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Analysis of BLDC Electric Motor Shaft Treatment Model Using Numerical Method

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ABSTRACTS

This research studies the shaft strength of a BLDC electric motor. A Shaft is one of the components in a rotary engine and functions to transmit power. The design calculation is needed to determine the effect of the strength of the material being treated. The strength analysis of the shaft used FEM (Finite Element Method). The shaft is modeled on the manufacturing design and tested by numerical simulation with Ansys Mechanical 14.5-BRIN commercial license software. The static simulation used a structural statics module with static and dynamic load input. The research method comparing the results of FEM simulations with two different types of materials is determined. Based on the simulation parameters, the selected material types are JIS S45C tempered and AISI 1045 cold-drawn. The simulation results represent the maximum stress (von Mises) and total deformation. The deformation value of S45C tempered material is slightly higher than that of AISI 1045 cold drawn. However, both materials have the same maximum von Mises stress.

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INTRODUCTION

The industrial development of BLDC motors has recently become very popular and is used many times, especially in electric vehicle applications. The electric motor is the main driving force for electric cars. The mechanical structure of the electric motor must also be able to support the vehicle's performance in terms of speed and ability as a driving force [1]. Shaft drive is a shaft that transmits from a power source or driving motor to the transmission link or wheel. Shafts must have good toughness, strength, and resistance to long-term operation. Shaft applications in the automotive field are designed based on power requirements and operational suitability. In industry, raw material shafts are usually processed in two pairs to increase the bending strength concerning the natural frequency during the manufacturing process [2]. Medium carbon steel AISI/ SAE 1045 is generally used as shafts, bolts, crankshafts, spline shafts [3], connecting rods, hydraulic tubes, pins, rolls, spindles, etc., which require higher strength [4][5]. The cold-drawn shaft product with JIS S45C material has a predictable thickness and shape in processing. Cold-drawn steel must be drawn several times through different molds to reach the right size, leading to higher production costs.

In general, exact structural static solutions can only be obtained in minimal cases, and clear solutions generally cannot be solved by equations. The finite element method (FEM) has been developed to overcome

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this difficulty as a powerful numerical method for obtaining approximate solutions to various elasticity problems [6]. The finite element method assumes an object of analysis as a collection of elements having a finite shape and size that varies according to partial differential equations with simultaneous algebraic equations and numerically solves various elasticity problems. The type of finite elements can be triangular or rectangular in two dimensions and tetrahedron, and cuboid or prism in the case of three dimensions.

The surface plastic deformation method plays an essential role in materials science to improve the uniformity properties, especially the yield strength of metallic materials [7][8]. This study tries to simulate the shaft of a 10 kW BLDC electric motor using the finite element method computationally. The purpose of the study is to obtain a comparison of the deformation and von Mises stress strength by using two different types of electric motor shaft materials, namely JIS S45C with a tempered manufacturing process compared to shafts with AISI 1045 type material and cold draw processing.

METHODS

In the initial research stage, the shaft was modeled with Catia V5-6R2013 License, then 3d images and converted into .stp format. The shaft is 252 mm long with a drive spline diameter of 35 mm. The detailed dimensions of the 10 kW BLDC electric motor shaft can be shown in **Figure 1**.

This research studies the strength of the shaft structure by changing different types of materials with the dimensions of the solid shaft remaining the same. The first candidate material is tempered JIS S45C, and the second candidate is AISI 104 cold-drawn material. Details of the material properties of the two types of materials can be seen in **Table 1**.

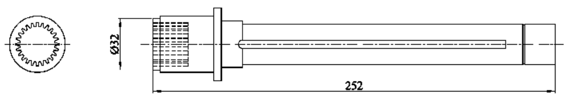

Figure 1. Motor shaft.

It solves the finite element method using Ansys Mechanical R14.5 commercial license software. Theoretically, the finite element method problem-solving procedure includes discretization, namely, the object of analysis into a finite number of elements. Next is the determination of the interpolation function, where the type of element or the interpolation function that approximates the displacement and strain in each finite element can be selected. The following process is the reduction of the element stiffness matrix, which relates the forces and displacements in each element. After lowering the elements, the stiffness matrix equations are compiled into a general stiffness matrix that relates the forces and displacements across the elastic area to be analyzed. The mechanical boundary conditions and the geometric displacement of the boundary conditions into the general stiffness matrix can be rearranged by collecting the unknown variables to set up simultaneous equations. The next stage in the meshing process is the reduction of the unknown forces and displacements. The solution for the unknown force is the reaction force and for the unknown displacement is the deformation of the desired elastic body given the geometric and mechanical boundary conditions. The final procedure for solving the finite element criticality problem is calculating the strain and stress obtained using the strain-displacement relationship and the stress relationship [9].

