The Role of Failure Analysis on Maintaining Reliability of Oil Refinery for Sustainable Development Goals

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Abstract. Reliability of oil refinery unit in energy industry is very important to enhance sustainable development goals in Indonesia. When an important component on a system fails, the whole system will be shut down. As a result, potential lack of energy supply will be high and give a huge impact to sustainable development goals. Therefore failure analysis should be done immediately to make the system working again. The purpose of this research is to find out the main cause of failure on shroud plate of orifice chamber on refinery unit in order to avoid similar problem in the future. Root cause analysis method is used to investigate the main cause of failure with performing several tests and examinations on the specimens. The specimen is taken from failed shroud plate made of SS 304H around failure area. Testing and examinations result shows that shroud plate of orifice chamber has a crack on both circumferential weld and horizontal weld. Further examination also shows some evidence of inter granular corrosion attack or sensitization and formation of chrome carbides. Another testing result also found some degradation of mechanical properties of the specimens. It is concluded that the main cause of failure of shroud plate of orifice chamber is a combination of overheating that promote sensitization and degradation of mechanical properties. By observing the main cause of failure on shroud plate of orifice chamber, quick repair or replacement can be done correctly and reliability of oil refinery can be maintained to support sustainable development goals.

1. Introduction

Oil refinery is one of the vital industries that produce fuel energy to supply daily need of fuel in Indonesia. Therefore, production process should not be interrupted to guarantee its continuous supply to the consumer. Considering with its important role, the reliability of oil refinery should be taken into account to keep the system always working as designated. If one of the components fails, the whole system will be shut down, and when this problem takes a long time, oil distributions can be affected as a result energy crisis may be occurred. Therefore, immediate repair or replacement should be done to make energy supply is kept on running. However quick and improper repair or replacement due to less information of the main cause of failure may even get worse, another fail can happen again in a short period operation [1,2]. So that, detail and correct failure analysis should be done to prevent similar failure happens again in the future.

In this research, examination is conducted to find the root cause of failure on the components of oil refinery in Indonesia which occurred during operation. The component name is shroud plate of orifice chamber. An orifice chamber is a vertical or horizontal chamber containing a series of perforated
plates, designed to maintain a reasonable pressure drop across the control valve. The chamber and the plates are generally metallic. The orifice chamber and the control valve thus ensure the control of the internal pressure of the regenerator. Shroud plate is a part of the orifice chamber which has a function as an internal wall of the chamber [3,4], so that failure of this component will make this chamber unable to be operated. Shroud plate in this research has also a function as a holder of grid plates made of perforated thin stainless steel. It was found that shroud plate crack circularly around welded area, as a result hot gas with 750 °C temperature flown out of orifice chamber wall.

The aim of this research is to find the root cause of failure on shroud plate in order to prevent similar problem in the future and immediate action to repair in a good way can be done, so that oil supply can be distributed continuously to maintain sustainable development goals in Indonesia.

2. Material and method

The specimens for examinations on this research are taken out from fail shroud plate obtained from an oil refinery in Indonesia. The position of the plate is on the wall of orifice chamber welded to perforated plate as is presented in figure 1. The fail shroud plate is cut out about 700 mm X 500 mm, starting from circumferential crack and the vertical crack position is set on the middle as presented on figure 2. The specimen was then sent to laboratory for further examinations and tests.

![Figure 1. Drawing of orifice chamber (a) and position of fail shroud plate (b)-(doted ellipse).](image)

![Figure 2. Cut out of fail shroud plate for specimens on outside view (left) and inside view (right).](image)
2.1. Material

Detail of material specification, all of technical data and operational parameters of shroud plate which is taken for specimen are listed in Table 1.

| Type of chamber | Cylindrical |
|-----------------|-------------|
| Inside diameter (ID) | 3800 mm |
| Outside diameter (OD) | 3832 mm |
| Operational temperature | 750°C |
| Operational pressure | 0.02 MPa/grid |
| Material | SS 304H (UNS S30400H) |
| Tensile strength | 515 MPa |
| Yield strength | 205 MPa |
| Allowable stress | 138 MPa (room temperature) |
| Allowable stress at high temperature | 17.2 MPa (at 750°C) |

From this table, it can be seen that the orifice chamber is operated at high temperature (750°C) however, the inside wall is covered by refractory to protect shroud plate from direct exposed to high temperature therefore, actual temperature on shroud plate must be lower than 750°C.

2.2. Method

Method that used in this research is implementing root cause analysis where all of possible aspects that may have contribution for failure are examined [1,5]. Some main sources of failure usually come from wrong design, manufacturing defect, improper operational parameters and wrong material specification. When the evidence of most dominant factor is found deeper examination is conducted to find other valuable scientific result. To execute this method many tests and examinations are performed including [6]:

- Visual Examination
- Macrographic Examination
- Metallographic Examination
- Chemical Composition Identification
- Hardness Testing
- Scanning Electron Microscope (SEM) and Energy dispersive X-ray analysis (EDX)
- Tensile Testing

2.2.1. Visual Examination. Visual examination is conducted to observe failure mode and to identify the initial crack which then selected to be a specimen for deeper examination. This method is performed by examining the texture and contour of surface failure accurately, and then it is documented by digital camera.

