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The Effect of Surface Finish and Fillet Design on Tie Rod Shaft Lifetime at Coal Mill Plant Operation

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Abstract: The tie rod shaft is one of the most essential parts in the coal grinder machine at the coal mill plant to support the roller grinder axial movement. Since the tie rod shaft receives the cyclic load constantly, the inappropriate design can cause the lifetime of the shaft to be short. The broken incidents of the tie rod shaft at coal mill the coal mill plant of PT X takes effect on the Steam and Power Supply to the ammonia and Urea Plant. This Research aims to analyze the abnormality on the tie rod shaft, which is always broken on the fillet section. The Stress concentration factor, Maximum Stress, and Surface roughness on the fillet section of the shaft have an extraordinary effect on the Fatigue lifetime. With the special tool assistant, the conventional lathe machine can compete with the CNC machine Quality to make Fillet contour as well as polished treatment and precise as the tool assistant can make the constant rotational movement produced by the human hand. The result showed that the tie rod shaft with 0.33 µm surface roughness level and fillet dimension strictly at 5mm could extend the lifetime of the tie rod shaft beyond the target after installed on the plant.

Keywords: *tie rod shaft, fillet, stress concentration factor, surface roughness, design*

1. Introduction

The tie rod shaft in the power plant area is one of the supporting components in the coal grinder machine to support the roller grinder axial movement. The coal grinder is essential to produce the power of coal. The coal powder is used for the boiler's burning process to bear the steam. Additionally, the steam aims to start up the turbine and generator to produce electrical power. In this case, There have been ten times of broken incidents in the Tie Rod shaft at the coal mill Plant of PT X from 2018 until 2019, which averages eight months of lifetime. The broken incident of the tie rod shaft can cause the shutdown of ammonia and urea plants as there is no power and steam supply from the power plant.

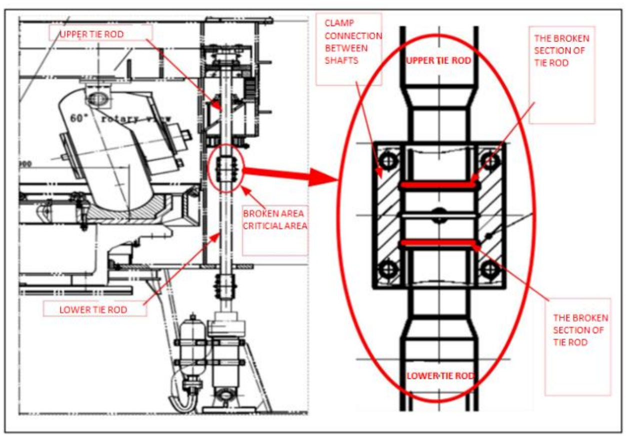

Figure 1. *The area of broken shaft.*

The research carried out to analyze the initial crack, line pattern, cleavage fracture, fatigue area, and visual inspection of the broken shaft on the fillet section. Fatigue is one of the abnormalities or cracks phenomena in the material due to receiving the cyclic load and is responsible for more than 80% of all engineering failures. The crack initiation and propagation correlate with the integrity of the machining process. Based on ISO 1302:1996, the machining process has several levels of surface finishing, commencing with at 0.025 µm (N1) and culminating with 50 µm (N12). In order to extend the lifetime of material, the surface finish of engineering material must be controlled.

Mohammad R. Bayoumi researched the correlation between various surface finish parameters and the endurance fatigue strength of a commercial aluminum alloy [1]. Since the surface finish can be control during machining process, it is considered by engineer to extend the life time of material [9]. Additionally, the effect of all surface finish condition are capable of reducing or escalating the lifetime of the product [10].

Osita Obiukwu et. Al (2015) studied the effect of surface finish on the low cycle fatigue of low and medium-carbon steel. It was found that the surface of the material with a lower grade (Ra = 0.32 µm) has a better fatigue life than a higher roughness (Ra = 1.58 µm) [2].

On the other hand, there is a correlation between the stress concentration factor, maximum stress, the area's size, and the material's lifetime. The formula of stress concentration is the ratio between maximum stress and stress average. Based on the S-N diagram, The increase of the maximum stress and reduction of the stress concentration can affect the lifetime of the material. To minimize the maximum stress, the size of the area must be higher. In the case of fluctuating loads, stress condition in the fillet area can arise the premature fatigue or sensitive crack [11].

