ANALYSIS OF THE INFLUENCE OF MANUFACTURING MATERIALS ON STRESS AND DEFORMATION OF CONTINUOUSLY VARIABLE TRANSMISSION (CVT) PULLEYS

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Abstract:

Continuously variable transmission is a type of transmission that can change torque continuously without dividing into gears like a mechanical transmission. This transmission is equipped on modern vehicles, so it requires the transmission to ensure the longevity and durability of internal components. Therefore, this article focuses on analysing the stress, deformation and safety factors of the gearbox pulley corresponding to each manufacturing material. The 3D model with the basic parameters of the pulley is built using SolidWorks software. The finite element method is applied to analyse using Ansys. Based on the simulation results, it shows that when compared with other materials, Stainless Steel still ensures durability and stress, so the study recommends that Stainless Steel be used as a material to manufacture gearbox pulleys in factories.

1 Introduction

Continuously variable transmission (CVT) is currently very popular in the world with many benefits it brings to users such as smooth operation, reduced fuel consumption, reduced environmental emissions based on a simple and optimal design with two pulleys, each pulley will be made up of two conical blocks facing each other, including a moving block and a fixed block, they are connected together thanks to a metal belt [1,2] described in Figure 1.

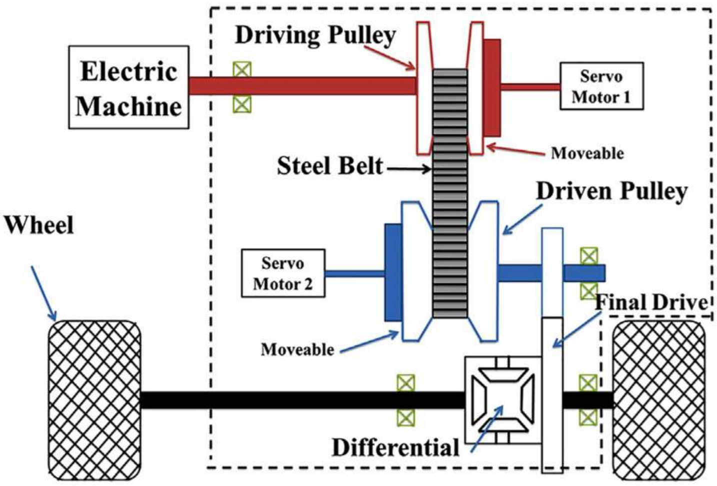

Figure 1. General layout of CVT gearbox

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Research on optimizing CVT continuously variable transmission is a topic of interest to many car manufacturers in the world. In which some typical research works related to CVT gearboxes on the deformation ability of metal belts compared to pulleys affect the performance of CVT gearboxes, the authors [3] use the finite element method to analyse the stress and deformation of the pulleys, the results after being analysed by the author in ANSYS show that when the transmission ratio increases, the deformation of the driving pulley decreases while the passive pulley increases, the total minimum and maximum deformation power loss are 43.92W and 240.69W respectively, it is concluded that the minimum deformation loss when the transmission ratio is 1.

In addition, improving transmission efficiency and reducing energy consumption with CVT gearboxes is studied [4] by the method of comprehensive model optimization. The proposed method is a predictive model and a predictive output equation, the model is designed and simulated in Matlab Simulink software. As a result, this method can improve the vehicle's transmission efficiency, help save fuel, reduce greenhouse effect and air pollution. Research [5] used CFD method to analyse the thermal performance of CVT gearbox, the goal of the research was to calculate the cooling of the gearbox, this method helps to optimize the simulation time from 93 days to 17 hours, the result is that asymmetric heat flows appear between the calculation model, leading to the conclusion that this simulation is not effective but will be a source of material for further research. To optimize the performance of CVT gearbox based on optimizing the clamping force in the pulley, the author group [6] studied the use of the simulation method of driving conditions in Matlab Simulink and AMESim software. The results after simulation were concluded by the author that in driving conditions such as uphill, urban and suburban respectively reduced fuel consumption by 0.37%, 0.32% and 0.27% compared to the safety factor method, so this method can be used to increase the vehicle's fuel control ability. In the study [7], the authors also proposed a controller for continuously variable transmission (CVT) to predict vehicle operating states based on vehicle speed, engine torque and reference data signals. This controller improves 8.92% of power transmission efficiency and 4.9% of fuel consumption, which is obtained based on simulation using AMESim and Matlab Simulink. The authors in the article [8] simulated the model of the CVT and analysed the slip characteristics of the metal belt on Malab Simulink software based on the equations governing the operation of the CVT. After obtaining the results, the author concluded that the slip increased as the speed increased, the torque ratio and the clamping ratio were proportional to each other, this study will help develop a control system to control the transmission efficiency of the CVT.

