly used where accurate alignment of shafts is maintained, and no relative motion is allowed between the connected parts. The working procedure of a rigid flange coupling involves mounting and securing two flanges each on the end of a shaft so that they are rigidly fastened together using bolts. A key is used between the shaft and the flange to prevent relative rotation, and bolts are tightened to ensure firm coupling.

Figure 3: Rigid flange coupling

3.2 Material Selection

Material selection is a critical aspect, directly influencing the strength, weight, and cost of the coupling. For this study, different materials will be considered for each component to Analyze their impact on the design. The choice of materials will be based on their mechanical properties, availability, and cost-effectiveness.

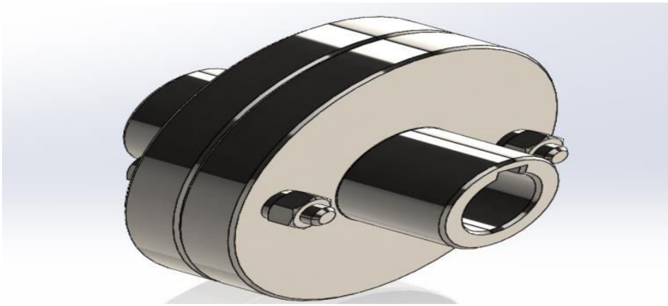

Figure 4: Structural steel rigid flange coupling

Rigid flange coupling design in Soild works 2026

A rigid flange coupling in SolidWorks involves designing two flanges that are bolted together to connect two shafts, creating a rigid connection. The design process in SolidWorks typically involves creating the flange parts, adding mounting holes for bolts, and then assembling them in a way that ensures proper alignment and connection.