Many researchers research to obtain the form of the fillet, commencing with minimizing the fillet area to keep the stress concentration underneath the limit [12-20], culminating with minimized maximum stress at the shoulders [21-25].

Santos (2013) investigated the determination of the stress concentration factor on flat plates of structural steel. The stress concentration factor of the hole is much lower while the relation of r/d increases [3]. It indicates that the larger diameter of the hole can produce high maximum stress and low-stress concentration. In This paper, to reach the appropriate surface finish and the size of the fillet dimension of The tie rod shaft, the research examined by tool assistant on conventional lathe machine to make fillet contour on the tie rod shaft as the CNC Machine can not cover overall dimension of the shaft

2. Methods

The research commences with analyzing the broken shaft based on design and surface characteristics. In Figure 2, it presented there is several abnormalities in area of broken shaft. There are crack, line pattern, cleavage fracture and fatigue area. Additionally, the surface of the fillet section seem to be rough approximately at N7 or 1.6 µm.

Basically, the uniformity of the manufacturing process can affect the material's fatigue endurance. According to the figure 2, AISI 4140 Steel with an Ultimate Tensile strength of 655 MPa or 95 ksi [6] Has a comparison in the mirror polished, commercially polished, and machined modes. In Figure 4, the surface with the machining process has much lower estimated at 15% of endurance than the surface with polishing surface and at 24% than mirror polished.

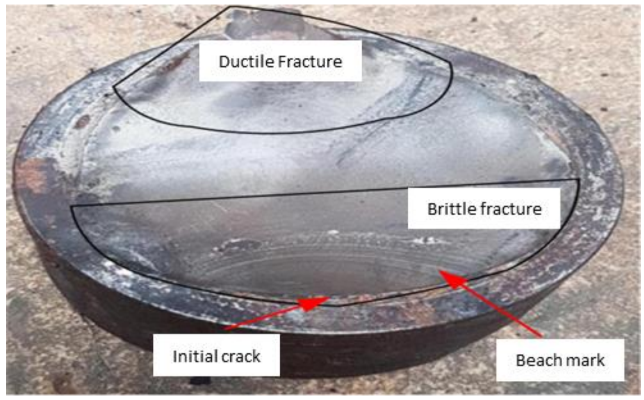

Figure 2. *Abnormality on the broken section.*

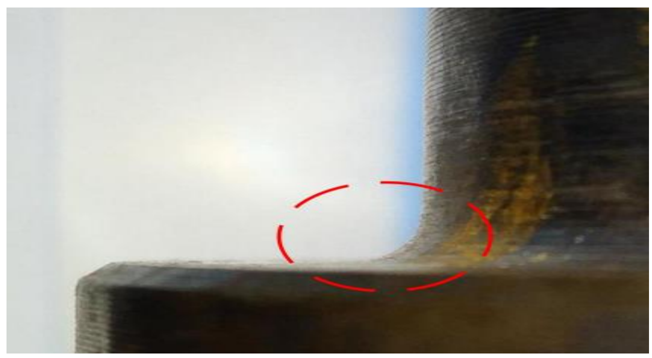

Figure 3. *Abnormality on the fillet contour.*

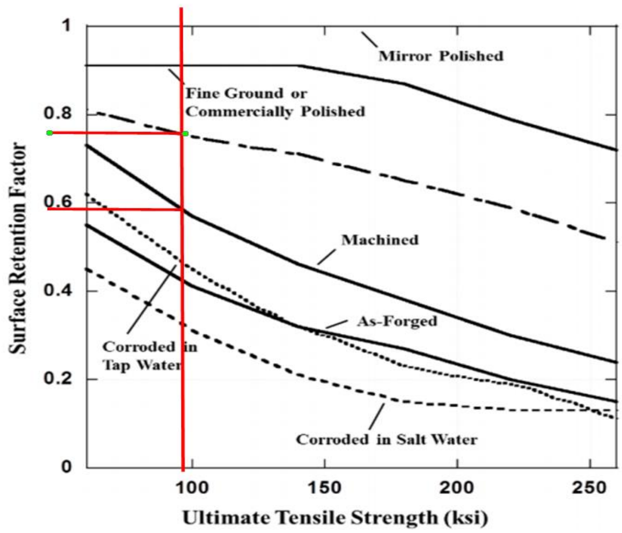

Figure 4. *Surface finish effect on fatigue endurance limit* [5].

