

Material Selection for Coal Flow Breaker Plate Based on Fatigue Life Analysis Using Finite Element Method

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Abstract

Fatigue failure in the coal flow breaker plate of the CV507 screen at PT. Bukit Asam–Tarahan Port has led to production delays and increased maintenance requirements. This study investigates the optimal material selection for the coal flow breaker plate based on fatigue life under bulk impact loading. The structure, modelled as a fixed vertical plate, was analyzed using the Finite Element Method (FEM) with two material options: ST37 and ST52, each at thicknesses of 15 mm and 20 mm. Static structural and explicit dynamic simulations were performed in ANSYS, using an impact load of 15 kN measured from site conditions. The results indicate that ST52 with a 15 mm thickness experienced the highest von Mises stress (2,223.4 MPa) and deformation (14.41 mm). Increasing the thickness to 20 mm reduced stress to 1,465.4 MPa and deformation to 10.99 mm, extending fatigue life to 8.54 months, making it the most suitable option. These findings provide a basis for selecting materials that enhance durability and minimize downtime in coal processing operations.

Keywords:

Fatigue life, von Mises stress, impact loading, finite element, coal flow breaker plate

1 Introduction

The utilization of coal as boiler fuel to produce electrical energy in Steam Power Plants (PLTU) is still very dominant and irreplaceable. It is projected that until 2050, the use of coal will still dominate, amounting to 301 million Tons of Oil Equivalent (TOE) (BAU), and only decrease by 4% from 2040 [1].

PT Bukit Asam Tarahan Port in Lampung Province is a National Company of Indonesia that processes coal for steam boiler fuel and also for export. In its operation, there are several main machines for processing coal: rotary car dumper, stacker reclaimer, crusher, vibrating screen, barge loader, and ship loader. Among these machines, there is one machine, namely a vibrating screen (sieve), that functions as a filter of coal with an inappropriate size. The screen is Equipped with a component called a flow breaker plate. The plate (coal flow reducer) is often broken due to the high impact load that occurs due to the fall of coal bulk at a height of 5 meters. Fig. 1 shows the components that are often broken and damaged.

Based on data owned by a company namely PT Bukit Asam Tarahan, breakdowns often occur within two to four weeks, hampering coal production. From 2022 to 2023, the total hitch time reached 695 minutes, which caused faster damage to the vibrating screen, breakdown time, and higher costs.

Damage due to impact loads experienced by structures and machines is a major concern of researchers. Cherukara and Yeddu [2] modeled the performance of F1 race cars due to impact loads using finite element simulation. The results of static analysis show

that the maximum von Mises stress is smaller than the yield stress so the impact load is said not to cause material failure.



Fig. 1. The coal flow breaker plate on the vibrating screen component is damaged.

Yusnayadi et al. [3] conducted research on the ability of the go-kart chassis to impact loading, which focused on impact/crash testing with speed variations from the horizontal direction. They produced the distribution of total deformation, von Mises stress and safety factors using explicit dynamics. The results show that AISI 1020 material was the most appropriate choice and is safe to use up to a speed of 10 km/h.

Maulana et al [4] analyzed von Mises stress, safety factors, and fatigue life of a coconut fiber chopping machine using Autodesk Inventor. It is generally suggested to review the performance of a machine from various aspects, including strength, quality, comfort, economy, and aesthetics [5]. Material selection involves researching potential materials and evaluating their characteristics to be used according to their qualities and properties is necessary. For a material to be suitable for a particular application, it must have predictable behavior [6]. Therefore, modeling is one of the fastest and most economical ways to determine the performance of a machine with different materials.

In recent decades, there have been many experiments and modeling using the concept of explicit dynamics [7]. Impact modeling in ANSYS™ Explicit Dynamics was carried out by Nofri [8] to determine the strength of materials against shock loading (shock resistance), such as brittleness caused by heat treatment or the brittleness of casting products and the influence of the product's shape. Finite element analysis on various structures and components in static conditions can be done using the ANSYS Static Structural. The main features and functions of ANSYS Static Structural include geometry modeling, material selection, meshing, boundary conditions, loading, structural analysis, visualization, and reports.

