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Fatigue Behavior of Copper Under Rotating Bending with Constant Reversed Amplitude

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Abstract Fatigue is a type of failure that affects structures that are prone to dynamic and fluctuating stresses, under cyclic loading over a period of time. It is a type of failure that arises due to the repetitive application of stress. The aim of this study is to find fatigue life, endurance limit of copper metal, study the effect of load distribution on the fracture surface under cyclic bending moments, and find the relationship between hardness and fatigue through experimentation analysis under cyclic bending moments. With a load ratio of (Fully Reversal R=-1) and a constant load amplitude of 60 Hz, the fatigue testing technique was used. According to the results of the experiment, it was determined that the endurance fatigue limit for copper was 86 MPa. Also it indicated that with increasing the applied loads, there were more dislocations and micro deformations and the possibility of deformation of the fracture surface increases. the defect size for the specimens was 17115 µm when utilizing the square root of the defect area as the defect parameter.

Keywords: *fatigue, copper, hardness, amplitude*

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1. Introduction

Copper alloys have been a staple throughout history due to their robustness and ease of manipulation. Their excellent properties make them a great option for many different uses, such as ornamental and structural components, as the metal can be polished to have the same golden hue as gold and can be found in a range of different colors. Additionally, they can be easily worked and machined, which is why they are used for making various items like musical instruments, electrical components, and pipes. Moreover, the S-N curve is seen as a core part of measuring the useful life of materials under cyclical loading.

In a study by Jonan-ku and Fukuoka [1], small structural flaws like graphite nodules and microshrinkage voids have an impact on the fatigue strength of ductile iron. On round-bar smooth JIS FCD400, FCD600, and FCD700 specimens, rotating bending and combined axial and torsional fatigue tests were conducted. The lower bound of the fatigue limit of ductile irons can be predicted using a method that uses the area parameter model to assess the effects of minor defects and matrix structures without doing a fatigue test. In a study by Aldeeb and Abduelmula [2], discussed the test of the fatigue life of S275 mild steel at room temperature The mechanism may fail for a while when subjected to cyclic loading; this is known as the fatigue phenomena. The behavior of the material must be taken into account to develop endurance, the limit of the metal in support of safe design, and infinite life as a result leading to reduced efficient cost and loss of in-person life in order to prevent the fatigue that creates failures. In a study by S. Khalilpourazary et al. [3], The ductile breakage of ultra-fine grain copper with a purity of 99.7% was looked into after it was exposed to equal channel angular pressing. A finite element method based on the Xue fracture model was applied to perform numerical testing of tensile testing for the samples of annealed and ECAPed copper in three passes. The outcomes demonstrate how the proposed model precisely and efficiently predicts the annealed and ECAPed copper damage. a study by S.H. Hoseini et al. [4], examined the ductile fracture of ultra-fine-grained copper. In order to compare the mechanical properties of copper specimens that have been annealed and ECAPed The results of experiments have demonstrated that the stress state has a major impact on fracture behavior and should be taken into consideration in constitutive models. In the ECAPed specimens, the experimental results demonstrate the change from tensile ductile fracture to shear fracture. Additionally, the experimental results show that the Lode angle parameter and stress triaxiality have a notable impact on the ductile fracture of the ECAPed specimens.

