

Visual Inspection and Hardness Test of Fatigue Damage in Shaft Latching of Slab Tong

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Abstract. Visual inspection and hardness tests were conducted to investigate the fatigue failure of the shaft latching component on a slab tong used in a truck-mounted crane system. After nearly nine years of repetitive operation under dynamic loading, the shaft latching fractured during use. The fracture surface displayed typical signs of fatigue failure, such as smooth, shiny areas and semi-circular patterns, indicating progressive crack propagation over time. To complement the visual findings, a hardness test was performed using an Equotip 2 device. The purpose of this research is to know the type of damage that occurs in shaft latching. The result showed a surface hardness of 41 HRC, significantly below the recommended 60 HRC for components subjected to cyclic loads. Based on visual evidence and comparison with theoretical references, the failure was classified as unidirectional bending fatigue. The shaft material, AISI 4140 alloy steel, may have experienced decreased fatigue resistance due to insufficient hardness and prolonged exposure to cyclic stress. The fracture occurred at a high-stress bending region, and the absence of plastic deformation suggested a sudden break following gradual crack growth.

1 Introduction

Truck mounted crane slab tong is a type of lifting equipment that is usually used to move steel slabs in industry, because it can lift such a large load but within a limited distance [1]. The Slab tong is located on the truck mounted crane. The Slab tong is used to move 200-250 mm thick steel slab sheets used as raw materials in the Hot Strip Mill for various products such as coils, pipes, and others. The Latching shaft is located on the latching slab tong [2].

The Latching or locking, which functions to maintain something in a certain position. In Slab tong, latching functions as a regulator of the arm that clamps the steel slab, when the slab tong works to lift the steel slab, the latching will release the arm so that the arm can clamp the steel slab and then lift it, after the steel slab is placed, the latching will re-enter to lock the arm in the open position then the slab tong will move up in the open clamping arm position.

Damage has occurred to the slab tong in the shaft latching. The shaft latching was damaged (broken) after 9 (nine) years of use. The damage to the shaft latching is indicated

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to have occurred due to fatigue. Fatigue is damage to a material caused by repeated loading. If a metal is subjected to repeated stress, the metal will break at a stress much lower than its maximum stress [3].

However, the damage of the shaft is common in the industry. Such as a failure of the gearbox shaft in a palletizer machine. The analysis revealed that the shaft, made of AISI 1030 steel, failed due to fatigue caused by continuous cyclic loading. SEM examination of the fracture surface showed crack initiation at the keyway, followed by striation marks and a rough surface indicating final fracture. Microstructural analysis revealed a ferrite-pearlite structure, and hardness testing indicated a reduction in hardness with increasing distance from the fracture. Residual stress and strain analysis near the fracture confirmed higher stress levels, validating fatigue as the main failure mechanism [4].

Another example is a failure of steel shafts are due to improper repair welding. The common causes of shaft failure due to improper weld repairs. The study emphasized that welding, even if well-intentioned, often leads to adverse effects such as grain growth, tensile residual stress, or martensite formation, particularly when procedures are unqualified. Multiple case studies showed fatigue cracks initiating at weld terminations, incomplete fusion, and heat-affected zones. The authors concluded that welding repairs significantly alter the mechanical behavior of shafts and can lead to premature failure, especially when the original shaft design is not respected or proper heat treatment is not conducted [5].

There is also research about the tensile and fatigue properties of carburized steels commonly used in shafts. It highlights that surface hardening (around 62 HRC) enhances wear and fatigue resistance, while the ductile core supports shock loads. Through extensive tensile testing of carburized and quenched samples, the study showed that tensile strength can vary significantly (900–2,200 MPa), depending on case depth and heat treatment. Interestingly, higher case depth did not always result in higher strength. The study also noted that factors like grain size, tempering temperature, and surface finish greatly influence final mechanical performance [6].

