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Investigation and failure analysis of a diesel generator connecting rod

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This article contributes to:
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
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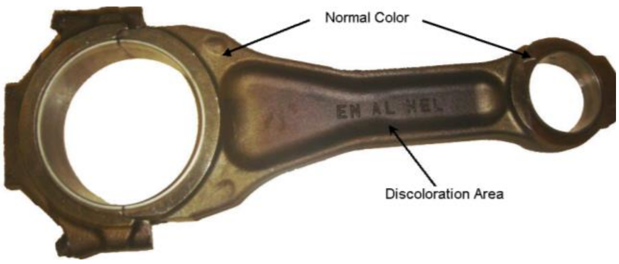

Highlights:

- Failure analysis on a connecting rod of a diesel engine generator set were reported.
- Visual inspection and laboratory tests were carried out for comprehensive analysis.
- Compression leak was suspected to be one of the causes of connecting rod failure.

Abstract

This article reports a failure analysis of a diesel generator set connecting rod type 3516 B that has operated for 79,678 hours. From visual observation, connecting rod cylinder #10 has changed color in the shank area. This phenomenon may represent many cases of generator failure, so an analysis to identify the root cause of the failure is needed for scientific literature. In this case, fault tree analysis, SEM-EDX, chemical composition, and microstructure testing were performed to obtain more comprehensive results. Through fault tree analysis, we found that the connecting rod damage was caused by compression leakage due to wear on the cylinder liner. Scanning Electron Microscopy (SEM) analysis shows that the piston rod material is discolored due to heat, namely the formation of iron oxide. The heat level received by the connecting rod is around 200 °C. We also found a finely formed, easy-to-clean scale where the thickness ranged from 0.00127–0.008 mm. Finally, EDX analysis showed high levels of iron (Fe) and oxygen (O) confirming that the formation of iron-oxide on the metal surface was due to the influence of heat.

Keywords: Connecting rod; Microstructure; SEM-EDX, Fault tree analysis

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1. Introduction

A normal engine generator set, even though using a diesel engine should produce a smooth engine sound. Adequate lubrication and standardized clearance provide good engine performance with less noise from the combustion chamber, not from mechanical components. However, excessive noise may be occurred if any of the mechanical components are damaged or worn, for example in the crank or valves mechanism. Currently, several methods have been introduced to predict and locate the source of engine failure by utilizing signals or vibrations captured by special diagnostic equipment [1]–[3]. However, not all component defects can be recognized by diagnostic equipment, especially those types of damage that do not transmit a signal such as component discoloration or minor cracks that do not cause abnormal vibration symptoms.

In one of the generators set type 3516 B which is operated by XXX Company, excessive engine noise is heard which indicates a failure. From the primary data obtained, the generator set has been operating for 79,678 hours. An overhaul job was carried out to identify the source of the problem and it was found that the connecting rod on cylinder #10 was discolored in the shank area. Based on visual inspection, the connecting rod cannot be reused, and it is suspected that its strength has decreased. Therefore, further analysis is needed to obtain scientific evidence as maintenance data in other cases. Then, an analyzed using fault tree analysis (FTA), microstructure testing, chemical composition testing, and SEM-EDX testing were carried out to determine the root cause of failure.

2. Literature Review

As it is known that the connecting rod is divided into several areas, namely the top is the pin-end, the middle area is called the shank, and the bottom is the crank-end/big-end [4]. The pin-end and crank-end bores are each equipped with bearing mounts with very high accuracy. When connected to the piston, the pin-end hole must be equipped with a solid bearing (bushing), while the crank-end part which in addition to getting the compressive and thrust forces from the piston movement also gets a high temperature due to the rotational movement of the crankshaft so that the presence of the bushing is also very important [5]. The crank-end bore is separated into two parts for easy attachment to the crankshaft. The bottom or connecting rod-cap is made of the same type of material as the rod and is connected by two bolts [6]. Likewise, solid bearings (bushings), are separated into two parts, each position following the connecting rod hole and the other following the cap bearing position [7], [8].