The meshing process is a finite element discretization process. So, to produce a good splitting of elements, global meshing, and local meshing must be controlled. This research limits the meshing process to the shaft model with fast transitions based on mechanical preferences. The quality of the mesh is set with a medium span angle center category. The bonding box ranges from 256.95 mm with an average brush surface of 219.18 mm^2. Mesh inflation settings using smooth inflation. With a transition ratio of 0.272. The maximum layer value is set to 5 with a growth rate of 1.2. The mesh size is set to 1 mm with the face sizing method.

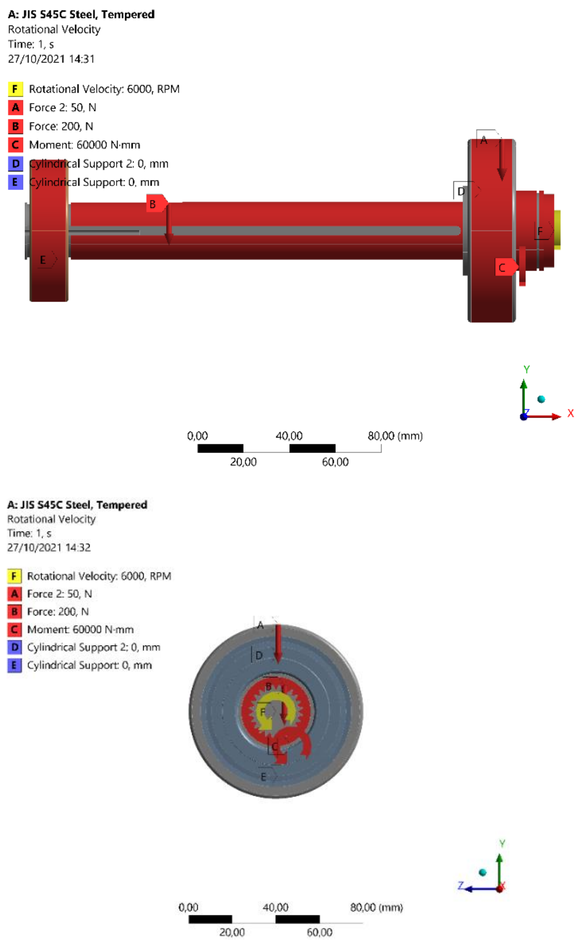

Figure 2. Loading Scheme.

The simulation boundary consists of static, dynamic loading, and vibration loading is neglected. For the type of static loading at point A, see **Figure 2**. Point A is defined as the shaft, rotor, winding, and stator load of 200 N. Point B is the weight of the bearing and housing of 50 N.

The shaft was supported by two ball bearing type bearings, as shown in points D and F. Point D is a drive bearing, and point F is a non-drive bearing. The drive bearing type used SKF 6307 2Z (double shield), and the non-drive bearing used SKF 6305 2Z (double shield). Loading details can be shown in **Table 2**.

The operational assumption of the BLDC motor works at a maximum speed of 6,000 rpm. The rotation is the condition of the motor rotating at maximum speed. Based on the design planning, the value of the moment on the shaft is 60 Nm. The motor loading conditions in this study ignore mechanical vibrations. The friction value between the ball bearing contacts and the bearing housing is close to 0. The shaft rotation is not affected by the frictional force of the ball bearing against the cylindrical bearing housing.

Based on the load and force acting on the shaft construction. The method of solving structural statics can be used **Equations (1), (2),** and **(3)**:

$$\sigma = \frac{P}{A} \quad (1)$$

$$\varepsilon = \frac{\sigma}{E} \quad (2)$$

$$\delta = \varepsilon . l \quad (3)$$

Stress (σ) can be formulated as a load or force (P acting on the shaft construction unit area (A). At the same time, strain (ε) is the amount of stress per unit of elastic modulus (E) of the material. The occurrence of deformation due to strain (ε) on each object with length (l).