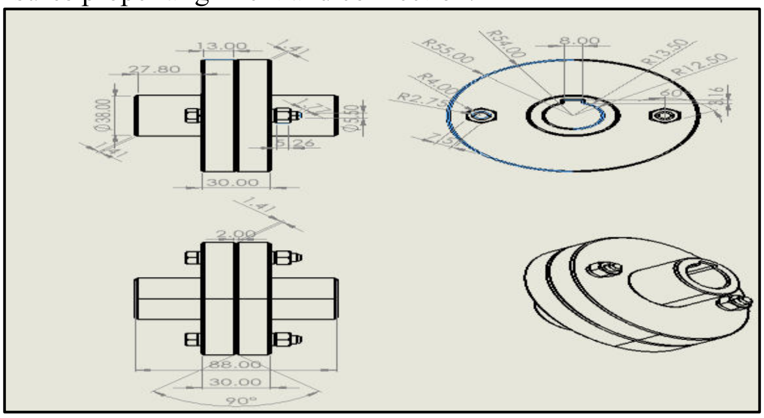

Figure 5: Rigid flange coupling to geometry model

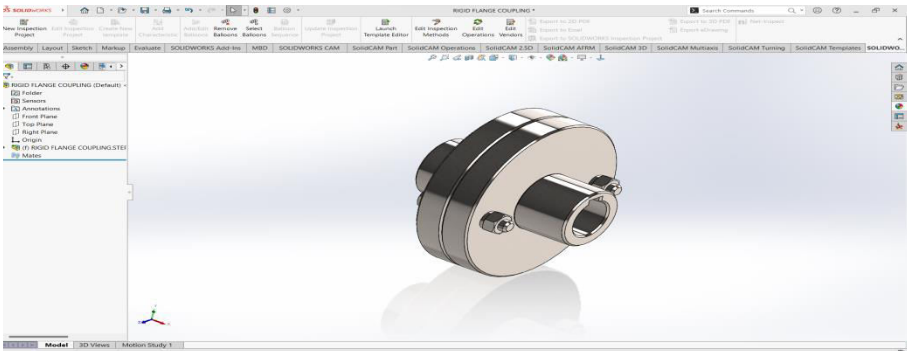

Figure 6: Rigid flange coupling Solid works model

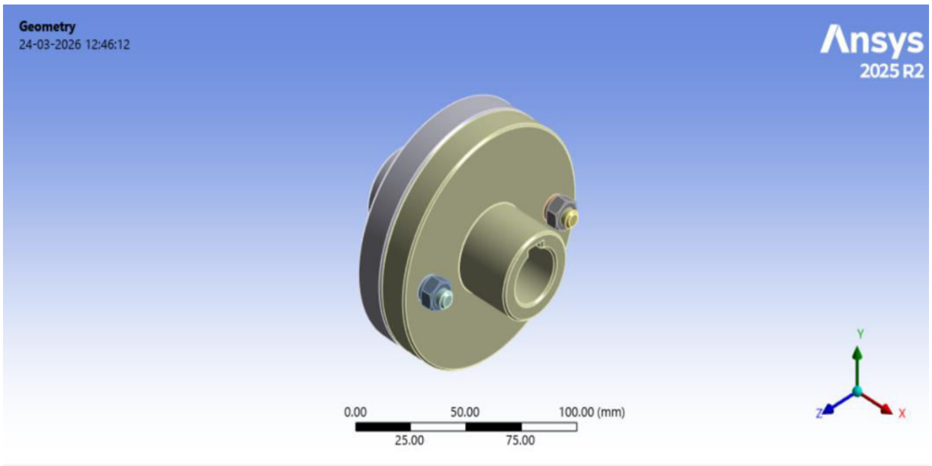

Figure 7: Imported geometry

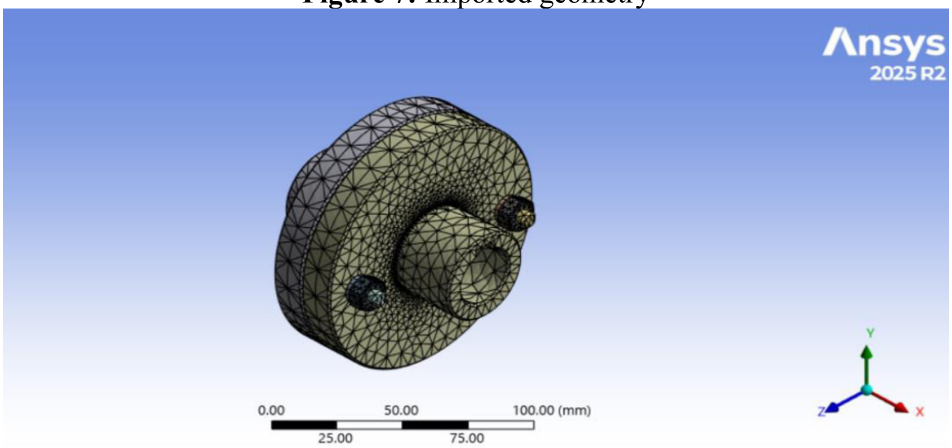

Figure 8: Meshing model

4. Results And Discussions

A rigid flange coupling is a mechanical device used to connect two shafts together so that they rotate as a single unit. Unlike flexible couplings, rigid couplings do not accommodate misalignment and are ideal where precise shaft alignment is possible. This chapter presents a detailed static structural analysis of a rigid flange coupling using finite element methods (FEM) to determine the stress distribution and deformation under operational loads.

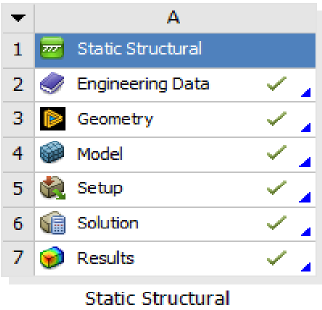

Figure 9: Structural analysis Solver

Static structural analysis of rigid flange coupling using Structural steel

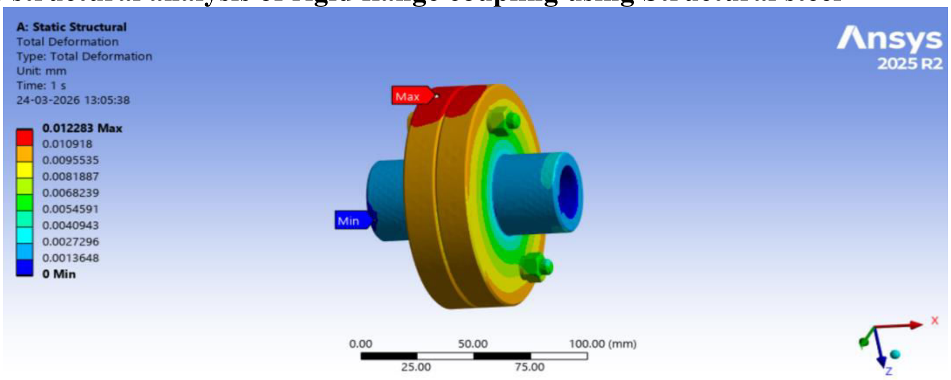

Figure 10: Total deformation in mm

Above figure to observed the maximum deformation value of approximately 0.012 mm is extremely small. This indicates that the rigid flange coupling, when made of Structural Steel and subjected to the specified loads (1000 N force and 80 MPa pressure), exhibits very little displacement.

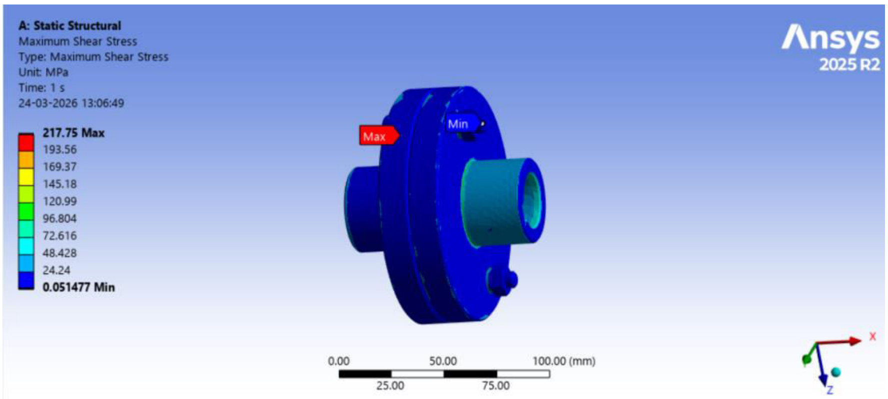

Figure 11: Maximum shear stress in Mpa

Above figure the highest shear stress value shown is 217.75 MPa, highlighted in red on the contour plot. The "Max" label points to the keyway region of the shaft, which is a common location for high stress concentrations in power transmission components like couplings.