To replace the damaged shaft latching with a new one, we need to identify the root cause of the damage to the shaft latching. This is because the latching shaft is an important component in a mechanical locking system that works repeatedly and receives dynamic loads. In order for this component to work optimally and have a long service life, a high surface hardness is required, which is around 60 HRC [7]. This hardness aims to increase wear resistance, maintain dimensional stability, and prevent plastic deformation due to repeated loads or impact forces during the locking process. To achieve this hardness, Hardening is carried out, an effort to heat the metal to a temperature of 300°C-500°C and cool it quickly to obtain the desired microstructure and hardness [8].

Based on the information regarding the shaft latching condition above, this research was conducted. Where this research has the aim to know the type of damage that occurs. To achieve this goal, two inspection methods were used: visual inspection and hardness testing as supporting methods.

2 Research Method

A visual analysis is performed on the damaged shaft latching section, which will be replaced with a new one. The shaft latching section will be mapped and then observed visually and compared theoretically.

The specimen used was a shaft latching located on a tong slab where it was damaged. The tong slab can be seen in Figure 1.



Fig. 1. Caption of the Figure 1. Below the figure.

The position of the latching can be seen in the part marked in red. For more details, see Figure 2.



Fig 2. Location of Shaft Latching

The Shaft Latching was damaged due to repeatedly holding the weight of the Slab Tong hand of 10.5 tons over a period of use for approximately 9 years. How the shaft latching itself works can be seen in the scheme in Figure 3. Where for the number and arrow number 1, the shaft latching will rise due to the pressure that occurs. Then, for the arrow and number 2, there is a movement process to the 45° point for the locking process. The third step is the process of lowering the shaft latching because the latching is lifted by the slab tong. Finally, the shaft latches in the 90° position to lock the slab tong arm and lift it.

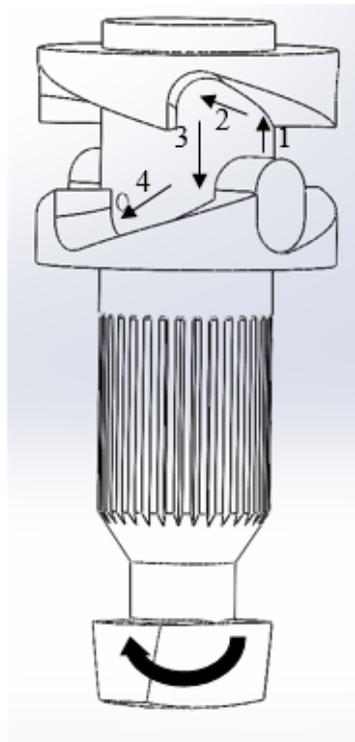


Fig 3. Scheme of Shaft Latching's Works

The fractured portion of this specimen will be removed and cleaned. This is done to ensure proper observation. The part used can be seen in Figure 4.



Fig 4. The part used as Specimen

The damage that occurred is suspected to be fatigue failure. Fatigue failure type data was analyzed by comparing the damage images on the components and images sourced from books as a fatigue failure reference [8]. The types of fatigue can be seen in Figure 5.