This research was conducted as an effort to extend the lifetime of the CV507 screen of the Port by selecting from available material for the coal flow breaker plate. The material selected was based on the results of Finite Element Analysis using ANSYS Static Structural and Explicit Dynamic.

2 Research methods

The coal flow breaker plate arrangement in Fig. 1 was modeled as a plate arrangement with a vertical orientation with both ends fully fixed (Fig. 2). The plate has a length of 1500 mm and a height of 200 mm. The plate thickness (width, as a beam) is modeled to be 15 and 20 mm.

Static and dynamic analyses were conducted on the coal flow breaker plate for four types of materials available in the field: ST37, ST52, Hardock HB400 and GS20Mns. However, in this study only the results of ST37 and ST52 are presented with mechanical properties in Table 1.

The simulation results were set for total deformation, stress (von Mises), and fatigue life (cycle) using ANSYS Explicit Dynamic and Static Structural to determine the durability of each material choice. Parameter input data was collected at the Port. All data obtained then were entered into engineering data in ANSYS. Other material properties were calculated by the following Eqs (1-7).

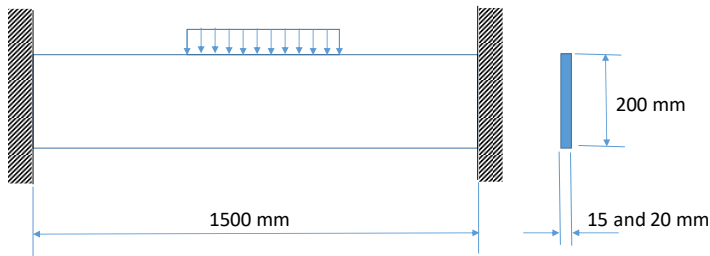


Fig. 2 Flow breaker plate modeled as a beam with fully fixed ends

Table 1. Mechanical properties of materials (DIN 17100)

Material properties	Symbol	Material	
		ST37	ST52
Tensile Strength (MPa)	S_{ut}	370	520
Yield Strength (MPa)	Y_s	225	345
Young Modulus (GPa)	E	210	210
Densitas (kg/m ³)	P	7850	8030
Poisson Ratio	V	0.32	0.30

Fatigue strength coefficient

$$\sigma'f = S_{ut} + 345 \text{ MPa} \quad (1)$$

Fatigue strength exponent

$$b = -\frac{\log\left(\frac{\sigma'f}{S'_e}\right)}{\log(2N_e)} \quad (2)$$

Fatigue ductility coefficient

$$\epsilon'f = 0.812 - 74 \times \frac{S_u}{E} \quad (3)$$

Cyclic strength coefficient

$$K' = \frac{\sigma'f}{(\epsilon'f)^{n'}} \quad (4)$$

Cyclic hardening exponent

$$n' = \frac{b}{c} \quad (5)$$

Strength endurance

$$Se' = 0.5 \times S_{ut} \quad (6)$$

The impact load was determined based on the falling mass of coal bulk on the transverse surface of the flow breaker plate by installing a load cell on the component. Furthermore, it was calculated using Eq. (7), where F is the maximum impact load. (kN), m is the mass of coal bulk (kg), and g is the gravity acceleration (m/s²).

$$F = m \cdot g \quad (7)$$

Fatigue life evaluation was carried out using ANSYS Static Structural, which analyzes material fatigue until the tested model

experiences a fracture condition and the resulting data will be in the form of an S-N curve [10].

3 Results and discussion

The mass of the falling coal bulk load (m) obtained from measurement using the load cell was 1550.21 kg, so the impact load on the plate (F) calculated using Eq. (7) is 15.2 kN. This load was input into the ANSYS in Fig. 3.