In a study by S. Fintová et al. [5], With frequencies ranging from 4 Hz to 20 kHz, pure polycrystalline copper has been exposed to cyclic stress. The S-N curve was altered to a higher number of cycles to fracture with increasing frequency. Analysis of localized cyclic stressing at high strain rates has focused on the creation of cavities as a result of vacancy generation within the slip band. For polycrystalline copper, there were no changes in the fatigue damage process at various frequencies. The distribution of cavities below the surface along the slip plane and the rough surface relief both played a role in the fatigue crack formation. In a study by Peyman Esmaeilzadeh1. [6], To examine how a friction stir-processed (FSPed) copper will fracture. Using the Newton-Raphson, the diffusion-type equation and linear momentum equation that make up the nonlinear coupled system that governs phase-field evolution are simultaneously solved. A fracture model is proposed by connecting the phase-field degradation function to a numerical quantification of plastic strain, and consequently, fracture takes place when the plastic strain accumulates to a certain critical value. Experimental studies are used to verify the outcomes of the numerical simulation. The results show that the proposed model is able to accurately reproduce the sequence of elastoplastic properties of the base material, the distortion caused by the FSP, and the fractures that took place in the samples. A study by Fukun Li1 et al. [7], research at the criteria for metal ductile damage, which is common in constructions subject to significant distortion. It goes from micro-level mechanisms to metal ductile fracture models and examines how the metal ductile damage criteria can be easily implemented in Abaqus FEA for practical applications. Moreover, it outlines a thorough method of incorporating the ductile damage criterion into Abaqus FEA for accurately simulating the process of ductile failure and defining metal degradation and damage. Mohammad Mashayekhi et al. [8], studied demonstrated that finite element simulations and the ductile damage criterion could be used to anticipate the beginning and advancement of breaking in deep drawing of copper/stainless steel clad sheets. A numerical model was used to study the effects of certain significant process factors on the development of damage, and the satisfactory range of changes for every parameter was included to prevent tearing of the blank during the procedure. The deformation and fracture performance predicted by mathematic calculations and experimental results showed good agreement. In a research conducted by N. Bonora et al. [9], the Continuum Damage Mechanics model was used to determine how ductile damage develops. It was discovered that, in the two impact scenarios, the stress triaxiality increases with plastic strain in a distinct way, thus resulting in unique conditions for the beginning of ductile damage. In a study by G. Chiantoni et al. [10], Experiments were conducted to investigate how the triaxiality ratio of various steels and high-grade copper affected the equivalent plastic strain at the point of fracture. Additionally, triaxiality has an impact on the critical damage at rupture and the threshold plastic strain for damage to start is experimentally investigated. The outcomes are evaluated against the damage model's prediction. The CDM prediction and experimental findings exhibit very excellent agreement. In a study by Lucas Lira Lopez Rego et al. [11], Thermography, a non-destructive testing technique, was used determine the S-N curve and the impact of the mean stress on its behavior by connecting an energy parameter with the presumption that it is dependent on the stress amplitude. The findings are given here and demonstrate good agreement between the mean stress-influenced S-N curves and predicted and measured fatigue limits. A study by A. Ghahremaninezhad, K. Ravi-Chandar. [12], to examine the ductile breakdown in polycrystalline oxygen-free, high-conductivity copper, researchers conduct uniaxial tension experiments. By inspecting samples from tests that were stopped at various stages of deformation and ruin progress, they employ quantitative microscopy to identify the processes of failure and the localized strain history. Measuring the alteration in grain size with deformation, they can then figure out the local strain levels. S. Henkel et al. [13], they used Uniaxial and biaxial experiments to examine the low-cycle fatigue behavior of copper and -brass CuZn30. The use of cruciform samples with proportional stain pathways and phase shift between the two axes allowed for the execution of planar biaxial fatigue testing. Electron microscopy and high-resolution Xray line profile analysis were both used for microcharacterization. The von Mises equivalent strain theory demonstrates good agreement between the biaxial cyclic stress-strain curves and the uniaxial ones. However, the biaxial case's dislocation density and microhardness values exhibit much lower values when compared to the uniaxial case at equal von Mises stresses. To assess how workpiece dimensions and grain size influence the material flow conduct in meso/micro-scale plastic deformation, B. Meng, M.W. Fu. [14] conducted a uniaxial tensile test on uniform copper sheets of different thicknesses and similar microstructures. The results of the experiment demonstrated that when the thickness of the specimen in relation to the grain size is diminished, the material flow strain, fracture stress and strain, and the number of microvoids on the fracture surface all decrease. In a study by Ridha Mnif et al. [15], Brass's fatigue behavior was investigated at a constant deformation rate to better understand its cyclic behavior and fatigue life when subjected to cyclic torsional strain. It was discovered that the strain amplitude has a significant impact on the cyclic hardening/softening behavior in the as-drawn condition. A short quasi plateau region in the moderate amplitude range was visible on the CSS curve, which displayed three separate sections. Microscopic measurements of surface cracks were used to quantify fatigue damage. An experimental program was run by Ridha Mnif et al. [16], To investigate into the outcomes of extremely high tension and prestrain on the durability and destruction conduct of brass alloy subjected to cyclic twist stress, a few fresh specimens were evaluated under fully-inverted strain control and consistent amplitude fatigue torsional burden until breakdown. The experimental results demonstrated that the prestraining type and strain amplitude had a significant impact on the fatigue life (monotonic or cyclic). Additionally, all experiments with periodic overstrain showed a positive impact on the fatigue life. In order to simulate simulation models of cylindrical voids by Maxim Zapara et al. [17], various arrangements of pre-drilled micro-holes in the specimens were subjected to uniaxial tension testing. For the evaluation of damage in the deformed material, two metrics are used. In the first, damage is associated with a rise in the void volume. The second measure compensates for the harm brought on by a modification in the void's shape. To examined the fatigue initiation life. M. Zheng et al. [18],evaluated specimens on the Instron 1341 machine at a frequency of 30 Hz, Additionally, the energetic method predicts the fatigue crack start life of this fine brass H62. found that an accurate estimate of the fatigue crack initiation life was provided by the energetic technique. In a study by C. Fang et al. [19], examines the pliable fracturing process of zirconium alloys in different pressure conditions, making use of a cohesive zone model that is contingent upon triaxiality. According to the findings, the presence of hydrides causes the crack to spread more quickly and lowers the post-peak load level. These simulation results shed light on zirconium alloys' resistance to crack propagation during ductile fracture. In a study by Mohammed Saad Abbas et al. [20], It was suggested to use a TMF (thermomechanical fatigue) damage model to forecast the high-temperature fatigue lifespan of the C46400 navel copper alloy. The damage caused by the interplay of high temperatures and fatigue was modeled using the stress-number of cycles curve. The comparison between the obtained prediction and the whole experimental TMF data was quite favorable. a paper by Martinez-Cazares G et al. [21], outlines a technique for estimating the rate at which cracks form and expand in steel subjected to rotational bending fatigue tests. Experiments were conducted in which the original load stayed static until a crack showed up, and then it decreased as the crack extended. This technique utilizes a deflection that is dependant on a material's elastic modulus instead of its yield strength, and the association created to guess the mean crack length as a function of the instantaneous load is unconnected to the pressure exerted or the type of steel utilized. In a study by Seifi R and Hosseini R. [22], explored the behavior of cracking in copper of 99.9% purity when cyclically loaded in various conditions. The fatigue life, crack growth rate, and constants of the Paris law and Dowling equation were all examined. Results revealed that, the Paris law parameters were dependent on the load ratio, whilst when graphed against, these parameters stayed virtually the same. In investigation by Deguchi T et al. [23], fatigue assessments were conducted on ferritic-pearlitic malleable cast iron specimens, some with circumferential notches and others without them, to quantitatively gauge the effects of the flaws. Both bending and tension-compression tests were employed. Through microscopic examination of fracture expansion close to the fatigue limit, it was discovered that the fatigue limit was based on the boundary for the spread of a tiny fracture originating from graphite particles. The stress ratios were R = -1 and 0.1.