2.2.2. Macrographic Examination. Macrographic examination is performed to observe initial crack on surface failure of plate investigated using stereo optical macroscope, so that the subject can be examined at higher magnification to obtain more clear information.

2.2.3. Metallographic Examination. Metallographic examination is done to investigate more detail on initial failure and surrounding area related to microstructure and its evolution during orifice chamber operation, and also to observe the possibility of micro void, inclusion or other micro structure changes that may exist and affects to the cause of failure.
2.2.4. Chemical Composition Test. Chemical composition test is done to examine elements content using spark spectrometer on base material of shroud plate and then compare it with its material standard specification for SS 304H.

2.2.5. Hardness Testing. Hardness tests are conducted to confirm the material with the specified classification and to evaluate the possibility of hardness value change which may affect to the cause of failure.

2.2.6. Scanning Electron Microscopy (SEM) and Energy dispersive X-ray analysis (EDX). SEM is done for deeper observation on specimen especially at initial crack, because SEM is able to explore on higher magnification than optical microscope so that valuable information can be obtained. While EDX analysis is done to identify the elements present on the failure area which may has contribution to the formation of initial failure.

2.2.7. Tensile testing. Tensile testing of shroud plate is done to evaluate the current tensile strength and to compare it with standard specification for SS304H, and also to analyse the possible effect of its strength to the formation of initial crack.

3. Result and Discussion
After conducting many tests and examinations several data were found and this scientific information gives accurate evidence for analysis of root cause on shroud failure.

3.1. Visual and macrographic examination
The result of visual and macrographic examination indicates that shroud plate of orifice chamber cracked at weld area. It can be seen from figure 2 and figure 3 that the crack was initiated from circumferential weld area and propagated to vertical weld direction. Circumferential weld is connection between shroud plate and perforated plate, while vertical weld is connection between the plates on the orifice wall [3]. Fracture surface of circumferential weld can be seen in figure 4.

![Figure 3](image_url)

**Figure 3.** Vertical crack of shroud plate occurred on weld metal. View from outside (a), view from inside (b), crack tip from outside (c) and crack tip from inside (d).
Figure 4. Fracture surface of crack on circumferential weld.

The contour of fracture surface as seen on figure 4 indicates that the crack on the circumferential weld started to initiate from inside of shroud plate then propagated into outside diameter and circumferentially along the weld. With the existing operational parameters the crack then propagated onto vertical direction as shown on figure 3.

3.2. Metallographic Examination Result.
Metallographic examinations were done both on welded areas around the crack and on base metal of shroud plate. The result conforms that the crack is propagated along the weld metal (figure 5.a). Examination result also shows that micro structure on weld metal is attacked by inter granular corrosion which normally called sensitization [7] (figure 5.b). Sensitization is not only occurred on weld metal, but also found on base metal around the crack (figure 5.c). Higher magnification of micro structure on base metal confirms the presence of sensitization on grain boundaries (figure 5.d).

Figure 5. Crack on weld metal revealed after metallographic examination (a), micro structure on weld metal shows inter granular corrosion (b), inter granular corrosion also seen on base metal (c) and confirmed on higher magnification of figure (d). Micro structure of base metal is austenitic.
3.3. Chemical Composition Test Result.
Specimen for chemical analysis is taken from shroud plate base metal. Result of chemical test can be seen in table 2. From this table indicated that shroud plate composition is in accordance with SS 304H specification [8]. No suspicious element is found which has contribution to the initial of fracture.

| Elements | Value in weight % | Base metal | SS304H Specification |
|----------|-------------------|------------|-----------------------|
| C        | 0.043             | 0.04-0.1   |
| Si       | 0.362             | Max.1.00   |
| Mn       | 1.620             | Max.2.00   |
| P        | 0.045             | Max.0.045  |
| S        | 0.006             | Max.0.030  |
| Cr       | 18.700            | 18.00-20.00|
| Ni       | 9.090             | 8-10.50    |
| Fe       | Rem               | Rem        |

3.4. Hardness and Tensile Test Result.
Hardness test has been done to either base metal, weld metal and on heat affected zone (HAZ) area. The result of testing indicated that the average hardness on base metal is 155 HV, average hardness on HAZ is 165 HV and hardness on weld metal is around 195 HV. Meanwhile, the hardness specification of base material is 199 HV [8,9], from this result shows that hardness of base metal has already been decreased significantly. Decreasing of hardness is an indication that material of shroud plate has been exposed to high temperature for long time.

