Failure analysis of railway freight car axle with finite method element

Raymond Philander Jeadi, Andoko Andoko*
Mechanical Engineering Department, State University of Malang
Semarang 5, Malang 65145, Indonesia
*Email: andoko.ft@um.ac.id

Abstract. Caring for goods transportation vehicles is a natural thing in maintaining conditions in order to stay in prime condition, especially in the most important parts. One of the sections of the most important in a vehicle carrying humans or goods i.e. as the wheel. Care extra is needed so that no occurrence of failure when used. The failure of a part when used can result in consequences are potentially disastrous to the possibility of man as the victim. Therefore, axle vehicles, especially rail are designed extremely reliable, with a maintenance inspection of a non-destructive manner periodically. However, in a situation unique, as the wheel to experience a state of tension complex as well as some of the conditions the voltage doubles, so that the failure of fatigue at the time used. Studies have clarified the equivalent stress, strain energy, as well as the safety factor of the cause of the fracture of the axle wagon railway transporter type of train railway that used to haul coal in which the analysis of the failure of the shaft fractures is done by simulation with the comparison material standards and materials that have been inspected by the journal related.

Keywords: axle, equivalent stress, strain energy, safety of factor

1. Introduction
Rail transportation is one of the oldest forms of transportation in the world. Although it is the oldest type of transportation, the type of transportation by rail ranks second in the domain of transporting cargo after sea transportation, and second in the domain of transporting passengers after land transportation [1]. In this day and age, rail transportation is commonly used to transport construction materials, food, and semi-products of the chemical industry in a considerable distance. The disadvantage of rail vehicles is that the number of rails used is very limited, so that work will be hampered if the rail vehicle has an accident while working. For this reason, safety at work is very important for rail vehicle owners, especially resistance in carrying heavy loads in a fairly intense period.

The axle is a part of a vehicle that has the purpose of supporting the load. The axle is the central axis of the wheel and the rotating gear. Axles are fairly common because their use is in almost all existing means of transportation. Where the axle itself rotates in tune with the wheel. Several ways of attaching the bearings and bushings to the axle depend on the producer of the motor vehicle. The axle is one of the load supports on the vehicle because the axle itself is between the wheel and the vehicle. Where the axle gets a vehicle load that will become a load, as
well as normal loads than the vehicle wheels. With the heavy load design, the axle has a stress at
the stress concentration point. Variables, exploitation conditions, material inspection, less
observant maintenance are the main causes of rail axle failure, as shown in the literature of Zerbst
et al. [2], Torabi et al. [3], Meral et al. [4]. Mohan [5], upon applying finite element methods,
conducted a prediction of the thermal and static behavior of the towed railway vehicle wheels.
In related journals, data is obtained in the form of axle analysis of fractures from railroad
freight cars used to transport coal, where axle conditions have been used for the last 35 years.
Previous researchers have analyzed the mechanical, micro-macro properties of the axle that failed
to break. Based on the experiment above, a simulation is carried out to strengthen the results
obtained previously.

2. Method
The raw data comes from previous research journals, where the journal belonging to Zerbst et al.
[2]. Has authentic evidence of the axle that has fractured, as shown in Figure 1. Because physical
evidence cannot be obtained, the method used is the simulation method. The simulation method
is one of the research methods that does not deal with physical evidence directly, but still follows
the standard standards found in manuals and physical evidence. Starting with designing the axle
(Figure 2) according to design standards using Solidworks software and providing properties that
match the physical evidence which can be seen in Tables 1, 2, and 3. This type of method provides
a way to conduct easy and efficient research on various parameters used with easily evaluated
design and manufacturing conditions [6]. Figure 3 shows the meshing size used for the simulation
of 25 mm and produces 21209 nodes and 12077 elements. The simulation is intended to analyze
several analyzes, namely equivalent stress, fatigue life, and safety factor. The parameters of the
load will be adjusted to the related journal where the accident occurred when the train was
carrying a load of approximately 200 kN.

Figure 1. Broken axle under exploitation used.
2.1 Material properties and chemical composition
It is clearly known that the properties of the material and the chemical composition of the axles in the field, which are used in the journal in this study are the AE1N1 standard.

| Chemical element | C  | Si  | S   | P   | Mn | Ni  | Cr  | Mo  | V   | Ti  | W   | Al  | Fe |
|------------------|----|-----|-----|-----|----|-----|-----|-----|-----|-----|-----|-----|----|
| Tested sample    | 0.441 | 0.260 | 0.005 | 0.009 | 0.640 | 0.034 | 0.097 | 0.012 | <0.003 | <0.003 | 0.020 | 0.069 | rest |
| Specified according to EN 13261:2010 standard | max | max | max | max | max | max | max | max | max | max | max | max | rest |

Table 2. Results of tensile test

| Test specimens position | Yield strength Re (MPa) | Tensile strength Rm (MPa) | Elongation A5 (%) | Contraction Z (%) |
|-------------------------|-------------------------|---------------------------|------------------|------------------|
| Longitudinal            | 235                     | 534                       | 30.70            | 51.58            |
| Transverse              | 233                     | 523                       | 16.25            | 17.86            |
| Specified by standard EN 13261 for longitudinal test specimens | min 320 | 550 - 650 | min 22 | / |

Table 3. Impact energy results of the steel axle

| Test specimens position | Test temperature T(°C) | Mean value KU₃₅₀₀(J) | Standard EN 13261 KU₃₅₀₀(J) |
|-------------------------|-------------------------|----------------------|-----------------------------|
| Longitudinal            | + 20                    | 21.8                 | min. 30 J                   |
| Transverse              | + 20                    | 11.33                | min. 25 J                   |

2.2 Meshing
Meshing technique of ANSYS workbench used to break down the model into a number of small parts to form certain that aims to sharpen the accuracy of the analysis. In the case of this study, the meshing was carried out at an element size of 25 mm for the Axle geometry. Results meshing of Axle showed that the presence of 12,077 elements and 21,209 nodes that exist on a design (Figure 3)
2.3 Boundary condition (fixed point & force point)

Boundary condition used to analyse, by using the finite element method, lies on the geometry of these three cylinders (Figure 3). Part of boundary condition is axel part attached to wheel. Meanwhile, load is given to the first cylinder geometry from the edge.