Since copper alloys possess a strong life fatigue, it is necessary to conduct more research with both experiments and computer simulations to fully comprehend the complex ductile damage that was revealed in previous studies.

Three main objectives, which were fully explored through experimentation and simulation of ductile damage in copper alloy, are presented and discussed in this study. The following are these three main objectives: (1) To find the number of fatigue cycles a copper alloy can withstand by doing fatigue testing and plotting the S–N curve. (2) to study the relationship between hardness and fatigue. (3) Study the effect of load distribution on the fracture surface under constant bending rotating amplitude.

The initial segment of this study elucidates the principles used to establish the damage model parameters for the tension test. The next section examines the fatigue specifications and then employs them to build an S-N curve and damage surfaces. The third part briefly outlines the association between hardness and fatigue. The last part summarizes the results and provides a conclusion.

Requirements for Ductile Damage and Analytical Equations:

Common metal fracture mechanisms for ductile fracture metal modifications brought on by precracking include the following:

(a) Ductile fractures that result from void coalescence, growth, or nucleation act as microcracks and finally cause failure.

(b) intergranular fractures occur Through the borders of the grains(c) Brittle fractures, Crystallographic planes are separated during cleavage.

Ductile fracture is an important concept to understand when it comes to copper alloys. It is a type of failure that occurs due to the sudden release of stored energy in the material, creating a fracture that can be seen in the form of cracks or fractures.

Ductile fracture is a common phenomenon in copper alloys, and it is important to understand its causes and effects in order to prevent and manage it. The ductile damage characteristics include the comparison of hydrostatic stress and equivalent von Mises strain, fracture strain, strain rate, as well as the material's elastic and plastic capabilities.

