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Design and Fabrication of A Bicycle Frame Under Static Loading Conditions

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***Abstract:** The design and fabrication of a bicycle frame require a careful balance between strength, weight, and durability to ensure optimal performance and safety. This study focuses on the structural analysis and manufacturing of a bicycle frame under static loading conditions. A detailed design process is carried out using computer-aided design (CAD) software, followed by finite element analysis (FEA) to evaluate stress distribution, deformation, and factor of safety under different loading scenarios. The material selection plays a crucial role in achieving a lightweight yet strong frame, with considerations given to aluminium alloys, carbon fibre, and steel. Based on analytical results, a prototype is fabricated using suitable manufacturing techniques, such as welding or brazing, to ensure structural integrity. Experimental validation is performed through static load testing to compare theoretical predictions with real-world performance. The results provide insights into the structural efficiency and reliability of the bicycle frame, contributing to advancements in bicycle engineering and material optimization.*
***Keywords:** Bicycle frame, Static loading, Finite Element Analysis, Material selection Structural integrity, Fabrication.*

I. INTRODUCTION

Bicycle frames are critical components that dictate the overall performance, safety, and durability of a bicycle. The structural integrity of the frame is influenced by various factors such as material selection, geometry, and manufacturing techniques. This study aims to investigate the structural behaviour of a bicycle frame under static loading conditions using computational and experimental methods.

II. DESIGN METHODOLOGY

The bicycle frame is designed using computer-aided design (CAD) software to ensure an optimized structure. The design process includes defining the frame geometry, tube dimensions, and joint configurations.

A. CAD Modeling

The initial step involves creating a 3D model of the bicycle frame using industry standard CAD software. The frame design adheres to ergonomic and mechanical requirements to ensure rider comfort and stability.

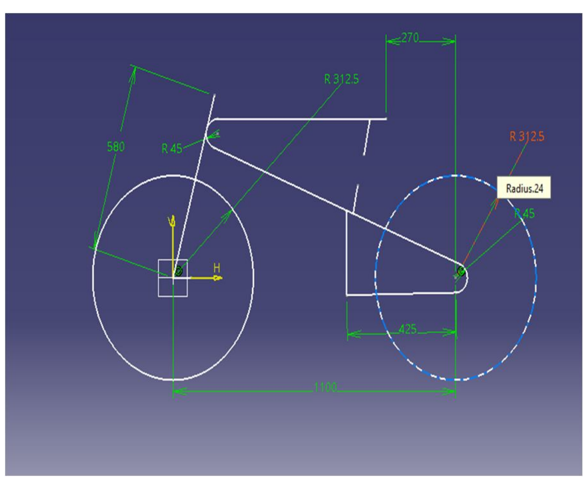

Fig No 2.1 2D Sketch of Bicycle Design

Fig No 2.2 Bicycle 3D Draft

B. Material Selection

Material selection is crucial for achieving the desired strength-to-weight ratio. Commonly used materials include:

- Aluminium Alloys: Lightweight and corrosion-resistant, suitable for high-performance bicycles.
- Carbon Fiber: Provides superior strength-to-weight ratio but is expensive.
- Steel: Offers high durability and affordability but increases weight.

Properties	Values
Density(kg/mm^3)	7.85E-06
Poisson's Ratio	0.3
Elastic Modulus(MPa)	2.00E+05
Ultimate Tensile strength(MPa)	460
Bulk Modulus(MPa)	1.66E+05
Shear Modulus(Mpa)	76923
Coefficient of Thermal expansion(10^-5/°C)	1.20E+00
Reference Temperature (°C)	22

Table No 2.1 Properties of Structural steel

III. FINITE ELEMENT ANALYSIS (FEA)

Finite element analysis (FEA) is used to simulate the structural response of the bicycle frame under different static loading conditions. The analysis provides insights into stress distribution, deformation, and safety factors.

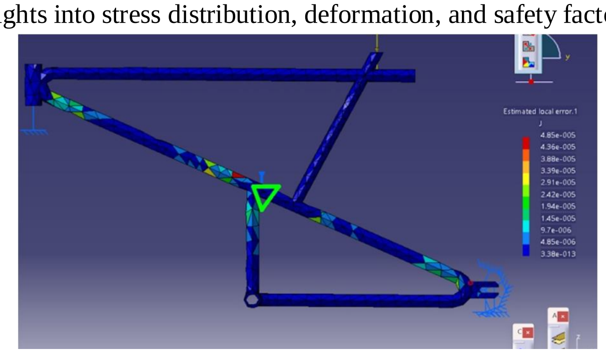

Fig No 3.1 Finite Element Analysis

A. *Loading Scenarios*

The frame is analyzed under various static loads, including:

- Rider weight distribution.
- Braking forces.
- Pedaling forces.

B. *Stress and Deformation Analysis*

The FEA results reveal critical stress points and deformation patterns, helping in refining the design to enhance durability and performance.

