

Design and Analysis of a composite Flywheel for Energy Storage Application

Bhavesh Kishor Talele¹, Prof. K.K. Chaudhari², Dr. G.E.Chaudhari³, Prof. T.D. Garse⁴.

¹Student, Department of Mechanical Engineering, J. T. Mahajan COE, Faizpur, Maharashtra, India.

²Professor, Department of Mechanical Engineering, J. T. Mahajan COE, Faizpur, Maharashtra, India.

³Professor, Department of Mechanical Engineering, J. T. Mahajan COE, Faizpur, Maharashtra, India.

⁴Professor, Department of Mechanical Engineering, J. T. Mahajan COE, Faizpur, Maharashtra, India.

Abstract – As one of the growing energy storage technologies that are currently accessible in various stages of development, particularly in advanced technological fields, flywheels function as kinetic energy storage and retrieval devices with the capacity to deliver high output power at high rotational speeds, i.e., spaceships. Three main criteria determine a flywheel's performance: rotating speed, cross-sectional shape, and material strength. The kinetic energy level that may be produced safely when linked with rotor speed is directly determined by material strength; however, the focus of this study is only on investigating how flywheel material affects the energy storage and delivery capacity per unit mass, also known as specific energy. The findings of a proposed computer-aided analysis and optimization technique demonstrate that choosing the right flywheel material could significantly impact the Specific Energy performance and lessen the operational pressures placed on the shaft and bearings at high rotational speeds because of the reduced mass. Three rim type flywheels are designed on Solidworks software and structural analysis is done on Ansys software. The first flywheel is made up of mild steel and for reducing its weight composite flywheel is also developed. Carbon fiber is used for making other two flywheel. Out of three the flywheel made-up of carbon fiber body and mild steel rim will be more efficient and lighter in weight.

Key Words: Flywheel, Composite, Steel, Carbon fiber, Weight.

1. INTRODUCTION

In today's fast evolving technological era, the need for efficient, sustainable, and high-performance systems is driving innovations in various engineering domains. Among these, energy storage solutions play a pivotal role, particularly as the world moves towards renewable energy integration and electric mobility. One such promising technology is the flywheel energy storage system (FESS), which offers the ability to store kinetic energy in a rotating mass, providing high power density, life fast charge-discharge capabilities, and long cycle.

Conventional flywheels, typically made from steel or other metals, face limitations in terms of energy density and rotational speeds due to their material properties. As a

result, there has been a growing interest in composite materials to design and optimize flywheels for enhanced performance. Composite flywheels, owing to their high strength-to-weight ratio and fatigue resistance, allow for higher rotational speeds, which directly translate into increased energy storage capacity. Furthermore, the ability to customize material properties of composites offers new avenues for reducing system weight while maintaining or even improving the overall mechanical integrity and efficiency.

Despite these advantages, the design and analysis of composite flywheels present significant challenges. Factors such as material anisotropy, dynamic stress distribution, and failure modes must be carefully considered. This research focuses on the design, analysis, and optimization of composite flywheels to maximize efficiency and energy storage capability. Through finite element modelling, material selection strategies, and stress analysis, the study aims to contribute to the growing body of knowledge on composite flywheel systems, addressing the critical need for efficient energy storage technologies in modern applications.

2. PROBLEM STATEMENT

In the quest for efficient energy storage solutions, traditional flywheels made from metallic materials, such as steel, are hindered by their high weight and limited rotational speed. While metallic flywheels offer good strength, their significant mass limits the energy storage capacity per unit weight, making them less suitable for applications requiring high energy density, such as electric vehicles and renewable energy systems.

The need for lightweight, high-strength materials has led to the exploration of composite flywheels, which offer the potential to operate at higher speeds, thereby increasing energy storage efficiency. Composite materials, particularly carbon fiber, exhibit excellent strength-to-weight ratios, which enable flywheels to achieve higher rotational speeds with reduced mass. However, the optimization of composite flywheels presents several challenges, including managing stress distribution, preventing delamination, and ensuring long-term durability under cyclic loading conditions.

This research aims to address these challenges by investigating the design, material selection, and structural analysis of composite flywheels, with the goal of improving energy storage efficiency while maintaining mechanical integrity. The study will explore the interplay between material properties, geometric design, and operational parameters to develop a more effective composite flywheel system for modern energy storage applications.

