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Transmission Shaft Performance Using Static Simulation for Brushing Simulator

Jennevy Tony[1], Salihatun Md Salleh[1]*, Ong Pauline[1], Low Cheng Yee[1]

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussien Onn Malaysia, Parit Raja, 86400 Batu Pahat, Johor, MALAYSIA

*Corresponding Author

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Abstract: The brushing simulator assists researchers and dentists in conducting investigations on human teeth and plaque removal. In this paper, the development of a brushing simulator is studied. Which focuses on the life expectancy of shaft material used in the development process in the future. The aim of this study is to analyse the stress distribution of the aluminium and brushing simulator's stainless steel threaded shafts. Besides, to analyse the brushing simulator's threaded shaft life expectancy. The motor speed of Set 1 can be modified to 450 rpm, 480 rpm, 510 rpm, or 540 rpm. Meanwhile, speeds for set 2 are 550 rpm, 580 rpm, 610 rpm, and 640 rpm. In this study, Solidworks software was used to construct a brushing simulator model and obtain the result of stress distribution in a static simulation. The life expectancy of the aluminium and stainless-steel threaded shafts was determined from the design calculation method by using the simulation data. The threaded shaft life expectancy result showed that stainless steel is more durable than aluminium which is 3522 hours from set 1 compared to 728 hours at 640 rpm for the aluminium threaded shaft. Based on its material properties, the findings indicate that stainless steel is stronger than aluminium. Furthermore, the study shows that life expectancy at speeds below 550 rpm is higher than at speeds above 550 rpm. Hence, the life expectancy of a threaded shaft decreases as the speed increases.

Keywords: Brushing simulator, life expectancy, aluminium, stainless steel, speed, SolidWorks

1. Introduction

The brushing simulator assists the researcher and dentist in performing an experimental study of teeth. The gloss, roughness, and colour change of the teeth affected by bristle contact with tooth surface examination may be assisted by the simulator [1]. By using SolidWorks software, the brushing simulator must be designed to confirm the actual machine's function. SolidWork is the software used to model all of the components in a 3D part workbench. It is possible to determine the mass of each component in the mechanism by using materials [2]. This project focuses on the material shaft's life expectancy utilised in the brushing simulator's creation. There are a variety of applications that are widely applied to threaded shafts. The maintenance costs will increase if the threaded shaft breaks. About 85% of threaded shaft failure is caused by fatigue [3]. Brushing simulator machines will be used multiple times with different speeds of motor by researchers and dentists in conducting their experiment. In addition, an inventive motion threaded mechanism was designed, specifically for the linear motion that supports the sheave in the threaded groove [4]. The study stated that the factor that causes lead screws to lose efficiency is friction, due to the heat energy and thermal expansion of the material produced by the friction. As the various speeds will affect the threaded shaft, it is very important to know the lifespan of the threaded shaft in the long run when selecting threaded shaft material. Fig. 1 shows a simulation of a brushing simulator with a stress analysis study as indicated in the pointed box. Other researchers applied simulators with different designs, such as reciprocal action and rotary action brushing [5]. The completeness should be simplified so that more can be studied on other mechanisms for simulation.

*Corresponding author: saliha@uthm.edu.my

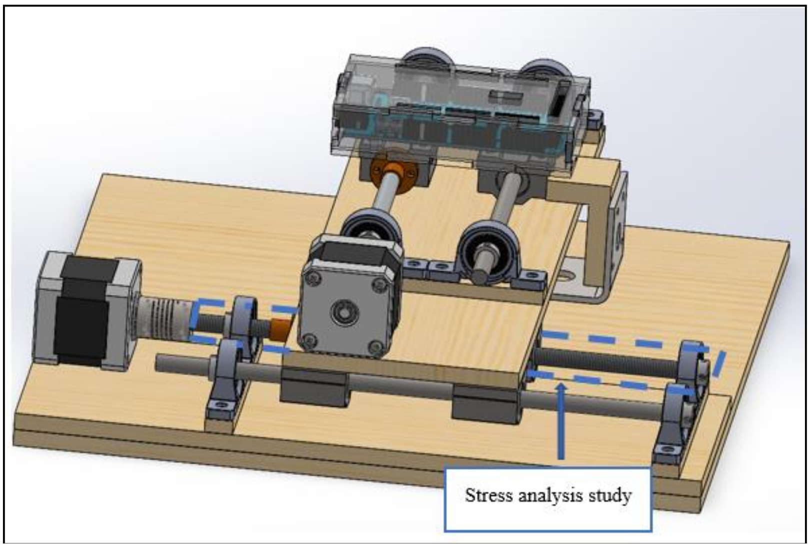


Fig. 1 - Brushing simulator

2. Material and Method

2.1 Material

In this study, stainless steel and aluminium are used on the threaded shaft of the brushing simulator. These materials are most commonly used in hospitals or healthcare institutions and will be used to check their suitability. The mechanical properties of aluminium and stainless steel are shown in Tables 1 and 2, respectively.