When a ductile metal fails, it goes through three distinct stages: firstly, the metal starts to bend due to its elastic properties, which are generally linear (stage one); then it begins to experience plastic deformation (stage two) which culminates in complete fracture (stage three). [24]

Constant Amplitude Fatigue:

In addition to being necessary in all electrical installations, copper alloys are frequently used in the construction of pressure vessels, distillation apparatus, piping systems, and gaskets. Dynamic fatigue can affect these applications. Two major criteria can be used to classify fatigue cycles. [26]

1- Low-cycle fatigue is a fatigue process that involves major plastic distortion and is characterized by a restricted quantity of cycles, with a life span that is comparatively brief. This type of fatigue typically has a range of 10 to 100,000 cycles. Low-cycle fatigue is known for its intense stress amplitude and low frequency. This pressure causes both elastic and plastic deformations. Because of the plastic distortion in LCF, breakdown will take place in a lesser number of cycles compared to high-cycle fatigue.

2- High-cycle fatigue, which is caused by very small deformation of material under a great number of loading cycles before failure, a strain that is limited to the elastic region and has a greater duration of fatigue life, surpassing 100,000 cycles.

Fatigue analysis is used to determine the magnitude of the sine waveform, which is a repetitive cycle of complete reversals with a certain level of stress and intensity (R=-1, $\mu_a = 0.45$). Using a Fourier series, the amplitude can be computed as shown below:

$$\mu_a = A_0 + \sum_{n=1}^{N}\left[A_n \cos n\omega(t-t_0) + B_n \sin n\omega(t-t_0)\right] \quad \text{(Eq 1)}$$

where, in this instance, a sine wave is used as the equation parameter $A_n = 0$, the first time change ($t_0 = 0$) $A_0 = 0$, $A_1 = 0.45$ where $N = 1$. the phrase "frequency" in rad/sec when $(\omega = 2\pi f)$. the (f) frequency is termed in Hz The frequency used is $60Hz$

Basquin Equation:

Gathering evidence of fatigue damage over multiple cycles is a lengthy and expensive process in numerical research. To save time and resources, a numerical investigation is conducted on a small section of the actual loading history. The remaining data can then be estimated for multiple cycles with the assistance of empirical solutions such as the Basquin equation. [27] This equation is commonly used to describe the S-N curve.

The Basquin equation is a mathematical equation that is used to predict the fatigue limit of copper. It takes into account the type of loading applied, the environmental conditions, and the type of copper alloy.

The Basquin equation is written as follows:

$$\sigma_a = \bar{\sigma}_f \, (2\text{N})^m \quad \text{(Eq 2)}$$

Where $\bar{\sigma}_f$ is the fatigue strength of the material, N is the number of cycles, and m is the slope of the fatigue s-n curve.

The Basquin equation is used to calculate the fatigue limit of copper for a given number of cycles. This is done by entering the parameters of the fatigue s-n curve into the equation and calculating the fatigue limit for the given number of cycles. The Basquin equation may typically be used to directly compute the plastic deformation brought on by high-cycle low-strain fatigue. [34]

2. Material and Methods

A. Specimen Preparation and Geometry:

In this study, the fatigue strength and tensile strength of brass at 240°C in the lab are taken into consideration. The flat bars that made up the material were supplied by College Workshop's warehouse, and careful fabrication of the constant radius between ends was done there using a Zwick CNC. The specimens' geometry for fatigue was created in accordance with the DIN standard, and the specimens' geometry for tensile was created in accordance with ASTM-E-8-YR-13. [28] as well as the chemical compositions shown in Table 1.

Table 1. Chemical composition of copper [29]

%Cu	%Zn	%Pb	%Sn	%Fe	%Ni	%Li
58.47	38.11	2.79	0.25	0.21	0.11	0.06

B. Tensile test:

Mechanical parameters of the material must be defined in order to provide baseline information for fatigue testing and analysis. The most common method for determining the mechanical parameters of isotropic materials is the tensile test (uniaxial). For high experimental accuracy, the tensile test run was carried out at 240°C by computer-aided universal testing equipment tensile testing machines from ZwickRoell. Tensile sample preparation followed the ASTM-E-8-YR-13 standard. According to the average of three micrometer measurements, the diameter of the uniform gage test section was 8.0 mm. In Figure 1 the tensile specimens are displayed. Three samples of tensile strength were measured, and the mean values were used as the basis for the study. The speed of the machine was 10 mm/min.

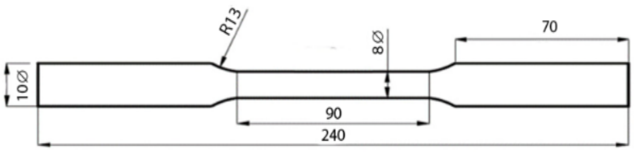

Figure 1. Tensile test specimen dimensions (mm)

C. Hardness test:

The C.A.M.S. Computer Assisted Measuring System from Newage Instruments was used in this test to observe and measure test impressions created by a microhardness tester using a video camera attached to a PC, as shown in Figure 2. Through the employment of a digital micro hardness testing device (H.V.) with a load of (500 g) and a dwell duration of 15 seconds, a sample's microhardness is evaluated. The specimen used has dimensions of (Ø 10 mm*6 mm). Three readings on average were used as the measurement of 0.5 (μm).

