Numerical Analysis of Stress Causing Fracture Failure in the Gear Transmission System Applied on an Agricultural Machinery Equipment

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Abstract. In general, failures often occur in gear transmission systems, even this case also occurs in an agricultural machinery equipment for example in a hand tractor. This study aimed to determine the cause of the spur gear fracture through numerical studies. The fracture surface was observed using a scanning electron microscope (SEM) in order to identify crack initiation. The results of the chemical composition test indicated that the material used was according to the AISI 8620 standard. It is necessary to create a finite element analysis (FEA) modeling. The stress, strain and stress intensity factor was next analysed near the crack tip using the FEA. The results of the FEA pointed out that the value of the maximum stress intensity factor \( K_I \) occurs in the center of the tooth which experiences an initial crack due to friction. The \( K_I \) value obtained from the FEA indicates that the value is higher than the fracture toughness \( K_{IC} \). Finally, crack propagation occurs in the teeth of the spur gear that causes the tractor to stop working.

1. Introduction

One of the most useful and vital tools used in agricultural production is the Tractor. A tractor is an engineering vehicle specifically designed to deliver a high torque at slow speeds, for the purposes of hauling a trailer or machinery used in agriculture. Tractors are designed specifically for high traction at low speeds and for pulling trailers used for farm activities [1]. The tractor engines also utilise gears as power transmitters. Gears are machine elements having a function of transmitting power and for shaft rotation to enable the engine mechanism system to perform correctly. Most farm tractors use a manual transmission with several gear ratios, typically three to six, sometimes multiplied into two or three ranges. This arrangement provides a set of discrete ratios that, combined with the varying of the throttle, allow final-drive speeds from less than one up to about 20 miles per hour (30 km/h), with the lower speeds used for working the land and the highest speed used on the road [2].

The gear plays a very important role in a mechanical system. One of the gear function is to continue power from one engine component to another [3]. Gear failure occurs due to bending and fracture failures. The failure occurs when the surface contact stresses are higher than the endurance limit of the material, wrong or insufficient lubrication and misalignment of gears. There are many researcher studied the causes of failure in an engine component in various point of view [4-6]. Therefore, research study on failure of spur gear is required to determine the cause of its damage.
The chronology of the failure of the spur gear, which is used on the hand tractor, can be explained that on June 26, 2017 a tooth fracture occurred in the spur gear pair, where the tractor had been operating for about 40 hours prior to failure occurring. Therefore, this study aims to investigate and find the stress value that occurs in the gear that causes failure of the gears on a hand tractor using the finite element method.

2. Methodology

2.1. Spur Gear
This study examined the spur gears of an incapacitated hand tractor after operating for only 40 hours, classified as premature failure. This research was conducted using the finite element analysis. The issue of this study is the fracture gear of gear transmission system used on a hand tractor as illustrated in Fig. 1.

![Figure 1](image1.png)

**Figure 1.** The series of gear systems used in the hand tractor and one of the spur gears has experienced a fracture (indicated by red circle).

2.2. Visual Observations and Chemical Composition Examination
First of all, a visual inspection of the hand tractor spur gear is carried out to observe and identify the broken surface of the spur gear, as shown in Fig. 2. It needs to be identified is the characteristic of static or fatigue fractures that are usually marked by the beach mark on the surface of the fracture.

![Fracture surface](image2.png)

**Figure 2.** Macroscopic view of broken spur gear.
Hereafter, chemical analysis was also carried out to determine the chemical composition of the gears so that it could be classified correctly into the proper standard groups, such as ASM or AISI.

2.3. Scanning Electron Microscope (SEM) Observation
SEM observation is carried out to identify the crack initiation location and crack propagation. Furthermore, it was to identify the type and mode of fracture. The result was expected to obtain information about the crack initiation, type of fracture and crack propagation direction in the gears by identifying the chevron mark on the fracture surface [7-8].

2.4. Finite Element Analysis (FEA)
FEA is a numerical method used to solve problems such as the analysis of stress and strain on a structure. The modelling of a spur gear with applying a crack on its surface can be analysed to measure the distribution of stress and strain by using FEA [9-10]. The type of load used was a moment on the axis of the gear, and the load value was 27,000 N.m with the number of nodes as many as 48,904 with the number of elements as much as 9,846.

3. Results and Discussion

3.1. Visual Inspection.
From the results of visually inspecting the gear, failure was observed to occur that began from the base of the tooth. However, to understand the exact cause of failure, further examination of the gear was needed especially by stress analysis using FEA.