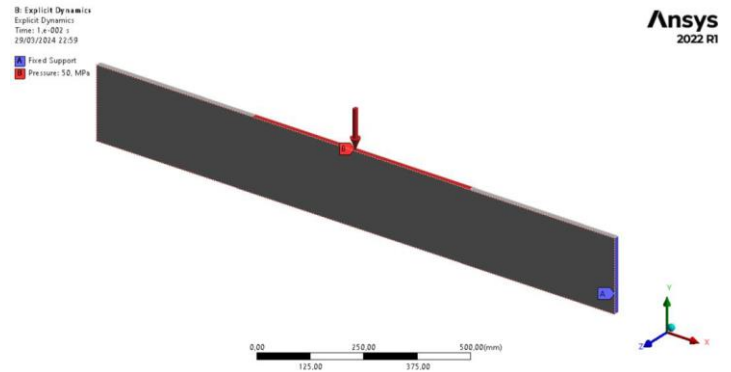


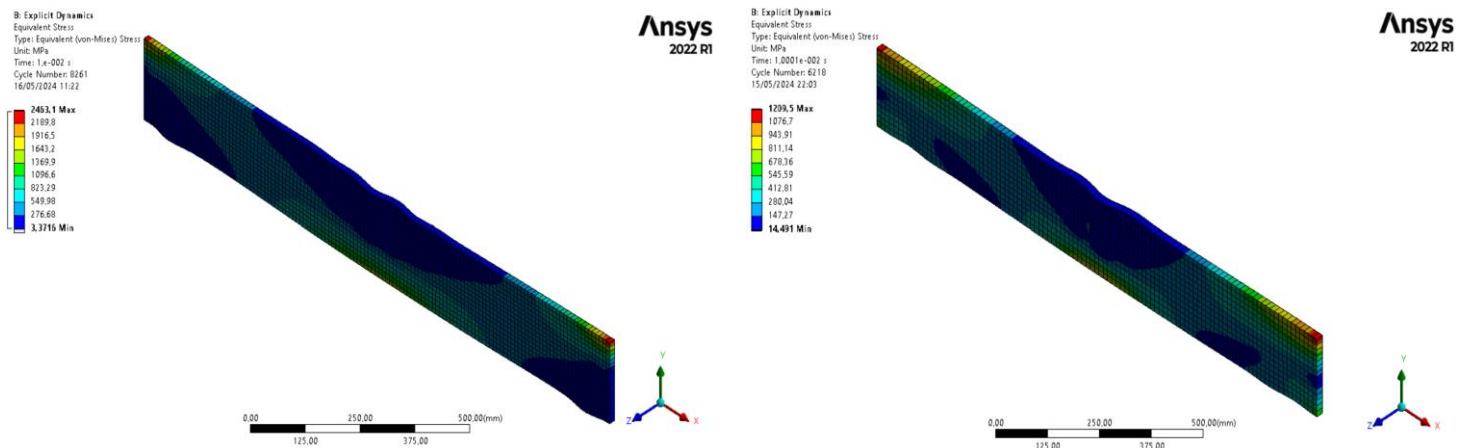
Fig. 3. Modeling the boundary conditions and loading a plate

3.1 Maximum Stress

The resulting (von Mises) stress contour plot in Fig. 4 and 5. From the stress contour plots Figs 4 and 5, several regions have bright red to dark blue colors. The red color indicates areas with higher stress than the blue color [11].

The maximum stress experienced by the coal flow breaker plate occurs at the fixed ends as expected from the theory of strength of materials. The maximum stress on the ST37 plat material having 15 mm and 20 mm thickness is 2504.9 MPa and 1554 MPa respectively. The corresponding maximum stress for the ST52 plate thickness having thicknesses of 15 mm and 20 mm is 2223.4 MPa and 1465.4 MPa respectively. Adding material thickness from 15 mm to 20 mm increases the plate's durability, indicated by the decrease in maximum stress (σ). The ST37 material, with the addition of 5mm plate thickness, was able to increase the strength by 61%, while the ST52 material increased by 52%. It can be understood from the theory of plate and shell that increasing plate thickness will increase the plate bending stiffness according to Eq. (8), where E is Young's modulus, t is plate thickness, and ν is Poisson's ratio. The maximum stress history at the plates in Fig. 6.