3. OBJECTIVE

The objective of this research is to design and analyze a composite flywheel for enhanced energy storage efficiency, focusing on optimizing its performance for high-speed rotational applications. The study aims to explore the benefits of using advanced composite materials, such as carbon fiber, to reduce weight while maintaining or improving the structural integrity of the flywheel. Key goals include maximizing energy density, improving stress distribution, and ensuring durability under dynamic loading conditions. The research will also evaluate the performance of composite flywheels in comparison to conventional metal flywheels, with an emphasis on potential applications in automotive and renewable energy systems.

4. ANALYSIS

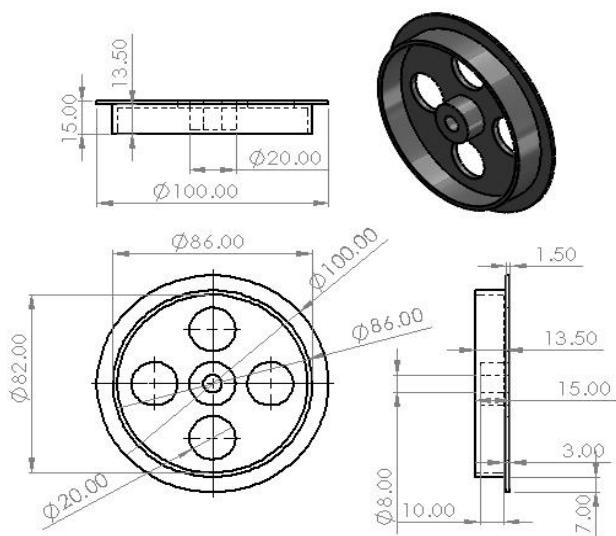


Fig -1: Drawing of Composite flywheel

The differences in deformation and stress can be explained by the intrinsic material properties of steel and carbon fiber.

Steel (MS): Has a high modulus of elasticity (stiffness) and yield strength, leading to low deformation but high stress under a given load.

Composite (CF + Steel): Combines the best properties of both materials. The steel provides stiffness and strength,

while the carbon fiber improves flexibility and reduces weight. This results in moderate deformation and stress values, making it an optimal choice where both stiffness and weight-saving are important considerations.

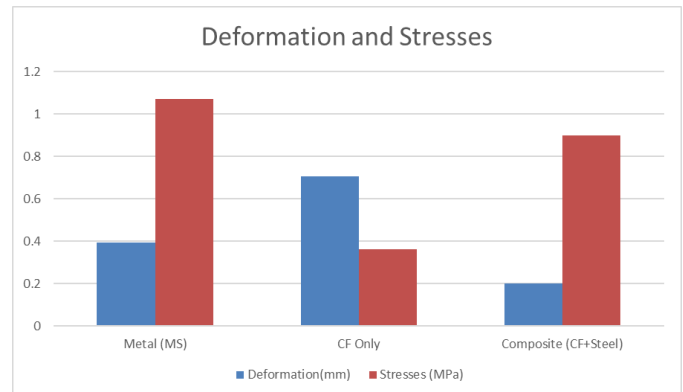


Chart -1: Deformation and stresses on flywheel

The results highlight that each material has unique advantages. Steel is optimal for stiffness and strength, while carbon fiber excels in applications where weight reduction is critical. The composite material offers a balanced solution, leveraging both the stiffness of steel and the flexibility of carbon fiber.

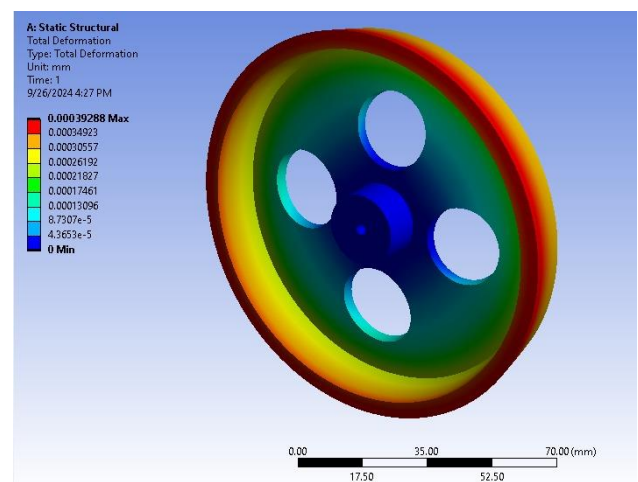


Fig -2: Deformation Plot for Metal (MS)