RESULTS AND DISCUSSION

Pre-Processing Mesh

The discretization of the shaft model structure is represented in a mesh consisting of nodes and elements. Based on the meshing process's boundary conditions, the mesh results are fully defined. The mesh size is set to be 1 mm. The nodal value is 336,551, with the number of mesh elements being 189,065 elements. **Figure 3** shows the model before and after the meshing process.

Deformation

Deformation formed when a force or stress was applied. The deformation in the shaft is related to strain and stress shaft deformation with material (JIS S45C Tempered). **Figure 4** shows the shaft deformation results with JIS S45C Tempered material. It is shown that the maximum deformation value is 0.1673×10^{-2} mm. In the center of the shaft, the direction of the deformation vector occurs, bending towards the (-y) axis. The deformation average at the shaft end is 0.47434×10^{-3} mm. **Figure 5** show the deformation of AISI 1045 cold-drawn material. The maximum deformation value of the shaft with AISI 1045 material is 0.10624×10^{-2} mm. A small deformation value is still in the safe category as long as the maximum stress value is still below the material's yield stress.

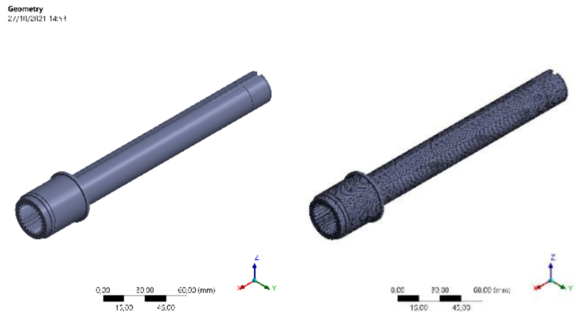

Figure 3. Shaft Model and Meshing Result.

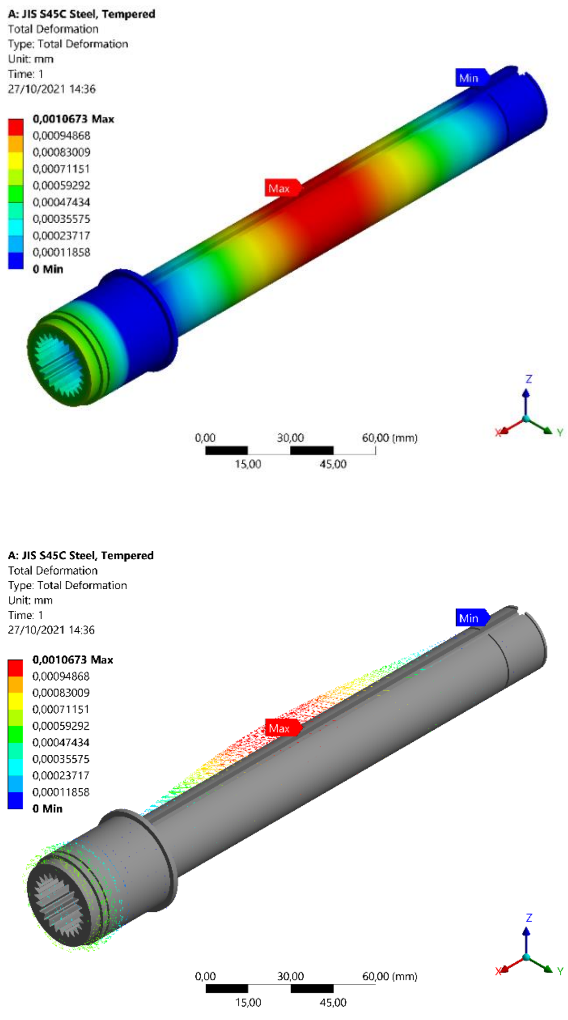

Figure 4. Shaft Deformation (AISI 1045 Tempered).