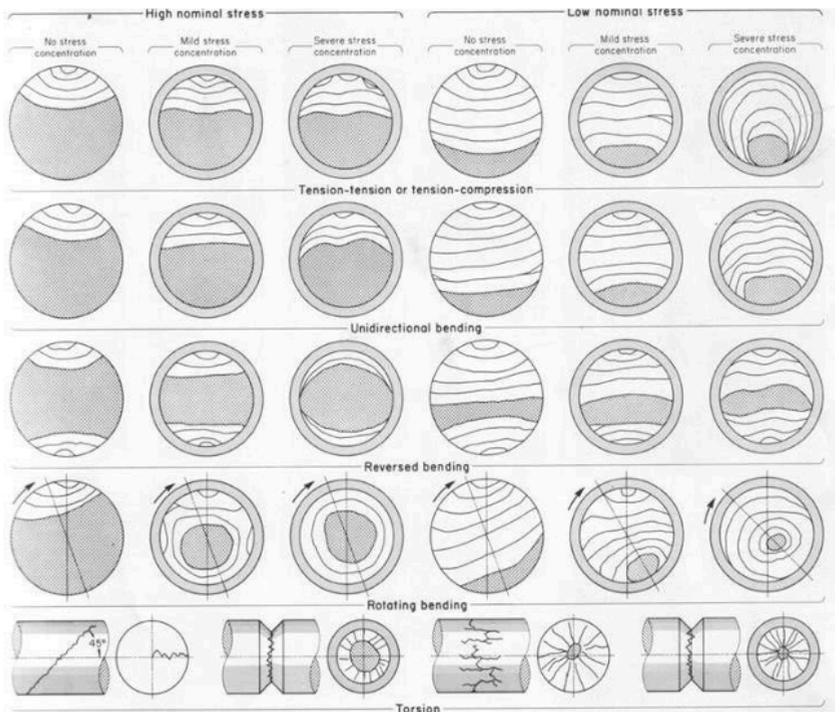


Fig 5. The types of fatigue [8]

In order to support the visual inspection, a hardness inspection of the broken latching shaft was also carried out. This examination uses the Equotip O2 machine [9]. This tool uses

a dynamic loading method. The pen is loaded by rotating it. Then, adjust the hardness unit you want to achieve from the test on the monitor. After that, position the pen on the surface of the specimen to be tested. The test is carried out by pressing the tip of the pen, then the impact body of the spherical test tip and the permanent magnet in the pen will fall and bounce. The results will appear on the screen. The testing tool can be seen in Figure 6.



Fig 6. Hardness Testing Tool

3 Test Methodology

A visual inspection was performed on the damaged latching shaft, which was broken. The inspection was conducted to determine the fatigue that had occurred on the latching shaft by comparing the damage with references from books. Visual inspection is the initial stage in material damage analysis, which is carried out by directly observing the physical condition of the component without the aid of a microscopic tool.

Once the broken part is cleaned, move on to the visual inspection process. The fracture site is then mapped. This mapping is divided based on the resulting fracture visualization. The mapping results can be seen in Figure 7.

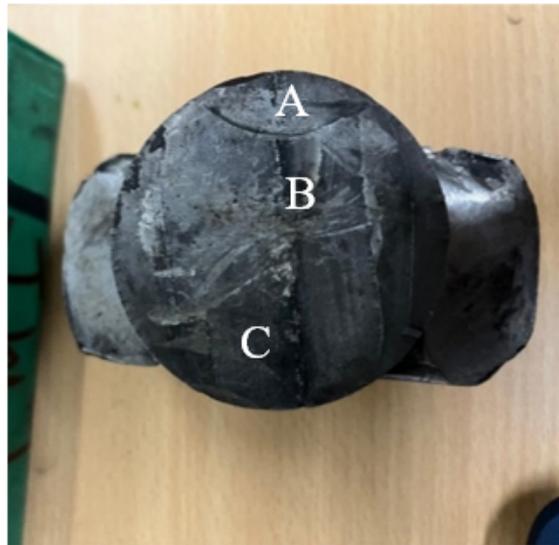


Fig 7. The Mapping Results

After mapping, the resulting fractures or damage clearly showed a typical fatigue pattern. Next, a comparison of the fracture shape was carried out with the literature reference. The fracture shape can be seen in Figure 8.

The fracture of the shaft latching is shown by the red circle in Figure 7. The fatigue failure above is unidirectional bending, which is a material fatigue phenomenon that occurs due to loading in one direction. This term refers to the process where the material experiences repeated stress or strain gradually and eventually fails. The structural integrity of the material decreases over time due to the application of repeated loads, even though the load is below the material's tensile strength limit. More clearly, the damage can be seen in Figure 9.

Hardness testing was also performed on the fracture surface of the shaft latching. This examination used equotip 2 with a dynamic loading method. The test results showed a hardness of 41 HRC. This clearly does not comply with the requirement for a hardness of 60 HRC.

