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Original Research Article

Analysis of Material Failure Due to Rigidity Changes on a Motorcycle Frame Body Structure

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Abstract

One of the most important things on a motorcycle is the frame. The motorcycle frame is a structure that supports almost all of motorcycle components, such as the engine, front and rear suspension, fuel tank, and others components. The purpose of this research is to determine the cause of the failure of the motorcycle frame in based on actual conditions in the field. In this study, a case study was carried out on a sport-type motorcycle frame with 150cc engine capacity, using a trellis-type frame, and had traveled 10,000 km as indicated on the odometer. The results of the case study and analysis on the failed part, it was found that the main cause of the failure of the motorcycle frame or frame body was due to the bolt flange on the engine hanger having a torque below the standard. This happens due to consumers who make modifications and add accessories. So the torque below the standard or low torque causes the frame body to break as a result of the reduced rigidity of the frame body structure and also as a result of repeated dynamic loads on the welding area, which is included in the HAZ area, which is the weakest part of the welding joint. Failure or fracture can occur as a result of the continuous load received on the frame structure, resulting in fatigue failure. The failure also occurred at the low torque bolt flange earlier.

Keywords: Frame, Low Torque, Trellis, HAZ, Failure.

1. INTRODUCTION

One of the most important things on a motorcycle is the frame or frame body. A motorcycle frame is a structure that supports most of the motorcycle components, such as the engine, front and rear suspension, fuel tank, and others. The frame is also responsible for the rigidity of the whole motorcycle [1]. In addition, a motorcycle frame must also be able to withstand static loads, such as an engine holder [2].

In general, one of the causes of the failure of a motorcycle frame structure is that the frame is not able to hold the load, which is influenced by many things, such as the load on the engine and other components, engine mounting tightening torque, moment of inertia, frame material, and so on. Frame failure will usualy occur at the weakest point or critical point of a structure. This failure is also caused by the varying loads during its service life, so that the most frequent failures that occur in the motorcycle frame are fatigue failure [3]. Therefore, to learn more about the causes of motorcycle frame failure, it is necessary to conduct research based on existing case studies to see actual conditions in the field.

2. MATERIALS AND METHODS

In this study, there were several stages carried out, which can be seen in Fig. 1.

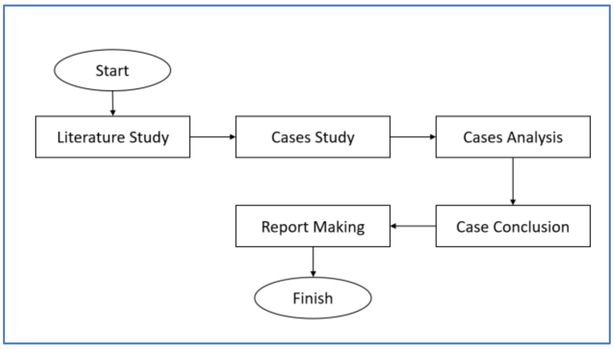

Fig-1: Research Flowchart

The experiment began with a literature study that focused on the Sport type motorcycle with a 150 cc engine capacity using the Trellis frame body type.

Trellis itself comes from the name of the small pipes that are connected to form a motorcycle frame. Trellis frames are similar to Perimeter frames in rigidity and weight [2]. It took more effort and time to manufacture this frame but the result is that the trellis frame is stronger than the perimeter frame because the trellis frame can handle and accept very heavy loads compared to other types of frames. The motorcycle engine that mounted on this Trellis type frame will also function as a reinforcing structure. The illustration of the Trellis frame can be seen in Fig. 2.

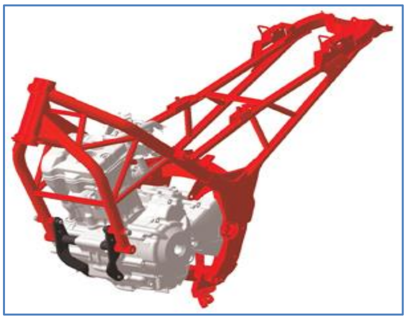

Fig-2: Trellis Frame Model

Furthermore, from every cases that occur, only similar cases are studied and analyzed in this study. The main problem in this case is that customer complain that the condition of the right and left body frames is broken, which can be seen in Fig. 3. The motorcycles that experienced this case have traveled an average of 10,000 km, which is read on the odometer.

