CATASTROPHIC FAILURE INVESTIGATION OF THE OIL FILTER MACHINE BOLTS

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ABSTRACT: An assessment of the fractured bolt of a cooking oil filter machine was performed. The objective of this assessment is to reveal the root cause of the failure. A series of necessary attempts were carried out for this analysis, i.e., site visit, fracture surface examination of the fractured bolt, collecting the maintenance and operation data, mechanical properties testing, chemical composition testing, and stress analysis. The fracture surface examination showed a catastrophic failure, especially at a repaired bolt. Meanwhile, according to the site visit investigation, some evident data indicated a sudden high-pressure load subjected to the filter machine. Most fractured filter bolts were repaired by welding. The design review shows that the critical operating pressure is around 14.5 bar, which is far above the reported operating pressure during the accident, which is 6 bar. This indicated that the strength of the genuine bolt is sufficient to ensure the operating pressure of the filter machine, which is normally 1 to 3.5 bar. Finally, it can be concluded that the root cause of the failure of the filter machine bolt is decreasing strength of the bolts because of improper repairment indicated by the welding process and assisted by sudden high load due to increasing pressure inside the filter vessel.

KEY WORDS: Catastrophic, Failure, Oil Filter Machine Bolts.

1. INTRODUCTION

The cooking oil filter, as shown in Fig. 1, is located inside the production room of the cooking oil company [1]. The main function of an oil filter machine is to filter palm oil during production. During operation, the vessel of the palm oil filter suffers fluctuating load, normally around 1 to 3.5 bars. The cylindrical vessel filter's internal diameter is 1370 mm, and it is mounted with a dome cover tightened by 15 fastening bolts. The leaf filter machine is connected to the piping system to support and control its operation. The damage periodically occurred in the middle of the bar of the fastening bolts; however, in most cases, to reduce costs and time for procurement and replacement, the repair was carried out using welding technology repair at the bolt rod shown in Fig. 1.

As shown in Fig. 1, a cooking oil filter bolt was reported failure during operation, as shown in Fig. 2. The fastening bolts were fractured simultaneously, which can affect serious accidents and interrupt the production process, mainly in this related line production [1]. Therefore, it is very necessary to perform a failure analysis. The main objective is to get the root cause of the failure of the fastening bolt. Some necessary attempts were performed: fracture surface examination, hardness testing, chemical composition testing, site visit examination, maintenance and operation data collection, and design review to conduct failure analysis. Several reference books on failure analysis of machine components have been used as basic references to carry out the analysis [2-4]. Some research works concerning connecting bolt failure which is proposed to investigate the main cause of failure have been studied comprehensively [5-8]. Other studies of the failure analysis of bolt aimed to investigate the failure mechanics and fracture mode have been conducted [9-11].

Fig. 1. Oil filter vessel indicating the numerous repaired bolts by welding process.

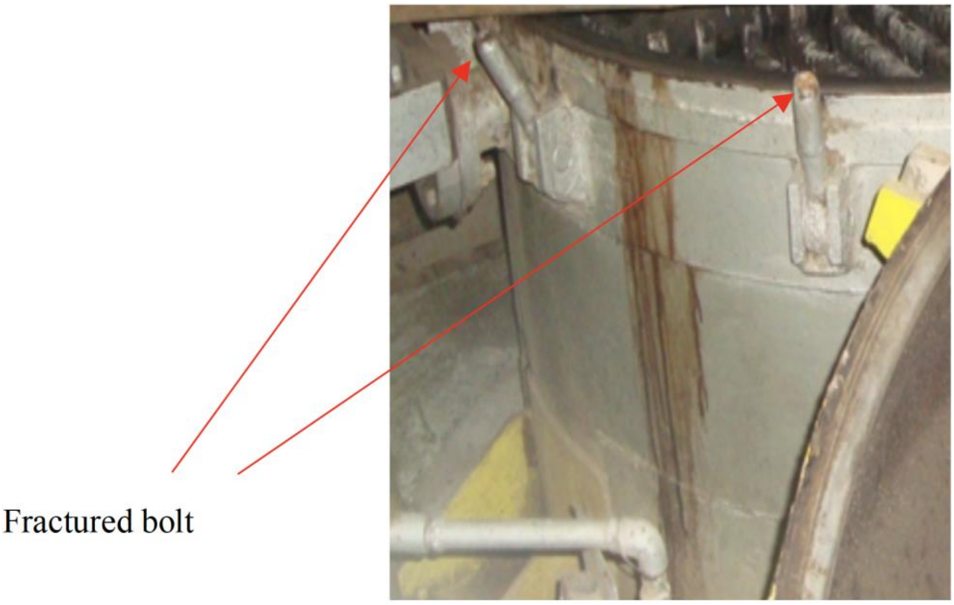

Fig. 2. Oil Filter showing the fractured bolts.