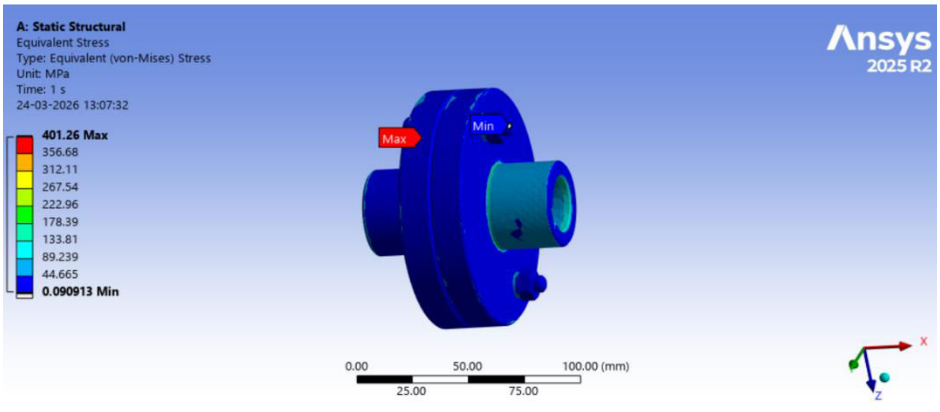

Figure 12: Equivalent Stress

the image presents a clear visualization of how stresses are distributed within the analyzed component under the given static loads. The maximum stress of 401.26 MPa indicates a critical area that would need to be carefully considered for material selection and design optimization to prevent failure.

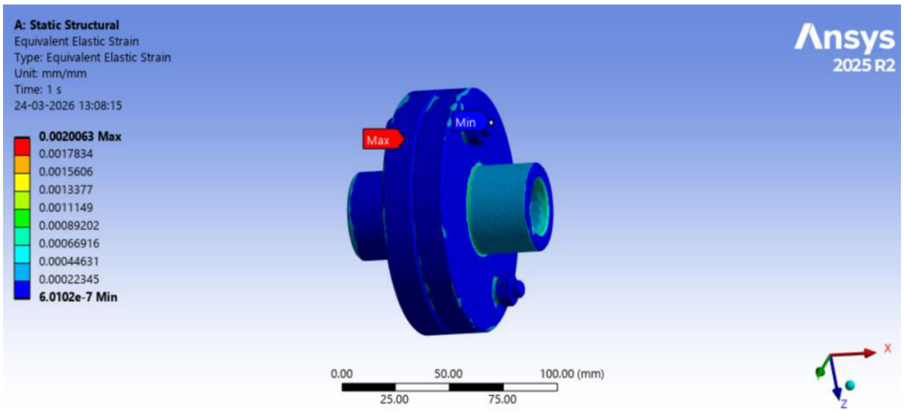

Figure 13: Equivalent elastic strain

The image displays the results of a static structural analysis performed using ANSYS 2024 R1, specifically showing the distribution of "Equivalent Elastic Strain" on the same mechanical component that was analyzed for equivalent stress.

Static structural analysis of rigid flange coupling using Titanium alloy

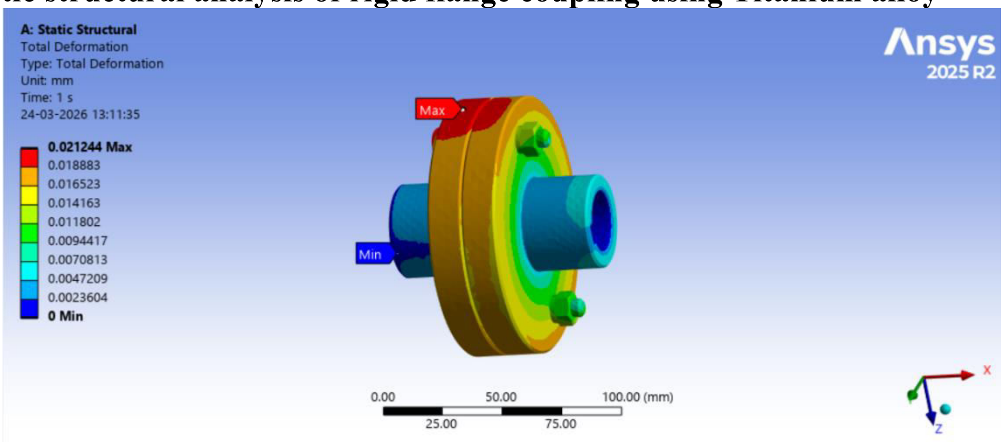

Figure 14: Total deformation in mm

Above figure to observed the maximum deformation value of approximately 0.0212 mm is extremely small. This indicates that the rigid flange coupling, when made of Titanium alloy and subjected to the specified loads (1000 N force and 80 MPa pressure), exhibits very little displacement.