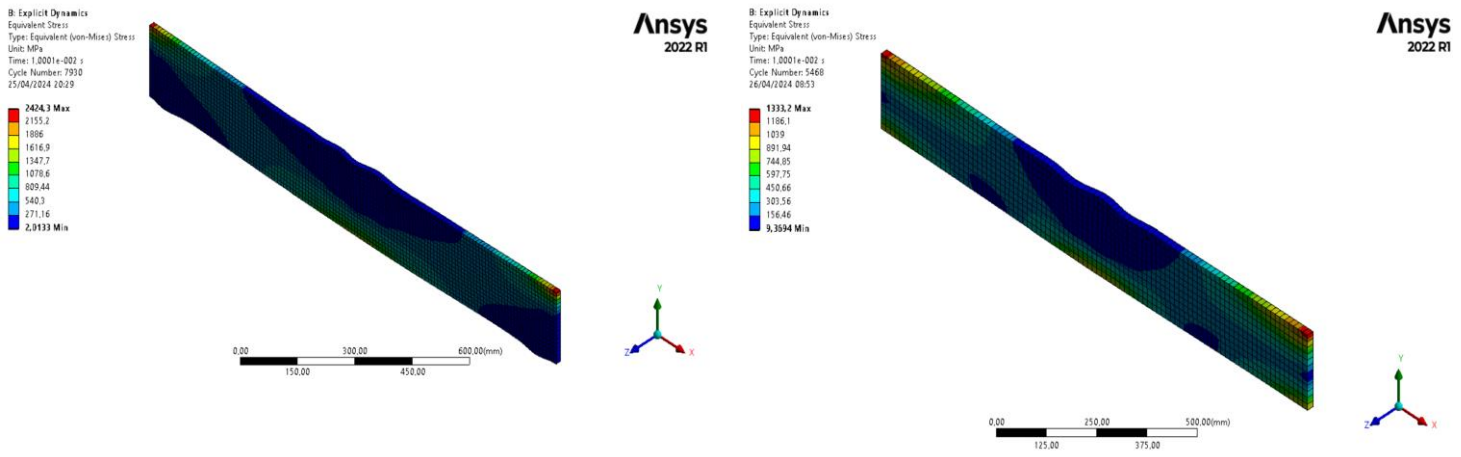
$$D = \frac{Et^3}{12(1 + \nu^3)} \quad (8)$$



(a) 15mm

(b) 20 mm

Fig. 4. Stress contour plot for ST37 materials having different plate thickness



(a) 15 mm (b) 20 mm
 Fig. 5. Stress contour plot for ST52 materials having different plate thickness