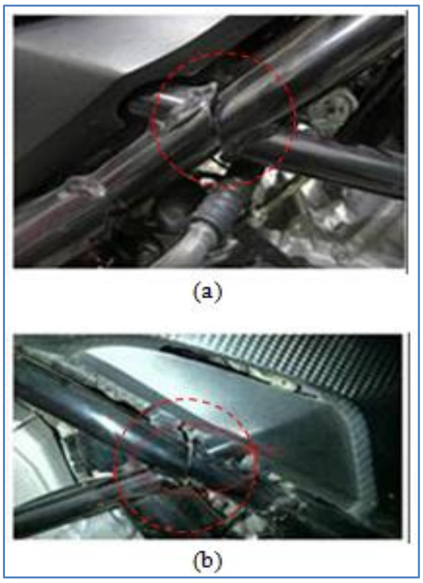

Fig-3: Broken frame body (a) Pipe Comp L, (b) Pipe Comp R

Based on the results of case studies and analysis, to find out the root cause of this case, there will be several parts of the frame body that are related and must be examined and analyzed further, as follows:

1. Body of the frame

In this body frame analysis, there will be a few test as follows:

a. Visual examination of the shape of the occurring fault
b. SEM (Scanning Electron Microscope) material analysis to determine the type of failure in the frame body [4].
c. Microstructural analysis of the frame body:
d. Material hardness and chemical composition analysis

The results of this analysis are expected to be able to find out whether there is a deviation from the side of the frame body causing a fracture or failure.

2. Bolt flange 10 x 250

This 10 x 250 bolt flange needs to be analyzed because it functions as a connector between the left side to the right side of the frame body and holds the engine in the middle of the frame, as shown in Fig. 4. So it is necessary to analyze whether there is a deviation in the bolt flange or not which can cause a fracture or not on the frame body. The analysis to be carried out is as follows:

a. Chemical composition analysis
b. Tensile Test
c. Microstructural Analysis
d. SEM

3. Engine hanger pipe

The engine hanger pipe needs to be analyzed because it is a connector between the frame body and the engine, and when installed it will acting as reinforcing structure for the frame body, which can be seen in Fig. 4. The engine hanger pipe will be compared in terms of dimensional tolerance with standard parts that are OK.

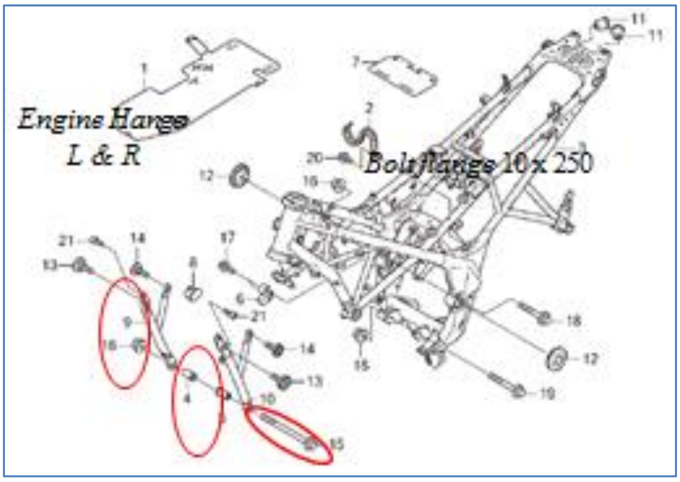

Fig-4: Engine Hanger & Bolt flange 10 x 250

4. *Re-Appear Test*

This test is carried out to represent the conditions of each part that has been checked, both in terms of properties and dimensions. This re-appear test is carried out using a CAE simulation and also performs a durability check simulation to ensure that the results are the same or not. In this CAE simulation, utilizing Finite Element Analysis (FEA), which is used to find out how much the estimated lifetime of a structure using 3 parameters, that is geometry, material, and load [5]. Schematically, the service life estimation procedure can be seen in Fig.5.