The according to the Figure 4, AISI 4140 steel with an ultimate tensile strength of 655 MPa or 95 ksi [6] has a comparison in the mirror polished, commercially polished, and machined modes. the surface with the machining process has much lower estimated at 15% of endurance than the surface with polishing surface and at 24% than mirror polished.

Based on the Figure 5, the polishing surface must contain the Ra Value at 0.1 µm – 0.4 µm

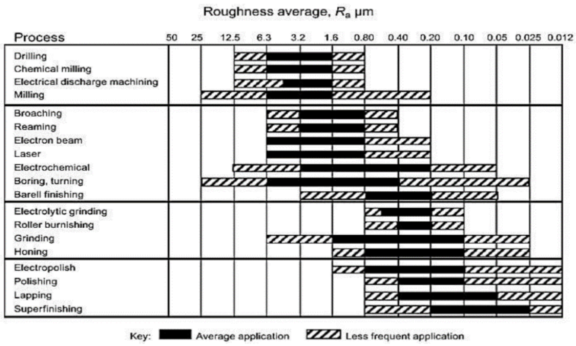

Figure 5. *Typical ranges of surface finish from common machining processes* [7].

On the other hand, one of the aspects of the fatigue of material is the alteration of dimension. The transformation of dimension from material will affect the stress distribution and concentration in a specific area.

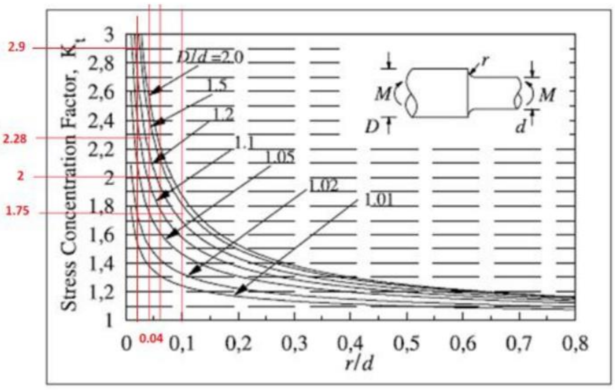

Figure 6. *Stress concentration factor for shoulder fillet in the flat and round bar* [8].

From Figure 6, it witnessed the effect of fillet contour with stress concentration factor (Kt). The value of the stress concentration factor shows a contrast with the radius dimension value. The stress concentration factor is the dividing between maximum stress and stress average. If the result of the stress concentration factor is 1, the maximum stress is equal to the stress average.

$$Kt = \frac{Maximum\ stress}{Stress\ average} \tag{1}$$

According to Figure 7, the increasing maximum stress due to the lifetime of the material that receives the dynamic load will lower. Steel endurance limit (Fatigue Life) is approximately 0.35 – 0.5 ultimate tensile strength, but never higher than 100 ksi.

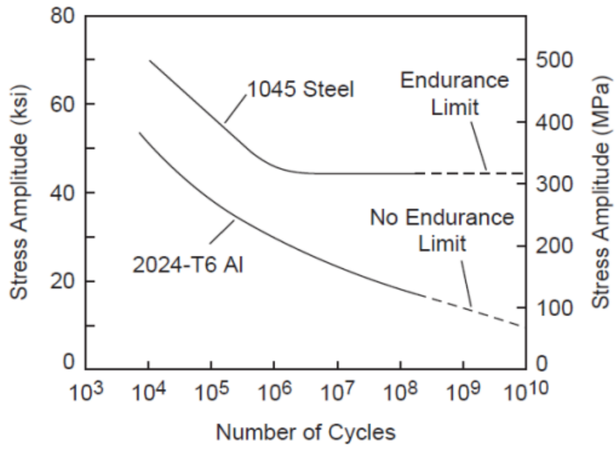

Figure 7. *Comparison of Steel and Aluminum Fatigue Behavior [4].*

In this case, the research attempts to formulate the concentration factor the initial dimension of the tie rod shaft and the prediction of fillet dimension to find the appropriate stress concentration points based on the Figure 6.