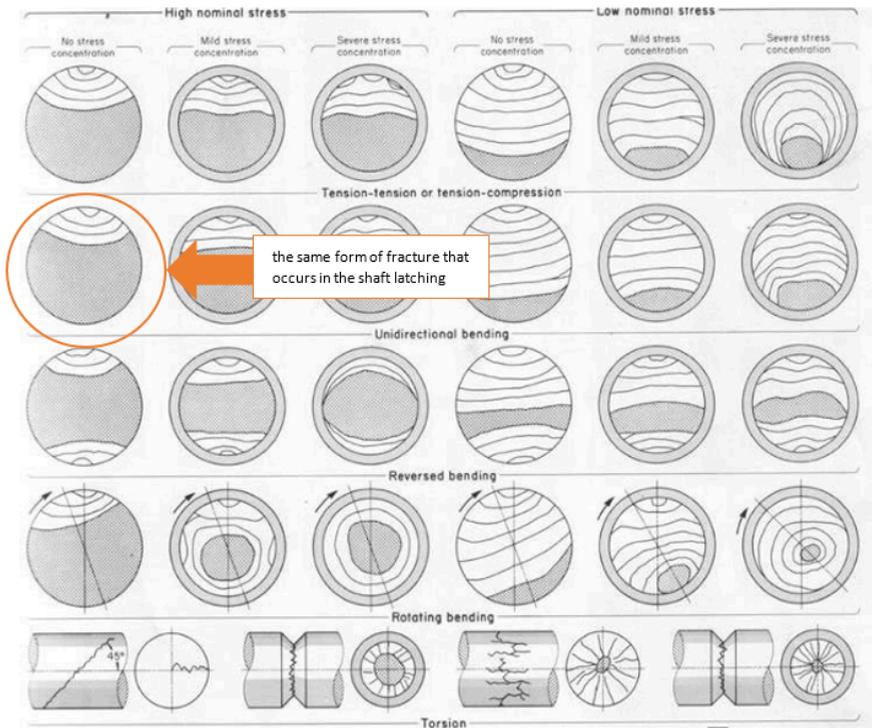


Fig 8. The Fracture Shape

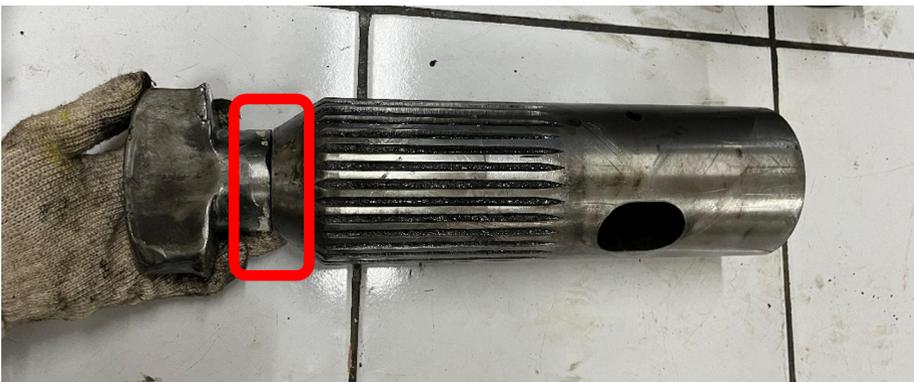


Fig 9. The Damage of Shaft Latching

4 Test Results and Discussion

The result of the visual inspection was the appearance of cracks and fractures in the center of the latching shaft. These fractures clearly show typical fatigue crack surfaces. The pattern is in the form of a semicircle that leads from one starting point of the microcrack

outwards. However, no traces of significant plastic deformation were found, indicating that the fracture occurred abruptly after the crack propagation phase.

Based on previous observations, the main damage was a fracture in the shaft, which was indicated as damage due to unidirectional bending fatigue. This can be influenced by the service life of the shaft latching. The shaft latching operates in a mechanical system that moves up and down and rotates repeatedly every time the slab tong is used to lift the steel slab. The load that must be supported by the slab tong is around 10.5 tons. Furthermore, this slab latching has been used for 9 years at a high working frequency. During time, the shaft latching has experienced cyclic or repetitive loads that ultimately cause stress accumulation at critical points. This repetitive stress is the main cause of the appearance of cracks in the material, which continue to spread until they cause complete fracture, even though there is no direct excessive load.