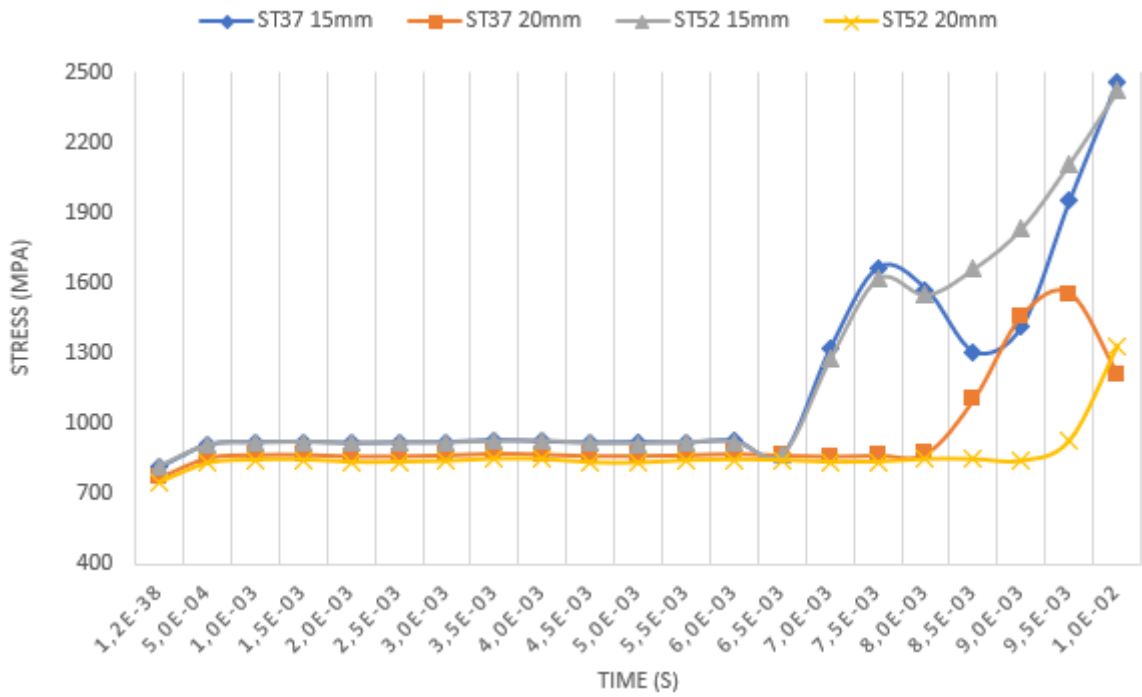
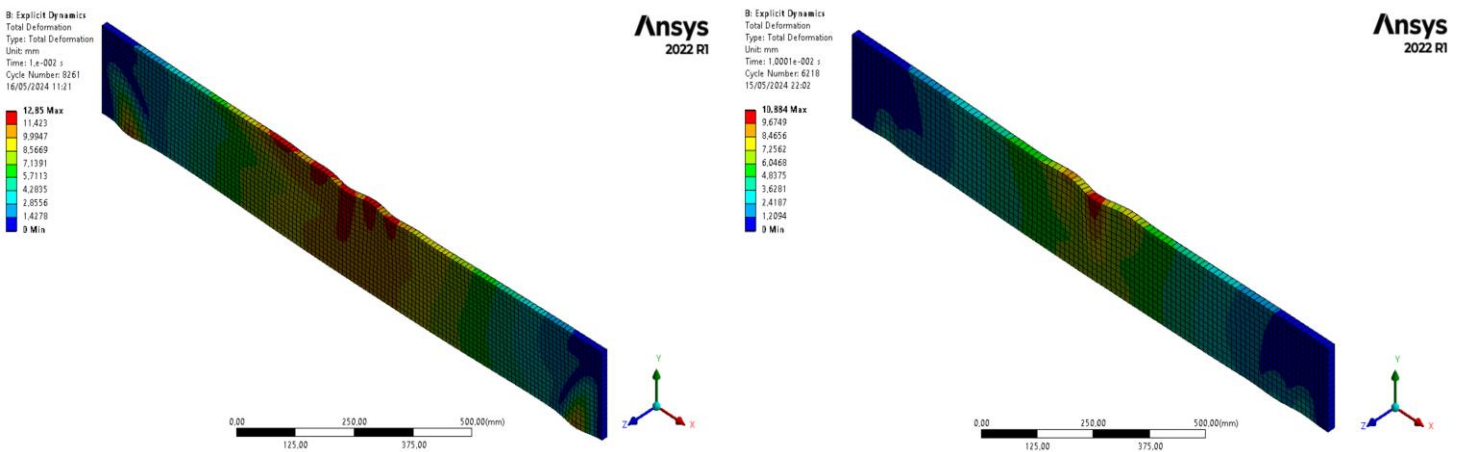


Fig. 6. Comparison of stress history of ST37 and ST52 materials with thicknesses of 15 mm and 20 mm

