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Experimental investigation on the various factors which influences the fatigue-life of brass materials

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ABSTRACT

Brass alloy is widely used because of some attractive properties such as high electrical and thermal conductivity. But its fatigue performance is not very well explored in literature. Thus, in the present work, particular emphasis was given to the fatigue behavior of brass of composition 70%-CU and 30%-ZN has been investigated with the aim of studying the factors such as annealing, corrosion and surface roughness which influence the fatigue-life of brass materials. The endurance limit of the specimens have been determined by testing under different loads on the fatigue testing machine and the life cycles of each specimens has been taken after failure of the specimen. Endurance limit is defined as the alternating stress that causes failures after some specified number of cycles. This study or investigation with the aim of studying the factors such as corrosion, annealing and surface roughness which influence the fatigue-life of brass materials has been investigated. Annealing was done by heating the specimens at temperature of 480 ^{0}C for 1 hours and then allowing the specimens to cool in the control atmosphere for 3 days. Fatigue test for annealed specimens was done and change in the fatigue endurance investigated. The specimens of groove 1 mm was prepared and the endurance limit of the specimens have been determined by testing under different loads on the fatigue testing machine and the life cycles of each specimens has been taken after fracture occurs on the specimen. Corrosion attack was obtained by immersion of specimens in an salt water for 14 days in order to investigate the effect of corrosion on the fatigue-life of the material. The corrosion agent was a solution of NaCl with a PH close to 6.5-6.8 and solution concentration of 38%.Fatigue test at a revolution of 2800 R.P.M at room temperature and without environment humidity control was carried out on the pre-corroded and non-corroded specimens in order to investigate the corrosion effect on the fatigue endurance Finally, conclusion is listed concerning change in fatigue-life behavior due to annealing, groove and corrosion attacks of surface of the brass materials.

I. INTRODUCTION

Most of engineering failures about 90% are mainly due to fatigue in which the components are subjected to fluctuating or cyclic loading such as suspended bridges, rails, or airplane wings. Though the fluctuating load is normally less than the yield strength of the materials, it results in fracture behavior which is more severe than that achieved from static loading. Fatigue failures are therefore unpredictable, and provide high-risk situations, if the operators are not aware of material behavior when subjected to fatigue loading. Fatigue failure is defined as the tendency of a material to fracture by means of progressive brittle cracking under repeated alternating or cyclic stress of intensity considerably below the normal strength. Although the fracture is of brittle type, it may take some time to propagate, depending on both intensity and frequency of the stress cycle. Nevertheless, there is very little, if any warning below failure if the crack is not noticed. The number of cycles required to cause fatigue failure at particular endurance strength is generally quiet large, but it decreases as the stress is increased.

A good example of fatigue failure is breaking a thin steel rod or wire with your hands after bending it back and forth several times in the same place. Another example is an unbalanced pump impeller resulting in vibration that can cause fatigue failure. The purpose of studying basic fatigue mechanism is to understand the process leading to fatigue failure. Without information about these mechanisms it is difficult to design materials with improved fatigue resistance. The fatigue resistance is measured by the number of cycles (N) a material can resist an imposed load before it fails. Cyclic loading in general has no repeated patterns or in situations where overloading occurs as seen in figure 1(a). However, in order to investigate the fatigue behavior according to engineering purposes, a simple relation between stress and number of cycles to failure (time) can be expressed in a sinusoidal curve. Fatigue behavior of materials can thus be practically described according to the parameters given as follows;

- Maximum stress (σ_{max})
- Minimum stress (σ_{min})
- Stress range ($\Delta\sigma = \sigma_{max} - \sigma_{min}$)
- Mean stress = ($\sigma_{max} + \sigma_{min}$)/2
- Stress amplitude = ($\sigma_{max} - \sigma_{min}$)/2
- Stress ratio = ($\sigma_{min} / \sigma_{max}$)

