

Novel Design and Stress Analysis of Bicycle Pedal Using Ansys R2

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Abstract. This study examines the stress and deformation behaviour of two distinct models of bicycle pedals under static loading circumstances. The original existing model was made of Polyethylene. The model was designed using Catia 3D Experience and examined using ANSYS 2023 R2. A vertical force was applied to replicate the real-life loading condition on the bicycle pedal. After getting the results the pedal underwent a redesign on Catia 3D Experience, and titanium alloy Ti-6Al-4V was used as the material to enhance its performance. The new design's higher strength and deformation resistance was demonstrated in a comparative data for stress and deformation. By examining existing research on material selection, force distribution, and stress analysis the comparison between two different materials was done to gain insights into enhancing pedal designs for improved strength and durability. The study also investigates how the choice of materials affects deformation in mechanical components as well as their long-term performance under repeated cycling forces.

1 Introduction

The pedal is a crucial component that requires structural optimization for both safety and performance because it is subjected to a variety of loads while riding a bicycle [1]. Design robustness can be accessed under realistic load circumstances using Finite Element Analysis [2]. This study aims to examine the structural behaviour of the Hercules Design number 238583 bicycle pedal under static loading conditions [3]. The original model was made of polyethylene which is a lightweight and cost-effective material but to enhance its performance and life the pedal was redesigned in Catia 3D Experience and the material assigned was Titanium alloy Ti-6Al-4V which provides more durability [4]. Studies on stress distribution, pedal dynamics [5][6] and material performance optimization [7] have influenced this strategy.

Davis and Hull's research [1] showed how crucial precise force modelling is for pedal dynamics. the forces encountered when riding in various conditions. Soden and Adeyefa [2] provided insights into the forces experienced during cycling under various conditions. The modelling approach used in this work was informed by this foundational research which

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made sure that actual boundary conditions and material behaviour were taken into account. To increase performance and durability recent research has also placed a strong emphasis

on lightweight materials for bicycle components [8]. Recent studies have also suggested that titanium alloy Ti-6Al-4V provides significant benefits due to its superior strength-to-weight ratios and corrosion resistance which helps in the long life of the component [9][10]. Materials in mechanical components experience various loads like static, dynamic, impact, and fatigue. Bicycle pedals undergo repeated loading during use, leading to material fatigue and potential failure [11]. This highlights the need for a balance between lightweight design and strength, encouraging engineers to explore new materials [12]. The shift from traditional materials like polyethylene to titanium alloy Ti-6Al-4V reflects progress in fields like sports equipment, aerospace, and biomedical implants [13].

2 Methodology

2.1 Modelling and Meshing

2.1.1 Original model

Using the design parameters listed in Table 1, the Hercules design model number 238583 bicycle pedal design as shown in Fig. 1, was modelled in Catia 3D Experience [1] as shown in Fig. 2. After that the 3D model was transferred to ANSYS 2023 R2 for examination.[2]. The model underwent meshing as depicted in Fig. 3 in order to guarantee precise stress and deformation findings as suggested by Gupta and Agarwal.[6]. A mesh convergence study was conducted to ensure reliability and consistency in the results adhering to best practices outlined by Gojny et al [10]. Previous research in structural analysis has demonstrated that optimizing the mesh significantly impacts accuracy, making it a critical step in simulation-based design [7].

A finer mesh was used in high stress areas to improve accuracy while maintaining its efficiency [8]. The choice of element type and size came from studies on Finite Element Simulation, ensuring high accuracy [13].The Finite Element Method is often used in structural engineering, including car crash tests and aircraft failure analysis [9].

