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# Fatigue Strength of Rotary Bending Copper Materials

N **Talango[1], S Ishak[2], *N S Dera[3], W Rauf[4]**
[1,2,3,4] Study Program of Mechanical, Faculty of Engineering, Universitas Gorontalo
Ahmad A. Wahab No. 247 Limboto, Kab. Gorontalo

*Corresponding e-mail: santydera@gmail.com novriyantitalango12@gmail.com

**Abstract.** Non-ferrous metal is a type of metal that does not contain iron (Fe). Pure non-ferrous metals do not need alloying elements because of their chemical resistance and good electrical conductivity. The non-ferrous metal in question is copper. Almost every human need can't be separated from the element of copper as a supporting material. In the industrial world, copper has an important role because many factory machinery construction utilizes this material. Copper is a material that conducts heat and electricity quite well and has smooth and soft properties. The durability of copper-based structures can be carried out by fatigue tests (fatigue). This study aims to analyze the fatigue strength of copper material with rotary bending type. The test was carried out on copper material without heat treatment. At each loading, the test was carried out five times on different test specimens (Sp1, Sp2, Sp3, Sp4, and Sp5) with variations in the load determined at 15 kg, 17 kg, and 19 kg. Preparation of test specimens using a lathe and photos of micro and macro structures using a microscope. While the fatigue test was carried out using a rotary bending type fatigue test machine. The results of microstructure observations for all loadings showed that the specimens had soft properties. Meanwhile, the observation of the macro structure shows that the specimen has brittle properties. The results of the fatigue test show that the flexural stresses for each load of 15 kg, 17, kg, and 19 kg are written as 33 kg/mm$^2$, 37 kg/mm$^2$, and 42 kg/mm$^2$, respectively.

**Keyword:** Copper, Micro structure, Macro structure, Fatigue, Rotary bending.

## 1. Introduction

Non ferrous metal is a type of metal that does not contain iron (Fe), where this metal has its own mechanical properties. The use of pure non ferrous metals is usually combined with other types of metals so that their properties fulfill the requirements of the specified standards. However, there are some pure non ferrous metals that do not require alloying elements because of their chemical resistance and good electrical conductivity. The non ferrous metal being referred is copper. Almost every human need cannot be separated from the copper element as a supporting material [1]. So that copper material has a special role in human life and at the same time supports today's technology. In the industrial world, copper has an important role because many factory machine constructions use the material. This is because the mechanical properties of copper materials are very suitable for various work applications based on their efficiency and effectiveness.

Based on its definition, copper is a chemical element which in the periodic table has the symbol Cu and atomic number 29. Copper is a fairly good conductor of heat and electricity, but has a fast corrosion rate [2]. This material has smooth and soft properties and a reddish orange surface which when mixed with tin will produce bronze material. In its application, the use of copper consists of 60% electrical wiring, 20% roofing and piping, and 15% industrial machinery and a small portion is used as a supplement and fungicide in agriculture. Copper utilization is usually in its pure metal element. However, if a higher level of hardness is required, it will be mixed with other materials. Copper material is used as an electrical conductor in almost all types of electrical wire. In addition, copper wire is also used as building cables, automotive cables, magnetic cables, telecommunications cables and so on. The durability of copper-based structures can be tested with fatigue tests

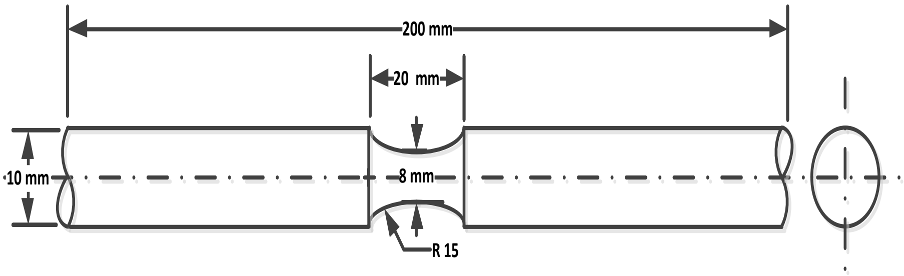


**Figure 1.** Specimen dimensions

Fatigue is a form of failure that occurs in structures caused by dynamic load fluctuations below the yield strength, where these fluctuations occur repeatedly and for a long time [3]. 90% usage failure is caused by the fatigue phenomenon, where there are 3 phases in fatigue fracture, including:

a. Crack initiation
   The process of crack initiation generally starts from crack initiation which is formed on the surface of weak materials or areas of stress concentration on the surface. This is caused by repeated loading.
b. Crack propagation
   Crack propagation usually develops into microcracks, where the combination of these microcracks will form macrocracks which result in failure.
c. Fracture
   Fracture occurs when the material undergoes a stress and strain cycling process that creates permanent damage.