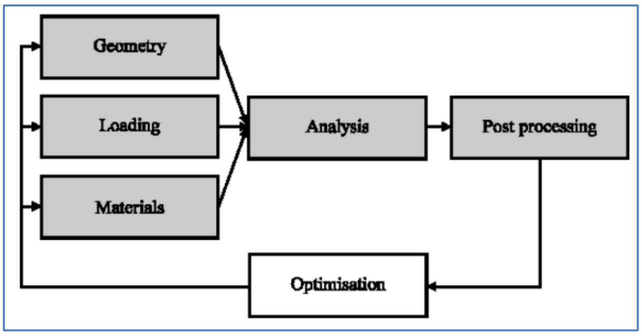

Fig-5: Schematic of mass estimation procedure [3]

3. RESULT

Based on the research method and analysis carried out, the following results were obtained:

1. *Frame body*

The following analysis was carried out to find out whether there was a deviation in the frame body that caused a fracture or failure:

1. Visual analysis on the shape of the fault that occurs

This analysis was carried out to see which part of the frame failed and to find out whether the fault had any effect on the welding process or the connection of the frame body.

From the results of the analysis it was found that the fracture in the frame body occurred at the edge of the weld on the pipe comp R/L which can be seen in Fig. 6.

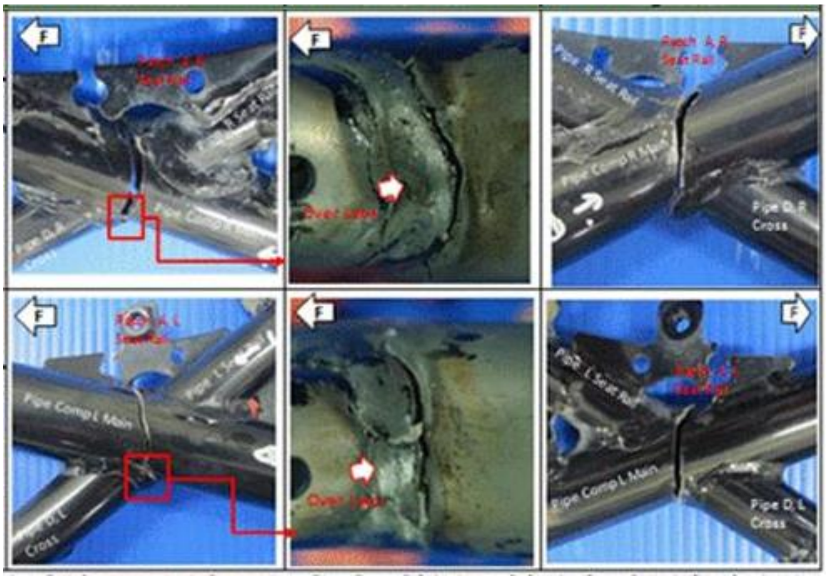

Fig-6: The results of the analysis of the frame body fracture

2. SEM (Scanning Electron Microscope) material analysis

Material analysis is carried out to determine whether there is a deviation in material properties or not. The results of the SEM show that the failure that occurs is a fatigue failure and the area of the fracture at the end of the welding bead is in the HAZ (Heat Affected Zone) area, which is the most critical area of the welding area [6]. There was also no undercut crack in this fault as the initial cause of the fracture. The results of the SEM can be seen in Fig. 7.