Table 1. *Calculation of stress concentration and fillet size on tie rod shaft design.*

Tie rod shaft dimension, d = 75 mm , D = 97 mm				
r	**r/d**	**D/d**	**Kt**	**Description**
1.5mm	0.02mm	1.3mm	2.9	Initial
3mm	0.04mm	1.3mm	2.28	Still High
5mm	0.067mm	1.3mm	2	Plan

Reaching the surface roughness in the fillet section at N5 – N6 roughness level and the dimension of the fillet strictly at 5mm requires the machining process using a CNC Machine. Since the CNC machine in the X workshop is inappropriate with tie rod overall dimension, the alternative uses the conventional lathe machine process. The machining process of the fillet section in the tie rod shaft is impossible to do using the handle of a conventional lathe machine or sharpening the cutting tool in line with the fillet contour demands, as the final result is rough and unprecise. The approach uses the methods to add the tool assistant in the conventional lathe machine to make fillet contour with a precise and polished surface.

The research started with the design of a tool assistant using Autodesk Inventor software. Continuously, the design is manufactured by several conventional machines, e.g., horizontal boring machines, hobbing machines, lathe machines, and milling machines. The manufacturing parts are assembled by bolting and installed on a conventional lathe machine. The tool assistant has a function to control the rotational axis when the machine manufacturing shaft is on the fillet section. With the handle of a tool assistant, the rotational movement can be smoother as a gearing system handles the movement of the tool assistant.

In addition, the experiment process conducted with three steps as the mock-up test before applying on the tie rod shaft manufacturing. First, use the wood as a raw material; second, use the steel to make the outside fillet contour; third, use the steel for inside fillet contour manufacturing before applying it to the manufacturing process of tie rod shaft. To ensure the quality of the fillet section, the author utilizes the finishing surface cutting tool of CNC.

Fillet gauge to ensure the fillet section is appropriate with fillet contour demand (5mm). The result shows that the fillet section measurement is exactly 5mm in the inside fillet contour.

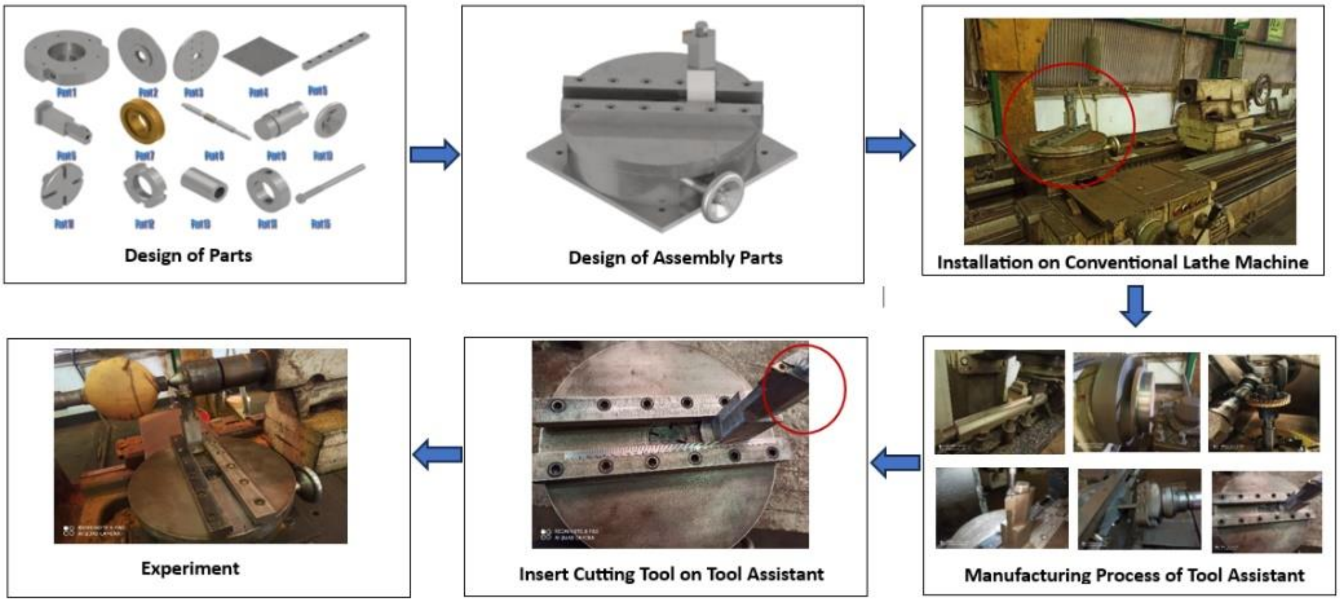

Figure 8. *The steps of tool assistant manufacturing.*

Table 2. *The Steps of Experiment*

Experiment	Process	Result
The wood Outside Fillet		
Steel Outside Fillet		
AISI 4140 Inside Fillet		

3. Result and Discussions

The experiment data examined the fillet section's quality in the tie rod manufacturing. The Figure 8 shows the point of the fillet section after machining by the tool assistant.