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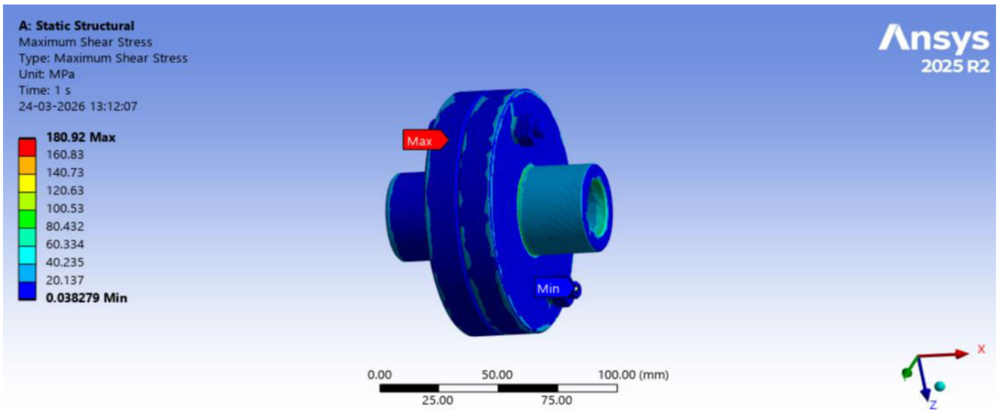

Figure 15: Maximum shear stress in Mpa

Above figure a "rigid flange coupling Maximum shear stress in Mpa (Titanium alloy and subjected to the specified loads The reduction in maximum shear stress from 180.92 indicates a slightly *improved* or more accurately captured stress state

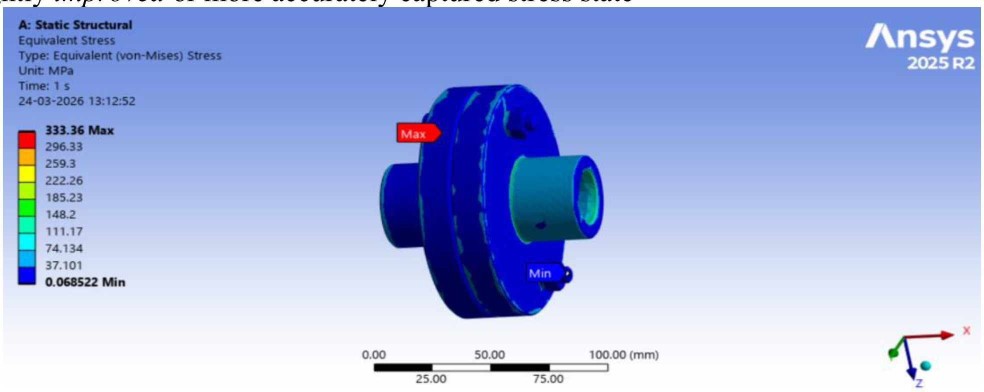

Figure 16: Equivalent Stress

Above figure shows the "Max" stress value as **333.36 MPa**. This point is marked on the component, located in an area that appears to be a stress concentration point, possibly near a fillet, a bore, or where two parts are joined.

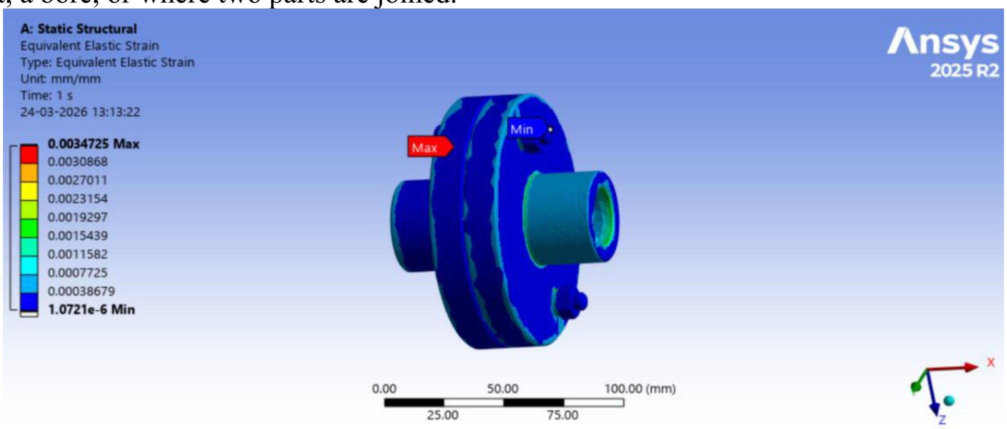

Figure 17: Equivalent elastic strain

This figure provides critical information about the elastic deformation of the coupling under the applied 1000 N force and 80 MPa pressure. The maximum equivalent elastic strain of 0.003472 mm/mm is an important metric for evaluating the structural integrity and performance of the component.