Moreover, studies [9-11] have modelled the performance loss mechanism of metal belts in all three cases of performance loss due to friction, performance loss due to pulley misalignment, and performance loss due to belt slippage. The results of the above studies are the premise for studies on improving performance loss caused by metal belts. The research [12] also proposed to change the structural parameters of the planetary gear assembly in the CVT gearbox, the authors used the finite element method and predicted the oscillation frequency to avoid deformation and resonant oscillation during operation.

In general, the above studies only focus on changing the internal structure of the CVT gearbox or building control units to improve power transmission efficiency and reduce fuel consumption, but have not gone into changing the materials to manufacture some components inside the CVT gearbox. Therefore, this study proposed using materials to manufacture CVT pulleys based on the deformation, stress and safety factor of the pulley. The above factors are obtained from designing the pulley model using SolidWorks and applying Ansys to analyze the finite element of the pulley.

2 Simulation model

The operation of the CVT is maintained by a passive pulley and an active pulley, adjusting the transmission ratio of the system through changing the radius of the CVT belt [13,14]. To keep the gearbox running smoothly, it is necessary to apply the appropriate pressure to the pulley on the belt. However, if the pressure is too large, it will easily wear and deform, affecting the performance of both the belt and the entire CVT system, or it can directly affect the level of slippage that the system encounters [15]. Therefore, it is necessary to choose the material to manufacture the pulley to ensure durability and reduce manufacturing costs. This study focuses on analysing the passive pulley because this part is under more pressure from the active pulley. First, SolidWorks is applied to build a 3D model of the continuously variable transmission (CVT) K310 pulley of a passenger car as shown in Figure 2.

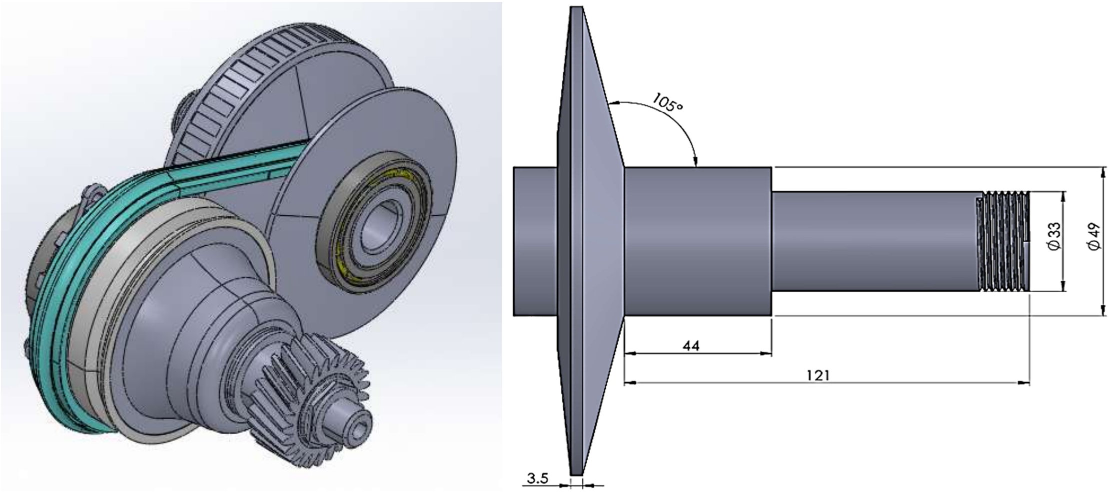


Figure 2. CVT pulleys and passive pulleys 3D models

After completing the model, it will be put into Ansys as shown in Figure 3 to declare the input parameters related to the properties of the manufacturing materials before the analysis process.