Figure 2. auto C.A.M.S hardness test

D. Roughness test:

International standards are extremely precise when it comes to defining the mathematical meaning of surface roughness characteristics. The choice of a number of parameters that the metrologist can adjust, however, is crucial to attaining the "right" result. Taylor Hobson is surface roughness, contour, and waviness measurement equipment with low noise, A vertical resolution range of 1mm / 16nm is available on the device. A roughness test was performed to confirm the consistency of the tested surface during fatigue, a stylus probe type instrument is used.

The average result across all samples Ra = 0.5 (µm).

Figure 3. Taylor Hobson Talysurf surface roughness testing test

E. Fatigue test:

The fatigue limit is a critical factor in the design of components and structures. It is a measure of the maximum stress that a material can withstand without failing when subjected to repeated cyclic loading. Fatigue limit is usually expressed as a percentage of the ultimate tensile strength of the material. There are several factors that affect the fatigue limit of copper. These factors include the type of copper alloy, the grain size of the material, the surface finish, the type of stress applied, and the environmental conditions. The surface finish of the material is also important, as smooth surfaces generally have higher fatigue limits than rougher surfaces.

The type of stress applied to the material also affects the fatigue limit of copper. Cyclic loading, which is the application of repeated stress, is the most common type of loading for determining the fatigue limit of a material. The type of cyclic loading, such as bending or rotating amplitude, also the Temperature and humidity in which the material is used affects the fatigue limit of copper.

Figure 4. The specimens brass on fatigue device WP 140

According to the Machines manual, brass specimens for the fatigue test were manufactured as indicated in Figure 4 and the dimensions of a fatigue specimen are illustrated in the Figure 5. An alternating bending standard rotating bending fatigue testing machine (WP140), shown in Figure 6 was used to test the specimens in order to produce the S-N curve.

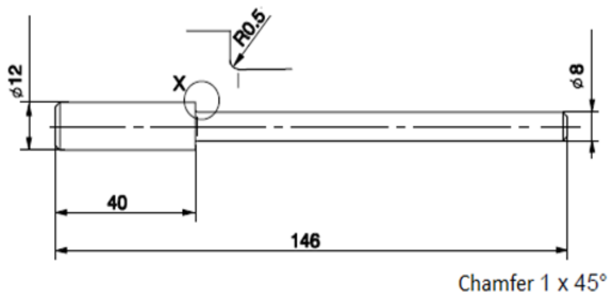

Figure 5. Fatigue test specimen dimensions (mm)

Fatigue tests were performed on the Gunt WP-140 from GUNT Hamburg, GmbH with a rotating bending load type and stress ratio (R = -1) 240 °C in the laboratory with a rotating sample clamped on one side. The sample was loaded by an alternating, sine-shaped bending stress while the load was gradually reduced from the maximum value of F = 120 N corresponding to $\sigma_a = $ 240 N/mm2. As a result, an alternating stress was created in the cylindrical sample. The machine frequency was 60 Hz, and machine speed was 3545 RPM. Cycles of (1×10*6) cycles were considered a run-out test. Also, the stress-number of cycles to fail (S-N curve) was plotted.[30]

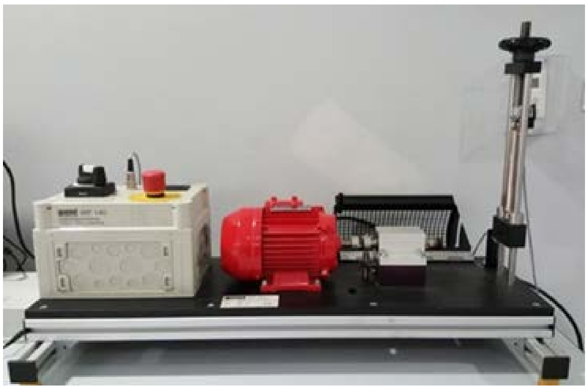

Figure 6. rotating bending testing machine (WP 140)

Relation between fatigue and hardness:

The relationship between fatigue and hardness is an important factor to consider when determining the fatigue limit of a material. Hardness is a measure of the resistance of a material to permanent deformation, and it is typically expressed in terms of the Brinell scale.

