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Process simulation of power screw failure on fatigue load using autodesk inventor

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Abstract. The paper presents the study on the use of simulation software in manufacturing industry. It is perceived as a tool for visualization of an on-going process in fatigue load. The design of this study is to simulate the stress distribution due to the loading of the power screw (or lead screw) fatigue using Autodesk Inventor software simulation version 2018. Power screw used is steel material with a round bar shape. It is called medium carbon steel (S 45 C) with specifications of tensile strength at 48 kg/mm2, creep limit at 29 kg/mm^2, hardness range (Hs) of 137 to 197 kg/mm^2, chemical elements in a percentage of 0.27 to 0.33, Si of 0.15 to 0.35, Mn of 0.60 to 0.90, P of 0.030 and, S of 0.035. The modeling used in this study is by finite element method analysis, which consist of several steps. The steps involve 3D geometry design based on the existing dimension, importing the CAD (Computer Aided Drawing) of 3D geometry design to finite element software, engineering the data by entering the mechanical properties, meshing which indicate the limit of the geometry of the model into numbers of elements in the properties, determining the fixed position of the central points of the static load and fatigue load given to power screw components application, and determining the coordinate system for the solution. The results shows the mechanical properties of S45C carbon steel power screw. It has a maximum von mises stress of 4.546 MPa with the first principal stress of 4.518 MPa. The third principal stress of the material is 0.538 MPa, the displacement is 0.001602 mm, and safety factor is 15 ul.

1. Introduction

The power screw or the leadscrew (a type of threaded shaft) is one of the parts of the crank mechanisms of the shaping machine. It is the continuation of the length step controller which is objected to static and dynamic loads that often fluctuates [1]. When the fluctuation occurs repetitively and on a specific limit, failure will occur. This will happen even if the maximum load is smaller than the static strength of the material.

This paper explains the inspection of the damage of the threaded shaft (fracture) on a shaping machine. Visual inspection, metallography observation, chemical analysis, SEM-EDS observation and design analysis with Software Autodesk Inventor version 2018 was done to support the damage examination [7]. Failure models can be determined using fractographic, metallographic, and mechanical testing methods. The root cause of failure is determined using knowledge of the failed model, cause and a particular process or system. Determining the root cause of failure requires complete information about the design, operation, maintenance, and acquisition of equipment [6].

Fractographic examination of fracture surfaces on threaded rods with fatigue fractures which begins from the beginning of the fracture that propagates at the beginning of the fracture found bench march in the first stages of fatigue, fanlike and bench march in the first stage of fatigue fracture[8].

2. Methodology

The failure of carbon steel material S45C used for the shaft is influenced by many factors. It should be understood that the fracture of a material always starts in the concentrated force locations depending on the load patterns[2].

Advances in information technology are very helpful in the design process so that it is faster and cost-effective, because the simulation process is done using software. From the simulation results can determine whether the design can be applied or not before the design is produced[7].

2.1. Research Steps:

The method of this research on shaft fracture of the shaping machine mechanism can be seen in figure 1 below.

Research steps:

- Study the application of case study
- Generate 3D CAD model using Autodesk Inventor software simulation version 2018
- To do the meshing of component
- To do static analysis using Autodesk Inventor software simulation version 2018
- Modify the material or geometry and conduct the analysis on same
- Recomend Solution
- Conclusion

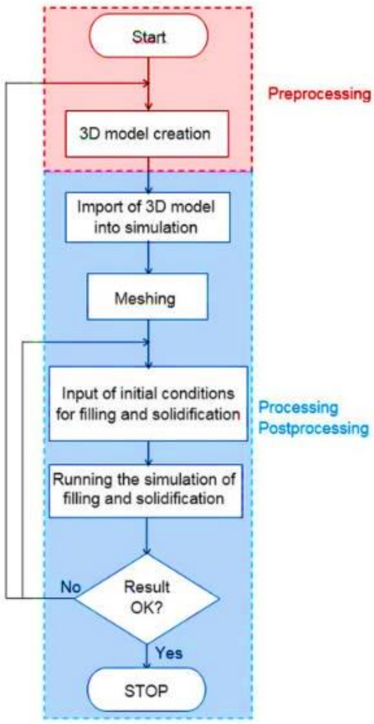

Figure 1. Flowchart of observation and testing of power screw fracture on the crank mechanism of the failed shaping machine