3. Results

3.1 Equivalent stress

Figure 4 shows the simulation results of the equivalent stress of different material properties. It can be seen that the simulation test for Equivalent stress on the Standard metric reaches 901.17 Mpa. The greatest stress value is achieved at the same point in the fillet axle connecting the wheel. This is fairly reasonable because the increase in stress must be at the center of the stress concentration of the design. Increasing the strength at this point is needed to reduce the stress level on the axle surface. The stress that accumulates at this point is due to this point being the basis of the stress concentration after the fixed point. Selection of a good stiffness is related to the selection of an appropriate geometric structure [5]. This equivalent stress value says that the load when the axle is broken is a load that can be supported by both types of axles in a healthy state, and can still maintain its original form and function. The greater the voltage that occurs, the lower the guarantee of safety and the greater the deflection. Deflection is a change in the position /
shape of a material from its original form due to the stress applied [7]. Therefore, the magnitude of the stress and the point of loading affect the amount of deflection that occurs.

3.2 Strain energy

The next simulation, namely the strain energy, the strain energy is one of the simulations of the resistance of a design by strain, where the strain energy itself is a type of potential energy that is stored in a structural member as a result of elastic deformation. There is an increase in energy near the fault area of the axle. The value of the strain energy tends to increase with point as the equivalent stress value increases. where the possibility of fatigue is possible if given continuous energy (excessive use). Recorded the maximum strain energy that occurs at the axle is 0.017675 Joule.

![Figure 5. Strain energy on the axle](image)

3.3 Safety factor

![Figure 6. Safety factor of the axle](image)

The safety factor is used to evaluate so that the safety of machine components is ensured evenly even though the dimensions used are the minimum [8]. The safety factor obtained by this
study is based on the maximum stress from the simulation. The use of maximum von Mises stress aims to identify the stress combination, namely the main stress (x, y, and z axes) and the maximum stress [6]. Visually, it can be seen that the lowest safety factor point is located in accordance with the location of the highest tension from the axle. The greatest stress is located at the center axle of the axle so that at that position it has the lowest fatigue. While the maximum value of the safety factor is 15, so it can be concluded that the standard design has a safety factor that is quite safe apart from the maximum point of stress. The value of the safety factor calculation shows that the lowest value possessed by the axle is 1.6112 where this value is still above the standard safety factor of the axle, where the value of the safety factor is > 1 which means that the design is still quite safe to use in accordance with the fatigue life of material standards.

4. Conclusion
Based on the Finite Element Method simulation process that has been carried out, it can be concluded that:
- the equivalent stress simulation of the design shows an increase in stress at the stress concentration point significantly. They need for redesign to reduce the concentration point at the axle.
- There is an increase in the strain energy in the area around the fault which allows the fracture to occur due to fatigue.
- Axle does not experience significant failure on design life, supported by safety factor data that is above 1.0, i.e. 1.6112
- Some changes that are needed to reduce the stress concentration level on the axle surface are changes in the type of cut at the axle.

5. References
[1] ‘(PDF) STATIC ANALYSIS OF BEHAVIOUR OF AXLE ASSEMBLY OF FREIGHT WAGONS’. https://www.researchgate.net/publication/314369126STATIC_ANALYSIS_OF_BEHAVIOUR_OF_AXLE_ASSEMBLY_OF_FREIGHT_WAGONS (accessed Oct. 30, 2020).
[2] U. Zerbst et al., ‘Safe life and damage tolerance aspects of railway axles – A review’, Engineering Fracture Mechanics, vol. 98, pp. 214–271, Jan. 2013, doi: 10.1016/j.engfracmech.2012.09.029.
[3] A. R. Torabi and M. Heidary Khavas, ‘Fatigue Crack Growth in a Solid Circular Shaft Under Fully Reversed Rotating Bending’, J Fail. Anal. and Preven., vol. 12, no. 4, pp. 419–426, Aug. 2012, doi: 10.1007/s11668-012-9578-9.
[4] M. Bayraktar, N. Tahrali, and R. Guclu, ‘Reliability and fatigue life evaluation of railway axles’, Journal of Mechanical Science and Technology, vol. 24, pp. 671–679, Mar. 2010, doi: 10.1007/s12206-009-1219-1.
[5] P. Murali Mohan, ‘Analysis of Railway Wheel to study Thermal and Structural Behaviour’, International Journal of Scientific and Engineering Research, vol. 3, Nov. 2012.
[6] S. Efendi and Andoko, ‘Design and Simulation of Cracks in A Four-Cylinder Engine Crankshaft Using Finite Element Method’, IOP Conf. Ser.: Mater. Sci. Eng., vol. 494, no. 1, p. 012004, Mar. 2019, doi: 10.1088/1757-899X/494/1/012004.
[7] Y. Nikam and D. A. Badadhe, ‘DESIGN ANALYSIS AND FAILURE MODES OF LEAF SPRING IN SUSPENSION SYSTEM’, vol. 03, no. 10, p. 6.
[8] Andoko and N. E. Saputro, ‘Strength analysis of connecting rods with pistons using finite element method’, MATEC Web Conf., vol. 204, p. 07009, 2018, doi: 10.1051/matecconf/201820407009.