Several inspection reports on connecting rods were found to determine and make appropriate maintenance recommendations [9], [10]. In other cases, follow-up inspection of connecting rod failure was reported by hardness test, surface crack analysis, and microstructure analysis due to overheating [4], [11], [12]. Other studies on connecting rod failures have also been carried out with validation using finite element analysis (FEA) simulations. Scanning electron microscope (SEM) was used to investigate the fracture mode mechanism, optical microscope to study the microstructure, and visual inspection was mainly used to determine the root cause of failure [13]. Moreover, the root cause of failure was reported due to pressure variations at the small end. The failure was caused by fatigue factors with various strain life theories [14]. It is known that casting defects can propagate, which depends on the cyclic load from the connecting rod to the crack point [15].

3. Method and Procedure

3.1. Visual inspection

This visual inspection aims to evaluate the condition of the connecting rod. In addition to performing a visual inspection of the damage to cylinder diesel engine the #10, a detailed visual inspection was also carried out on the discolored connecting rod. The inspection was carried out following the inspection guide issued by the diesel engine manufacturer.

3.2. Laboratory testing

3.2.1. SEM-EDX testing

SEM testing aims to identify the source of the cause and the beginning of crack propagation from components that experience temper color, surface oxidation, corrosion products, and certain texture forms. The test was carried out using an optical microscope or scanning electron microscopy (SEM) on the discolored surface of the connecting rod. In testing using EDX, X-rays were fired at the sample, then some of the rays were reflected by the sample and some were absorbed or penetrated the sample. With the difference in the amount of light reflected or absorbed, the composition of the constituent elements of the sample were known.

3.2.2. Chemical composition

Evaluation of the chemical composition aims to determine the material of the connecting rod manufacture so that a comparison can be made between the design material and the actual composition of the connecting rod material. The tool used to check the chemical composition is the optical emission spectrometer. Chemical testing steps are carried out by cutting, grinding, and sanding the test object. After the surface smoothness is obtained, the test object is shot with argon gas up to 99.99% at the surface.

3.2.3. Microstructure

This observation aims to determine what phases are present in the material. Microstructure observations were carried out with a stereomicroscope. The magnification used is 100X and 500X. Observation of the microstructure is done by giving 2% nital etching agent to the sample so that the formed phases can be known.

4. Results and Discussion

4.1. Visual inspection and fault tree analysis

Discoloration of the connecting rod occurs in the shank, from the shape that occurs not completely to all parts of the connecting rod, as shown in **Figure 1**. In the center of the shank, the color appears darker than the other parts being evaluated. We suspect that there is a compression leak and lubrication failure in the observed cylinder that affects the discoloration of the connecting rod.

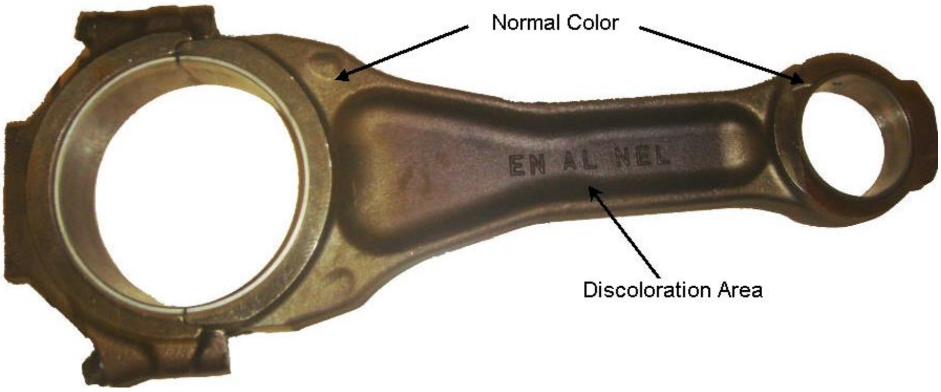


Figure 1. Discoloration in the shank area of the connecting rod #10

To obtain more detailed results on the cause of heat discoloration on the connecting rod in the shank area, a fault tree analysis (FTA) was implemented as presented in **Figure 2**. There are four blocks representing compression leak, lubrication system failure, incomplete combustion system, and twisting on connecting rod, respectively. *Compression leak* **-** Wear on the liner wall causes