Static structural analysis of rigid flange coupling using Aluminium alloy

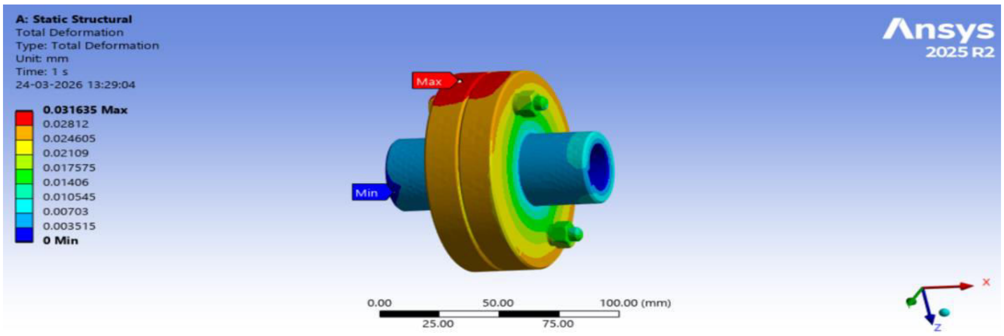

Figure 18: Total deformation in mm

Above figure to observed the maximum deformation value of approximately 0.031 mm is extremely small. This indicates that the rigid flange coupling, when made of Aluminium alloy and subjected to the specified loads (1000 N force and 80 MPa pressure), exhibits very little displacement.

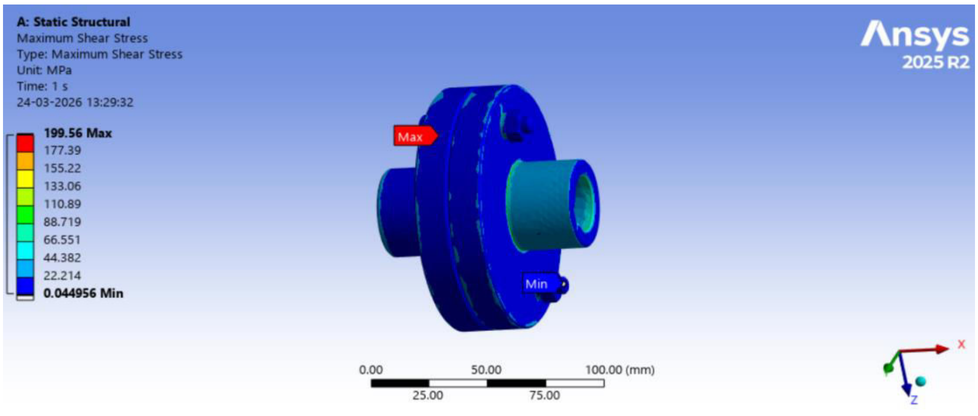

Figure 19: Maximum shear stress in Mpa

This figure provides crucial information about the shear stress distribution within the coupling under the applied loads. The maximum shear stress of 199.36 MPa is a key value for design validation.

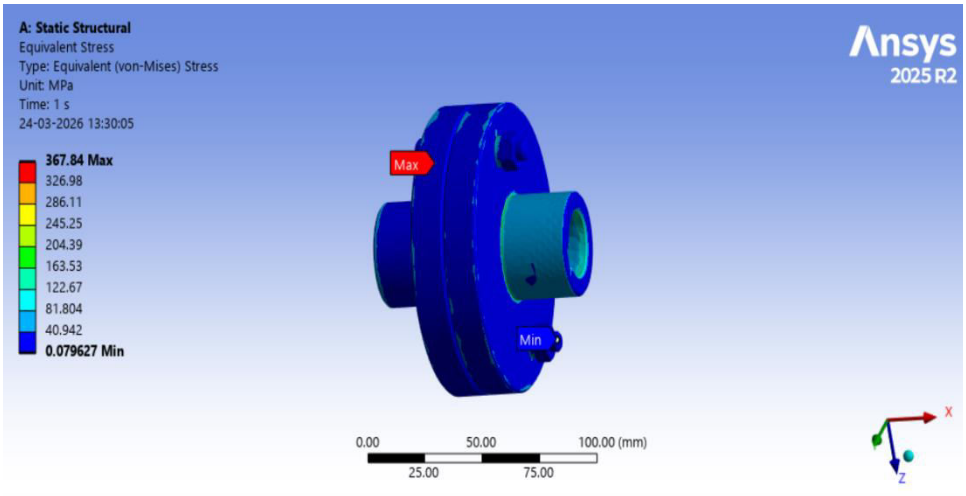

Figure 20: Equivalent Stress

This figure provides a critical visualization of the stress state within the coupling under the applied loads. The maximum equivalent stress of 367.84 MPa is a key design parameter. to ensure that the component does not yield or fail under these operating conditions.

