Structural and Performance Analysis of Mild Steel vs. Hardened EN8D in Automotive Rigid Couplings Using ANSYS

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Abstract -*This study investigates the design and performance evaluation of rigid couplings in automotive power transmission systems, focusing on a comparative analysis of Mild Steel and Automotive grade EN8D metal materials. Rigid couplings play a crucial role in ensuring efficient torque transmission and maintaining alignment between connected shafts. Finite Element Analysis (FEA) using ANSYS is employed to simulate and assess stress distribution, deformation, and fatigue resistance under varying load conditions. Key performance metrics such as torque capacity, wear resistance, and lifespan are evaluated. The results indicate that rigid couplings made from EN8D exhibit superior mechanical performance, including higher resistance to stress-induced deformation and enhanced durability in high-load scenarios. The study also explores the trade-offs in material selection, considering factors like cost, manufacturability, and application-specific requirements. This research provides a comprehensive framework for material selection in the design of rigid couplings, offering practical insights for improving the reliability and efficiency of automotive drivetrains.*

Key Words: Rigid couplings, FEA, torque, Durability, Lifespan, Wear Resistance, ANSYS.

1. INTRODUCTION

Rigid sleeve couplings are critical components in mechanical systems, providing the necessary alignment and torque transmission between rotating shafts. Their design and material selection are crucial for optimizing performance, reliability, and durability in various applications. This study investigates two types of rigid sleeve couplings: one constructed from Mild Steel material and the other with EN8D through heat treatment and surface treatment processes. While the untreated MS material coupling offers advantages in terms of lightweight construction, it often falls short in terms of strength and resistance to wear. Conversely, the treated EN8D coupling, presents improved mechanical properties that can significantly extend service life and reduce maintenance needs. This introduction sets the stage for a comparative analysis of these two coupling types, aiming to provide insights into their respective advantages and limitations in real-world applications.

2. Rigid Sleeve coupler:

A **rigid sleeve coupler** in the automotive industry is a mechanical device used to connect two shafts in a power transmission system, ensuring precise alignment and efficient torque transfer without allowing any relative motion between the shafts. It consists of a cylindrical sleeve that fits tightly over the ends of the shafts, creating a rigid and fixed connection. This type of coupler is commonly used in applications where maintaining strict alignment and structural integrity is critical to prevent misalignment-related failures and ensure optimal drivetrain performance.

Key Features:

- Rigid Connection: Maintains precise alignment between shafts, essential for systems requiring high accuracy.
- Simple Design: Typically composed of a single sleeve, making it easy to manufacture and install.
- Applications: Commonly used in automotive systems where flexibility is not needed, such as in precise power transmission setups like gearboxes or differentials.

2.1 MS material coupler

Parameter	Description
Material	Mild Steel
Tensile Strength	560 MPa
Yield Strength	460 MPa
Outside Diameter	64 mm
Total Length	61 mm
Motor Keyway Dimension	12 X 6 mm
Bore Length	35 mm
Motor Shaft Diameter	42 mm
Weight	1084.81 g