Table 1. Description of the pedal parameters

Parameter	Value (in mm)
Length of pedal	110
Width of pedal	80
Thickness of pedal	20
Length of shaft	100
Radius of connecting rod	10



Fig. 1. Original Pedal

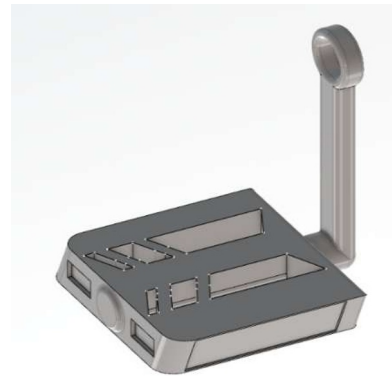


Fig. 2. Modelling of Original Pedal

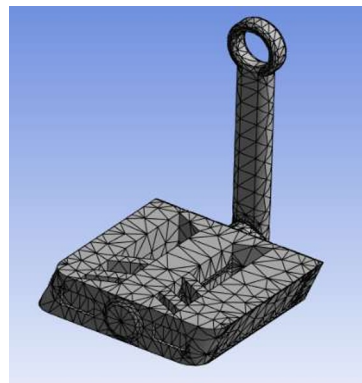


Fig. 3. Meshing of the Model

2.1.2 Redesigned model

In order to improve performance and durability, titanium alloy Ti-6AL-4V and other cutting-edge materials were incorporated into the bicycle pedal model redesign. Additionally, extraneous material was eliminated. Fig. 4 illustrates how the original design made in Catia 3D Experience, was altered to accept these materials by modifying the geometry and dimensions for the best possible load distribution. Fig. 5 illustrates how ANSYS 2023 R2 was used for meshing. Reinforcing high stress locations, choosing lighter materials, and improving the structure to reduce deformation under static loads were important design enhancements. [8][3]



Fig. 4. Modelling of Redesigned Pedal

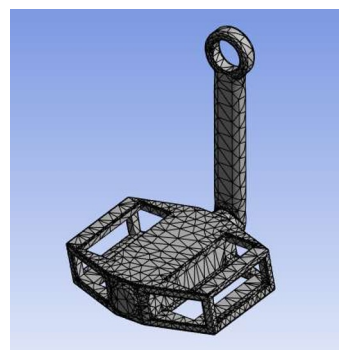


Fig. 5. Meshing of the Model

2.2 Boundary Conditions

2.2.1 Original model

As seen in Fig. 6 the shaft that connected the pedal and gear wheel was fixed to mimic real world limits [2]. As illustrated in Fig. 7, a vertical force of 295 N (a 75 kg person with about 40% of their weight on the pedal) was evenly distributed across the pedal surface to simulate the force a cyclist would apply when riding [8]. Previous studies like by Gupta and Agarwal [6] which described typical force distributions on bicycle components, served as the basis for the application of boundary conditions. For static loading cases, the technique compiles with industry requirements [5]. A thorough examination of stress distribution was ensured by taking into account by the dynamic impact of pedalling forces as investigated by Soden and Adeyefa [2]. Mechanical systems in engineering research shows that boundary conditions in FEA are crucial in making reliable simulations [13,14].

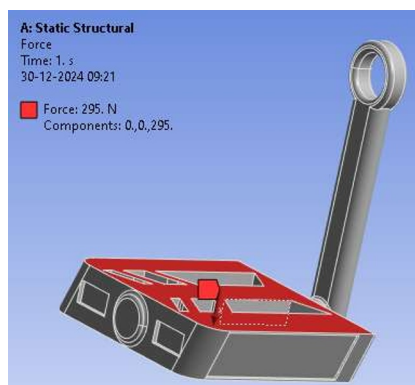


Fig. 6. Fixed support on Original Model

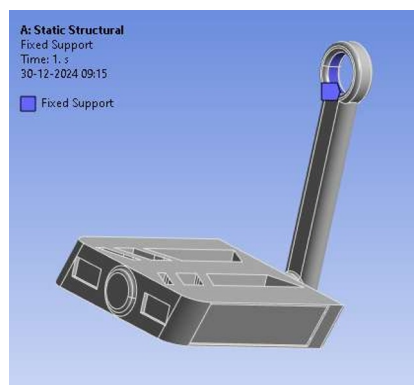


Fig. 7. Vertical Force on Original Model

2.2.2 Redesigned model

The same boundary conditions were applied to the redesigned model as shown in Fig. 8 and Fig. 9.