2. METHODOLOGY

2.1. Fracture Surface Examination

Fig. 3 to 5 show that visual fracture surface examinations were performed. Based on the observation of those Fig.s, it can be described that bolts failed mainly by ductile fracture. High tension force has occurred on the bolt and generated high tension stress significantly, as shown in Fig. 3, shown by the occurrence of necking. Visually fracture surface examination shows the catastrophic failure of those bolts subjected to sudden high load. All bolts were fractured around welded area, indicating the area is a very critical area. Macroscopically fracture surface examination of several views for a number of fractured parts, as shown in Fig. 4 and 5, also indicated that the fracture surface around welded area was a crumpled surface, indicating that the failure was not fatigue failure. However, it is exhibited that the failure was a catastrophic failure due to a high sudden peak load.

Fig. 3. Fractured bolt showing that ductile fracture was occurred.

Fig. 4. Visual view of the fracture surface of bolts showing that catastrophic fracture occurred around welded area.

Ductile Fracture (DF) dominantly controlled the bolt's welded joint strength, shown as the fracture surface's inner area. However, brittle fracture (BF) occurs circumferentially shown on the fracture surface.

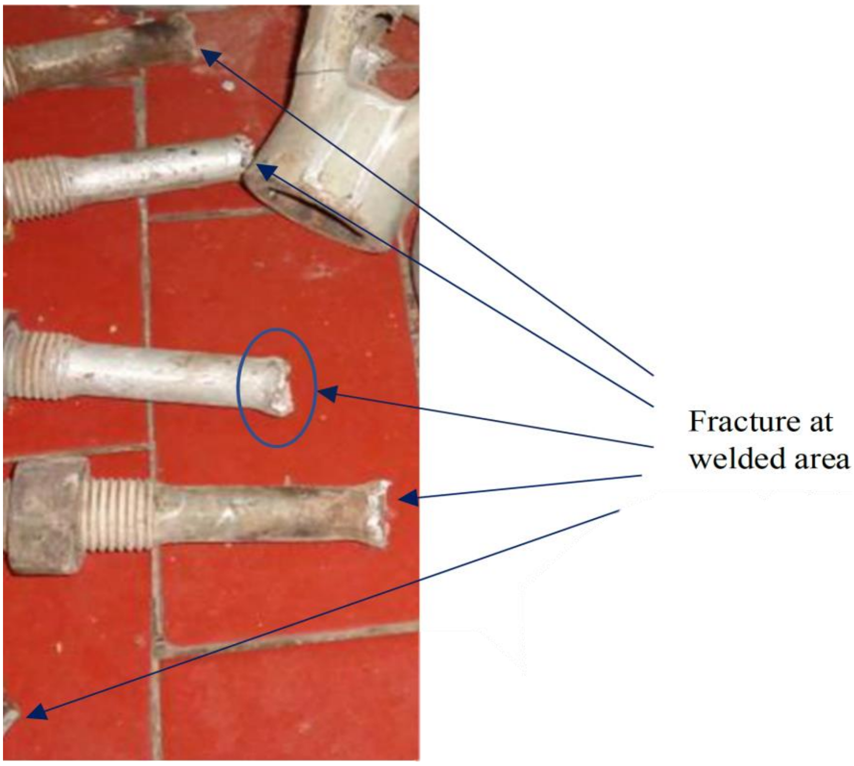

Fig. 5. Most fractured bolts, indicating catastrophic failure occurred at the welded area in the bolt bar's middle.

2.2. Fracture Surface Examination

Hardness testing according to the ASTM E18 was conducted at the surface of the sliced bolt material, as shown in Fig. 6a and 6b. The hardness value of bolt material is necessary to predict its yield strength. The result can be summarized in Table 1. This estimated yield strength data is essential as input data during stress analysis of the bolt numerically.