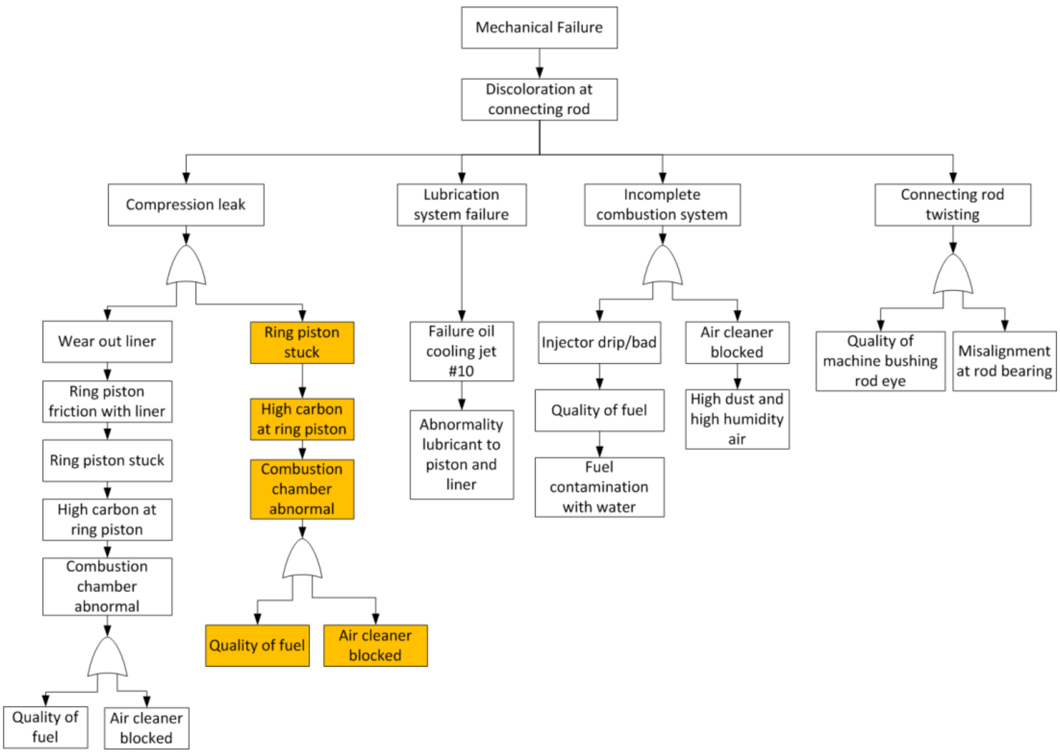


Figure 2. Fault Tree Analysis (FTA) on the connecting rod diesel engine 3516 B

compression leakage, where the liner wall is already shiny. In addition, the piston ring was stuck because there is carbon in the piston ring gaps, so it cannot expand. *Lubrication system failure* - Failure of the lubrication system on the oil cooling jet, where the oil cooling jet cannot lubricate the bottom of the piston, so the oil cannot absorb heat and cause heat propagation to the connecting rod. *Incomplete combustion system* - Bad/drip injectors due to fuel quality, where the combustion ratio is not perfect between air and fuel or blocked air filter caused by air quality contaminated with dust or humid air [16]. *Twisting on connecting rod* - The cooling system on the diesel engine has a considerable impact on engine operations, where this cooling system functions to absorb heat generated from the combustion process, as well as friction between metal and metal, if the cooling system is hot, performance of the engine components will decrease [17], [18].