Fig. 8. Fixed Support on Redesigned Model

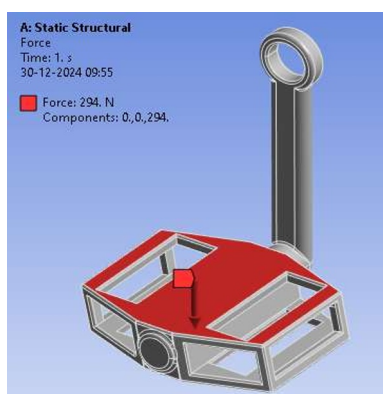


Fig. 9. Vertical Force on Redesigned Model

2.3 Material Properties

The material properties are listed in Table 2.

Table 2. Mechanical properties of Selected Materials

Material	Modulus of Elasticity (GPa)	Poisson's Ratio	Density(kg/m ³)
Polyethylene (Original Model)	0.8	0.42	950
Titanium Alloy Ti-6Al-4V (Redesigned Model)	115	0.32	4500

The selection of material attributes was focused on how well they relate to durability and mechanical performance in dynamic situations [5]. According to Kyles research titanium alloy Ti-6Al-4V was selected because of its exceptional strength to weight ratios [5]. As Dickinson recommended [3], the anisotropic structure of carbon fibre was taken into account during the research the account for directional strength changes. Titanium alloy Ti-6Al-4V outperforms traditional materials in stiffness and durability[9][10].

3 Results and Discussion

3.1 Original Model Analysis

The analysis of original model showed the following results:

- **Total Deformation:** 0.155165mm (Fig. 10)
- **Von Misses Stress:** 1.178×10^8 MPa (Fig. 11)

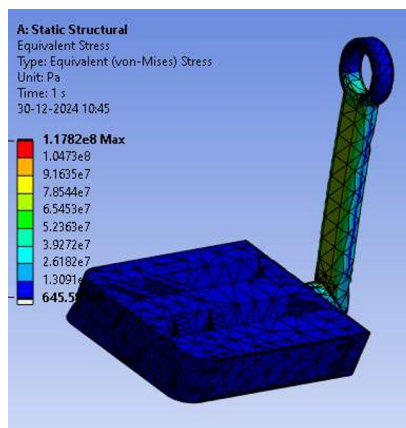
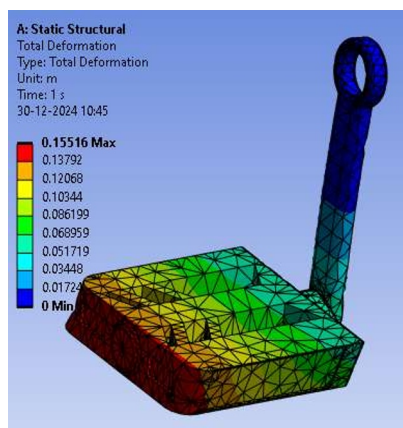


Fig. 10. Total Deformation of Original Model **Fig. 11.** Equivalent Stress of Original Model

Polyethylene showed considerable deformation and stress concentration when subjected to the applied load, which is consistent with previous studies highlighting its limited structural capacity under cyclic loading. This supports the findings of Soden and Adeyefa [2] regarding the drawbacks of using lightweight plastic or high-stress applications. These

results underscore the necessity for materials that possess greater stiffness and exhibit lower deformation under comparable loading conditions.