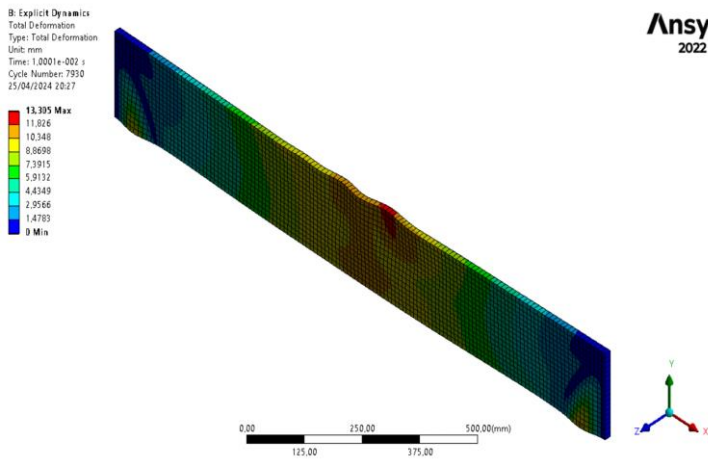
3.2 Maximum deformation

For beams with fully fixed at both ends, maximum displacement occurs at the mid-section of the beam [13]. The beam's mode shape and resultant deformation shape, when it receives an opposing

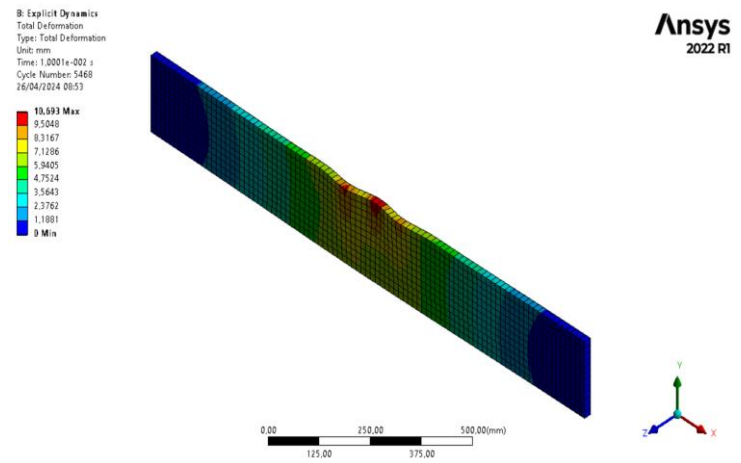
reaction force (from the top of the beam/pedestal), form the first mode shape of beam deformation. This is to the modeling results where the maximum deformation also occurs at the midpoint of the plate, in Figs 7 and 8.



(a) 15 mm (b) 20 mm
 Fig. 7. Contour plot of deformation for material ST37 having different plate thickness



15 mm



20 mm

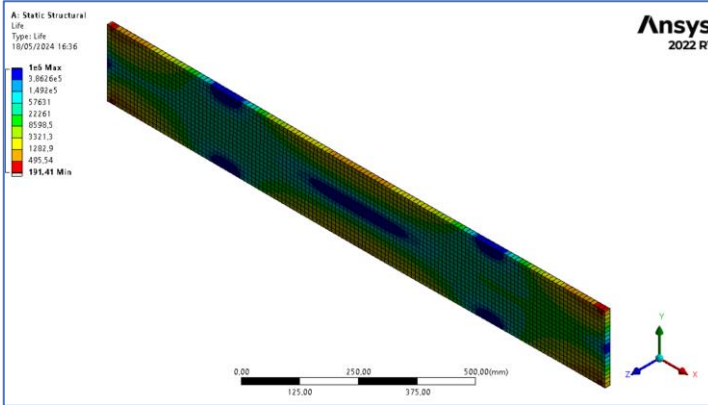
Fig. 8. Contour plot of total deformation for ST2 materials having different plate thickness

Close observation of Fig. 7 reveals that the maximum total deformation for ST37 materials having thicknesses of 15 mm and 20 mm is 11.90 mm and 11.92 mm. This result is somewhat peculiar in that an increase in plate thickness results in a slight increase in total deformation. From Fig. 8 for ST52 materials having thicknesses of 15 mm and 20 mm, the maximum total deformation is 14.41 mm and 10.99 mm respectively. This is expected that increasing plate thickness will increase its bending stiffness. Knowing the maximum deformation of different materials and thicknesses can determine which material and size is the safest and strongest to withstand the load [14]–[16]. The coal flow breaker plate material with the lowest deformation, i.e., ST52 with a thickness of 20 mm, is the best choice.