4.2. SEM-EDX analysis

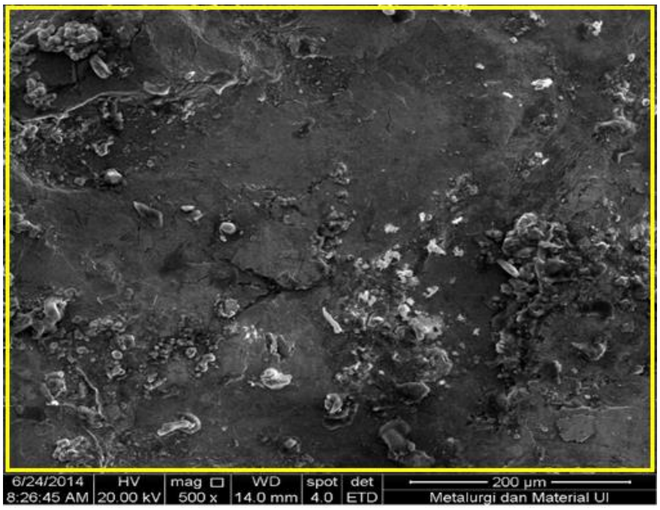
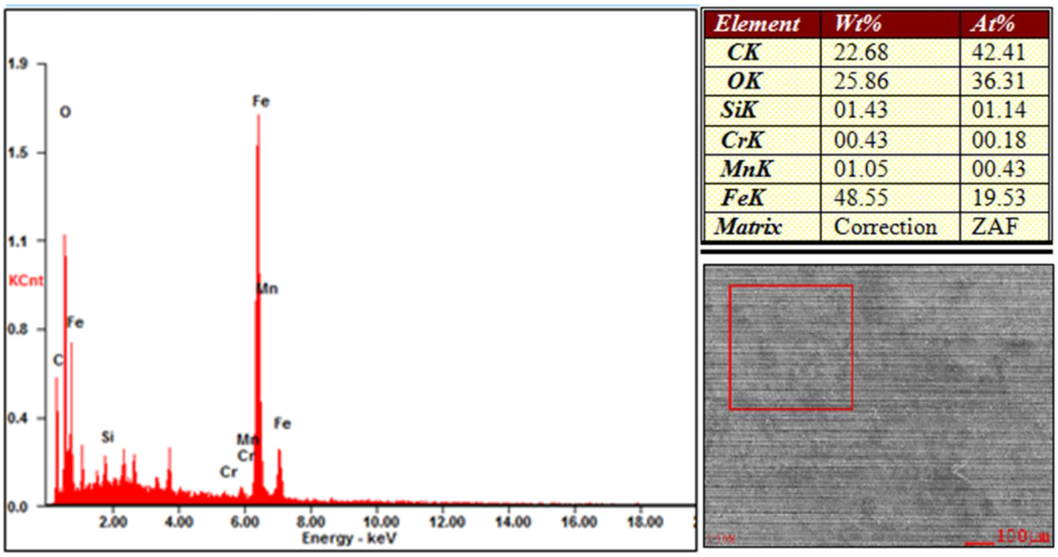


Figure 3. The results of the SEM material discoloration test with a magnification of 500x

SEM analysis was carried out on a surface that had discoloration. SEM test were intended to determine the cause of discoloration on the connecting rod surface [19]–[21]. The surface of the tested object shows the formation of an iron-oxide structure, namely the formation of morphology. Morphological test results with SEM are shown in **Figure 3**. The area highlighted by the yellow box is the cracked part of the connecting rod under investigation. Then, EDX analysis as presented in **Figure 4** shows the high levels of iron (Fe) and oxygen (O) confirming that the formation of iron-oxide on the metal surface is due to the influence of heat.



Element	Wt%	At%
CK	22.68	42.41
OK	25.86	36.31
SiK	01.43	01.14
CrK	00.43	00.18
MnK	01.05	00.43
FeK	48.55	19.53
Matrix	Correction	ZAF

Figure 4. The results of the EDX test of the discolored connecting rod material in the shank

4.3. Chemical composition analysis

Based on the service guide of the diesel engine, the material for making connecting rods is included in the type of alloy steel. Alloy steel is an alloy steel that has ductile properties and high tensile strength. This steel is composed of 0.05 – 0.25% carbon using micro alloys V, Ti, Nb, or Mo (0.01 – 0.1%). From the chemical composition test, it was concluded that the connecting rod material is H15220 AISI 1522H alloy steel, as described in **Table 1**. Based on the chemical elements from the test results, there is no relationship between chemical elements with color changes on the connecting rod.

Table 1. The test results of the chemical composition of the connecting rod

No	Element	Value of Elemental Content (% by weight)	Grade Limit H15220 AISI 1522H
1	Fe	98.003	
2	C	0.238	0.170-0.250
3	Si	0.188	0.150-0.350
4	Mn	1.249	
5	Cr	0.162	
6	Ni	0.017	
7	Mo	0.15	
8	Cu	0.011	
9	Al	0.034	
10	V	<0.002	
11	W	<0.002	
12	Ti	0.029	
13	Nb	<0.002	
14	S	0.036	
15	P	0.010	
16	Co	<0.002	

4.4. Microstructure analysis

Microstructure analysis on the connecting rods was carried out by comparing the areas that had changed color to the normal areas [5]. This microstructure test aims to determine whether there are elements of material defects from the connecting rod. From the change in color and type of heat transfer that occurs and as a reference the connecting rod is feasible to operate again or not [22]. Based on **Figure 5** and **Figure 6**, the structure is composed of tempered martensite which both have sulfide impurities. From the three microstructure tests in sample 1, the discolored cross-section of the connecting rod is seen that there is no difference between the three and they are still in normal condition.