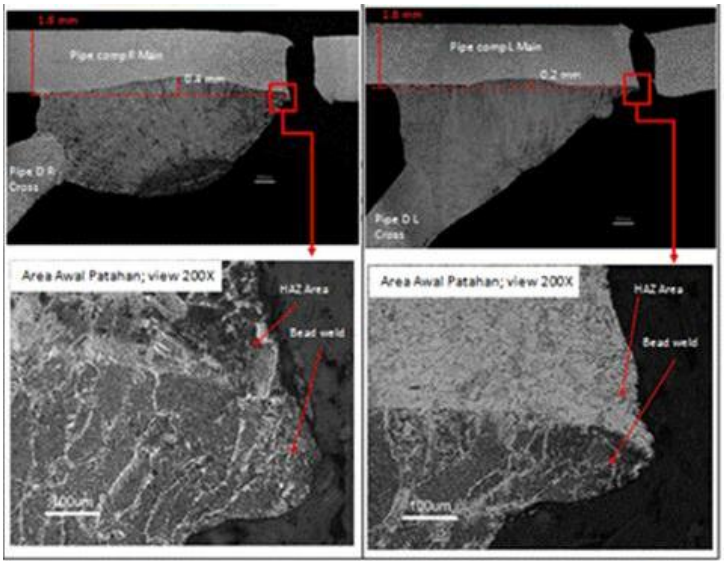

Fig-7: SEM Results

3. Frame body microstructural analysis

In this analysis, it was found that there was a penetration of 25% for Pipe Comp R Main and 12% for Pipe Comp L Main, while for the reference standard it was only 10%.

4. Analysis of material hardness & composition

This analysis puprose is to find out whether there are deviations in material properties or not. Based on the results of the hardness test using the Vickerss method, the values are still above the standard, for Pipe Comp R Main 580 N/mm2 and Pipe Comp L Main 420 N/mm2, with a minimum standard of 390 N/mm2. Meanwhile, in terms of chemical composition, the results are also in accordance with the STAM390G standard.

The summary of the results of the frame body analysis can be seen in Table 1.

Table-1: Test Results on Frame body

Crack Pipe Rear Frame		Test Result		Spec/Std	Judge
		Pipe Comp R	Pipe Comp L		
Visual Examination		Crack at overlapping *welding* area		Reference	-
SEM		*Fatigue failure*		-	-
Microstructure	Visual	Ferrite pearlite, failed at HAZ Area		-	-
	Penetration	25%	12%	Reference	-
Hardness vickerss		180 Hv (580N/mm^2)	129 Hv (420N/mm^2)	Min 390 N/mm^2	OK
Chemical Composition		STAM390G	STAM390G	STAM390G	OK

The temporary conclusion is that the material properties are good, the type of fault is fatigue failure, and microstructural failure is not found in the welding joint.

2. Bolt Flange 10 x 250

Furthermore, an inspection and analysis were carried out for the related parts of the frame body, namely the bolt flange 10 x 250, with the following test results:

a. Analyze chemical compositions

Table-2: Results of chemical composition analysis on bolt flange 10x250

Bolt flange **10 x 250**	C	Si	Mn	P	S	Ni	Cr	Mo
Failed	0,39	0,19	0,74	0,008	0,01	0,18	1,0	0,15
SCM435	0,33-0,38	0,15-0,35	0,60 – 0,90	0,030 max	0,03 max	0,25 max	0,9-1,2	0,15-0,30
SCM435	0,32-0,39	0,15-0,35	0,55-0,95	0,030 max	0,03 max	0,25 max	0,85-1,25	0,15-0,35

The results of the test of the chemical composition of the failed bolt flange 10 x 250 can be seen in Table 2, which shows that the bolt flange is match with the SCM 435 and 435H standards.

b. Material hardness analysis

Table-3: The results of the analysis of the hardness of the bolt flange material 10x250 on the surface and center.

Bolt flange **10x250**		Hardness Surf. (Hv) & Inside (HRC)						Reference HES D3211	Judge
		Avg	1	2	3	4	5		
Failed	Surface	353	351	353	356	351	352	Max HV 372	OK
	Core	34	33	33	34	34	34	HRC 32~38	OK
	Core	345	348	347	336	347	347	HV 318~372	OK

The result from hardness test can be seen at Table 3. Which shows that the hardness on failed bolt flange 10x250 match with bolt standard 10,9 (HES D3211).

c. Tensile Test

Table-4: Tensile test results

Bolt flange 10x250	Tensile Strength N/mm^2	Elongation %	Yield Strength N/mm^2	Note
Failed	1102	13	966	Failed in gauge length
Std HES D3211	980-1177 N/mm^2	Min 12%	Min 883 N/mm^2	-

The results of the tensile test can be seen in Table 4. which shows that the tensile test on the failed bolt flange sample 10x250 to be included in the Bolt 10.9 classification.

