International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 7, Issue 11, pp 576-580, November-2023

https://doi.org/10.47001/IRJIET/2023.711075

Failure Investigation of Connecting Rod on Four-Stroke Motorcycle

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***Abstract* - The purpose of this research is to examine the mechanism of connecting rod failure on a 110 cc 4-stroke motorcycle that exhibits plastic deformation at the connecting rod neck. Visual inspection, chemical composition testing, metallographic testing, hardness testing, and numerical simulation are the analytical techniques employed. The connecting rod material is classified as SAE-AISI 4140 steel based on the findings of the chemical composition test. The results of the metallographic tests revealed the presence of a martensite phase in the microstructure. The connecting rod material's average hardness value, as determined by the Vickers technique of hardness testing, is 500 HV. Similarity between the buckling failure mode, which happens when the load absorbed by the connecting rod exceeds the normal load and occurs in the vicinity of the maximum stress point, may be shown from stress analysis (von Mises) and buckling mode analysis (eigenvalue buckling). The history of riding motorcycles that have been altered by adding compression to get the required speed without taking the strength of the connecting rod components into account further supports this conclusion.**

Keywords: Buckling failure, Connecting Rod, Failure analysis, SAE-AISI 4140.

I. INTRODUCTION

Failure analysis is the process of carefully examining a component that fails or is damaged due to several variables that affect a tool's performance. When a machine component malfunctions, it can be extremely harmful to the industry if the malfunctioning machine component is crucial to the industry's operations. A motorcycle's connecting rod component is one instance of an engine part that may malfunction.

Connecting rod failure can be caused by a number of circumstances, including inadequate lubrication, faulty manufacturing procedures, connecting rods receiving high load capacities, and bad road conditions in Indonesia. In order to identify the precise reasons and features of a failure, a failure analysis must be conducted, taking into account the numerous contributing elements as well as the volume of failure instances that transpire. The findings of this failure study can serve as a guide or lesson for all motorcycle riders, encouraging them to give their bikes greater attention during maintenance in order to prolong the bikes' useful lives.

The connecting rod component plays a crucial role in transferring power from the combustion process to the crankshaft, where it is transformed from heat energy to mechanical energy and from translational motion to rotational motion [1]. High amounts of combustion gas will be produced by the cylinder's internal combustion process. It is inevitable that the piston, connecting rod, or crankshaft will fail if they and other associated parts are not able to endure the explosive force of combustion. Understanding the component's strength is essential to reducing or avoiding this failure.

In order to prevent hydrolock failure, Pani et al.'s research [2] examined buckling failure and connecting rod material selection in a 645E3B heavy duty diesel engine. Following analysis, it was determined that forged steel connecting rods had a significantly higher bending strength than aluminum alloy connecting rods. Thus, heavy-duty diesel engines cannot be equipped with connecting rods made of aluminum alloy. Research on fretting-fatigue-related connecting rod failure was also done by Chao [3]. The findings suggested that fretting-fatigue, which is caused by tiny movements between the housing bore and the rear bearing, could be the cause of the engine failure mechanism.

Research on the stress and failure of connecting rods in turbocharged diesel engines that suffered fracture failure was carried out by Witek and Zelek [4]. The primary reason for connecting rod failure, according to the findings of the finite element analysis, was a high stress level in the area close to the bolt hole, which was brought on by the bolt's high tension. Research on the connecting rod failure of an EMD645 heavy duty diesel engine that suffered side bending failure was also carried out by Rezvani et al. [5]. According to the findings of the finite element analysis, a high compression ratio followed by the hydrolock phenomenon, or fluid entering the combustion chamber, was the reason behind connecting rod failure.

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Research by Lee et al. [6] examined the impact of a connecting rod's bending sensitivity on the decrease in the shank's cross-sectional area following a front-back bending failure. According to the analysis conducted using the finite element method, the connecting rod buckles when the shank's cross-sectional area is reduced in areas where the buckling sensitivity is comparable to or higher than the yield and fatigue properties. In order to enhance the design and stop such failures from happening in the future, Bari et al. [7] also studied the forensic examination of connecting rods that suffered fracture failure in motorcycle engines. The study's findings indicated that scale accumulation, which resulted in microcracks during the component fatigue process, was the root cause of the connecting rod's fracture failure.