In general, usage failure occurs due to tensile stress resulting in fatigue. The initial process of fatigue occurs when the material receives repeated loads resulting in slip [4]. When slip occurs and the material is on a free surface, there is material displacement along the slip area. When the stress reverses, the slip formed becomes negative (opposite of the initial slip) which has an effect on the appearance of deformation due to repeated loading and the formation of cracks along the slip plane. Basically, the fatigue phenomenon begins with the formation of cracks in the structural material. This indicates that fatigue properties are very susceptible to surface conditions (roughness, changes in properties, surface residual stresses) [5].

The cycle of crack initiation and crack propagation depends on the stress affecting the structure [6]. If the applied stress has a high intensity, the crack initiation time is faster. However, if the applied stress has a low intensity, the entire fatigue life is used to form the initial crack. The crack initiation is usually so small that it cannot be seen with the naked eye [7]. Once a crack appears, the effect of stress becomes greater and the subsequent cracking process will occur more quickly. As the area receiving stress decreases, the remaining material area will fail to resist stress. So overall fatigue failure is characterized by the creation of cracks and sudden fracture with an area similar to the fracture of brittle materials.

## 2. Research Materials and Methods

This research used analysis methods systematically and accurately by applying appropriate procedures. The research procedures include:

### 2.1. Specimen manufacture

The dimensions of the specimens for fatigue testing follow ASTM E466 which is shown in figure 1. The manufacturing process uses a lathe so the dimensions of the specimens obtained are all the same. The copper specimens are shown in figure 2.

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**Figure 2.** Test specimens

*2.1. Rotary Bending testing process*

1. *Install the specimen on the rotary bending machine as shown in Figure 3.*
2. *Installing the load on the rotary bending machine, where each load is determined to be 15 kg, 17 kg, and 19 kg.*
3. *Turning on the rotary bending machine until the test specimen is broken.*
4. *When the specimen is broken, the machine will stop automatically and the test data will be displayed on the logger memory card panel counter as shown in Figure 4.*
5. *Record the rotation results displayed on the panel counter. This is necessary to anticipate if the rotation results are not recorded on the data logger.*

**Figure 3.**Position of test specimen on rotary bending machine


**Figure 4.** Counter panel

The bending stress value formed on the surface of the material can be obtained using the moment of inertia and the transverse distance of the test specimen through the following equation:

$$\boldsymbol{\sigma = \frac{M.y}{I}}$$
$$\boldsymbol{M = W.L}$$
$$\boldsymbol{\sigma = \frac{d}{2}}$$
$$\boldsymbol{\frac{\pi.d^4}{64}}$$

Hence the equation:

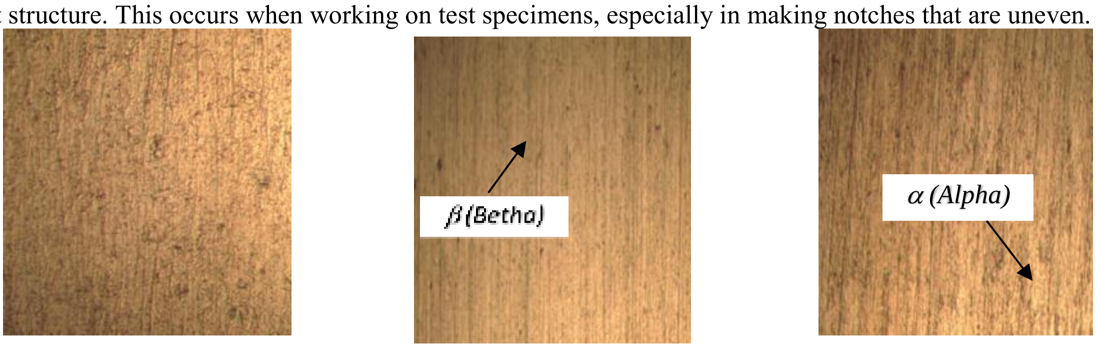
$$\frac{32\, W.L}{\pi.d^2}$$

Where:
σ = Bending stress (kg/mm2)
W = Working load
L = Distance between load and test area (mm)
d = Diameter of test specimen (mm)
π = Phi (3.14)

## 3. Results and Discussion

### 3.1. Microstructure

The results of microstructure observations on copper for loading 15 kg, 17 kg, and 19 kg are shown in Figure 5. It can be seen that the microstructure that occurs in copper (Cu) specimens with loading of 15 kg, 17 kg, 19 kg has a soft structure. This occurs when working on test specimens, especially in making notches that are uneven.