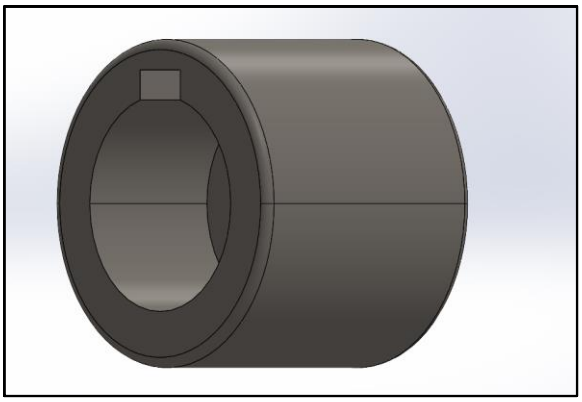

Figure 1: Model of MS material Rigid Sleeve

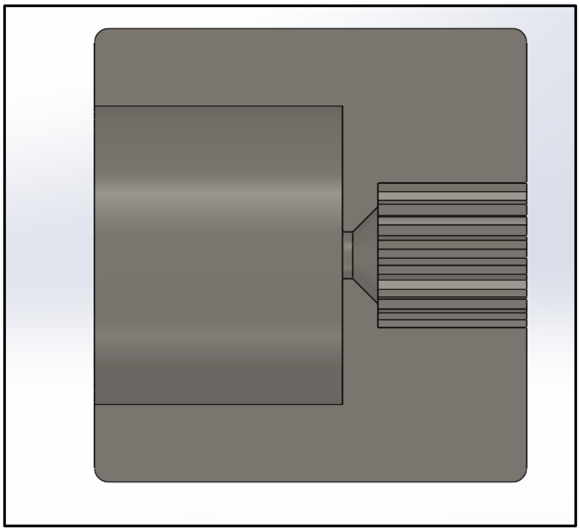

Figure 2: Half Section of Rigid Sleeve

2.2 EN8D Hardened material coupler:

Parameter	Description
Material	EN8D
Tensile Strength	1262 MPa
Yield Strength	930 MPa
Hardness	40 HRC
Outside Diameter	64 mm
Step Diameter	44 mm
Total Length	61 mm
Motor Keyway Dimension	12 x 4.85 mm
Bore Length	35 mm
Motor Shaft Diameter	42 mm
Weight	847 g

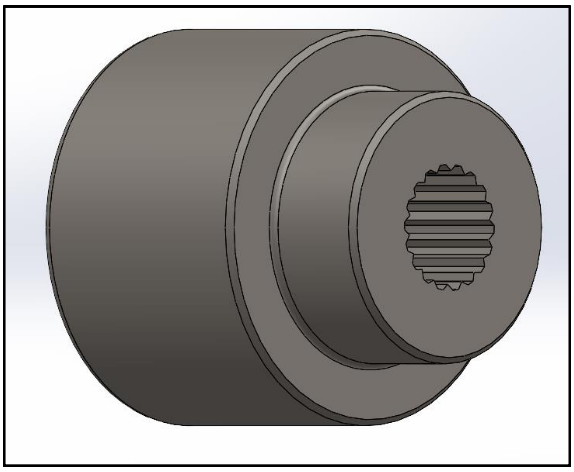

Figure 3: Model of EN8D material Rigid Sleeve

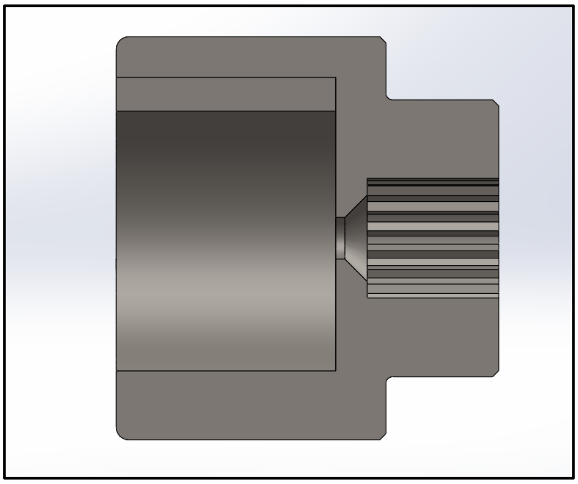

Figure 4: Half Section of EN8D Rigid Sleeve

3. Need of Hardening and Weight Reduction:

Rigid sleeve couplers in automotive systems are subjected to significant mechanical stress due to the high torque and rotational forces they transmit. Over time, these forces can lead to wear, deformation, and fatigue, especially in harsh operating conditions. To enhance their performance and longevity, **hardening** processes, such as case hardening, induction hardening, or nitriding, are applied to the coupler's surface. These processes increase the hardness and wear resistance of the outer layer while maintaining a ductile core, allowing the coupler to resist surface damage and withstand cyclic loading more effectively. This reduces the likelihood of failure and extends the component's service life, which is critical for maintaining drivetrain reliability.

In addition to improving strength and durability, **weight reduction** is a vital consideration in modern automotive design. Reducing the weight of the rigid sleeve coupler contributes to the overall reduction of the vehicle's unsprung and rotating mass. This has multiple benefits, including improved fuel efficiency, better handling, and reduced emissions. Achieving weight reduction can be done by utilizing lightweight materials like high-strength aluminum alloys or advanced composites, or by optimizing the coupler's design, such as incorporating hollow or ribbed structures. These innovations ensure that the coupler remains strong and durable while minimizing its impact on vehicle weight, aligning with the automotive industry's goals of sustainability and performance enhancement.