2.2. Loads on Shaft
The loads that are received by the shaft are torsional, component weight, and radial and axial force. When designing a shaft, the maximum allowed deflection, working time and load must be co nsidered. The critical speed of operation should also be understood. This is so as to appropriate the shaft to withstand the loads objected upon it.

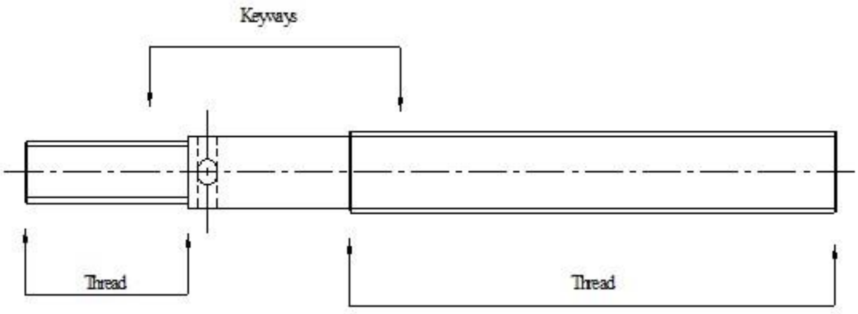

Figure 2. Load concentration on shaft

Figure 1. shows the concentrations of force where the fracture might initiate. Generally, it starts on the smallest radius on the keyways and sharp angles on the cross section of the shaft. This type of stress concentration must be avoided in the shaft design. Steel (not including stainless steel) has a fatigue limit where the fatigue stress propagation would not occur without the availability of repeating stresses. Because of this, stress concentration decreases the stress limit on the point of the shaft objecting it to be more prone to fatigue. For the case of stainless steel, it has an endurance limit where it can withstand a limited repeated stress before fracture due to fatigue.

2.3. Failure Analysis
Failure Analysis where we examine the failure or damage on a component which includes the situation and conditions of the failure is important for this study. With this analysis it is possible to understand the cause of the failure/damage on the component. The objectives of this analysis are as follows:
- To find the main cause of failure
- To avoid the same failure/damage in the future by forming prevention steps.
- To serve as a technical complaint towards component manufacturers
- To be a step in improving the quality of components
- To help determine the times of maintenance
- To identify the type of failures.

Failure can be due to unnatural damage or premature damage. The main causes of these failures are grouped as follows:
- Errors in design
- Errors in material selection
- Errors in the work process
- Errors in installation / assembly
- Operational errors
- Maintenance errors

In general, components can be considered “failure” if they fall into the following criteria:
- Components cannot operate or cannot be used at all

- Components can be used but their lifetime is limited (not according to the desired service life)
- Components experience abnormalities and can be dangerous if used

2.4. Fatigue constituents

Fatigue according to ASM (1975) is defined as the process of changing permanent structures where it is "progressive" and "localized" under conditions that produce strain fluctuations and stresses. This can be under their tensile strength at one point or many points where it can peak and turn into cracks or fractures after certain fluctuations. "Progressive" refers to the process of fatigue that occurs during a certain period or during use. "Localized" means the process of fatigue operates on a local area that has a high stress and strain due to the influence of external loads. This can also be due to the change in geometry, change of temperature, and stress residue.

During fatigue, material damage is caused by fluctuating stresses of which the magnitude is smaller than the maximum tensile strength (ultimate tensile strength). It is also smaller than the yield stress of material with a constant load. There are three instances when the fatigue failure occurs.

2.4.1. Crack initiation

Fatigue generally starts from crack initiation that occurs on the surface of weak material or areas where there is a concentration of stress on the surface (such as scratches, notches, hole-pits, etc.) due to repeated loading.