a. 15 kg b. 17 kg c. 19 kg

**Figure 5: Micro structure of copper**

### 3.2. Macro Structure

The results of macro photographs with loading of 15 kg, 17 kg and 19 kg are shown in Figure 6. From the picture it can be seen that fatigue fracture occurs, where from the fracture surface it can be seen that the specimen has brittle properties. This is characterized by the presence of a coastline or a number of ring-shaped lines found on the surface of the fault or fault area.

a. 15 kg b. 17 kg c. 19 kg

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**Figure 6: Macro structure of copper**

3.3. Flexural Stress

The results of flexural stress testing based on average cycles at load variations of 15 kg, 17 kg, and 19 kg are shown in Table 1. At a load of 15 kg, the number of cycles for each specimen Sp1, Sp2, Sp 3, Sp 4, and Sp 5 is sequentially written as 184,966, 162,424, 152,625, 125,807, and 109,463. So that a total of 735,285 cycles and an average cycle of 147,057 were obtained, resulting in a fatigue stress of 33 kg/mm2. As for the load of 17 kg, the number of cycles for each specimen is written Sp 1 as much as 131,721, Sp 2 as much as 130,611, Sp 3 as much as 116,972, Sp 4 as much as 98,911, and Sp 5 as much as 79,611. So obtained a total of 557,826 cycles and an average cycle of 111,565. So the fatigue stress of copper material at a load of 17 kg is obtained at 37 kg/mm2. Meanwhile, for a load of 19 kg, the number of cycles for each specimen Sp1, Sp2, Sp 3, Sp 4, and Sp 5 is sequentially written as 23,715, 20,922, 16,028, 13,966, and 11,742 so that a total of 86,373 cycles and an average cycle of 17,275 are obtained. Thus, the fatigue stress of copper material at a load of 19 kg is obtained as 42 kg/mm2.

**Tabel 1.** Flexural Stress Calculation

| No | Load (kg) | Number of cycle | | | | | Total cycle | Average cycle | A ($mm^2$) | $\sigma$ ($kg/mm^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sp 1 | Sp 2 | Sp 3 | Sp 4 | Sp 5 | | | | |
| 1 | 15 | 184.966 | 162.424 | 152.625 | 125.807 | 109.463 | 735.285 | 147.057 | | 33 |
| 2 | 17 | 131.721 | 130.611 | 116.972 | 98.911 | 79.611 | 557.826 | 111.565 | 50.24 | 37 |
| 3 | 19 | 23.715 | 20.922 | 16.028 | 13.966 | 11.742 | 86.373 | 17.275 | | 42 |

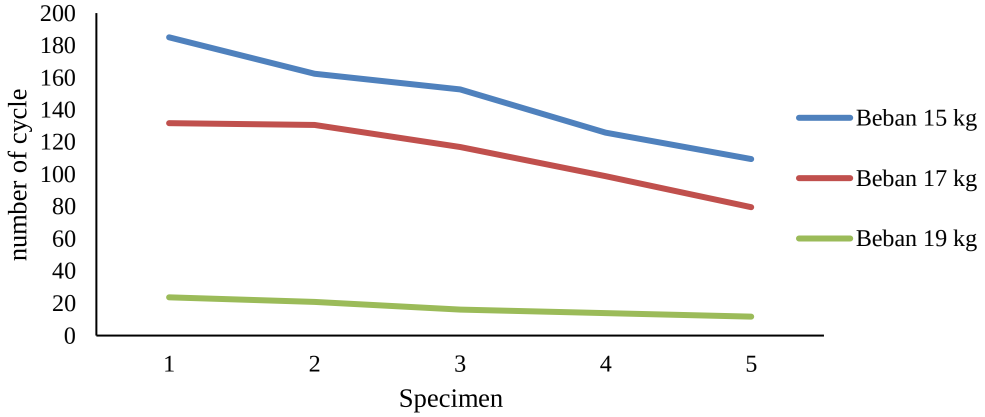


**Figure 5. Number of cycles of various loads**

**4. Conclusion**

Through the research results, it can be concluded that copper material with rotary bending type fatigue testing shows the micro and macro structure of the material has soft and brittle characteristics. While the bending stress for each 15 kg loading is 33 kg/mm2 at an average number of cycles 147,057, 17 kg loading is 37 kg/mm2 at an average number of cycles 111,565, and 19 kg loading is 42 kg/mm2 at an average number of cycles 17,275.

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