d. Microstructure Analyze

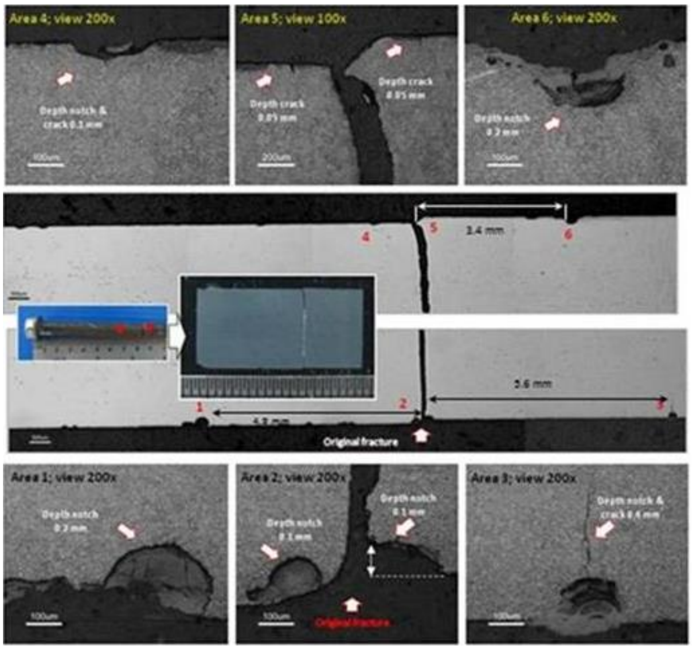

Fig-8: Microstructure test results on failed bolt flange 10x250

The results of the microstructural analysis on the failed bolt flange 10x250 showed that in the initial area of the fault there was a notch with a depth of 0.1 mm which can be seen in Fig. 8.

e. SEM

The results of the analysis using SEM can be seen in Fig.9, which shows that the fracture starts from the notch area (area A), then moves slowly upwards, and the fracture pattern that occurs is a fatigue fracture pattern.

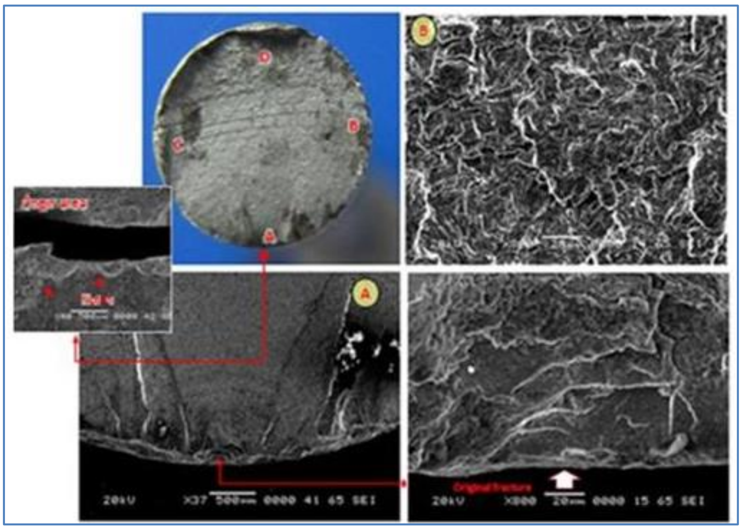

Fig-9: SEM analysis results on failed bolt flange 10x250

3. Engine Hanger Pipe

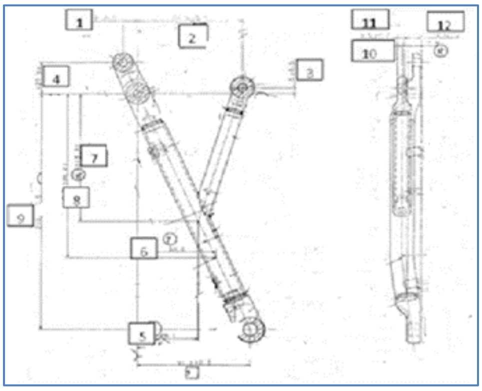

Fig-10: Drawing engine hanger

The engine hanger used in this study can be illustrated as shown in Fig. 10. To find out whether the condition of the failed engine hanger is deformed or not, a comparison is made between the failed engine hanger, standard, and OK.