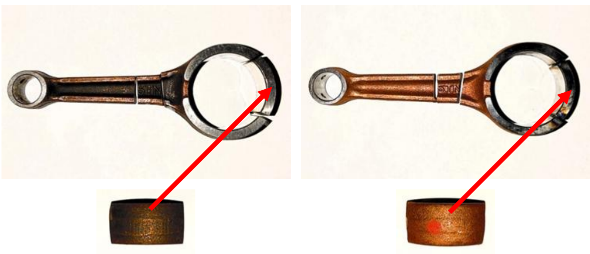
II. RESEARCH METHODOLOGY

This study analyzes connecting rod failures through a number of series of process stages, such as:

2.1 Testing for Chemical Composition

Determining the chemical makeup of the connecting rod material is the goal of chemical composition testing. An optical emission spectrometer, as depicted in Figure 1, is the instrument utilized to conduct this test. The big ends of the failed connecting rod and the new connecting rod, as depicted in Figure 2, are the sources of the two specimens used in this study's chemical composition test.

Figure 1: Optical emission spectrometer



(a) (b)

Figure 2: Test specimen for the chemical composition of connecting rods(a) Failed (b) New

2.2 Testing for Metallographic

Determining the connecting rod material's microstructure is the goal of metallographic testing. The Olympus BX53M optical microscope, as depicted in Figure 3, was the instrument utilized to observe the microstructure. In order to conduct metallographic tests for this study, two specimens were obtained from the necks of the new connecting rod and the failed connecting rod, as seen in Figure 4.

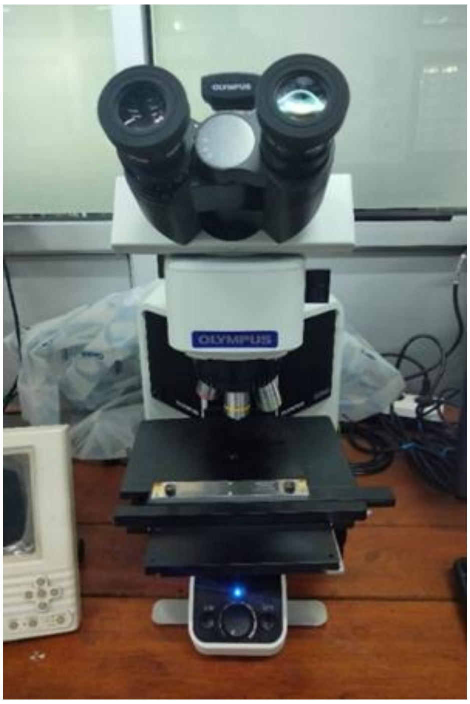


Figure 3: Optical microscope Olympus BX53M

(a) (b)

Figure 4: Test specimen for the metallographic of connecting rods (a) Failed (b) New

2.3 Testing for Hardness

The purpose of hardness testing is to ascertain the connecting rod material's distribution of hardness values. The micro Vickers hardness tester, depicted in Figure 5, is the instrument utilized in this test, which follows the Vickers method. As seen in Figure 4, this study uses two specimens for the hardness test and the same specimen for the metallographic test.

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Figure 5: Micro Vickers hardness tester

2.4 The Numerical Simulation

In order to ascertain the point and maximum stress value as well as the bending mode that takes place in the connecting rod, this study uses numerical simulations with the finite element method. Using Solidworks 2016 software, a 3D connecting rod model is first designed in the simulation. Ansys Workbench 2020 R1 software is then used for structural analysis.