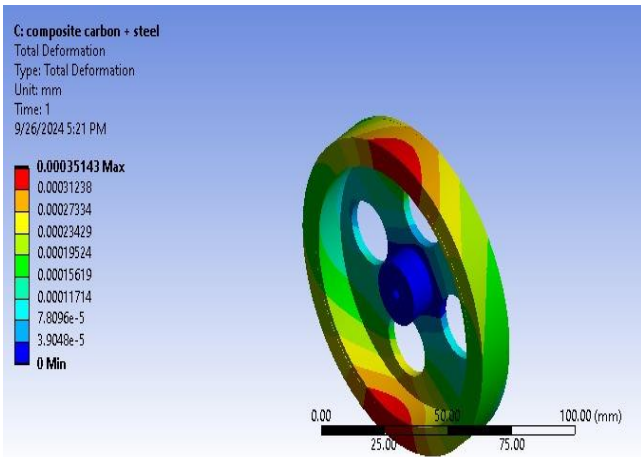


Fig -3: Deformation Plot for Composite (CF + Steel)

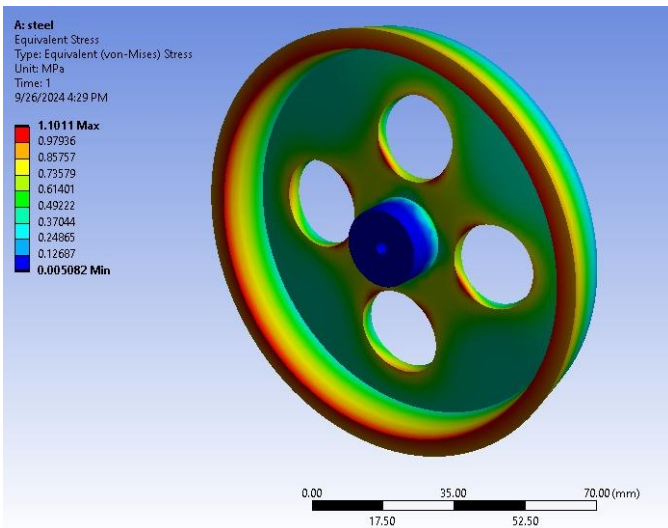


Fig -4: Von Mises Plot for Metal (MS)

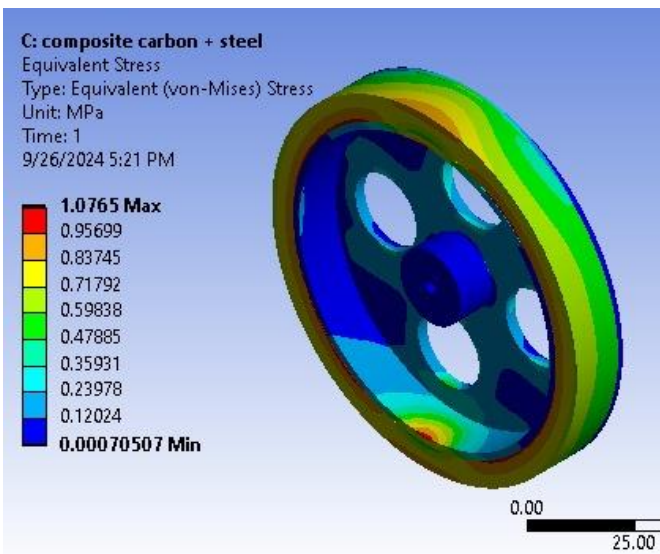


Fig -5: Von Mises Plot for Composite (CF + Steel)

Stresses of all materials are less than material yield and ultimate tensile strength and hence it is material are meeting static analysis acceptance limit.