2.4.2. Crack propagation

This crack initiation develops into microcracks. The propagation or integration of these microcracks then forms macrocracks which will lead to failure.

2.4.3. Fracture

Fracture occurs when a material has experienced stress and strain cycles that produce permanent damage.

It can be stated that the crack is the beginning of fatigue failure where then the crack propagates due to repeated loads. Fracture is the final stage of the fatigue process where the material cannot withstand the existing stress and strain so that it breaks into two or more parts. Presentation of engineering fatigue data uses the S-N curve that maps stress (S) to the number of cycles until failure occurs (N). This S-N curve is preferred using the semi log scale as shown in Figure 3.

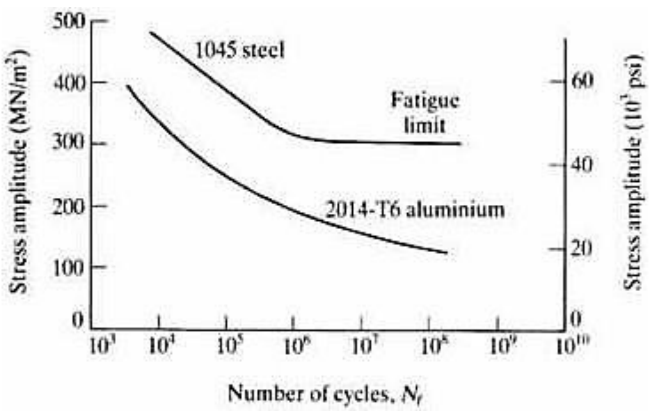

Figure 3. S-N curve

The curve is obtained from stress mapping on the number of cycles until failure of the test object. In this curve the cycle uses a logarithmic scale. The endurance limit of steel fatigue is determined by the number of cycles N> 107 (Dieter, 1992). The general equation of the S-N curve is expressed by the equation (Dowling, 1991).

$$S = B + C \ln (Nf) \tag{1}$$

Where B and C are material empirical constants, fatigue testing is done by giving a certain stress level so that the specimen breaks in a certain cycle.

3. Result and Discussion

3.1. Visual and Fractographic Examination

Visual inspection results show damage / fracture in the area in the peg hole holding area (pen). At the peg hole (see arrow in figure 4), we can see the peg hole with fracture suspected of fatigue fracture.

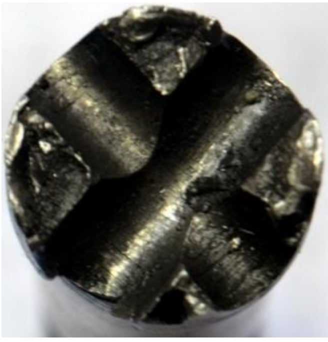

Figure 4. Macro photograph of power screw fracture on the crank mechanism of the shearing machine that has broken in the area of peg hole (pen)

3.2. SEM and EDX analysis

Samples for SEM (Scanning Electron Microscope) analysis are taken from the surface area of the power screw fracture. SEM examination shows the inclusion on the surface of the fracture site. It also shows the existence of cracks on the surface of the power screw fracture as shown in Figure 5.

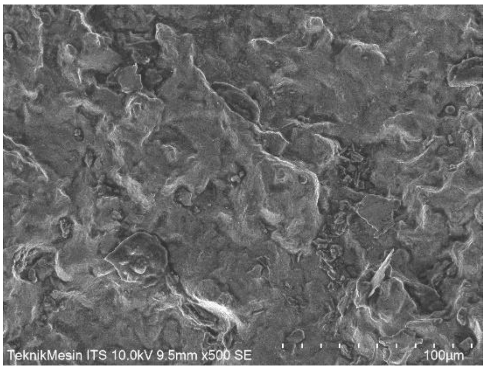

Figure 5. SEM results from the power screw fracture surface shows that the crack begins with inclusions (a) and striation is parallel to the beachmark (b)