For more detail, the surface of the crack looks relatively smooth and shiny. This is a strong indication that the damage occurred due to fatigue (material fatigue) and not just a momentary overload. Furthermore, no signs of damage caused by severe friction were found, suggesting the damage was not caused by a direct impact, but rather by the accumulation of cyclic stresses.

The fracture occurred in the area of the shaft experiencing the highest stress, which is the bending area due to the load from the locking and unlocking mechanism of the slab tong. The result of the fatigue is unidirectional bending. This is a material fatigue phenomenon that occurs due to loading in one direction. Where the material experiences a gradual, repeated process of pressure or strain and eventually fails. The structural integrity of the material decreases over time due to the application of repeated loads, even if the loads are below the tensile strength limit of the material. This can be seen in Figure 10.

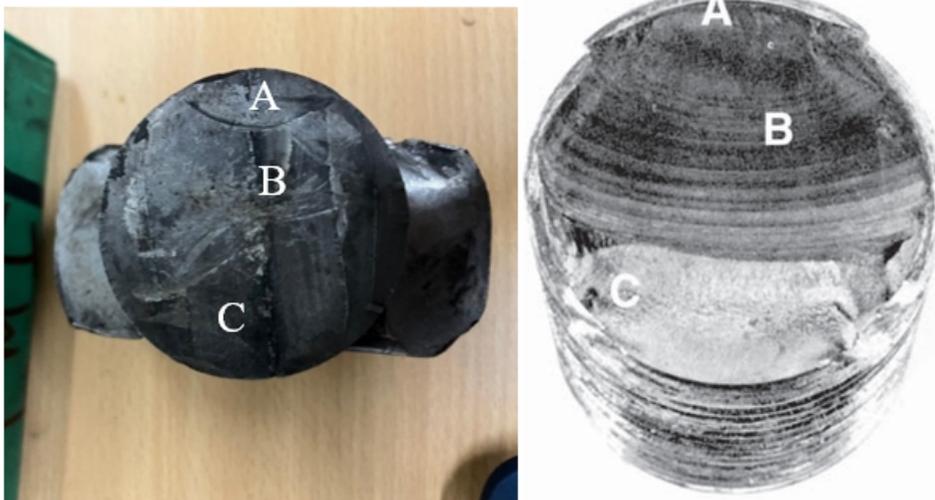


Fig 10. The Undirectional Bending Fatigue's

This shaft latching damage is also affected by material hardness that is significantly lower than the standard, which is only around 40 HRC. This can occur due to the continuous repetitive stress received by the latching shaft.

Furthermore, the shaft latching material can also affect this damage. The shaft latching material is AISI 4140, an alloy steel. This material is good for general applications, but it has limitations. This limitation lies in the resistance to wear if the hardness is low. In addition, the fatigue resistance of a material is greatly influenced by its hardness. Inspection revealed the shaft latching had a 41 HRC, indicating the material was relatively soft for heavy, repetitive applications. In addition, the material is no longer hard enough to withstand long-term friction and pressure.

5 Conclusion

Based on the analysis, it can be concluded that the primary failure mechanism of the shaft latching was unidirectional bending fatigue, initiated and propagated under long-term cyclic loading. The operational demands lifting loads of approximately 10.5 tons at a high frequency over nine years subjected the component to repeated stress accumulation at critical points, ultimately leading to crack initiation and catastrophic fracture without the presence of an immediate overload event. Material properties further contributed to the failure; the AISI 4140 alloy steel, measured at 41 HRC, possessed insufficient hardness for prolonged heavy-duty service, thereby reducing its fatigue resistance and wear performance. The combination of sustained cyclic loading and suboptimal hardness accelerated fatigue crack growth, underscoring the importance of both proper material selection and periodic condition monitoring in high-frequency, high-load applications.

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