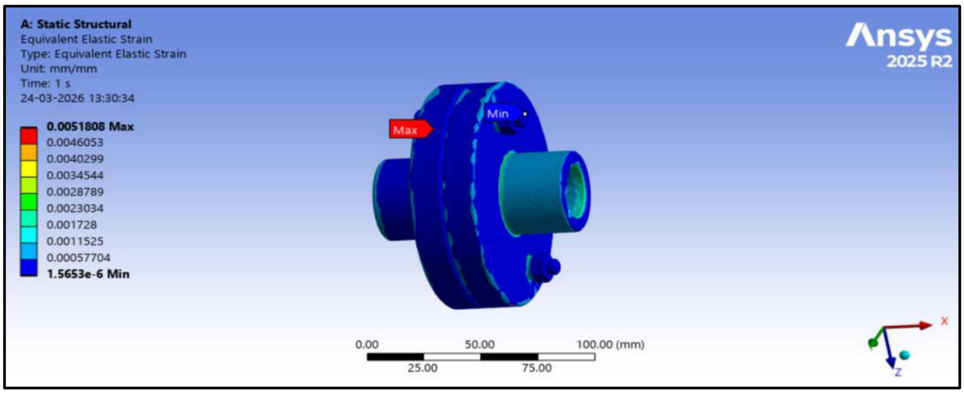

Figure 21: Equivalent elastic strain

This figure provides crucial information about the elastic deformation experienced by the coupling under the applied loads. The maximum equivalent elastic strain of 0.0051808 mm/mm is an important metric for evaluating the component's structural integrity

Static Structural Analysis of Rigid Flange Coupling Using Gray Cast Iron

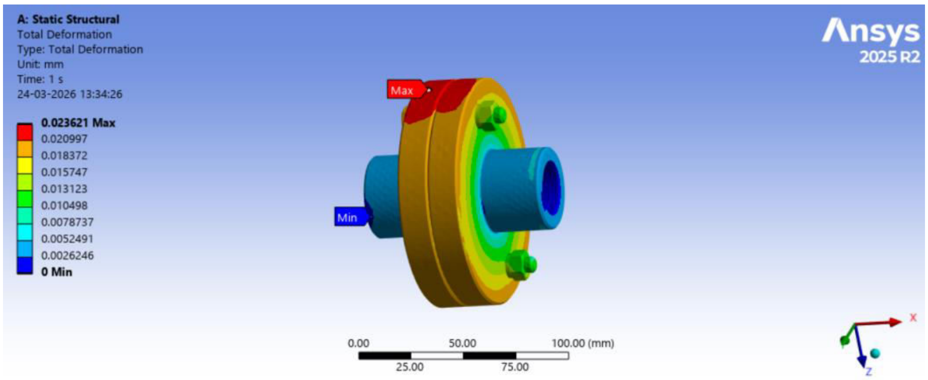

Figure 22: Total deformation in mm

Above figure to observed the maximum deformation value of approximately 0.023 mm is extremely small. This indicates that the rigid flange coupling, when made of Gray cast iron and subjected to the specified loads (1000 N force and 80 MPa pressure), exhibits very little displacement.

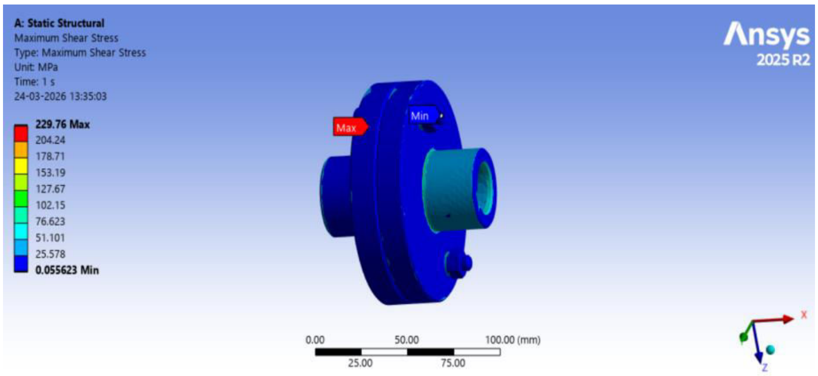

Figure: 23 Maximum shear stress in Mpa

Above figure to the analysis was performed with a force of 1000 N and a pressure of 80 MPa applied at specific locations on the flange. (τy) or allowable shear stress of the specific grade of Cast Iron used. A maximum shear stress of 229.76 MPa is concerning for a material like Cast Iron, which is relatively weak in tension and shear compared to steel, and also brittle.