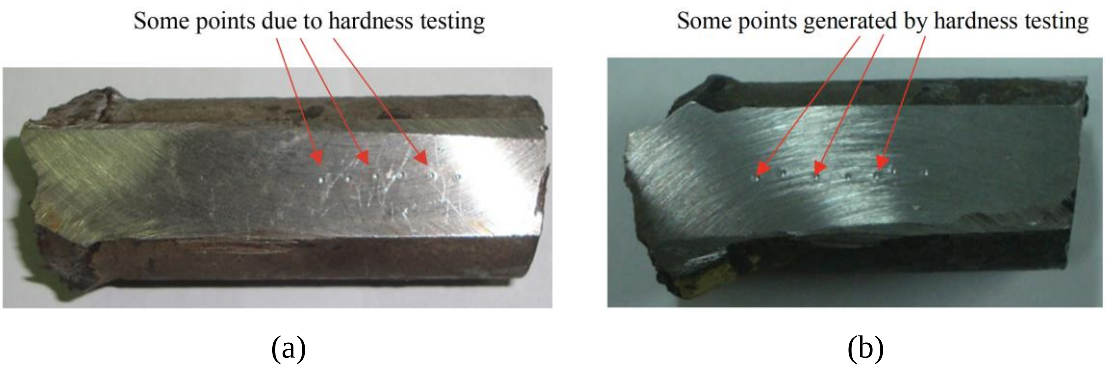

Fig. 6. (a) Hardness testing performed for some points at bolt material of specimen 1, (b) Hardness testing carried out for some points at specimen 2.

Table 1: Hardness testing result of some fractured bolts

No	Hardness (Rockwell)	Hardness (BHN)	Estimated Yield Strength (ksi)
1	100	241	118 ksi (831.45 MPa)

Relationships between hardness and tensile strength for steel, brass, and cast iron, see Fig. 7. Simple formulas can also express as Tensile strength (MPa) = 3.45 x HB, or Tensile strength (psi) = 500 x HB.

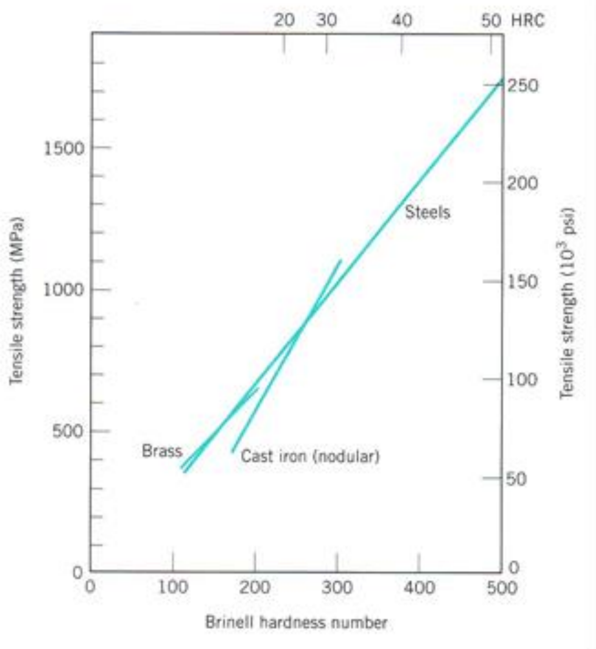

Fig. 7. Hardness and tensile strength for steel, brass, and cast iron *[12]*.

Chemical composition testing was performed for several fractured fasten bolt rods using an XRF analyzer of Oxford. The testing was focused on the based materials area, not welded area since it was only to clarify the genuine materials of the bolt. Knowing the bolt rod's genuine material will give more confidence when estimating its mechanical properties by comparing it with some references. According to the chemical composition test, it can be confirmed that the bolt material is Carbon steel: 1.25Cr – 0.5Mo. The detailed chemical composition can be seen in Table 2.

Table 2: Chemical composition of fastening bolt materials

Element	Fe	Cr	Mo	Mn	V	Zn	Ni	Cu
%	97.03	1.17	0.71	0.57	0.32	0.14	0.03	0.03
+/-	0.121	0.014	0.005	0.022	0.010	0.006	0.007	0.005

2.3. Stress Analysis

The design review aims to predict critical design operation and evaluate the strength of genuine or unrepaired bolts since the fracture commonly occurs in the middle of the bolt rod, which is supposed to be far from the stress concentration area. Stress simulation focused on fastening the bolt to conduct a design review. The detailed stress simulation process has been described comprehensively [13], indicating the modeling in Fig. 8, mesh generation in Fig. 9, and stress distribution in Fig. 10. The main dimensions of the filter machine model, which are the filter vessel's inner diameter and the dome cover's thickness, were determined based on measurements during the site visit—the bolt's dimension was obtained directly from prudent measurements. As mentioned previously, the bolt material is Carbon steel: 1.25Cr – 0.5Mo, and the tensile strength value can be generated based on a conversion from hardness test results. During the simulation was assumed that all filter machine materials had isotropic and homogeneous material. The mechanical behavior of the material during simulation is considered linear elastic materials.