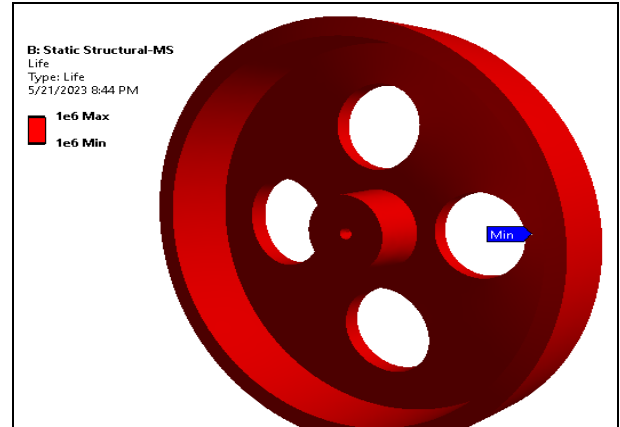


Fig -6: Life plot of Metal (MS)

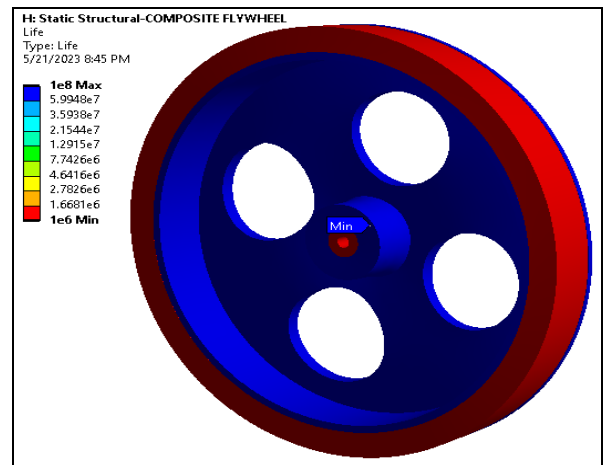


Fig -7: Life plot of Composite (CF + Steel)

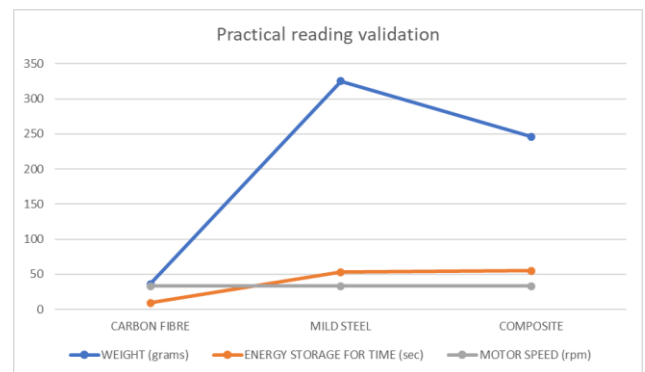


Chart -2: Practical reading validation.

5. RESULTS AND VALIDATION

Table -1: PRACTICAL VALIDATION READINGS

FLYWHEEL MATERIAL	WEIGHT (GM)	TOTAL ROTATING TIME (SEC)	MOTOR SPEED (RPS)
CARBON FIBRE	36	9.2	33.33
MILD STEEL	325	53	33.33
COMPOSITE	246	55	33.33

The composite flywheel, weighing 246 grams, achieved the longest rotational time of 55 seconds at a motor speed of 2000 RPM (33.33 RPS), outperforming both carbon fiber (36 grams, 9.2 seconds) and mild steel (325 grams, 53 seconds). While the carbon fiber flywheel was the lightest, it had the shortest rotation time, indicating less energy retention due to low inertia. The mild steel flywheel, though heavier, stored energy for longer. The composite flywheel demonstrated the best balance of weight and performance, making it the most efficient for energy storage and lightweight applications.

6. CONCLUSIONS

The analysis of carbon fiber, mild steel, and composite flywheels revealed distinct advantages and limitations in terms of energy storage and efficiency. Carbon fiber, while offering the lightest weight and highest strength-to-weight ratio, showed the shortest energy storage time due to its lower inertia. Mild steel demonstrated the longest energy retention, thanks to its high mass and inertia, but at the cost of significantly higher weight. The composite flywheel provided the best balance, achieving prolonged rotational time while maintaining a moderate weight. Thus, composite materials offer the most promising solution for applications requiring both energy efficiency and weight reduction.

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