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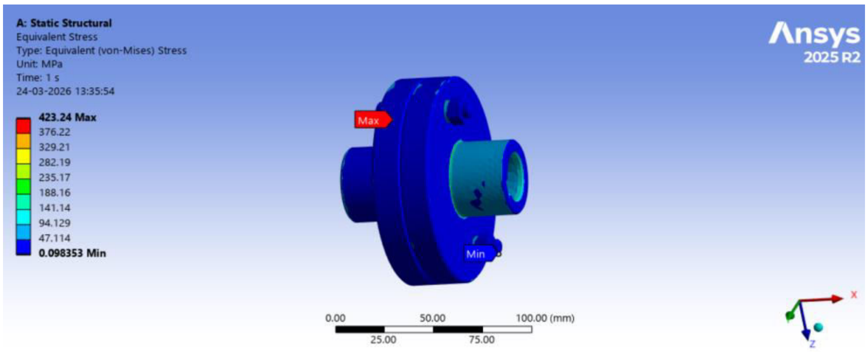

Figure 24: Equivalent Stress

The image effectively visualizes the stress landscape within the coupling under the applied loads. The maximum equivalent stress of 205.86 MPa is a critical value for design evaluation. Engineers would compare this value against the yield strength of the material to ensure that the component does not yield or fail under these operating conditions.

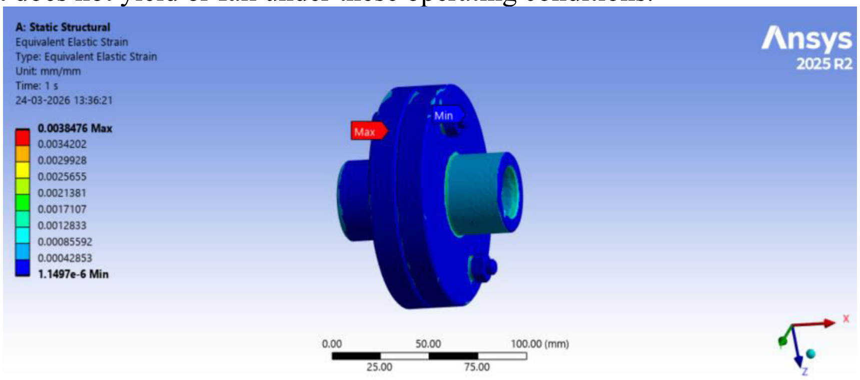

Figure 25: Equivalent elastic strain

The figure shows the equivalent elastic strain distribution of the rigid flange coupling made of grey cast iron under static structural analysis. The maximum equivalent elastic strain is 0.0038476 mm/mm, while the minimum value is 1.1497×10^{-6} mm/mm. This indicates that the highest strain is concentrated near the flange region, whereas the rest of the component experiences relatively low elastic deformation under the applied load.

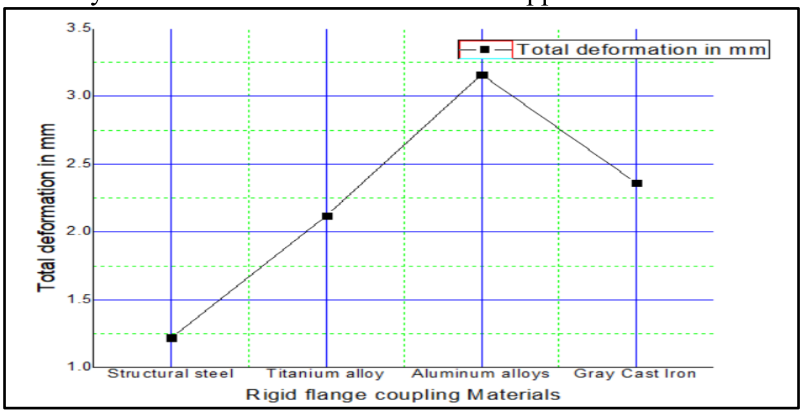

Figure 26: Validation of flange coupling maximum deformation at different materials

The figure shows the validation of maximum deformation of the rigid flange coupling for different materials such as structural steel, titanium alloy, aluminum alloy, and gray cast iron. It is observed that aluminum alloy exhibits the highest total deformation, indicating lower stiffness under the applied load, while structural steel shows the lowest deformation, reflecting better rigidity and dimensional stability. Titanium alloy and gray cast iron display intermediate deformation values, showing moderate structural performance compared with the other materials.