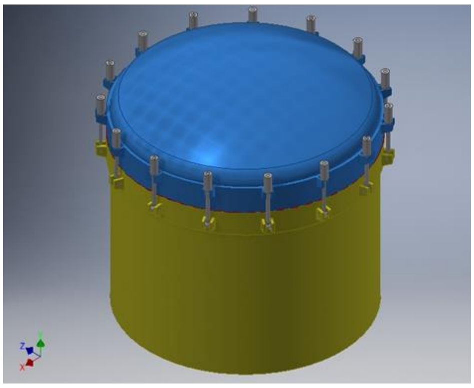

Fig. 8. Modelling of filter vessel structure.

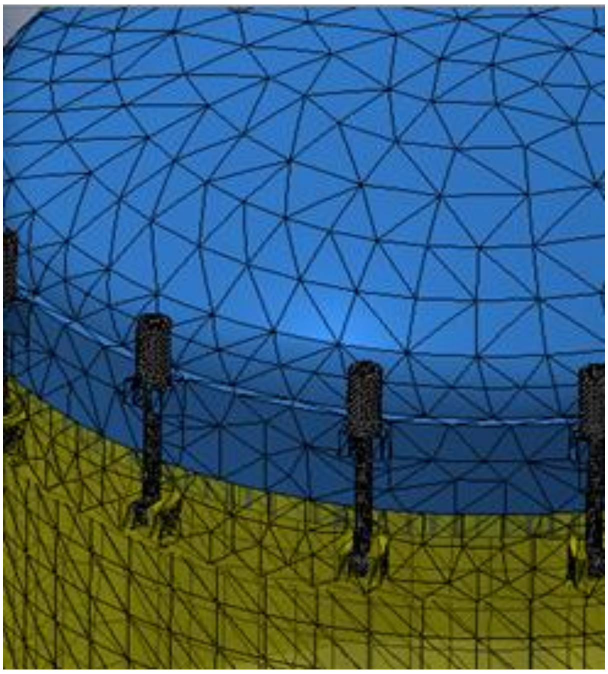

Fig. 9. Mesh generation of the filter vessel structure.

During simulation, the load was modeled as the internal pressure of the vessel, which is about 6 bar as static maximum pressure. The mass of the dome cover and the initial preload acting on the bolts are also considered during the simulation. There are two methods to determine initial tensile loads that are based on bold diameter and the percentage of yield strength of bolt material. A comprehensive study of the externally bolted joints was conducted analytically, computationally, and experimentally [14]. Contacts between components have also been adjusted. The mesh has an average element size parameter of 0.1, a minimum element of 0.2, and a maximum turn angle of 30 degrees. For the stress simulation results, see Fig. 11 and Table 3.

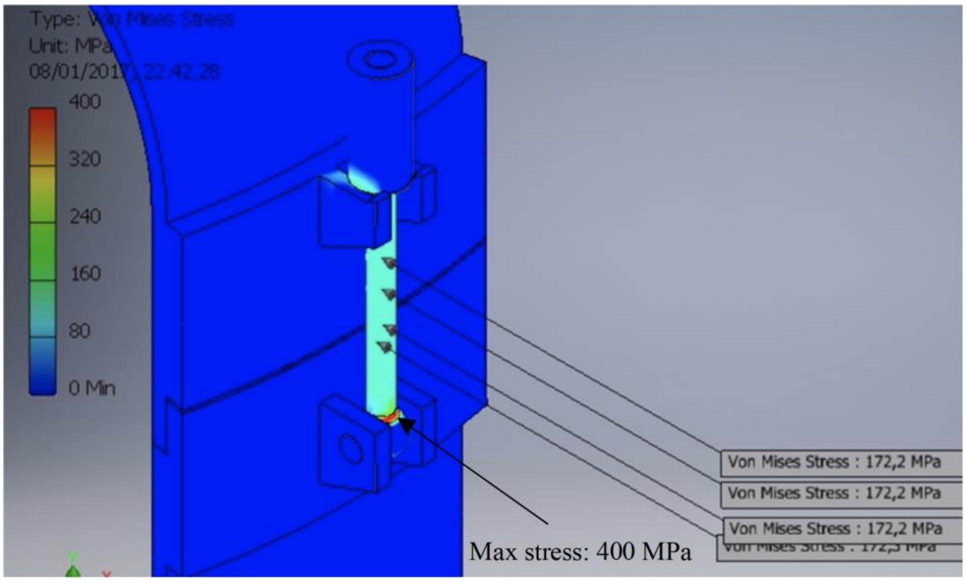

Fig. 10. Stress distributions focused on bolt bar.