III. RESULTS AND DISCUSSION

3.1 Results of Chemical Composition Tests

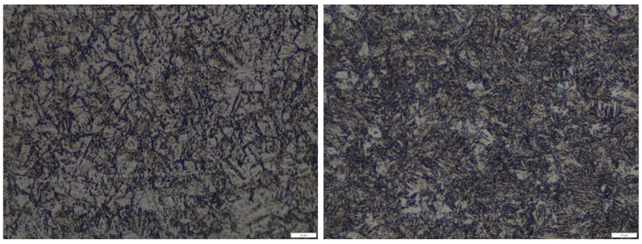
The results of the chemical composition test are displayed in Table 1. Based on their chemical composition, it is known that the two connecting rods are classified as SAE-AISI 4140 steel, which is the same as 41CrMo4 in the German designation (DIN) [8].

Table 1: Results of chemical composition tests

Element	Chemical Composition (wt%)		
	Failed Specimen	New Specimen	AISI 4140
Fe	97,1	97,1	Balance
C	0,409	0,405	0,38-0,43
Cr	1,11	1,09	0,80-1,10
Mo	0,156	0,156	0,15-0,25
Si	0,159	0,162	0,15-0,35
Mn	0,837	0,805	0,75-1,00
P	0,0341	0,0311	≤0,035
S	0,0382	0,0372	≤0,040

3.2 Results of Metallographic Tests

According to the metallographic test results displayed in Figure 6, the martensite phase is present in both connecting rods. These findings suggest that the connecting rod that failed did not have any mistakes or manufacturing flaws. The martensite phase results are also consistent with the heat treatment used in the production of connecting rods, which includes tempering to raise the toughness value and quenching to achieve high strength. This microstructure can be demonstrated by comparing it to the microstructure of AISI 4140 steel, which is depicted in Figure 7 and likewise underwent heat treatment in the form of quenching and tempering with the same phase form, namely martensite.



(a) (b)

Figure 6: Results of the metallographic test a connecting rod using a 1000x magnification (a) Failed (b) New

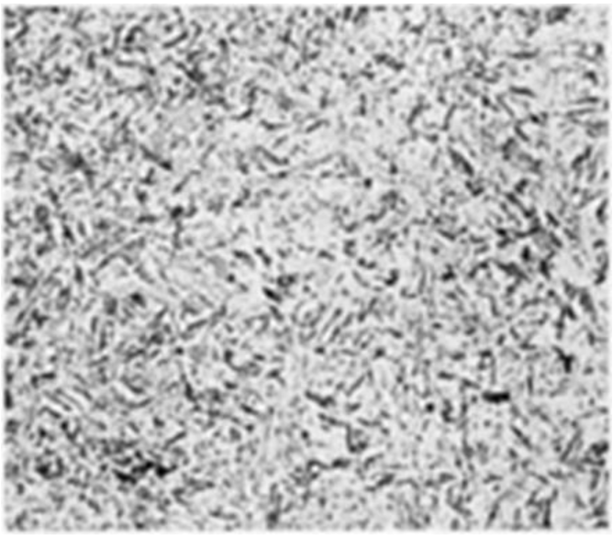


Figure 7: 500x magnification of the AISI 4140 steel microstructure [9]

3.3 Results of Hardness Tests

Table 2 displays the findings of the Vickers method hardness testing that was conducted at 13 points. With an average hardness value of 500 HV, it is known that there are no appreciable differences between the two connecting rods' hardness value distributions. These findings suggest that wear factors on failing connecting rods do not alter the hardness values [10].