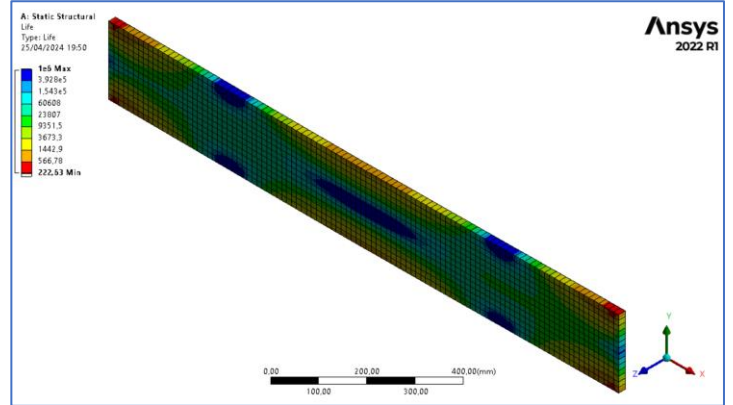
bright red color indicates the minimum fatigue life, while the dark blue color shows the highest value. In all four models, the area with the minimum fatigue life point is at the position of both fixed ends and the mid-section of the plate. Based on the color contours, it can be seen that the plate experiences the same fatigue life on two different sides. At the same time, the maximum fatigue life is found in the center of the plate. It can be understood that the impact load from coal bulk falling at a certain height causes damage to the upper side or the side that collides with the impact load directly. The load causes this damage due to the impact. This condition will be exacerbated by loads that occur repeatedly. This condition becomes necessary because a material's mechanical performance can be shown when the material experiences an impact load. The performance of the material during impact load varies, which can be influenced by temperature, free fall height distance, and load speed [17]

3.3 Fatigue life

The contour plot for the fatigue life of the coal breaker plate for ST37 and ST52 materials is given in Figs 9 and 10 respectively. The

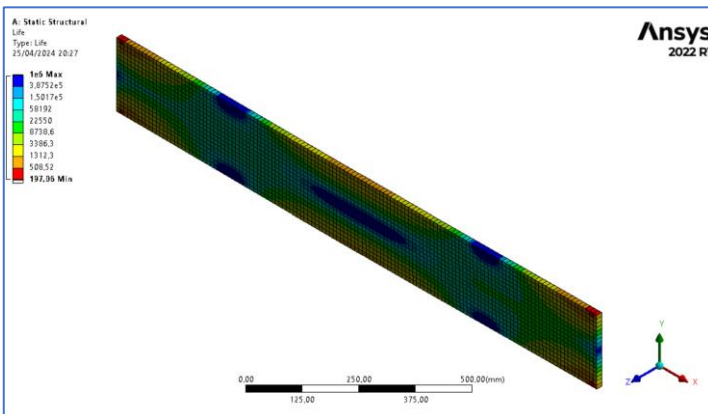


(a).15 mm

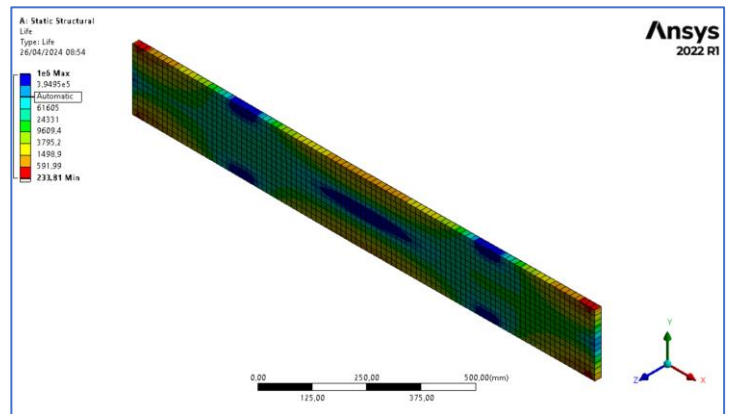


(b).20 mm

Fig. 9. Contour of fatigue life for ST37 materials having different plate thicknesses



(a). 15 mm



(b). 20 mm

Fig. 10. The contour of fatigue life for ST52 plate having a different plate thickness

The difference in the value of fatigue life in each material can be understood as the type of material and thickness are important factors that affect the propagation speed of fatigue cracks.