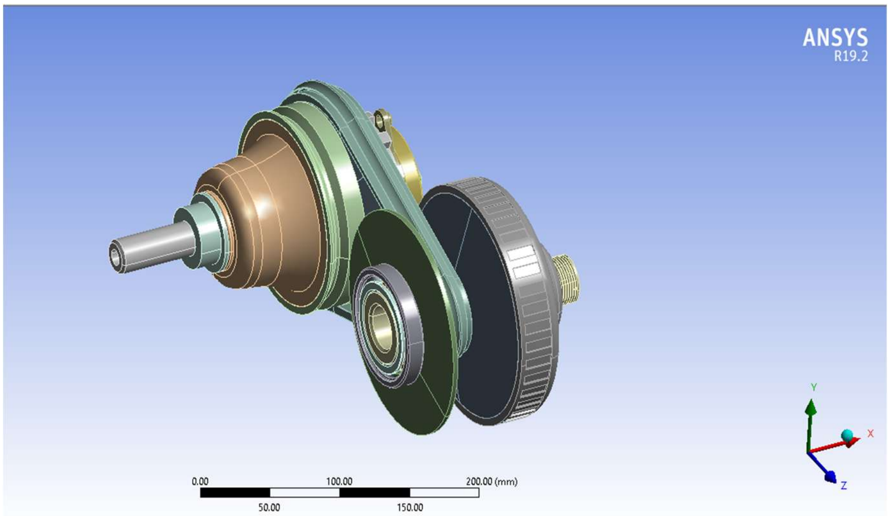


Figure 3. Continuously Variable Transmission (CVT) model in Ansys

This study proposes some materials with basic properties [16-20] for pulleys presented in Table 1 as follows:

Table 1. Basic parameters of materials used for simulation

Materials	Coefficient of friction	Density, kg/m^3	Poisson's Ratio	Young's Modulus, GPa
Stuctural Steel	0.28	7850	0.3	200
Gray Cast Iron	0.28	7200	0.29	110
Aluminum Alloy	0.23	2770	0.33	70
Stainless Steel	0.64	7750	0.31	193

3 Simulation results

This uses the finite element method to analyse the stress and deformation of CVT pulleys using Ansys. Because the 3D model of CVT pulleys is quite complex, it cannot be described by equations like the numerical method, so it is necessary to mesh the model [21,22] in Ansys as shown in Figure 4:

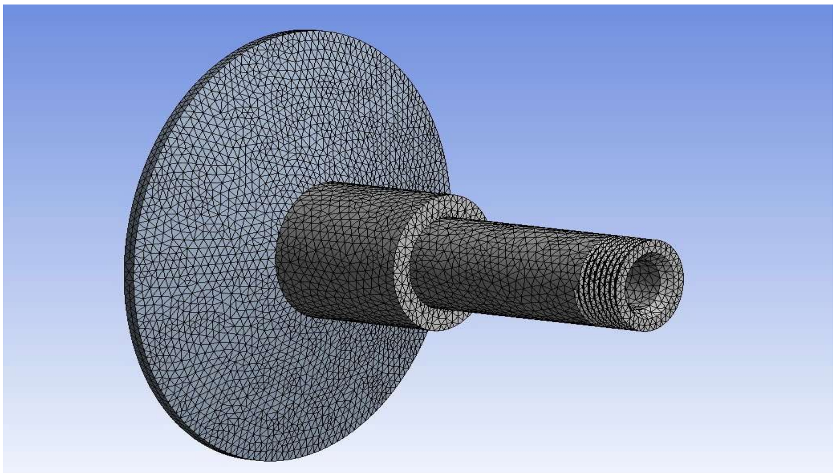


Figure 4. Meshing model of passive CVT pulley

When the car moves on the road, the continuously variable transmission (CVT) operates continuously, the vehicle speed changes thanks to the change in the working radius of the belt connected to the two pulleys, at this time the diameter of the two pulleys will change continuously. When the torque from the engine is transmitted to the input shaft of the gearbox, the active pulley is then driven by the belt to drive the passive pulley. At this time, the mechanism is affected by the maximum input torque of 160 Nm [3,23], leading to the passive pulley receiving this torque, it is affected by the belt and changes its diameter depending on the vehicle speed. The working radius of the transmission and the driving pulley ranges from 31.5-74 mm, the transmission ratio varies from 0.42-2.35. Therefore, it is necessary to set the torque parameters acting on the pulley in Ansys as shown in Figure 5:

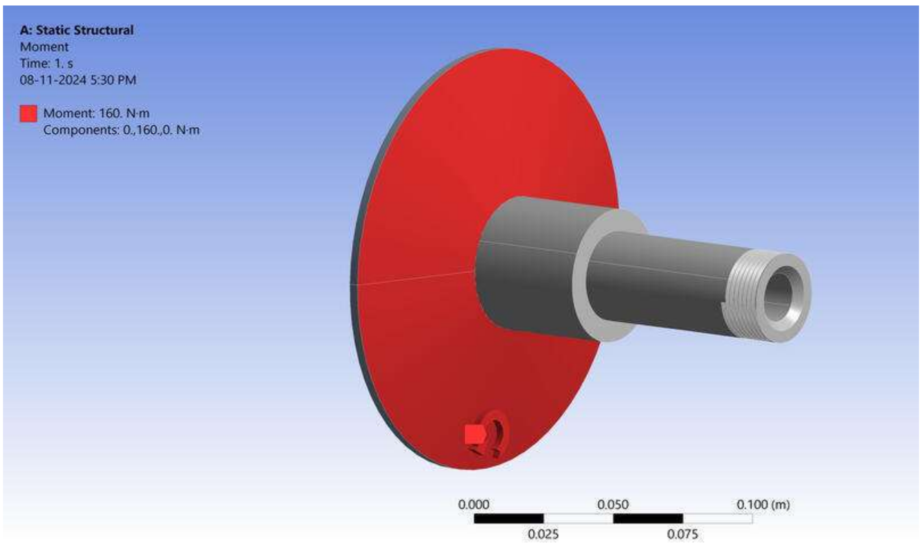
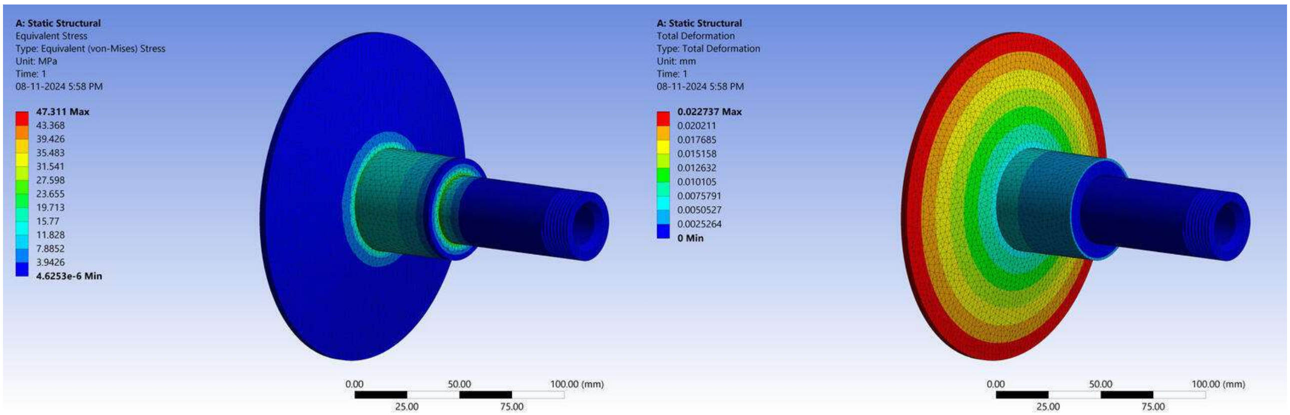


Figure 5. Simulation model of torque acting on pulleys

In addition, the torque converter slip does not affect the transmission of power of the gearbox, the torque converter is locked so the input shaft torque is the engine torque so the torque is transmitted directly to the passive pulleys [24]. At this time, finite element analysis by Ansys gives the simulation results of stress (a) and deformation (b) corresponding to the following materials:

For Stainless Steel material:

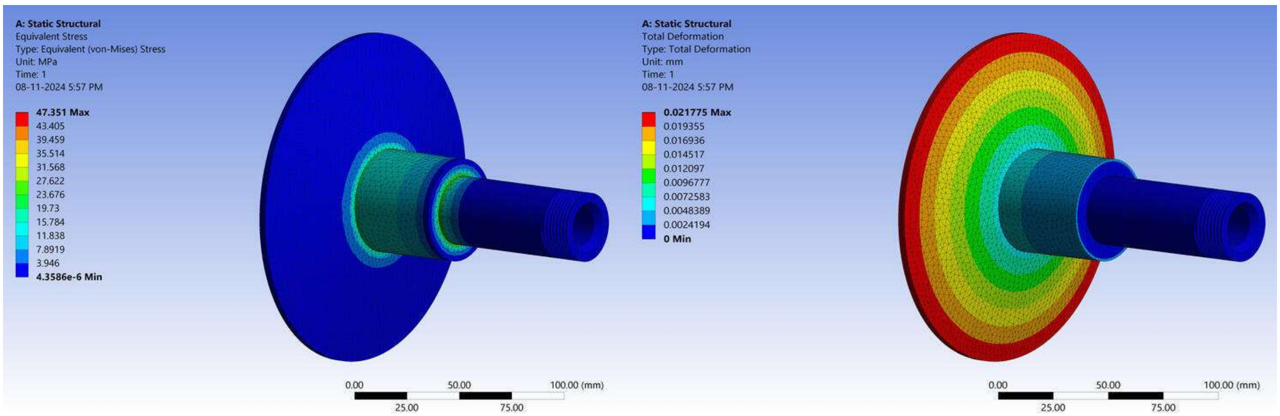


(a) (b)

Figure 6. Simulation results of Stainless Steel pulley

Figure 6 shows that the smallest stress is concentrated on the pulley surface because this part is directly affected by the belt, the highest stress is 47.311 MPa concentrated on the passive shaft because this part only transmits the torque to the car differential. On the other hand, the deformation increases from the inside to the outside of the pulley rim, the rim edge is deformed the most at 0.022737 mm.

For Structural Steel material:

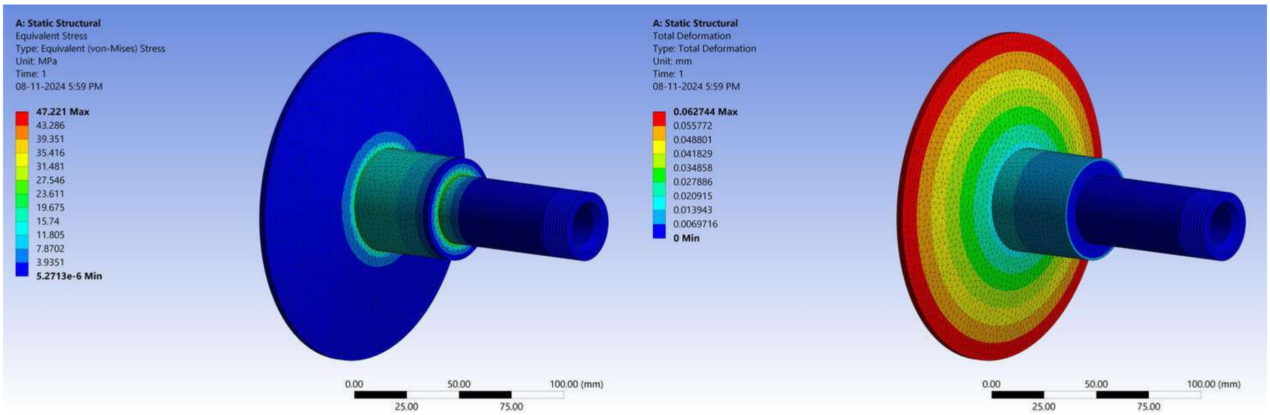


(a) (b)

Figure 7. Simulation results of Structural Steel pulley

The simulation results in Figure 7 when using Structural Steel material to manufacture the pulley show values close to those of Stainless Steel material in Figure 6. The stress value is 47.351 MPa, the deformation is 0.021775 mm.