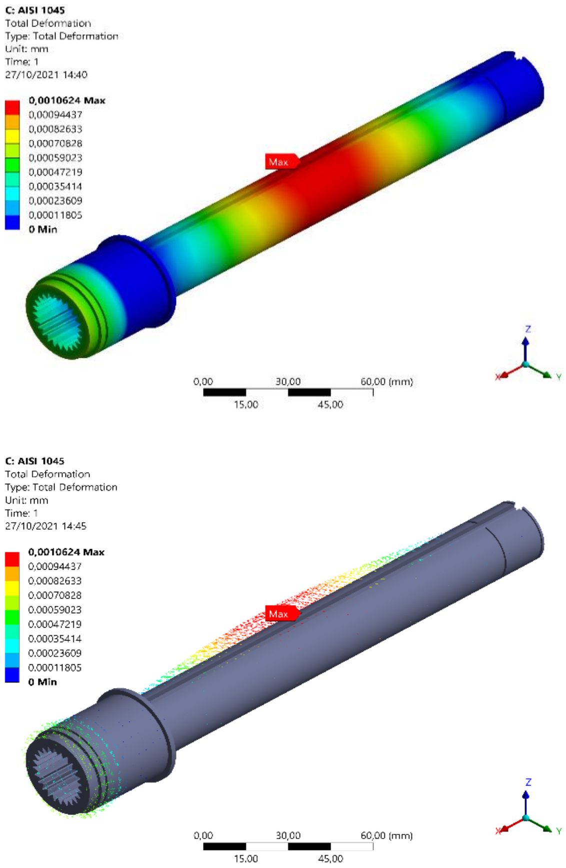

Figure 5. Shaft Deformation (AISI 1045 Cold-drawn).

Von-Mises Stress

The von Mises failure criterion was introduced by Von Mises (1913) and has been used as one of the most reliable failure criteria for engineering materials. Generalized von Mises criteria based on general convexity theory [10].

The distribution of the von Mises shaft stress with JIS S45C material can be seen in **Figure 6**. The maximum stress that occurs by applying this material is 14,586 MPa, and the minimum von Mises stress is 0.27 MPa. The maximum stress value is far below the material yield stress, as shown in **Table 1**, 490 MPa for tempered JIS S45C material. However, the maximum value of the shaft with AISI 1045 cold-drawn material is the same. The difference in yield strength of the two materials is only around 25 MPa, so the same simulation results do not significantly affect the maximum von Mises stress.

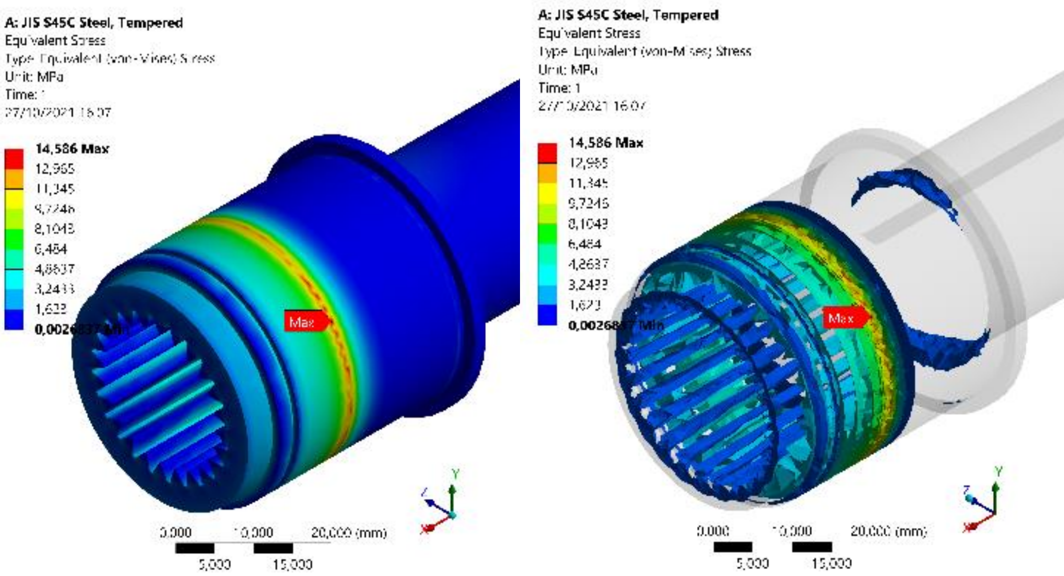

Figure 6. Shaft Von Mises Stress (JIS S45C Tempered).