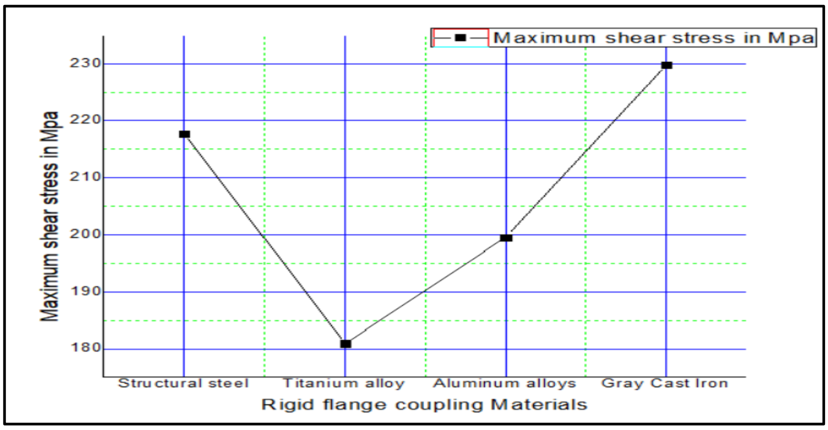

Figure 27: Validation of flange coupling Maximum shear stress in Mpa

The figure presents the validation of maximum shear stress in the rigid flange coupling for different materials such as structural steel, titanium alloy, aluminum alloy, and gray cast iron. Among these materials, gray cast iron shows the highest maximum shear stress, while titanium alloy exhibits the lowest shear stress under the same loading condition. Structural steel and aluminum alloy show intermediate values, indicating moderate shear stress behavior compared with the other selected materials.

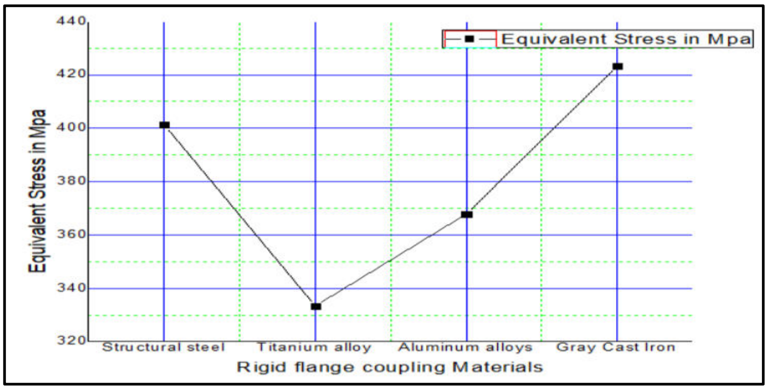

Figure 28: flange coupling Equivalent Stress in Mpa at different materials

The figure compares the equivalent stress developed in the rigid flange coupling for different materials such as structural steel, titanium alloy, aluminum alloy, and gray cast iron. It is observed that gray cast iron shows the highest equivalent stress, followed by structural steel, while titanium alloy exhibits the lowest stress value among the selected materials.

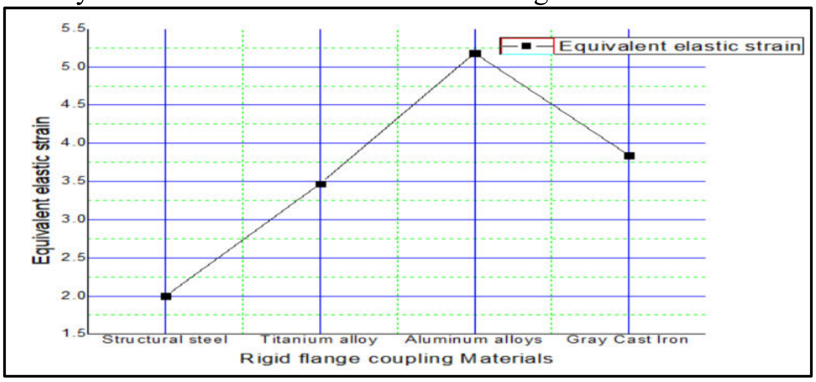

Figure 29: Validation of flange coupling Equivalent elastic strain at different materials

The figure presents the validation of equivalent elastic strain for the rigid flange coupling using different materials such as structural steel, titanium alloy, aluminum alloy, and gray cast iron. Among these, aluminum alloy shows the highest equivalent elastic strain, indicating greater elastic deformation under the applied load, while structural steel shows the lowest strain, reflecting better stiffness. Titanium alloy and gray cast iron exhibit intermediate values, showing moderate deformation behavior compared with the other materials.

Conclusions

This study evaluated the mechanical performance of a rigid flange coupling under identical loading conditions of 1000 N force and 80 MPa pressure using Structural Steel, Titanium Alloy, Aluminum Alloy, and Gray Cast Iron. The materials were compared based on equivalent (von Mises) stress, total deformation, maximum shear stress, and equivalent elastic strain. From the analysis, Titanium Alloy is identified as the most suitable material for rigid flange coupling applications because it provides a balanced combination of high strength, low stress, reduced deformation, and good ductility under the applied load. These characteristics make it highly appropriate for applications requiring long service life, reliability, and precise mechanical alignment, especially in aerospace, marine, and other high-performance engineering systems. Although Structural Steel is economical and durable, its higher deformation makes it less suitable for precision applications. Aluminum Alloy offers the advantage of low weight but exhibits higher deformation, while Gray Cast Iron shows higher stress concentration and brittleness risk. Therefore, Titanium Alloy is concluded to be the best material among the selected materials for rigid flange coupling performance

Future scope:

- Future work can include fatigue and dynamic analysis of the rigid flange coupling under varying load and rotational conditions.
- Further studies can be carried out using advanced composite or hybrid materials to improve strength and reduce weight.
- Experimental validation of the simulation results can be performed to enhance the reliability and practical application of the design.

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