For Aluminum Alloy material:

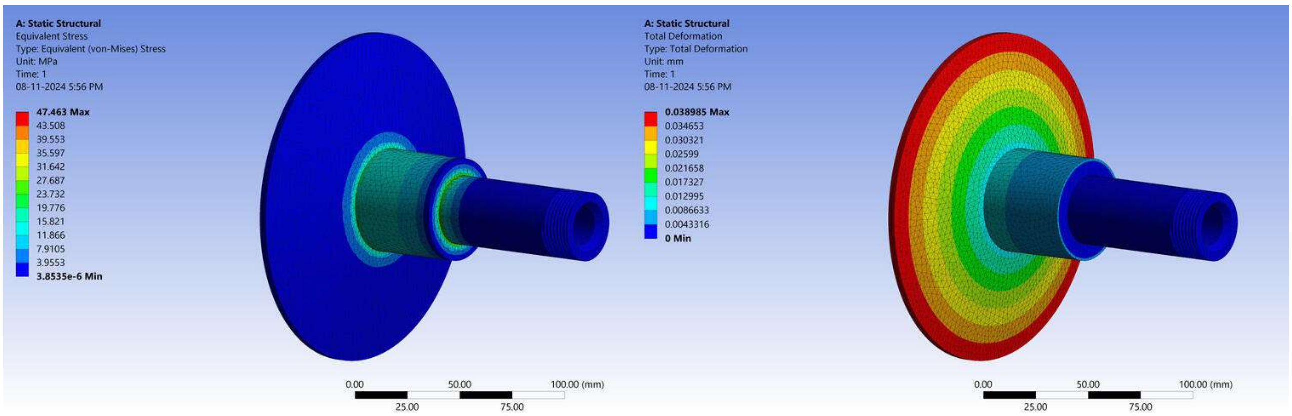


(a) (b)

Figure 8. Simulation results of Aluminum Alloy pulley

In the case of CVT pulley made of Aluminum Alloy material, the results are more different. Specifically, in Figure 8, the stress is determined to be 47.221 MPa, the deformation is 0.062744 mm.

For Gray Cast Iron material:



(a) (b)

Figure 9. Simulation results of Gray Cast Iron pulley

The final proposed material used to fabricate the CVT pulley part is Gray Cast Iron material. The simulation in Figure 9 shows the stress value as 47.463 MPa, the deformation is 0.038985 mm.

The study only relies on the stress and deformation values of the CVT assembly, it will only determine its durability but not confirm whether the material brings economic efficiency to the manufacturer. Therefore, the study conducts additional simulations of the material safety factor presented in Figure 10 similar to the study[25] to select suitable materials.