Table 1 - Properties of AA6082 aluminium alloy [6]

Properties	Maximum Value in units
Density	2.71g/cm^3
Young's Modulus	71 GPa
Ultimate tensile strength	140-330 MPa
Yield strength	90-280 MPa
Thermal expansion	23.1 $\frac{\mu \text{m}}{\text{m K}}$
Proof stress	85 MPa
Tensile strength	150 MPa

Table 2 - Properties of stainless steel [7]

Properties	Value in units
Ultimate Tensile Strength	685 MPa
Ultimate Yield Strength	295 MPa
Compressive Yield Strength	365 MPa
Elastic Modulus	195 GPa
Poisson's Ratio	0.27

2.2 Methodology

Using SolidWorks software, every single component is presumed to be a rigid body [8], [9]. Fig. 2 presents the overall method applied in this project. The designation of a brushing simulator required SolidWorks software. After completion of assembling all components, in motion analysis, the brushing simulator's motions were run to both determine the load and torque at the stepper motor using a threaded shaft. Lastly, the static simulation was then performed in SolidWorks.

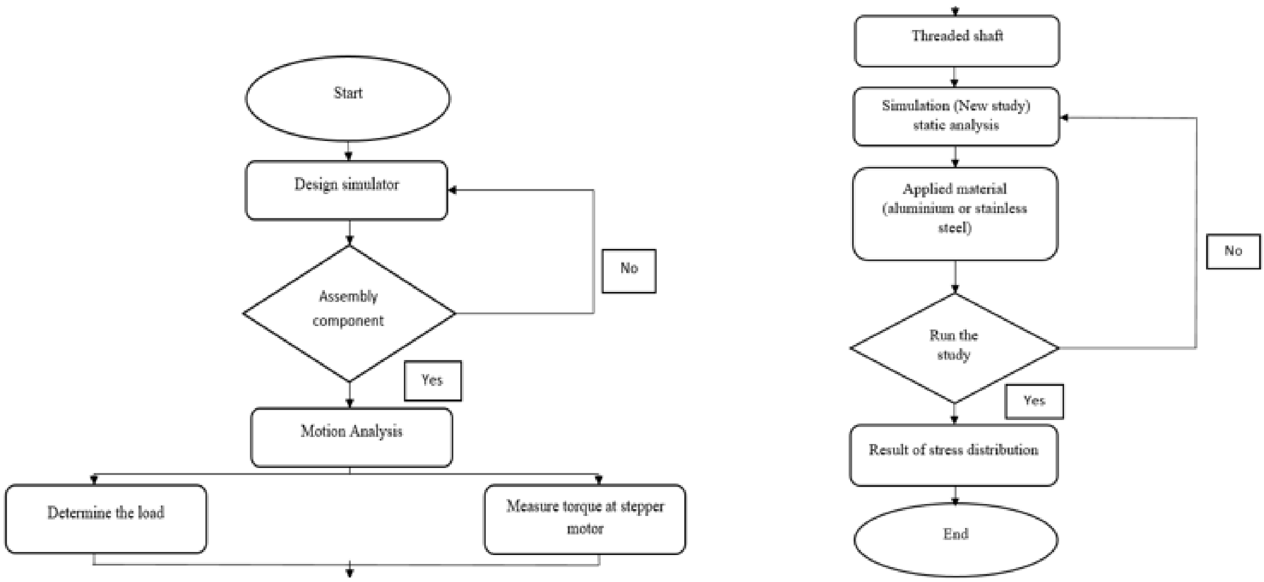


Fig. 2 - Flow chart procedure

2.3 Life Span Equation

Equation (1) provides the endurance limit (Se) equation, interpreted as a factor that quantifies the surface condition, size, loading, temperature, and other variables' impacts [10]. The Von Misses values of maximum and minimum are obtained by simulation in SolidWorks. Equation (2) shows the total number of rotations of threaded shafts (N). All these equations are used to find the total lifespan hours, as in Equation (4). The equation can be written as follows:

$$S_e = K_a K_b K_d K_e S_e' \tag{1}$$

$$N = 10^{-\frac{c}{b}} S_f^{1/b} \tag{2}$$

$$c = \log \frac{(0.8 S_{ut})^2}{S_e} \tag{3}$$

$$L_t = \frac{N}{N_p} \tag{4}$$

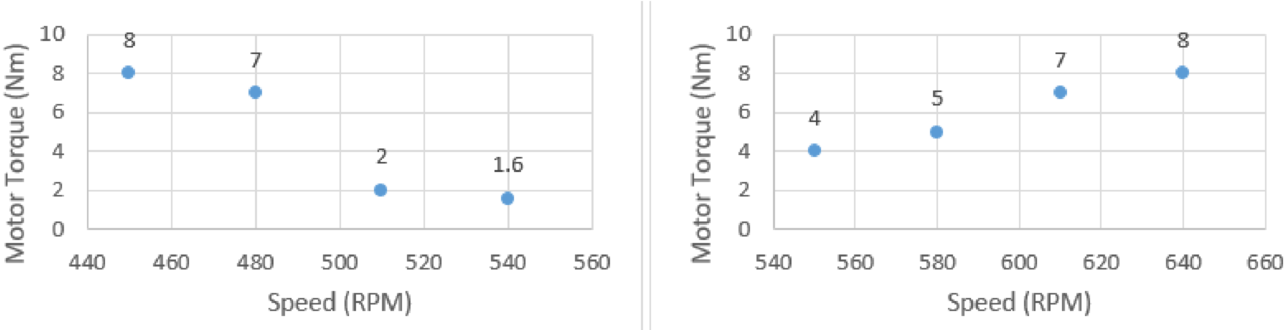
3. Result and Discussion

3.1 Motion Analysis

The motion can be simulated after all the component elements have been completely assembled. Visualizing the mechanism's motion increases confidence in simulation results [11]. Fig. 3 depicts the graph of speed (rpm) versus torque (Nm) for speeds lower than 550 rpm and speeds higher than 550 rpm. The torque values at speeds of 450 rpm, 480 rpm, 510 rpm, and 540 rpm are 8 Nm, 7 Nm, 2 Nm, and 1.6 Nm, respectively. It demonstrates that torque and speed are inversely proportional [12]. However, torque values for speeds of 550 rpm, 580 rpm, and 610 rpm are 4 Nm, 5 Nm, 7 Nm, and 8 Nm, respectively. The torque values increase significantly as the speed increases. It means that the maximum limit has been passed by the device. The value of torque will be used in the static simulation.

3.2 Static Simulation

The stress distribution result can be obtained only in static analysis. The results of simulation in SolidWorks show Von Mises' findings. According to Von Mises's results, the red colour signifies the highest value or critical value of stress distribution, while the blue colour signifies the lowest value of stress. In this study, stainless steel and aluminium threaded shafts were used in static simulation. Fig. 4 shows the example results for an aluminium threaded shaft, and Fig. 5 depicts the results for a stainless threaded shaft in Set 1. Fig. 4 shows that the maximum value of stress is 164.3 MPa. 27.6 MPa is a yield strength value, which is lower than the highest stress value. In conclusion, the use of aluminium threaded shafts for the brushing simulator is less reliable. Fig. 5 indicates the maximum value of stress is 164.4 MPa and the yield strength value for stainless steel threaded shafts, 206.8 MPa, is higher than the critical strength value. Therefore, in terms of the reliability of threaded shafts for brushing simulators, stainless steel is more reliable than aluminium threaded shafts.



(a) Speed below 550rpm (b) Speed 550rpm and above

Fig. 3 - Graph of speed (rpm) against motor torque (Nm)