As shown in Fig. 10, the maximum Von Mises Stresses is about 400 MPa, located at a radius near the bolt head. However, those maximum Vos Mises stresses do not correlate with the failure of the bolt since all bolts are fractured at the middle of the bolt shank, which is far from the maximum stress location. Meanwhile, Von Mises stresses along bolt rods are commonly around 172.2 MPa. Therefore, it could be considered that the stresses of 172.2 MPa occurred in the middle of the bolt rod, directly controlling the bolt load in normal operation.

The simulation results indicated that the internal pressure acting inside the filter vessel, which is a maximum of 6 bar, does not give excessive stress to the bolts. Therefore, it can be concluded that theoretically, the unrepaired bolts should still be in a safe condition at the time of the failure.

Table 3: Von Mises stresses at bolt rod

Load condition and location	**Stress on bolt (MPa)**
without pretension	169
Pretension 10% yield strength	168
Pretension 2840* bolt diameter	172,2
Maximum stress at bolt head fillet	400

2.4. Operation and Maintenance Evident Data

According to existing operation and maintenance data and chronological accident reports, it can be summarized as follows:

1. The operation data list of the filter machine shows that mostly the technical operation data are still within their specification range. This condition indicated leaf filter machine was under proper operation.
2. The chronological accident report mentioned that a steam supply pressure of around 6 Bar indicated overpressure since the range of steam pressure is around 1 to 3.5 Bar.
3. The maintenance record of the filter machine is deficient; however, its existing condition could be seen evidently during the site visit examination.

3. FAILURE MECHANISM

The catastrophic failure mechanism was constructed based on several assumptions, i.e., All bolts are tightened by the same torsion, internal pressure distribution of the filter vessel is the same.

After considering all evident data, operation, maintenance, and chronological accident report, fracture surface examination, laboratory testing, and stress analysis, the catastrophic failure mechanism was constructed as follows: suddenly high peak load, failure of one or several bolts having weakest strengths, which are predicted at welded bolt shank, then finally followed by fracture of other bolts catastrophically.

4. DISCUSSION

Results of chemical composition testing of fractured bolts taken at the point of genuine bolt rod material indicated that the chemical composition and mechanical properties correspond to the quality of Carbon steel: 1.25Cr – 0.5Mo. The visual appearance of the fracture surface, as shown in Fig. 3, Fig. 4, and Fig. 5, indicates the fracture was caused by catastrophic failure. Still, it is not fatigue failure in which the common characteristic signs of fracture surface were shown [5]. The repair of bolts by the welding process can generate numerous problems like inhomogeneity of materials, various damage modes or defects, stress concentration, residual stresses, and so on, which may occur during the welding process or services at weld joint materials. Those can decrease materials' strength, especially in weld materials and their closed surrounding like transition zone. Therefore, it should be performed and analyzed properly and maintained properly. As with other references, a repairment on machine components by welding process has already affected the failure[15], and a weld joint of straight and elbow pipe has affected a failure due to stress corrosion cracking [16].

The design review for genuine or unrepaired bolts indicated that the bolt is very strong. Its critical operating pressure is around 14.5 bar, far from the normal operating pressure of 1 to 3.5 bar, and its operating pressure during the accident is around 6.0 bar. Indeed, it is difficult to accurately evaluate the strength of repaired bolt since the properties of materials, especially at the weldment area, are inhomogeneous materials. It is also supposed to be various damages and stresses condition due to the welding process.

5. CONCLUSION

After considering all information and data collected during the investigation and analyzing it comprehensively, it can be concluded that the main cause of failure for the filter bolt is decreasing strength caused by improper repairment indicating welding repairment subjected to some of the bolts. It was also assisted by the sudden high load generated by the blocked pipe. Therefore, it is recommended that bolts under high loads are not repaired, especially by the welding process but should be replaced with new ones. Meanwhile, the piping system should be assured to work very properly and safely without any trouble.

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