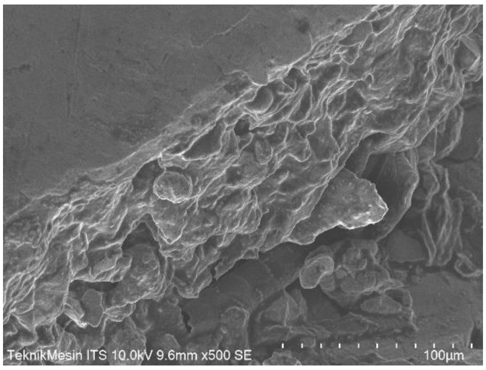

Figure 6. SEM results from the power screw fracture surface shows striation is parallel to the beachmark (b)

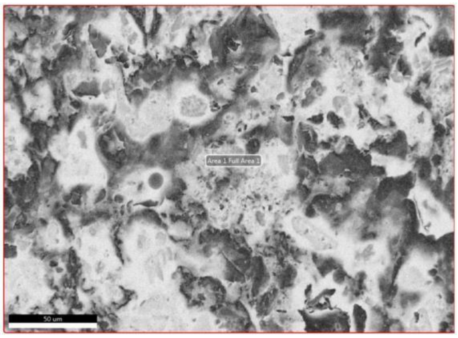

Figure 7. EDS analysis of inclusions on the surface of the power screw fracture on the crank mechanism of shaft

The power screw or the leadscrew (a type of threaded shaft) is the type of steel construction machinery, symbol S45C with the following specifications: Tensile strength of 48 kg / mm^2, elongation limit 29 kg / mm^2, Hardness (Hs) 137-197 kg / mm^2, Chemical Elements (%): C = 0.27-0.33, Si = 0.15-0.35, Mn = 0.60-0.90, P = 0.030, S = 0.035.

Table 1. Smart quant results

Element	Weight %	Atomic %	Net Int.	Error %
C K	15.51	39.59	31.76	99.99
O K	6.51	12.48	30.20	10.06
F K	2.86	4.61	18.71	11.84
AlK	1.03	1.18	6.06	18.12
SiK	1.63	1.78	11.98	12.17
S K	0.61	0.58	4.21	25.31
CaK	1.54	1.18	7.09	15.31
FeK	70.31	38.61	131.17	3.34

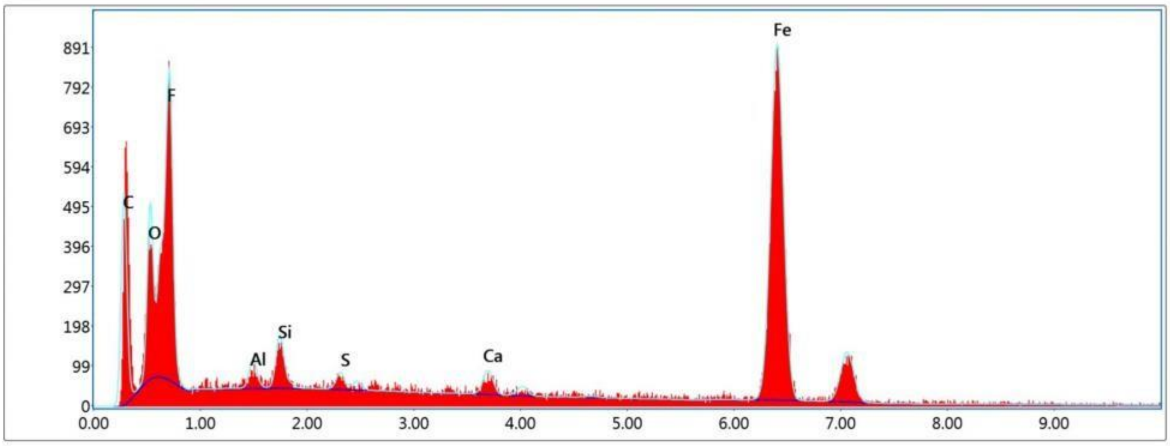

Figure 8. The inclusion spectrum on EDS. This shows the results on the surface inclusions of the power screw fracture on the crank mechanism of the shaping machine

3.3. Stress Analysis on Autodesk Inventor

The Relevance setting listed below controlled the fineness of the mesh used in this analysis. For reference, a setting of -100 produces a coarse mesh, fast solutions and results that may include significant uncertainty. A setting of +100 generates a fine mesh, longer solution times and the least uncertainty in results. Zero is the default Relevance setting. Bounding box dimensions represent lengths in the global X, Y and Z directions.