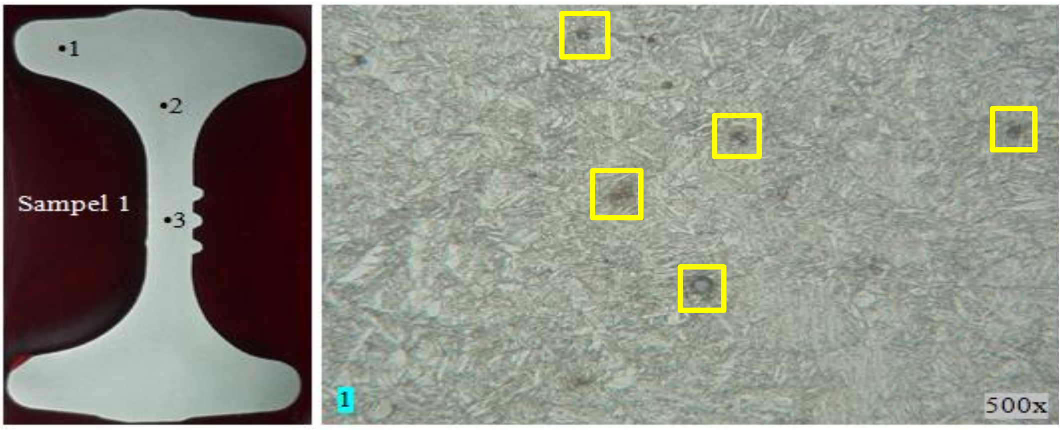


Figure 5. Microstructure of location 1 on sample 1

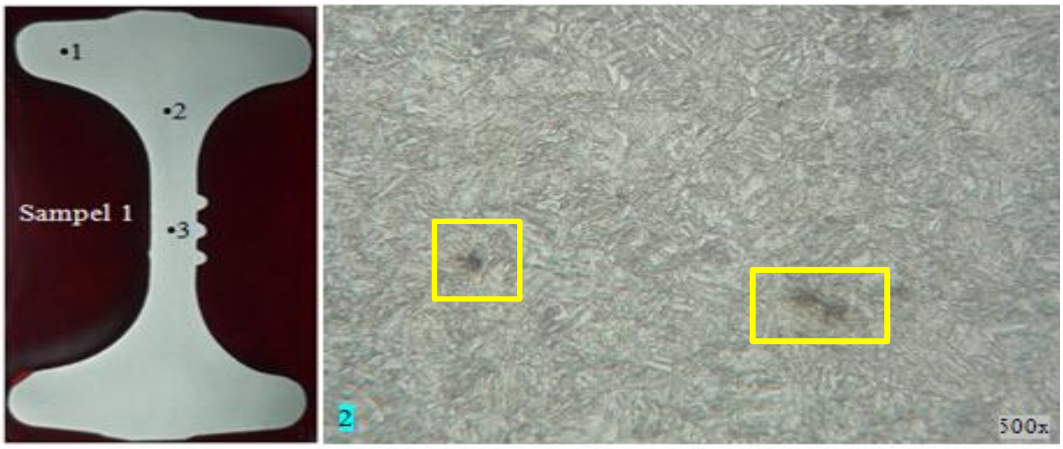


Figure 6. Microstructure of location 2 on sample 1

Based on **Figure 5** and **Figure 6**, the structure is composed of tempered martensite which both have sulfide impurities [20]. The impurity sulfide does not affect the color change of the connecting rod and has no relationship with the occurrence of color changes. Then, based on **Figure 7**, the microstructure is the same as that of sample 1, the microstructure is in the form of tempered martensite with sulfide impurities, and the metal is still in normal condition.

Figure 8 presents the microstructure of sample 1. The temperature increasing that occurs in cylinder liner #10 in the engine has not changed the microstructure of the connecting rod material. From the microstructure test carried out, it was found that the temperature was 200°C, this condition has not been able to change the hardness, strength, and structure of the connecting rod. Based on Pacina et al. [23], the alloy steel will experience temper embrittlement or temper brittleness at temperatures between 300-600 °C where the steel will increase hardness and decreased ductility. Finally, the type of heat transfer that occurs causes discoloration of the connecting rod due to radiation.