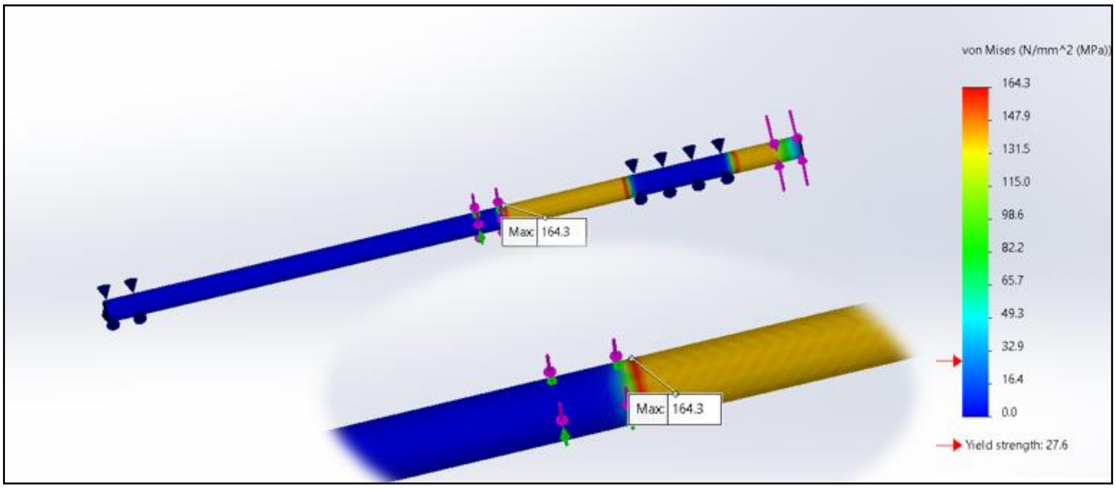


Fig. 4 - Stress distribution of aluminium threaded shaft (8 Nm)

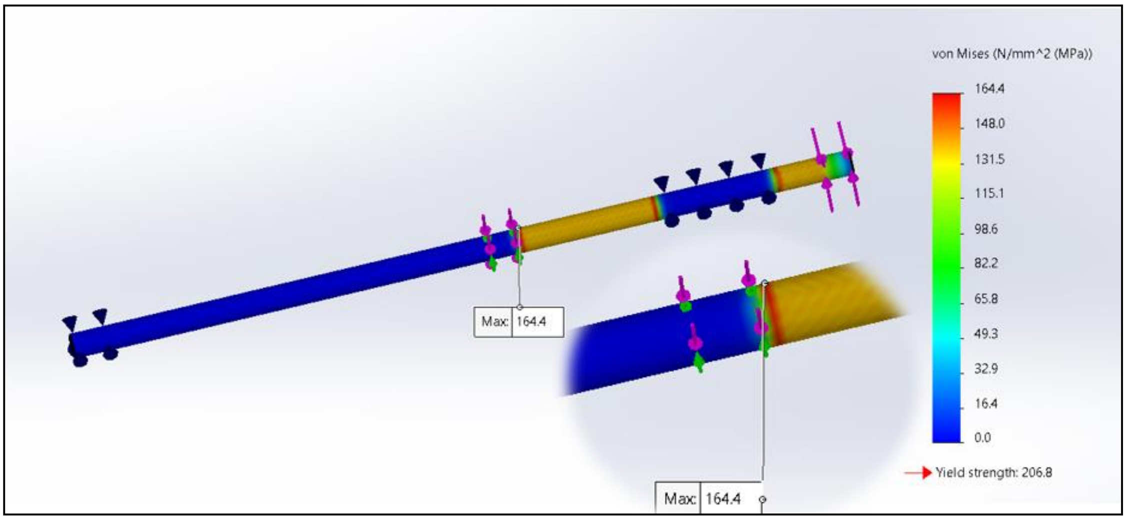


Fig. 5 - Stainless steel threaded shaft's stress distribution (8 Nm)

3.3 Life Expectancy

The results obtained from the static simulation will be used to calculate the aluminium and stainless-steel threaded shaft life expectancies. Figs. 6 and 7 show the overall results for the life expectancy of threaded shafts. The speed shown in Fig. 6 ranges from 450 to 540 rpm. While Fig. 7 shows a speed range from 550 to 640 rpm,