Hardness and fatigue are related in that the higher the hardness of a material, the higher its fatigue limit. This is because harder materials are more resistant to deformation and can therefore withstand higher levels of stress before failing.

In an effort to determine the fatigue limit of a material with flaws of several hundred micrometers or greater, Murakami et al. demonstrated using equation (3), it was demonstrated that the fatigue limit could be precisely predicted for the material with faults less than 1,000 μm.

$$\sigma_w = \frac{\alpha(HV+120)}{\sqrt{area}^{1/6}} \quad \text{(Ep3)}$$

a is a coefficient that changes depending on where a defect is located: it equals 1.43 if the fracture origin is close to the surface and 1.56 if it is inside. $\sqrt{area}$ of which the unit is μm is the square root of the area found by extrapolating the defect to the main stress surface that is the greatest. [31].

3. Result and Discussion

A. Tensile test Results:

To guarantee that the tensile test was conducted under quasi-static conditions, a constant strain rate of 0.000694 s^{-1}. Testing on the materials continued until damage.

The usual mechanical properties, such as elastic modulus, 0.2% offset yield strength, and ultimate tensile strength, were found when we investigated the mechanical characteristics of copper. Table 2 show the mechanical properties of copper, which were determined by analyzing the stress-strain curve.

Table 2. Tensile test results

Properties	Value
Density	8520
Young's modulus (GPa)	77
Yield strength (MPa)	360
Ultimate strength (MPa)	557
Fracture strain	0.0543
Strain rate, (mm/mm)/s	0.000694
Poisson's ratio	0.34
n	0.19
K MPa	954
Elongation %	10.78

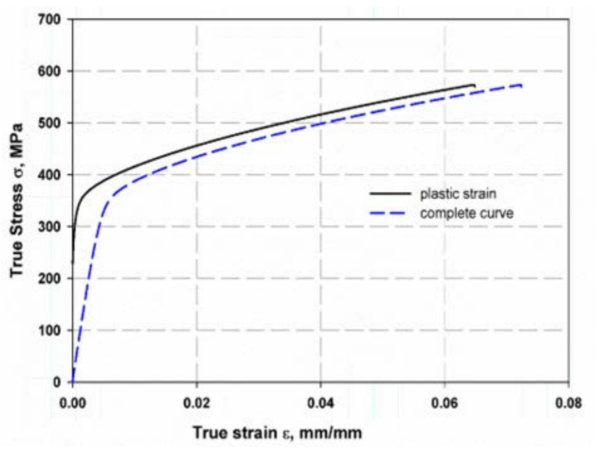

Figure 7. Stress and strain relation for tension test

As a result, Copper has an elastic elasticity of 77 GPa. The maximum tensile strength is 557 MPa, and the 0.2% yield strength is 360 MPa. The relationship between true stress and true strain, as depicted in Figure 7. Copper had a low strain hardening of 0.19, and the stress hardening (K) is 954 MPa. A high ductility level can be seen, making it ideal for use in most instruments, electrical components, and pipelines. These findings are quite in line with earlier literature.

Fatigue Behavior:

Before the fatigue test, a roughness evaluation was conducted to make certain that the surfaces of the test samples were of the required roughness. In order to calculate the fatigue limit of the applied copper in terms of a stress-number of cycles to failure (S-N) curve, a rotating bending fatigue testing machine was used. On a copper sample, rotating bending fatigue testing with a load ratio of R = -1 and a frequency of 60 Hz was performed to collect experimental fatigue data. Based on the experiment's results, the relationship between stress amplitude and fatigue life is plotted on a logarithmic scale to show the significance of fatigue strength at different stress levels. To define the material fatigue behavior, the data gathered from the experiment has been utilized to fit it into the power law equation, also known as the Basquin Equation. This equation is commonly used to describe the S-N curve. The equation of copper according to Basquin, which is derived from the least squares regression line, can be restated in this manner:

$$1659(2N)^{-0.2} \quad \text{(Eq 4)}$$

Table 3. The number of cycles of stress experienced by the samples

No	Stress (MPa)	Number of Cycle	Standard deviation
1	240	12073	197.989
2	220	12900	353.553
3	180	16285	424.264
4	120	461591	707.106
5	80	1086316	848.5281

The results obtained from the experimental work shown in table 3, it is shows that as the applied load decreases, the number of cycles increases. This trend continues until the material reaches its endurance limit, at which point the area or zone below the endurance limit becomes incapable of failing. At High Cycles Fatigue HCF, it was found that copper's endurance limit is 86 MPa as shown in Figure 8-b.