4. Types of Hardening:

1. Flame Hardening
   - A rapid surface heating process using an oxy-fuel flame, followed by quenching.
   - Provides a hard, wear-resistant surface while maintaining a tough core.
2. Induction Hardening
   - Uses electromagnetic induction to heat the surface, followed by quenching.
   - Ensures precise control over hardened depth and is suitable for cylindrical components.
3. Case Hardening (Carburizing/Nitriding)
   - Diffuses carbon or nitrogen into the surface layer at high temperatures to increase hardness.
   - Creates a wear-resistant surface while preserving a ductile core.
4. Quenching and Tempering:
   - Involves heating the material to austenitizing temperature, rapid quenching, and then tempering.
   - Provides uniform hardness and improved toughness throughout the component.
5. Through Hardening:
   - The entire cross-section of the material is uniformly hardened by heating and quenching.
   - Ensures high strength but may reduce ductility.

For EN8D material, induction hardening is often the best choice. It provides a hardened surface with excellent wear resistance and retains the material's toughness in the core, making it suitable for applications like shafts, gears, and other load-bearing components. This method also ensures precise control over the hardening process and is cost-effective for localized surface treatment.

5. ANSYS Analysis:

We have performed following Static Structural Analysis test on both the rigid sleeve iteration for our benchmarking:

1. **Deformation Analysis**: Assesses the displacement of the sleeve under axial loading.
2. **Stress Analysis**: Evaluates Von Mises stress distribution to identify critical regions.
3. **Safety Factor**: Determines the margin of safety based on material yield strength.
4. **Fatigue Life Analysis**: Estimates the sleeve's operational life under cyclic loading.

5.1 Boundary Condition:

We made fix support end from the motor shaft side and here the given details which we gave as an input:

Torque of Motor (Moment)= 18Nm
RPM of the motor that acts on the Couple= 2600 rpm
Force = 7500N
Factor of Safety = 1.3
Shear force acting along the plane= 10000N

5.2 Meshing:

Both iteration were meshed using the fine tetrahedral elements. A mesh convergence study confirmed the accuracy of the results.

6. ANSYS results for following test:

The analysis is carried out in ANSYS software 2021 workbench. Following results were observed:

1. *Total Deformation:*

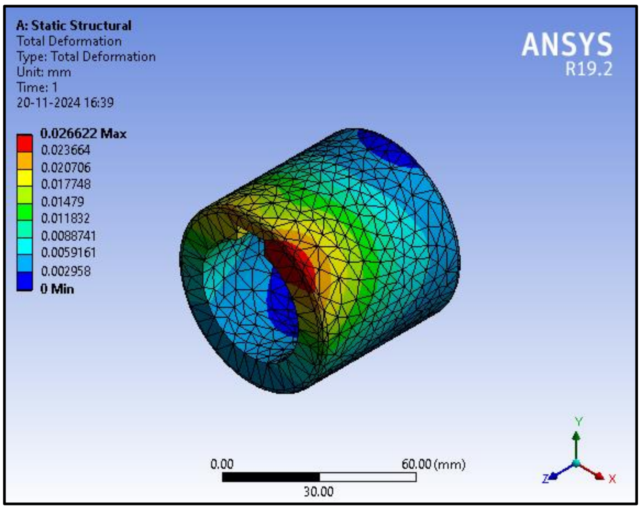

Figure 5: Total Deformation on MS rigid Sleeve

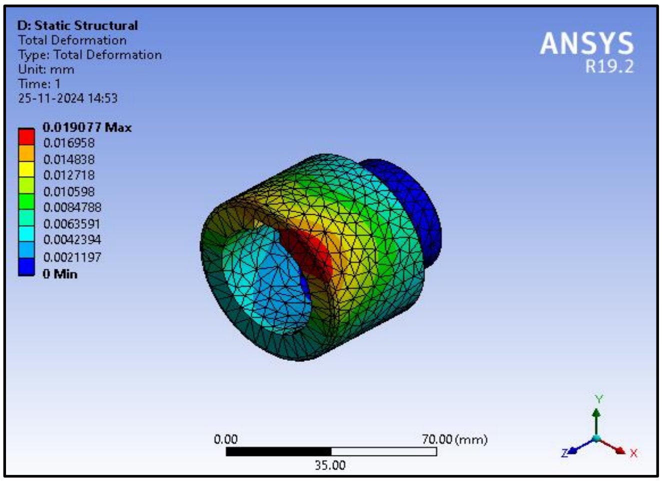

Figure 6: Total Deformation on EN8D Rigid sleeve

2. *Equivalent Stress:*

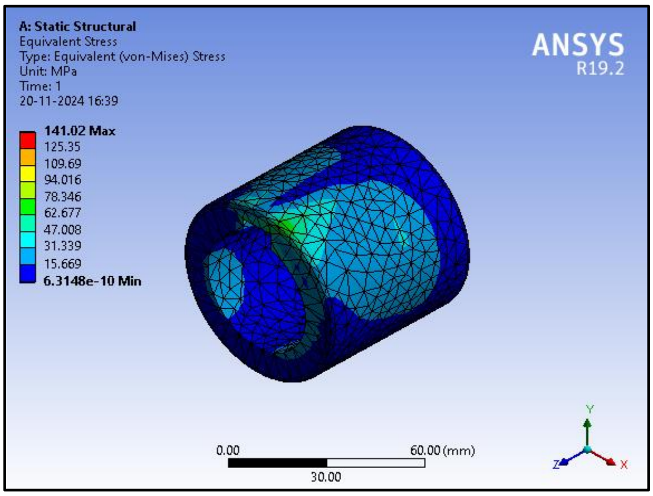

Figure 7: Equivalent Stress on MS Rigid Sleeve

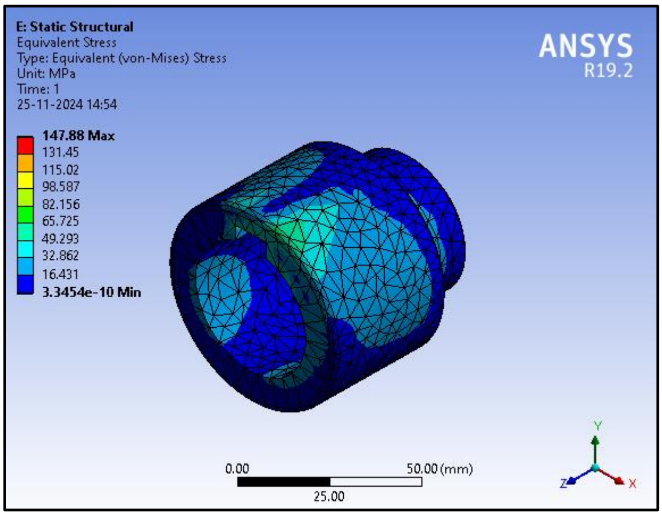

Figure 8: Equivalent Stress on EN8D Rigid Sleeve

3. *Safety Factor:*

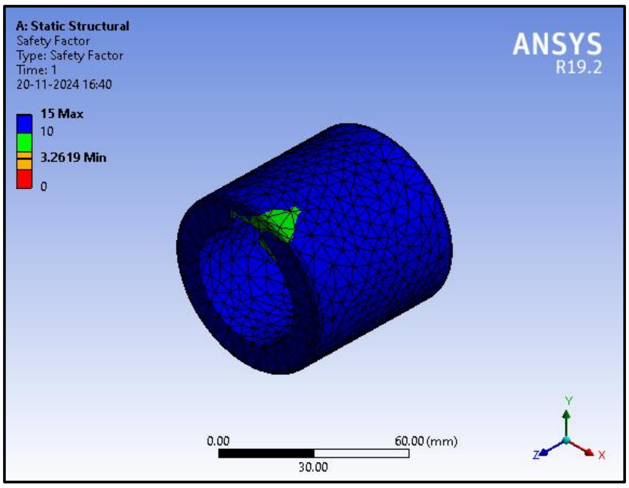

Figure 9: Safety Vector value on MS Rigid Sleeve

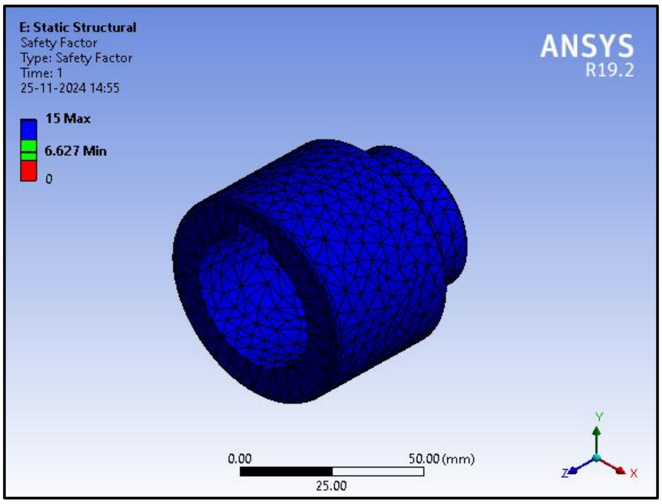

Figure 10: Safety Factor Value of an EN8D Rigid Sleeve

4. *Life Cycle:-*

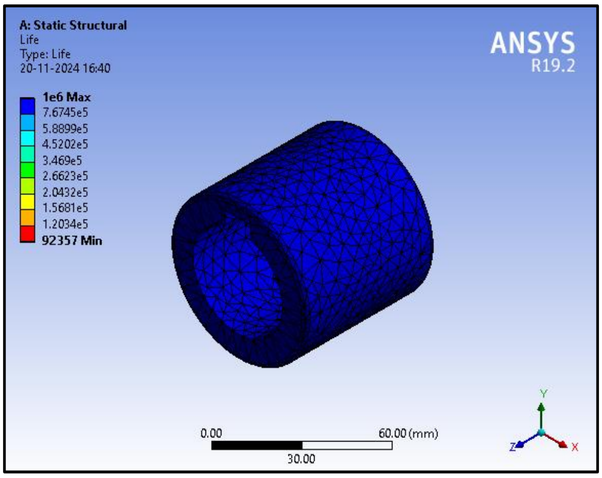

Figure 11: Life calculated of MS Rigid Sleeve

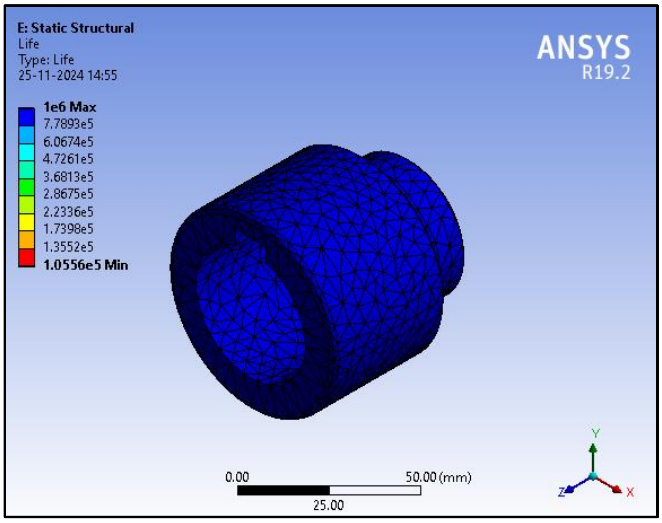

Figure 12: Life Calculated of EN8 Rigid Sleeve

7. Results

The results of the various tests are summarized below:

Parameter	MS Rigid Sleeve (Iteration I)	EN8 Rigid Sleeve (Iteration II)
Max Deformation (mm)	0.026	0.019
Max Von Mises Stress (MPa)	141.02	147.88
Safety Factor	3.2619	6.627
Fatigue Life (Cycles)	92357	105560
Weight reduction (%)	-	~22

8. Conclusion

This study has demonstrated the significant impact of material selection on the performance of rigid couplings used in automotive power transmission systems. Through a detailed comparison of mild steel (MS) and hardened EN8 steel, supported by Finite Element Analysis (FEA) in ANSYS, it was found that hardened EN8 steel outperforms mild steel in several critical aspects.

Hardened EN8 exhibited superior mechanical properties, including higher stress resistance, reduced deformation, enhanced fatigue strength, and better wear resistance, making it highly suitable for high-stress and demanding applications. In contrast, mild steel, while more cost-effective and easier to manufacture, showed limitations in durability and load-bearing capacity under similar conditions.

This research concludes that while MS may be adequate for low-load or non-critical applications, hardened EN8 is the optimal choice for rigid couplings in automotive power transmission systems requiring high reliability and performance. However, the trade-offs in cost and manufacturing complexity associated with hardened EN8 must be carefully considered during the material selection process. These findings provide a valuable framework for engineers and manufacturers to optimize coupling design and material choice, ensuring improved efficiency and longevity of drivetrain components.

9. REFERENCES

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