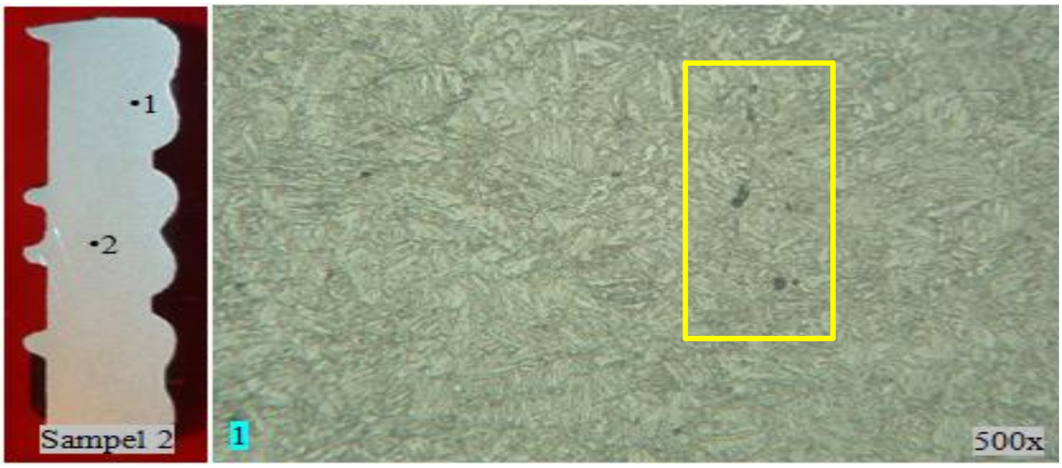


Figure 7. Microstructure of location 1 on sample 2

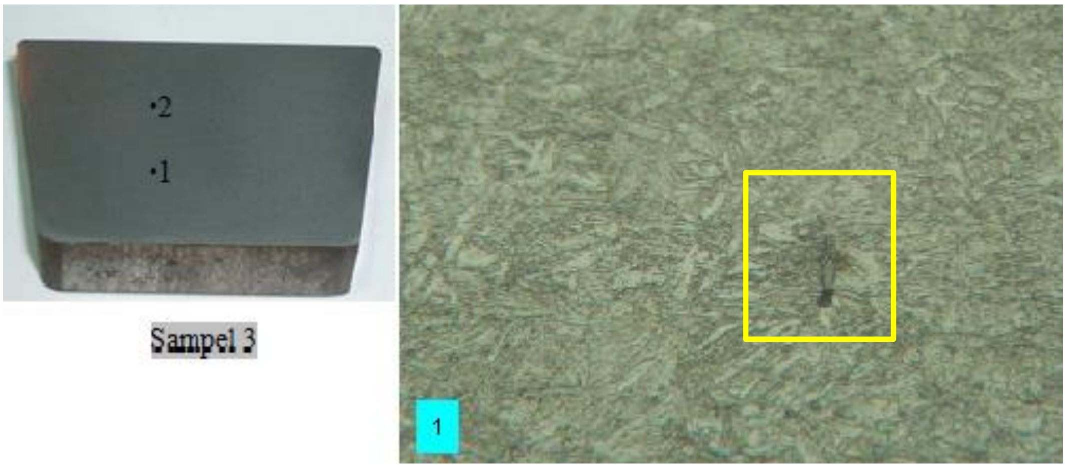


Figure 8. Location 1 in sample 3

5. Conclusion

Scanning Electron Microscopy (SEM) analysis shows that the connecting rod material is discolored due to heat, which generates the formation of iron oxide. The heat received by the connecting rod was estimated at 200°C. Based on the fault tree analysis, the color change on the connecting rod was dominated by radiation from the cilinder wall due to exhaust gas leakage into the crankcase. The results of our investigation showed that there was damage to the piston ring on cylinder #10, which causes the piston ring to stack and cannot expand, resulting in a compression leak. Finally, EDX analysis showed high levels of iron (Fe) and oxygen (O) confirming that the formation of iron-oxide on the metal surface was due to the influence of heat**.** This phenomenon may represent many cases of generator failure, so the results of this study are useful as a new insight and literature.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials - All data are available from the authors.

Competing interests - The authors declare no competing interest.

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