Table-5: The results of the comparison of the dimensions of the failed part with the OK sample

No	Sample	Sample Failed		Sample OK	
	Standard	Act R	Act L	Act R	Act L
1	**11.9** ± 0.1	-0.5	-0.14	- 0.1	+ 0.1
2	**84.5** ± 0.5	-1.1	-0.1	- 0.5	+ 0.1
3	**5** ± 0.5	-0.6	-0.44	+0.1	- 0.1
4	**27.5** ± 0.5	+ 0.3	+ 0.1	+0.1	- 0.1
5	**49.1** ± 0.7	-2	-0.5	+0.4	+ 0.3
6	**63.4** ± 0.7	-2.5	-1.1	-	-
7	**113.3** ± 1	+ 0.4	+ 0.5	+0.6	+ 0.7
8	**146.2** ± 1	-0.9	-3.4	-	-
9	**210.4** ± 0.5	+ 0.3	- 0.27	-0.1	+0.2
10	**1.5** ± 0.5	-1	-0.3	+0.4	- 0.5
11	**5.5** ± 0.3	+0.6	-0.2	-0.2	-0.3
12	**14** ± 0.3	-0.1	+4	-0.3	-0.2

From the results of the comparison between the standard part and the sample, the failed sample, which can be seen in Table 5. It shows that in the failed sample there has been deformation, which is indicated by the very large difference in dimensions when compared to the OK sample or standard sample.

4. *Re-Appear Test*

The re-appear test is done by making a model of the broken frame body to see if the frame body here acts as a cause or effect. Therefore, CAE simulation and calculation of stress value or actual stress are carried out. In general, the modeling carried out by applying a force load to the frame body structure can be seen in Fig. 11.

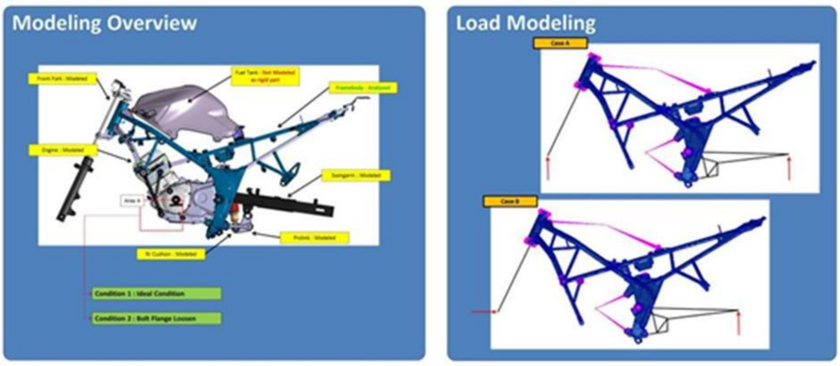

Fig-11: Modeling overview

The results of the CAE simulation on the models that have been made show that the frame body has failed due to a 10x250 bolt flange whose torque value is below the standard (low torque). The comparison between the CAE frame body simulation results in normal conditions and low torque conditions can be seen in Fig. 12.

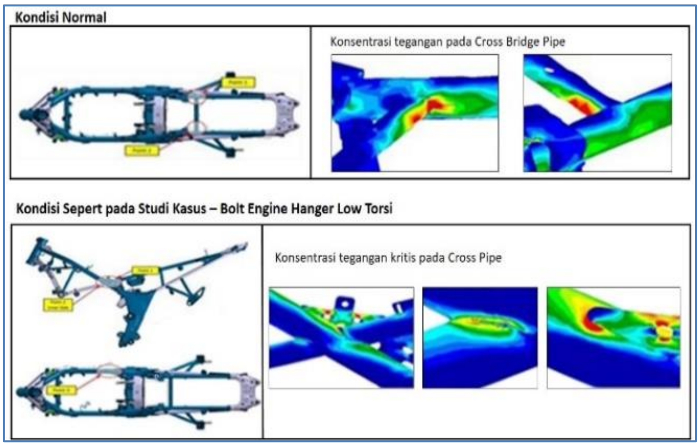

Fig-12: Comparison result for CAE simulation of normal bolt flange 10x250 with low torque