In order to ensure the measurement and surface quality of the tie rod shaft, the author analyzing the data use the in order to ensure the measurement and surface quality of the tie rod shaft, the author analyzes the data using qualitative and quantitative.

The qualitative methods were prioritized to ensure the measuring of fillets in the tie rod shaft. This method uses the

Figure 8. *The positions of fillet in the tie rod shaft.*

Figure 9. *The measurement using fillet gauge.*

The quantitative methods were used to ensure the surface quality of the Radius Section on the tie rod shaft. The test was conducted at the laboratory using the specimen of AISI 4140 in the fillet section, which the tool assistant manufactured. Mitutoyo surf test 3, based on the ISO 1302:1992 fundamental, examined the fillet section's surface roughness. The result from the testing indicates the averages of roughness level in the fillet section touch at 0.33 µm. According to the roughness Category Table, The roughness level is 0.33 µm, similar to the N5 surface grade. It was proved that the fillet contour manufactured by the tool assistant with insert surface cutting tool has a resemblance result with the process of polishing, which has a requirement grade of 0.1 µm – 0.4 µm .

Figure 10. *The surface roughness measurement.*

Table 3. *The result of roughness test on fillet section.*

No.	Rougness Measurement			Length. Meas.		Instr. Range		Gr
1	Max	0.4	µm	5	mm	0-3	mm	N4
2	Max	0.3	µm	5	mm	0-3	mm	N3
3	Max	0.3	µm	5	mm	0-3	mm	N3
	Average 0.33		µm					

The after the analysis, the author conducts the surveillance in the field installation. The installation using the tie rod shaft manufactured by the tool assistant was carried out between 2020 and 2022 when there was trouble in the coal mill area. The timeline table presented that the tie rod shaft manufactured by the tool assistant can extend the average lifetime by more than 12 months. The quality of the fillet section, foremost in the surface characteristic and dimension of the fillet, can reduce the stress concentration while receiving the cyclic load in the field.

Table 4. *Observation of tie rod shaft on the field.*

Time of Installation	Observation	Lifetime
Upper tie rod roller A1 (Broken)(24/07/20) 24/07/20 : Stop normal, corrective actions: - Change The Shaft with the improvement shaft - Repack Tie rod A1	There is no occurrence until 2021	17 months
Leaking from bushing tie-rod B2 CM 1B 26/06/20 : Stop Coal Mill 1B, The leaking on tie rod B2 .Corrective actions in coal Mill 1B : - Change Upper Tie rod B2 with improvement shaft - Repairing Guide plate/ guide block stress B2 dan B3 (CM2A)	(16/08/21) : Change The upper tie rod roller B2 with the improvement shaft (CM 1B)	14 Months
Middle tie rod roller A2 was broken : (28/07/20) Stop normal → Change with improvement shaft	There is no occurrence until 2022	26 months
Shut down in coal mill 2B, The lower tie rod roller B2 was broken (04/05/20) 04/05/20 : Change The Middle tie rod roller B2 with the improvement shaft	There is no occurrence until 2022	26 months

4. Conclusion

After the surface roughness of the material, stress concentration, and maximum stress correlate with the material's fatigue life. The surface roughness by the machining process engaged with the quality endurance of the material. It was observed that with the lower grade of Ra, the ratio of comprehensive strength increased. The stress concentration in the tie rod shaft fillet section decreases when the radius dimension and r/d increase. However, to reach a lower surface finish grade and ensure the dimensional quality of the radius section, it is only sometimes machined by a CNC machine. However, it can be solved with a conventional lathe machine, as CNC machines occasionally have specific limits for the workpiece's overall dimension. The tool assistant is designed to accommodate the precise and smooth fillet contour manufacturing with an insert cutting tool as the support. The tool assistant is installed on the conventional machine to eliminate the inappropriate movement produced by the human hand while machining in the fillet section. After the tie rod shaft was manufactured by the tool assistant of the conventional lathe machine, it was witnessed that the surface roughness in the fillet section could reach 0.33 µm and a precise dimension of 5mm. The observation has been done in the field to prove to what extent the effect of fillet quality on tie rod shaft lifetime. The surveillance also proves that after the improvement of the tie rod shaft installed on the plant, there is an extended lifetime beyond the target until more than 12 months in the specific period.

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