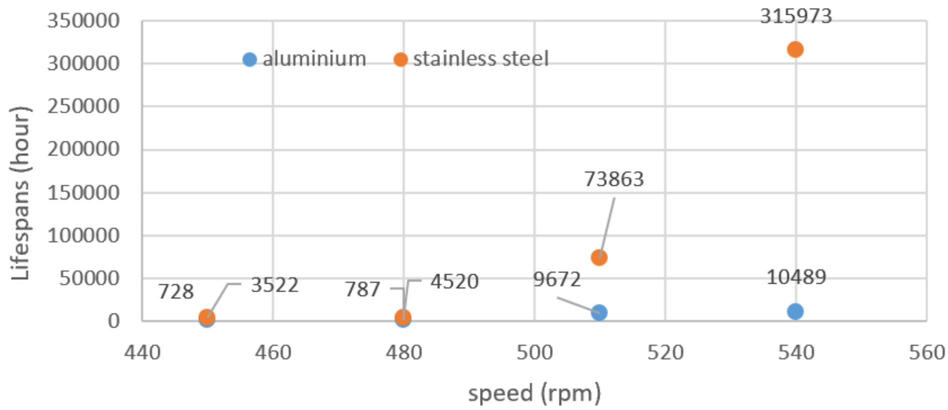


Fig. 6 - Graph speed against lifespan for set 1

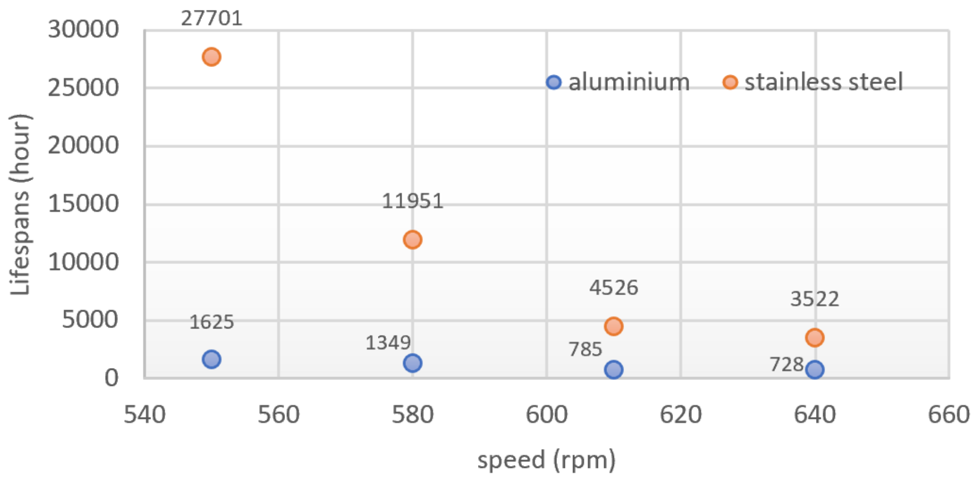


Fig. 7 - Graph speed against lifespan for set 2

For set 1, as in Fig. 6, at a speed of 450 rpm, the lifespan (days) of the aluminium threaded shaft is 728 hours, or 30.33 days (0.1 years). Meanwhile, the lifespan (days) for a stainless threaded shaft is 3522 hours, or 146.75 days (0.4 years). When the speed is increased, the life expectancy increases as well. At a speed of 540 rpm, the lifespan (days) for aluminium and stainless threaded shafts is 10489 hours or 473 days (1.2 years) and 315973 hours or 13165 days (36 years), respectively. This finding indicates that stainless steel is more durable than aluminium. However, at 550 rpm for Set 2 (as in Fig. 7), a lifetime (days) of 1625 hours or 67.7 days (0.2 years) for aluminium and 27701 hours or 1154.21 days (3.2 years) for stainless steel The life expectancy decreases as the speed increases. At 640 rpm, the lifespan (days) of aluminium and stainless-steel threaded shafts is 728 hours or 30.33 days (0.1 year) and 3522 hours or 146.75 days, respectively (0.4 years).

It determines that as the speed increases, the threaded shaft's lifespan reduces. Consequently, stainless steel is more durable than aluminium threaded shafts due to the properties of the material used. Additionally, the results from Figs. 6 and 7 show the difference between the graph's rise and decline while using a speed lower than 550 rpm and a speed higher than 550 rpm. The graph demonstrates that the threaded shaft life expectancy rises as the speed increases to 450 rpm, 480 rpm, 510 rpm, and 540 rpm. However, the life expectancy of a threaded shaft decreases when the speeds are modified to 550 rpm, 580 rpm, 610 rpm, and 640 rpm. It explains that increasing the speed reduces the lifespan of a threaded shaft.

4. Conclusion

To conclude, the brushing simulator's development is substantial in assisting dentists and researchers in their studies of plaque removal. This research focuses on the material shaft's life expectancy utilised in brushing simulator development. Based on the findings, stainless steel is more durable and stronger than aluminium threaded shafts. Furthermore, the stainless-steel life expectancy is greater than that of aluminium due to the material's qualities. Besides, the study found that speeds less than 550 rpm have a higher life expectancy than speeds over 550 rpm. Thus, the threaded shaft's life expectancy will reduce as the speed increases.

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