maximum stress that was seen on the specimen when a force of 120 N was applied. It found that a weight of 120 N resulted in a stress of 240 MPa. The fatigue life of a 120 N applied load was determined to be 12073 cycles with a 197.989 standard deviation over a period of time of 3.41 min. While it was found that by reducing the applied load to 110 N, we obtained a fatigue life of 12900 cycles over a period of time of 3.64 min and a standard deviation of 353.553. When reducing the applied load to 90 N, the fatigue life of the sample occurred at 16285 cycles, where the standard deviation was 424.264 with a longer period than the previous sample at 4.6 min. When applying the load of 60 N, the fatigue life doubled about 30 times what it was at the previous applied load, reaching 461591 cycles, where the standard deviation was equal to 707.106 within a period reaching 130.32 min. The minimum load was applied at 40 N, as it reached 1,086,316 cycles in a period of more than 306 minutes with a standard deviation estimated at 848,5281.

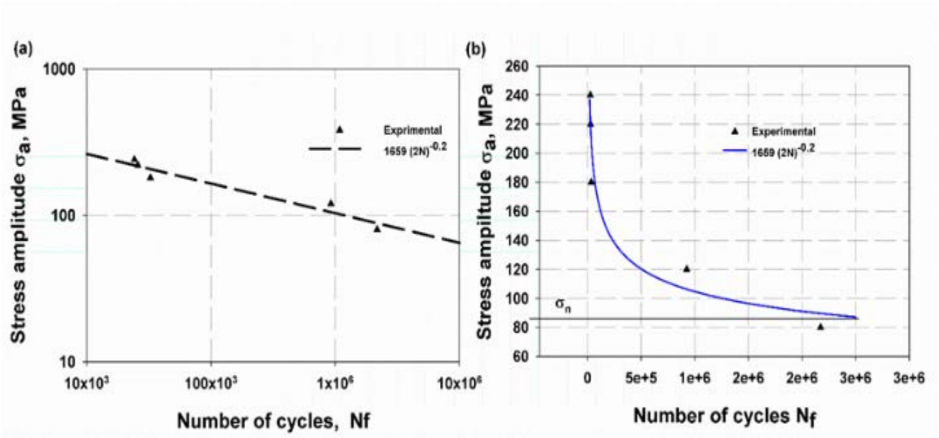

Figure 8. S-N curve for copper rotating bending fatigue (a) log-log (b) complete scale

the fatigue limit on the experimentally maximum stress load (240MPa) is (12073) and on the minimum stress load (80MPa) is (1086316) as the average results of the values, and this is in accordance with previous literatures. To prevent unexpected damage, industrial firms invest significant funds in developing safer and more effective component designs. They leave no stone unturned to ensure that their products are fabricated with the utmost care and attention to detail. The research conducted has successfully determined the fatigue strength of copper.

Fracture analysis of fatigue specimens

There is a fundamental coherence between the quasi-static material qualities, such as yield strength, and the macrohardness. It is necessary to investigate the position-dependent hardness in order to set up Murakami's area mode consistently for the investigated specimen series. Vickers hardness measurements are thus performed using a testing force of 500 g at room temperature.

The local Vickers hardness HV is considered in Murakami's area model because it has a strong correlation with fatigue strength. Therefore, it is necessary to investigate the local hardness at the sample places. The square root of the effective defect area and other geometrical metrics are used to describe the observed crack-initiating faults. The square root of the projected area of the flaw, perpendicular to the load direction, serves as a measure of the size of fatigue fracture-initiating defects.[32,33,34,35,36,37,38,39]

When the fracture surface was examined on a macroscopic level, it became clear that loads had a big impact on the fracture surface's macroscopic appearance. (Figure 10) shows the specimens' resulting fracture surfaces based on the chosen load configuration. Its ability to alter shape based on load was given careful consideration.

In the case of the load (40 N), it is possible to clearly differentiate two zones (Figure 10a). This indicates that the load's impact is concentrated in this area, which is highlighted in black. In other words, it can be said that the area in which the load is concentrated is equal to the area in which the effect of the load is weak. This is one of the reasons for the sample's resistance to fracture. dimples were apparent in the black area, which may be a sign that the highest primary stresses (or strain) predominated in the fracture process. In the black region of the fracture surface, the presence of dimples can be observed, indicating the concentration of the load in the region, which resulted from the load applied in the form of a bending moment.