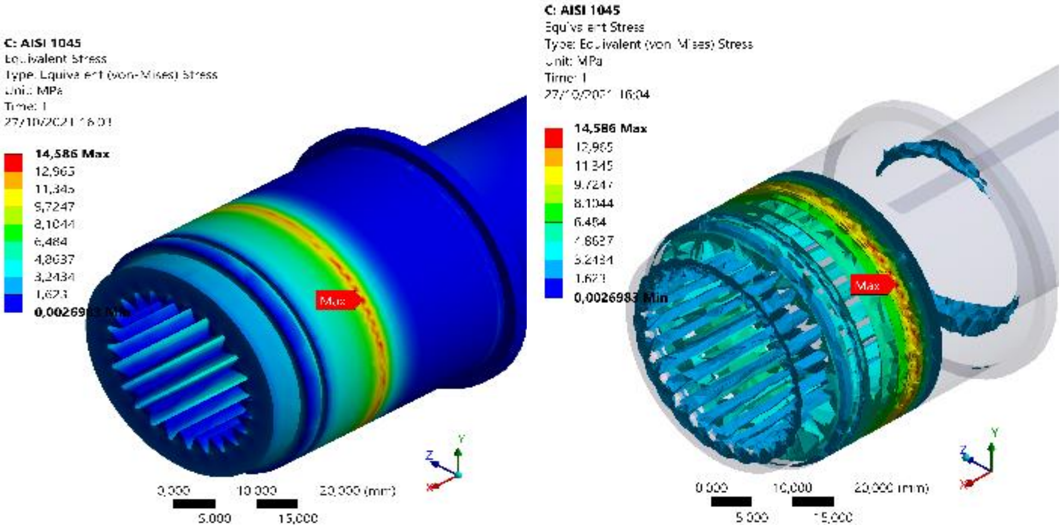

Figure 7. Shaft Von Mises Stress (AISI 1045 Cold-drawn)

Table 1. Material Properties of Shaft.

Material	**JIS S45C *Tempered***	**AISI 1045 *Cold Drawn***
Density (Kg.mm^{-3})	7.85 × 10^{-6}	7.85 × 10^{-6}
Tensile Yield Strength (Mpa)	490	515
Tensile Ultimate Strength (Mpa)	686	585
Young Modulus Mpa (Mpa)	2.05 × 10^{5}	2.05 × 10^{5}
Poison Ratio	0.29	0.29
Bulk Modulus (Mpa)	1.627 × 10^{-6}	1.627 × 10^{-6}
Shear Modulus (Mpa)	79,457	79,845

Table 2. Properties Materials of Shaft.

Loadings	**Value**
Cylindrical Support 1 (Non-Drive Bearing)	Fixture
Cylindrical Support 2 (Drive Bearing)	Fixture
Load (Stator, Rotor, Shaft)	200 N
Load (Housing, Bearing)	50 N
Moment	60 Nm
Shaft Velocity	6,000 Rpm

Safety Factor

For shafts with different materials applied, the safety factor is determined based on the yield stress limit of the material. In structural applications, the yield stress is always an important reference compared to tensile strength because in the tensile condition and after it exceeds the acceptable limits [12]. The simulation results of shafts safety factor with JISS45C tempered material compared to AISI 1045 cold drawn is 2.11 and 2.15 respectively. The safety factor is based on the deformation and von Mises stress results. The simulation shows that both materials have an SF above >1 (varies from 1.2 to 4), which is structurally safe. The working value for tensile strength s_w (working stress) is its s_T tensile stress divided by the amount of safety. For work carried out by Farren and Taylor [13] showed that the proportion (s_w -sh)/ s_w of work performed during cold working, the latent value remains in the metal almost constant over the experimental range, which predicts the strength of the material in the same range is very good.

CONCLUSION

This research has discussed the study of the material strength of a shaft from an electric motor component with the finite element method. The FEM method is visually represented as the result of deformation and von Mises stress. FEM simulation results show that the strength of the two materials is almost the same. However, the deformation of the tempered JIS S45C material is slightly larger than that of the shaft with AISI S45C Cold drawn material. So that the difference in results from the use of the two types of material does not have a significant effect on deformation because the difference in yield strength of the material between the two materials is negligible. The maximum voltage from the simulation also does not change.

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Author Contributions

The first author contributes to the FEM simulation processing. Basic theory and FEM modeling are done computationally. The author also analyzes the stress and deformation between the simulation results and article drafting. The second author contributes to mechanical modeling and data collection processes and participates in drafting articles, data analysis, and interpretation of results. The third author contributes to design planning, electrical design modeling, design validation, and article drafting.

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