IV. FABRICATION PROCESS

Based on analytical findings, a prototype frame is fabricated using suitable manufacturing techniques such as welding or brazing to ensure structural integrity.

A. *Welding and Brazing*

The joining method depends on the selected material:

- Aluminium Frames: TIG welding is used to ensure strong and lightweight joints.
- Steel Frames: Brazing provides reliable connections with enhanced fatigue resistance.

Fig No 4.1 Welding

V. EXPERIMENTAL VALIDATION

The fabricated prototype undergoes static load testing to validate the theoretical predictions obtained from FEA. The experimental setup includes:

- Load application at critical stress points.
- Measurement of deflection and strain using strain gauges.
- Comparison with simulated results to evaluate discrepancies.

Fig No 5.1 U Turn Test

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The "U-turn test" in bicycle testing is typically used to assess a bike's handling, stability, and maneuverability. A U-turn is a sharp turn in the road, and testing how well a bike can handle this maneuver helps understand how responsive it is when making tight turns.

- Rider Comfort and Control
- Manoeuvrability
- Stability and Balance
- Geometry and Frame Design

Fig No 5.2 Bump Test

The "Bump test" in bicycle testing is typically used to evaluate how well a bike's suspension system (especially on mountain bikes or other bikes with shock absorbers) handles different terrains and conditions. It primarily focuses on how the bike responds to small bumps and how effectively it absorbs shock without losing performance or comfort.

- Suspension Performance:
- Efficiency and Comfort
- Durability and Maintenance

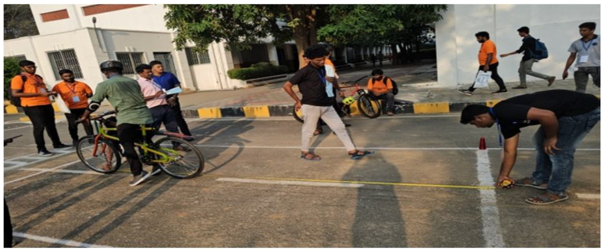

Fig No 5.3 Break Test

The "brake test" in bicycle testing is crucial for ensuring that the bike's braking system is functioning properly, safely, and effectively. Brakes are one of the most important safety features on a bicycle, so this test is designed to evaluate their performance in various conditions.

- Safety
- Brake Performance Evaluation
- Brake Wear and Durability
- Adjustment and Maintenance

Fig No 5.4 Pedal Stroke Test

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The pedal stroke test in bicycle testing is used to evaluate the efficiency, smoothness, and overall performance of a bike's drivetrain, especially when it comes to pedaling. This test involves assessing how the bike performs while the rider applies pressure to the pedals in a full stroke (from the downstroke to the upstroke).

- Smoothness of Pedalling
- Power Transfer Efficiency
- Crank and Pedal Alignment
- Pedal Stroke Symmetry

Fig No 5.5 Weight Test

The weight test in bicycle testing is used to assess and measure the overall weight of a bike, which can have significant effects on its performance, handling, and comfort.

- Performance and Speed
- Comfort and Ride Quality
- Material and Design Evaluation
- Comparison and Market Positioning

Fig No 5.6 Slow Cycle Test

The slow cycle test in bicycle testing is used to assess a bike's stability, handling, and overall performance at low speeds. It is particularly useful for evaluating how well a bike behaves when the rider is cycling slowly or navigating tight spaces.

- Stability at Low Speeds
- Maneuverability in Tight Spaces
- Comfort at Low Speeds
- Control Over Pedaling and Braking

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VI. RESULTS AND DISCUSSION

The experimental results confirm the reliability of the FEA model, with minor deviations attributed to material imperfections and fabrication tolerances. The frame demonstrates adequate strength and rigidity under operational loads.

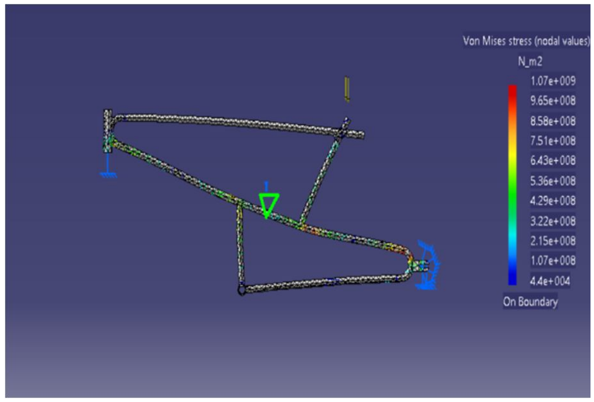

Fig No 6.1 Static Case Solution Von Mises stress

The maximum Von-Mises stress generated in the frame is 3479 Pa.
The minimum Von-Mises stress generated in the frame is 4.309E+007 P

VII. CONCLUSION

This study presents a systematic approach to designing, analyzing, and fabricating a bicycle frame. The combination of CAD modeling, FEA, and experimental validation ensures an optimized design with enhanced structural efficiency. Future work may focus on dynamic loading conditions and fatigue analysis to further improve frame performance

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