The white area of the load case decreased as the black area on the fracture surface increased (60 N). When subjected to a load of (90 N), the fracture surface's form completely changed, and a larger load distribution was present. A similar shape was also obtained for the load (110 N), demonstrating that the sample damage process will proceed more quickly with these load configurations on the fracture surface than with the prior load distributions. In the case of the load (120 N) load, we notice an almost complete spread of the black color area, which indicates a uniform distribution of the load along the fracture surface, and this accelerated the sample damage process.

When comparing images from Figure 9, it is possible to see the fatigue damage effect due to how closely spaced and nested the dislocations are in Figure 9a, which has fatigued to 1086316 cycles, compared to Figure 9e, which has fatigued to 12073 cycles. It was also noted that there were more dislocations and micro deformations overall.

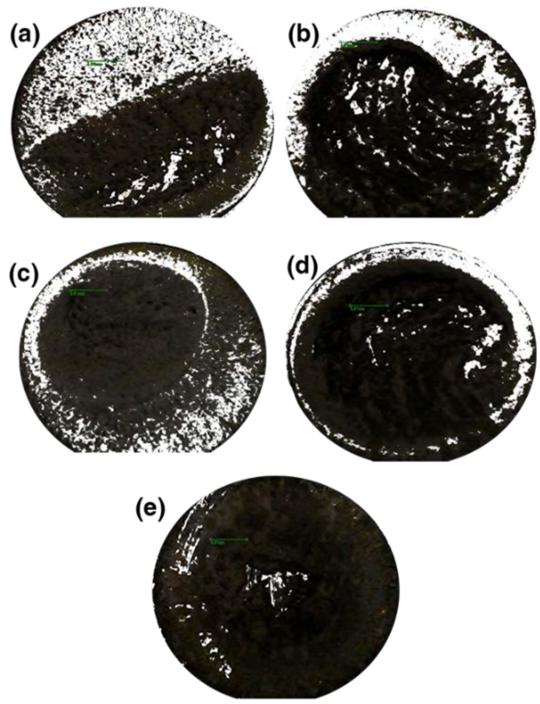

Figure 9. fracture surface of the samples. (a) load applied (40 N). (b) load applied (60 N). (e) load applied (120 N). (d) load applied (110 N). (c) load applied (90 N)

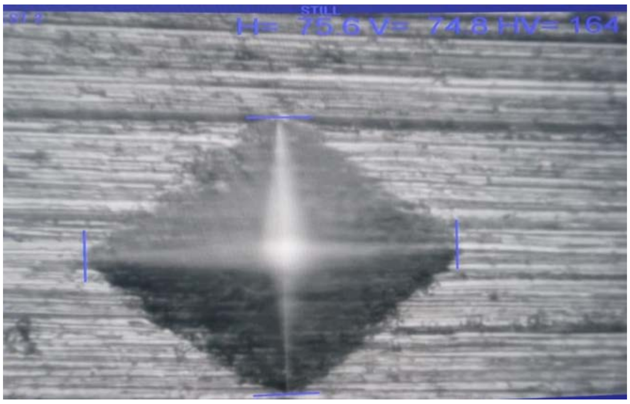

Figure 10. Pictures show the hardness of brass sample

Hardness test Results

The square root of the defect's area is one of the various defect parameters that could be defined for analyzing the faults. The hardness test result, as shown in Figure 10, was 164 (Kg/mm) with a load of (500 g) and a dwell time of (15 seconds). Equation (3) can be used to get the area's square root while the rotational bending loading condition is present. The defect size for the specimens was 17115 µm when utilizing the square root of the defect area as the defect parameter.

4. Conclusion

Copper alloys have more competitive properties due to their robustness and ease of manipulation. The fatigue limit of copper can be predicted using the Basquin equation, which takes into account the type of loading applied, which was used in this study, as it gave us a fatigue limit value of approximately (86 MP). The fracture surface of the sample is affected by the loads applied to an alternating rotating bending fatigue machine. According to the results of the experiment, a significantly faster failure of fatigue life can occur under high amplitude loading, as opposed to low amplitude loading, as a result more dislocations and the possibility of deformation of the fracture surface increases. Through the microscope images that were taken of the fracture surface, it was observed that at high loads the affected area is larger, while its concentration is confined to one side of the surface at low loads. Finally, the relationship between fatigue and hardness is important to consider when determining the fatigue limit of a material, the defect size for the specimens was 17115 µm when utilizing the square root of the defect area as the defect parameter.

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