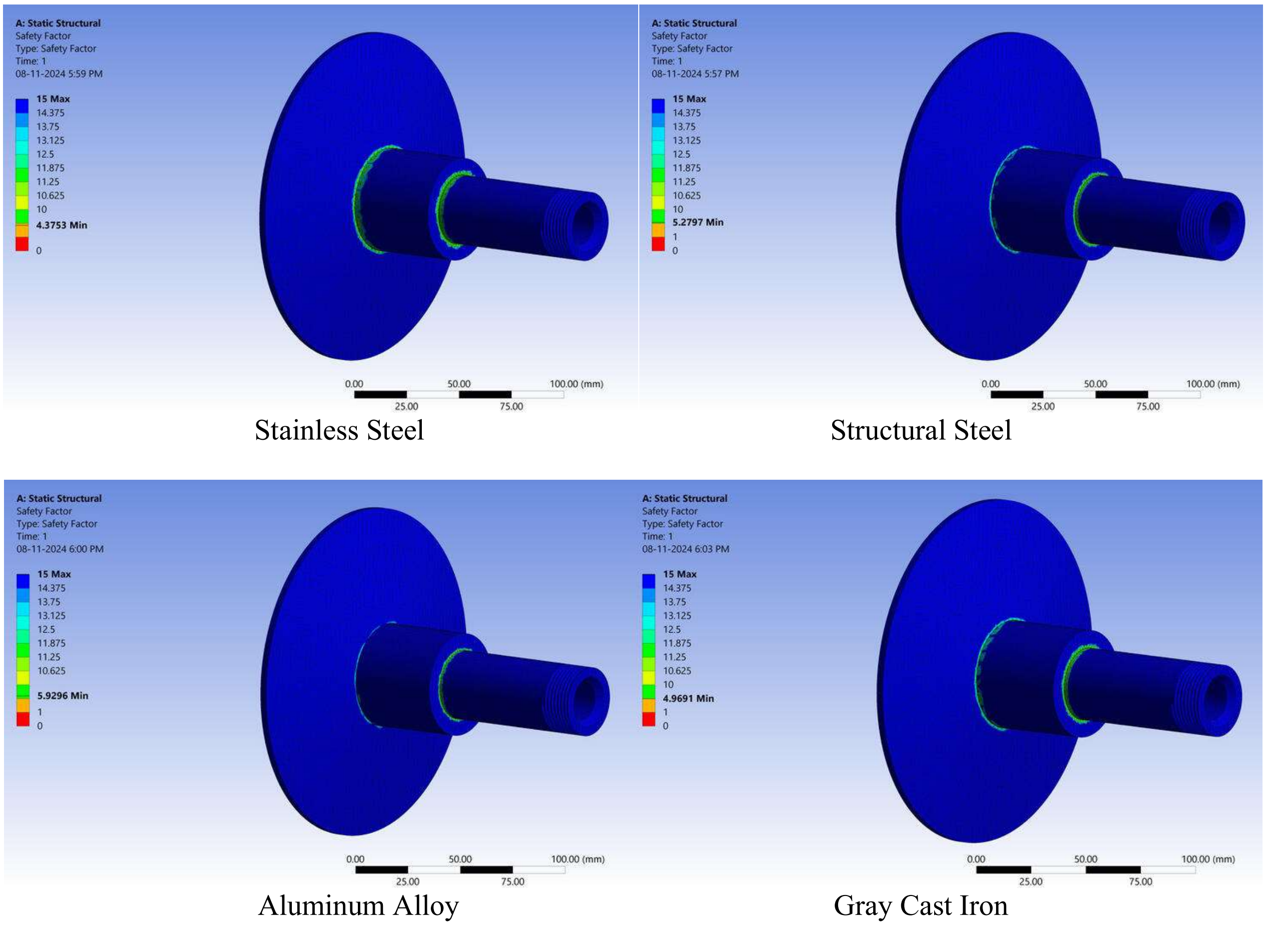


Figure 10. Simulation results of CVT pulley safety factor for different materials

The simulated values of safety factor of CVT pulley corresponding to different materials in Figure 10 and the stress and strain values from the above analysis are summarized in Table 2 as follows:

Table 2. Summary of simulation values

Materials	Stress, MPa	Deformation, mm	Safety Factor
Stainless Steel	47.311	0.022737	4.3753
Structural Steel	47.351	0.021775	5.2797
Aluminum Alloy	47.221	0.062744	5.9296
Gray Cast Iron	47.463	0.038985	4.9691

Based on Table 2, the values show that the material with the highest stress is Gray Cast Iron 47.463 MPa, the lowest is Aluminum Alloy with 47.221 Mpa, the material with the highest deformation is Aluminum Alloy 0.062744 mm, the lowest is Structural Steel 0.021775 mm. In addition, the study also considers the safety factor because the material with the highest safety factor is Aluminum Alloy of 5.9296, the lowest is Stainless Steel of 4.3753. However, if considering stress and deformation, Stainless Steel and Structural Steel are almost the same, the safety factor of Stainless Steel is smaller than that of Structural Steel, so the article proposes the option of choosing Stainless Steel material because when the safety factor is lower, it saves costs and manufacturing materials, these values are still within the allowable range as in the study [26,27].

4 Conclusion

This study proposed a material for manufacturing pulleys for Continuously Variable Transmission (CVT). This result was obtained based on the finite element method (FEM) using Ansys software. Simulation was performed on the pulleys model in space corresponding to the materials Stainless Steel, Aluminum Alloy, Gray Cast Iron, Structural Steel. Analysis showed that the passive pulleys for continuously variable transmission (CVT) using Stainless Steel material had a deformation of 0.022737 mm, a stress of 47.311 MPa, and a safety factor of 4.3753. Although these values are close to those of other materials, the manufacturing cost will be greatly reduced because the safety factor is the smallest. Therefore, the article proposes the use of Stainless Steel material in the production and fabrication of CVT pulleys.

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