3.2 Redesigned Model Analysis

The analysis of the redesigned model showed the following results:

- **Total Deformation:** 0.0016875mm (Fig. 12)
- **Von Misses Stress:** 1.19675×10^8 MPa (Fig. 13)

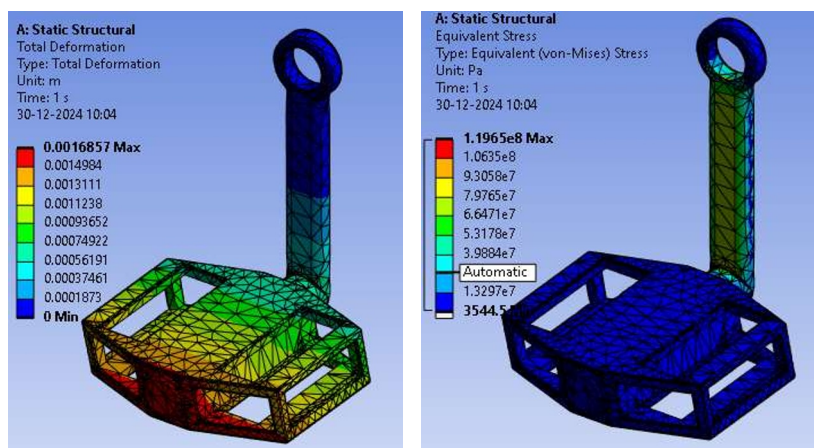


Fig. 12. Total Deformation of Redesigned Model **Fig. 13.** Equivalent Stress of Redesigned Model

Titanium alloy Ti-6Al-4V demonstrated superior strength and deformation characteristics compared to polyethylene. These results reinforce established hypotheses regarding material selection for applications that require high strength-to-weight ratios.[5]

Additionally, these findings align with Dickinson's [7] emphasis on the critical role of improved materials in reducing deformation while maintaining structural integrity. These also support Whitt and Wilson's [4] focus on endurance under cyclic loads, the observations regarding material performance in dynamic situations are validated by the titanium alloy Ti-6Al-4V pedal's ability to effectively balance strength and weight as well as the carbon fibres pedals remarkable capacity to minimize deformation [6][9].

The comparison of stress distribution between the two showed that both have similar stress patterns but the titanium alloy Ti-6Al-4V model has significantly reduced deformation making it the perfect suitable model for present-day cycling scenarios. Final result is shown in Table 3.

Table 3. Final Results

Model	Total Deformation	Equivalent Stress
Original (made of Polyethylene)	0.155165	1.178×10^8
Redesigned (made of Titanium Alloy Ti-6Al-4V)	0.0016785	1.19675×10^8

3.3 Comparative Analyses

The following Table 4 shows the comparison between the original model (made of polyethylene) and the redesigned model (made of Titanium alloy Ti-6Al-4V) based on various features [9][10].

Table 4. Comparison between original model and final model

Feature	Original Model	Redesigned Model
Deformation	High Deformation	Reduced Deformation
Weight	Lightweight	Moderate weight
Durability	Limited Durability under cyclic loads	Excellent durability and fatigue resistance
Material Strength	Low Strength	High Strength
Corrosion Resistance	Susceptible to environmental degradation	High resistance to corrosion
Manufacturing Ease	Easy to mold and fabricate	Requires precise manufacturing

This comparison highlights that the new pedal model made of Titanium alloy Ti-6Al-4V outperforms other models in several key areas, showcasing its superiority. The updated titanium alloy Ti-6Al-4V model excels in performance safety and comfort and it seamlessly integrates with the new design featuring material reduction. A few features of polyethylene are better.

4 Conclusion

The analysis of bicycle pedal using Finite Element Analysis highlighted key differences between polyethylene and titanium alloy Ti-6Al-4V material. The result showed that the titanium alloy Ti-6Al-4V pedal performed better, with less deformation. Its higher modulus of elasticity and strength to weight ratio enhances its resistance to deformation, which is crucial for high-performance cycling.

While the polyethylene pedal was lightweight and cost-effective, it experienced higher stress concentration and more deformation under the same condition, revealing its limitations in demanding situations. Previous research supports the idea that material choice is vital for improving the durability and efficiency of cycle parts. Overall, titanium alloy's strong properties make it more suitable option for bike pedals.

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