The following material behavior assumptions apply to this analysis:

- Linear - stress is directly proportional to strain.
- Constant - all properties temperature-independent.
- Homogeneous - properties do not change throughout the volume of the part.
- Isotropic - material properties are identical in all directions.

The table below lists all structural results generated by the analysis. The following section provides figures showing each result contoured over the surface of the part. Safety factor was calculated by using the maximum equivalent stress failure theory for ductile materials. The stress limit was specified by the tensile yield strength of the material.

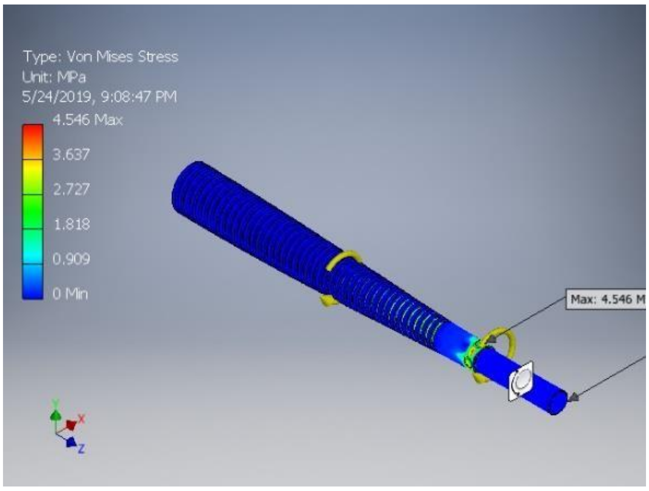

Figure 9. The Stress Analysis of Autodesk Inventor has a maximum von mises stress of 4.546 MPa

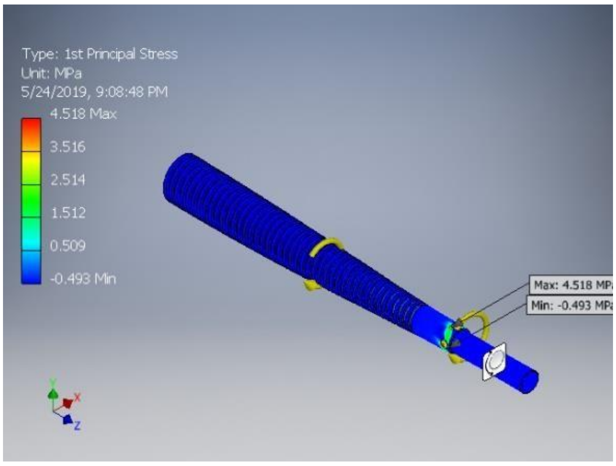

Figure 10. The Stress Analysis of Autodesk Inventor with the first principal stress of 4.518 MPa

The results shows the mechanical properties of S45C carbon steel power screw. It has a maximum von mises stress of 4.546 MPa with the first principal stress of 4.518 MPa. The third principal stress of the material is 0.538 MPa, the displacement is 0.001602 mm, and safety factor is 15 ul.

4. Conclusions

The Stress Analysis of Autodesk Inventor examination demonstrates that von mises stress of 4.546 MPa was achieved. While, the first principal stress of 4.518 MPa, the third principal stress of 0.538 MPa. Other result revealed that the displacement was 0.001602 mm.

Three observations are concluded for the power screw failure based on the result observed:

- Power screw failure was due to fatigue fracture.
- Maximum stress zones were located near the peg hole and overlaps the crack origins.
- Main reason of fatigue fracture of the screwed shaft was due to high torque of shaft.

5. Acknowledgments

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