The Stress (σ) to the Number of Cycles (N) curve of each material to determine fatigue life in Fig. 11. The highest fatigue life is for 20mm thick ST52 material with a value of 256.11 cycles. This is followed by ST37 material having thicknesses of 20 mm and 15 mm with a fatigue life of 233.29 and 232,32 cycles respectively. The lowest fatigue life for 15 mm thick ST52 material with a value of 231.09 cycles. The fatigue life value is directly proportional to the average fatigue life of each specimen by connecting the total impact data that occurs per day when taking the initial data, namely four impacts for 15 minutes.

The highest total fatigue life in Table 2 is for 20 mm thick ST52 material with a fatigue life of 8.54 months, followed by 15 mm thick ST52 with a fatigue life of 7.7 months, and 20 mm thick ST 37 with a fatigue life of 7.78 months. The shortest fatigue life was for 15mm thick of ST37 with a fatigue life of 7.74 months.

Table 2. Fatigue life for each material

Material Type	Thickness	Cycle average	Impact/Day	Fatigue Life (Month)
ST37	15 mm	89210	384	7.74
	20 mm	89585	384	7.78
ST52	15 mm	88739	384	7.70
	20 mm	96348	384	8.36

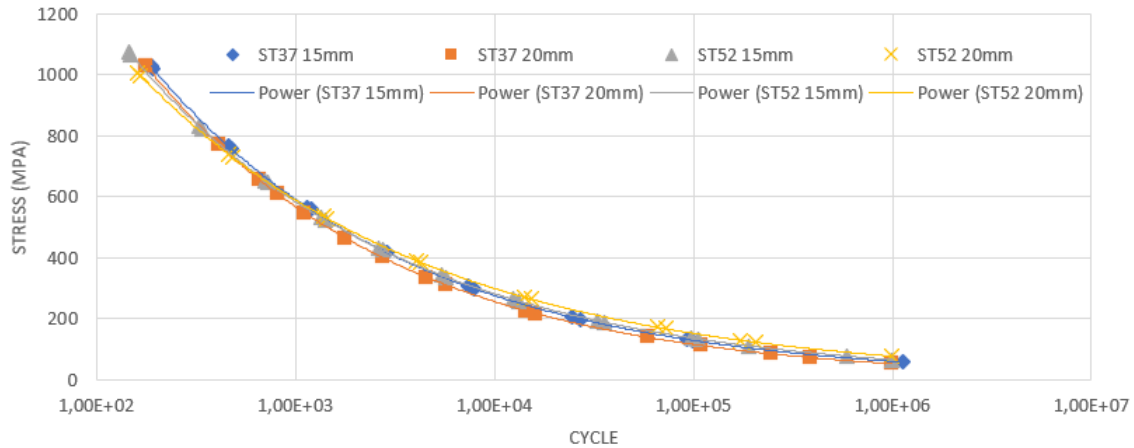


Fig. 11. Comparison of S-N curves of plate materials

4 Conclusions

This study concludes that ST52 material with a 20 mm thickness is the optimal choice for coal flow breaker plates subjected to impact loading. Compared to ST37, ST52 demonstrated lower von Mises stress, reduced deformation, and significantly longer fatigue life. Increasing the thickness from 15 mm to 20 mm reduced stress by 34% and improved service life to 8.54 months, making it the most durable option. These results provide valuable insights for material selection in coal handling infrastructure, helping to reduce maintenance frequency and operational downtime. Future research may explore additional reinforcement strategies or coatings to further enhance fatigue resistance.

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