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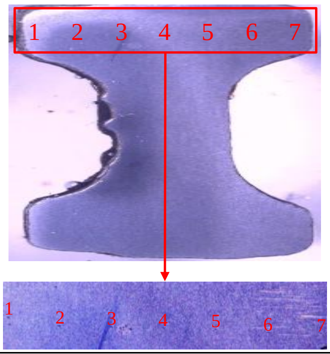
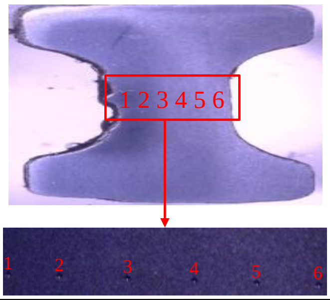
Table 2: Results of hardness tests

Area	Point	Vickers Hardness Number (VHN)	
		Failed Specimen	New Specimen
Side Part 	1	558	583
	2	515	565
	3	478	523
	4	474	521
	5	496	532
	6	506	537
	7	517	565
Middle Part 	1	530	558
	2	506	551
	3	480	521
	4	474	515
	5	488	551
	6	510	563

3.4 Results of Numerical Simulation

The inner circle of the big end is determined as a fixed support [11] as illustrated in Figure 8. The results of stress analysis (von Mises) with a normal load of 4,165 N applied to the inner circle of the small end in the direction of the connecting rod neck axis show that the maximum stress point occurs in the area near the small end of the connecting rod with a maximum stress value of 156 MPa under the connecting rod's yield strength of 415 MPa, indicating that the connecting rod should be safe for use under normal loads.

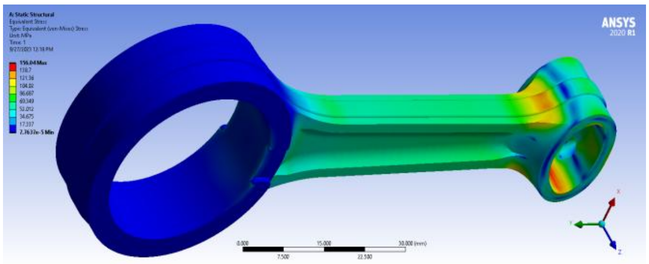
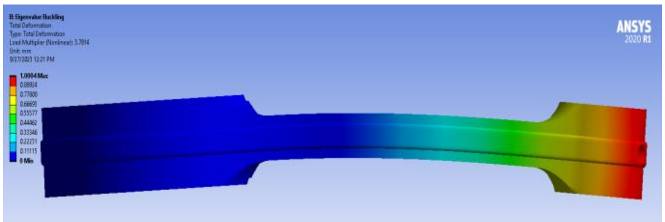


Figure 8: Von Mises connecting rod stress analysis results

Additionally, it was discovered through buckling mode analysis (eigenvalue buckling) that the first buckling mode—with a maximum buckling load value of 15,743 N, or 3.78 times greater than the normal load—was the one that actually occurred. As seen in Figure 9, the first bending mode that arises from the bending mode analysis results resembles real connecting rod failure. The point of maximum bending stress, which is situated in the region of the connecting rod neck with the smallest cross-sectional area and occurs close to the point of maximum stress [6], provides evidence of the similarity of this bending mode.



(a)

(b)

Figure 9: (a) Analysis of buckling modes (eigenvalue buckling) (b) Connecting rod failure that occurred

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IV. CONCLUSION

According to the test results, the connecting rod material's chemical makeup is low alloy steel, which falls under the SAE-AISI 4140 steel category. An average hardness value of 500 HV is used to characterize the microstructure formed by the connecting rod material, which is martensite. Since the connecting rod's material satisfies SAE-AISI 4140 steel standards, it cannot be the reason for the connecting rod's failure. Excessive load applied to the connecting rod causes buckling failure at the connecting rod neck, which is the mechanism of failure.The findings of the buckling mode (eigenvalue buckling) and stress analysis (von Mises) demonstrate that the maximum bending stress point and maximum stress point are comparable to the real failure circumstances that arise in the connecting rod. The primary reason for failure is that the connecting rod experiences an excessive load, which happens when the motorcycle is altered by adding more compression to reach the intended speed without taking the connecting rod's strength into account.

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Citation of this Article:

Sri Nugroho, Munadi, Insannul Fikri, "Failure Investigation of Connecting Rod on Four-Stroke Motorcycle" Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 7, Issue 11, pp 576-580, November 2023. Article DOI https://doi.org/10.47001/IRJIET/2023.711075

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