3.2 Chemical Composition.
Moreover chemical composition analysis also performed on the gear material, where the results display in Table 1. From the results, it was found that the material of the gear followed the material specification of AISI 86820 standard with the mechanical properties of the material are shown in Table 2.

| Element | Results of chemical composition testing by spectroscopy (%) | Chemical composition of AISI 8620 (%) |
|---------|-------------------------------------------------|-----------------------------------|
| Cr      | 1.14                                            | 0.40 – 1.10                       |
| Mn      | 1.00                                            | 0.75 – 1.0                        |
| Fe      | 96.5                                            | 96.895 – 98.02                    |
| C       | 0.142                                           | 0.140 – 0.230                     |
| Mo      | 0.201                                           | 0.150 – 0.250                     |
Table 2. Material properties of AISI 8620 [11]

| Properties                  | Value | Unit  |
|-----------------------------|-------|-------|
| Tensile strength ($\sigma_B$) | 530   | MPa   |
| Poision Ratio ($\phi$)      | 0.27-0.30 |       |
| Density ($\rho$)            | 7850  | Kg/m$^3$ |
| Yield strength ($\sigma_{YS}$) | 385   | MPa   |
| Shear stress ($\tau$)       | 60    | MPa   |
| Modulus young (E)           | 190-210 | Gpa   |
| Shear modulus (S)           | 80    | Gpa   |
| Fracture Toughness ($K_{IC}$)| 51    | MPa/$\sqrt{m}$ |

3.3. SEM Observation Results.
From the SEM observation results found that the fracture surface feature was characteristic of a brittle fracture, as shown by Fig. 3. In addition, no evidence was observed of plastic deformation. This may also suggest an impact load occurred on the gear that exceeded the toughness of the materials. From observations of the fracture surface using a magnitude of 100x magnification, it was observed that the initial crack occurred at the base of gear of a teeth. Moreover, It was observed that the crack propagation direction that marked with feather marks [12].

Figure 3. SEM observation on the fractured surface.

3.4. Investigation of the Stress,Strain and Stress Intensity Factor using Finite Element Analysis.
Stress and strain analysis was then conducted on the spur gear using FEM. From the results of the stress analysis on the gears, it was found that the region with the highest shear stress was at the contact surface of the gears with the value of 13,309 MPa, as illustrated in Fig. 4.
Figure 4. Shear stress distribution

From the simulation results can also be plotted a shear stress curve from the tooth base to pitch as shown in Fig. 5. Where the value of shear stress is taken at the node near the teeth around the crack tip.

Figure 5. Shear stress curve.

From the curve it can be seen that from the base of the tooth to tooth pitch there is an increase shear stress up to point 3 as the maximum value of shear stress. This suggests that in addition to tooth contact point where the maximum shear stress occurs, the base or roots of the teeth also hold a fairly large shear loads. The shear stress maximum occurred near the crack tip at the node 3 as shown on the curve in Fig. 5 with the value of about 11,600 MPa. This value far exceeds the permissible shear stress value of the material gear of about 60 MPa. Therefore this issue causes a fracture to the teeth of the gear. From simulations using the FEA was also obtained the value of equivalent elastic strain on the gear. The maximum strain also occurs on the contact point of the gear with the maximum value of 0.15022. Fig. 6 shows the equivalent elastic strain simulation on the gear with the maximum value indicated by red color. Fig. 7 shows the strain curve for which data is taken from a node near the tooth contact point, where the maximum strain occurs at the contact point.
From the simulation result can be plotted a strain curve along the gear tooth. It shows that the strain only occurred near the contact point.

![Equivalent elastic strain](image1)

**Figure 6.** Equivalent elastic strain

![Strain curve](image2)

**Figure 7.** Strain curve

The stress intensity factor $K_I$ was then conducted on the near crack tip using FEA. From the results of the stress analysis on the gears, it was found that the region with the highest $K_I$ was at the contact surface of the gears with the value of 53 MPa$\sqrt{m}$, as illustrated in Fig. 8. This value larger than fracture toughness $K_{IC}$ of the material with the value of 51 MPa$\sqrt{m}$. Therefore, crack propagation occurred starting from the initial crack [13-14].
4. Conclusions

The failure of the hand tractor gear was found to be caused by an initial crack contained in the gear. Subsequently, from the FEA results it was found that the value of the shear stress that occurs around the crack tip far exceeds the permissible shear stress value, so this shows one of the causes of tooth fracture. Moreover, from the FEA results also showed that the stress intensity factor $K_I$ occurred at the center of the tooth which is the tooth contact point indicating the maximum value of about 53 MPa√m. This value $K_I$ is greater than $K_{IC}$, it also causes crack propagation to the final fracture.

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