Furthermore, the measurements carried out to get the actual stress in the area that simulated in CAE. In this process there is finding that in there is modification that customer did which caused the stress difference :

Standard max stress : 184 MPa

Modification max stress : 1052 MPa

Conclusion is the strees number increasing 5,7 time from standard specification when pass through the bad road. From CAE simulation shows that critical area on the crack area and the simulation carried out for the modified condition from customer to see the effect of installation of R & L collar to torque which can be seen in Fig. 13.

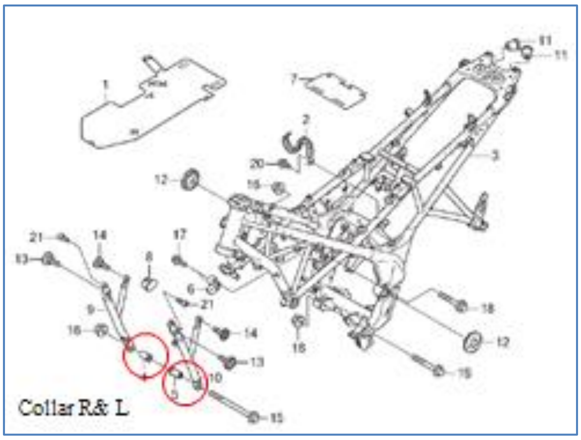

Fig-13: R & L Collar position at motorcycle frame

From the simulation of R & L collar installation shows us that installed backwards and the torque is bigger than normal or standard.

Next simulation is to check the frame body durability test with condition as follows :

Tabel-6: Hasil durability test frame body dengan bolt flange 10x250

Result	**New Bolt Torque = 0**	**New Bolt Torque = 45 Nm**	**Bolt Red Rust Torque = 0**	**Bolt Red Rust Torque = 45Nm**
Frame body	X 62800 Cycles	O 345000 Cycles	X 66800 Cycles	O 345000 Cycles
Bolt Eng. Hanger	O 345000	0 345000	X 66800 Cycles	O 345000 Cycles

explanation :
O : OK
X : Crack/Broken

The results of the durability test showed that the 10x250 bolt flange that was broken after the durability test was the same as the one found on customer motorcycles. This can be seen in Fig. 14.

Fig-14: The results of the 10x250 bolt flange fracture and the frame body after the durability test

4. DISCUSSION

Based on the results of simulations and analysis that have been carried out on the frame body and bolt flange 10x250, failure is caused by the bolt flange 10x250 being installed on the frame body with a torque value below the standard (low torque), which results in structural failure and the bolt flange itself [7]. This is due to indications of modifications to the bolt flange made by customer.

Due to these modifications made by customer, torque tightening is not standard because customer are not accompanied by proper knowledge and tools (torque wrench).

The low torque 10x250 bolt flange causes excessive vibration in the bolt flange and frame body. With this vibration, the level of rigidity or rigidity of the structure on the frame body also decreases. So a critical point arises in the weakest part of the frame body, namely the welding section, which is included in the HAZ section. For a long time, this condition and the load received continuously and repeatedly cause fatigue failure of the frame body and the bolt flange 10x250.

5. CONCLUSION

Based on the results of research and analysis of the methods that have been carried out, it shows that frame body failure occurs because of bolt flange 10x250 fastned with a torque less than the standard. Inthis case, the low torque from the 10x250 bolt flange is due to modifications made by customer when installing additional accessories. Due to the torque on the bolt flange of 10x250, which is less than the standard or low torque, it causes stress in the weakest part of the frame body, on the welding section, which occurs repeatedly, causing fracture or failure in the frame body, which is a fatigue failure.

The advice that can be given based on the results of the research that has been done above is to pay more attention to the torque value on the 10x250 bolt flange on the engine hanger. If a bolt is found in a state of below standard torque, it must be tightened immediately by following the instructions in the Owner's Manual, or it can be taken directly to the nearest authorized workshop for service if an indication of a loose bolt flange is found.

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