Tensile test of shroud plate was done for base metal, and the result is 458 MPa for ultimate tensile strength, 221 MPa for yield strength and 8% for elongation. However, specification of ultimate tensile strength of SS 304H is 515 MPa, yield strength is 205 MPa and elongation is 40 % [8]. From this result it can be seen that the tensile strength of failed shroud plate also decreased, on the contrary yield strength increased but elongation is significantly lower than specification. This phenomenon indicates that base material of fail shroud plate has changed from ductile to brittle [10].

3.5. SEM and EDX examinations result.
Deeper examination on micro structure using SEM and EDX were done to investigate the presence of black dot on metallographic result which identified as intergranular corrosion or sensitization. Result of SEM confirm that sensitization as can be seen in figure 6, while EDX spectrum and chemical test can be seen in figure 7 and table 3.

![Figure 6](image1.png)  
**Figure 6.** SEM result on sensitization area.  

![Figure 7](image2.png)  
**Figure 7.** Spectrum of chemical test by EDX at black dot on sensitization area of shroud plate base metal.
Table 3. Chemical testing by EDX on black dot.

| Element Symbol | Element Name | Weight Conc. |
|----------------|--------------|--------------|
| Fe             | Iron         | 49.97        |
| Cr             | Chromium     | 32.61        |
| O              | Oxygen       | 6.66         |
| C              | Carbon       | 3.04         |
| Ni             | Nickel       | 3.75         |
| P              | Phosphorus   | 0.85         |
| Si             | Silicon      | 0.73         |
| Mo             | Molybdenum   | 2.40         |

Spot chemical test by EDX was conducted on that black dot and the result indicates that the black dot has composition of Cr and C higher than normal SS 304H (see table 3). Cr content of this dot is 32.61% and C content is 3.04%, this evidence indicate that the black dots are Cr carbides. When Cr in the matrix form carbides in the grain boundary, therefore Cr content is reduced consequently corrosion resistance in this area decreases, as a result intergranular corrosion occur, this phenomenon usually called sensitization [7]. From figure 6 it can be seen that voids and cracks are exist on most of the grain boundaries, these are tracks of inter granular corrosion which attack grain boundaries during operation at high temperature.

3.6. Discussion.
From chemical test result indicated that failed shroud plate is in accordance with SS 304 H specification therefore, failure of this shroud plate is not caused by wrong material selection. There is no evidence of design error or manufacturing defect, so that those two factors are not the root cause of failure. Based on the valid information from the owner of refinery unit, it was found that refractory which cover shroud plate of orifice chamber was broken for a few month, no immediate action was done to repair it.

Figure 8. Schematic figures of shroud plate protected by good refractory (a) and direct heat transfer to shroud plate on broken refractory (b).

In a normal condition, shroud plate is protected by refractory against heat and corrosive agent, so that most of the heat is absorbed by refractory and corrosive agent has not contacted to shroud plate however, if the refractory broken the shroud plate is not effectively protected. Therefore shroud plate had been exposed to high temperature through the broken refractory for a long time (figure 8). It can be seen from tensile test and hardness test result that shroud plate investigated has lower tensile strength and hardness value compared to its specification, this mechanical properties change is caused by exposure on high temperature for a period of time [11]. Meanwhile, from table 1 it can be seen also that the orifice chamber is operated at high temperature (750°C), but allowable stress of SS304H
at operational temperature is much lower than that at room temperature, so that with existing load and pressure at high temperature the shroud plate is easier to failure. In fact, stainless steel SS304H is prone to sensitization at high temperature [7] because Cr element which has a function to increase corrosion resistance is easy to react with carbon (C) at high temperature to form Chrome carbide, as a result its corrosion resistance is reduced, consequently sensitization process may occurred. In this research it is found some evidence of sensitization as presented in figure 5 and figure 6, moreover another result of chrome carbide formation is also detected by EDX as presented in figure 7 and table 3, so that the occurrence of sensitization is scientifically proven. It is found that the percentage of sensitization on weld metal is higher than that in base metal (figure 5.b) therefore, the possibility of crack occur in weld metal is higher than in base metal. Moreover, local heating during welding process can generate residual stress which is higher than base metal [11]. The presence of high residual stress can promote crack and corrosion to occur, that is why crack was developed at weld area on shroud plate.

4. Conclusion
From examination and testing result and from further analysis, it can be concluded that the root cause of shroud plate failure is initiated by the broken of refractory which lead to heat and corrosive agent inside orifice chamber penetrated into the shroud plate. Afterward the shroud plate was directly exposed to high temperature and directly contact with corrosive media. Because shroud plate is made of SS 304H which is prone to corrosion at high temperature so that sensitization occurred. As sensitization was formed the material become weak especially at weld metal which has high residual stress, consequently the shroud plate is easy to crack with existing operational condition [1]. Initial crack was formed at circumferential weld because this area supported load from perforated plate and might contain higher volume of corrosive agent. As crack was formed it would propagates circumferentially and vertically through vertical weld. By knowing the exact root cause of failure on shroud plate of orifice chamber, the management of oil refinery unit can make immediate decision to repair or to replace the component to keep the system reliable so that energy supply can be maintained and sustainable development goals can be achieved.

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