1.1 PROBLEM STATEMENT

It has been estimated that at least 75% o all machine and structural failures have been caused by some form of fatigue (Richard G. Budynas, 1998). Fatigue failures occur most often in moving machinery parts, example shafts, axles, connecting rods, valves and spring. However, the wings and fuselage of an airplane or the hull of a submarine are also susceptible to fatigue failures because in service they are subjected to variations of stress. As it is not always possible to predict where and when fatigue failure will occur in service and because it is essential to avoid premature fractures in articles such as aircraft components, it is common to do full-scale testing on aircraft wings, fuselage, engine pods and others. This involve supporting the particular aircraft section or submarine hull or car chassis in jigs and applying cyclically varying stresses using hydraulic cylinders with specially controlled valves. According to the problems stated above, there are two main problems related to this research which are:

1. When component breakdown down time is inevitable.

2. Unable to predict the time for preventive maintenance.

1.2 OBJECTIVE OF RESEARCH

The objective of this research is to investigate on the various factors which influence the fatigue life of a Brass material.

II. LITERATURE REVIEW

Hani Aziz Ameen et. Al.[1] studied the effect of short and long cracks for brass alloys specimens exposed to bending cyclic load was investigated, this test applied on a group of standard specimens until its fracture, data taken could be drawn as a curve between stress and number of cycles (S-N) curves which gives the fatigue limit. Results obtained theoretically and experimentally, that were concluded decreasing in the applied load cause increasing the age and applying high loads in the beginning and at the end given almost smaller number specimen age and the quick growth of short cracks followed by quick growth of long cracks, that the values taken from the theoretical equations were always greater than experimental number of cycles of failure.
G. Li et. Al.[2] This paper reviews expressions to quantify fatigue lifetime for four copper alloys, Cu-Ag-P, Cu-Cr-Zr, Cu-Ni-Be and Cu-Al_2O_3. These property models were needed to simulate the mechanical behavior of structures with copper components that were subjected to high heat flux and fatigue loading conditions, such as molds for the continuous casting of steel and wall in a fusion reactor
W. Knapp[3] analyzed the results of a study of the effects of grain size and environment on the fatigue life of OFHC copper specimens.

Tests conducted in alternating torsion on specimens of two different grain size groups showed that an increase in specimen grain size results in a decrease in fatigue life at both high and low strain amplitudes. Similar tests under low and high humidity showed that humidity has a negligible effect on fatigue life for either high or low strain amplitude and for large or small grain size. The effects of elevated temperatures were found to be more complex.

Ahmad Fitri Bin Zainal Abidin[4] Investigated about the endurance limit of aluminum, brass and mild steel that had been done at the surface of the specimens on different surface roughness. The endurance limit of the specimens have been determined by testing under different loads on the fatigue testing machine and the life cycles of each specimens has been taken after crack occur on the specimen. The different surface roughness will give different life cycles. Then, comparison of the result needs to be done to get the best materials on different surface roughness to create a good choosing of materials in industry.

III. EXPERIMENTATION TEST EQUIMENT, SPECIMEN PREPARATION, AND TEST PROCEDURE

3.1 Test Equipment

3.1.1 Fatigue Machine :-The rotating bar fatigue testing machine is shown in the figure1.Two separate test bars can be clamped at same time , one at each end of revolving shaft , one end of the test bar is fixed in clamping sleeve , the other being loaded through a bearing with dead weight.

The number of revolutions are read off from the revolution counter, actuated by the shaft, when rupture occurs in one of the bars, the bearing and weight fall down , where as the clutch disengage the corresponding revolution counter when the other test bar breaks , it's revolution will be disengaged and at the same time current supply is cut-off thus causing the machine to stop .

Figure 3.1.1:- Fatigue testing machine

Figure 3.1.2:- Fatigue specimen.

3.2. Materials and equipment

3.2.1 Fatigue specimens

3.2.2 Micrometer or vernier caliper

3.2.3 Permanent pen

3.2.4 Fatigue testing machine

3.3 Specimen Preparation

3.3.1 Material

The material selected for these experiments was Brass .The specifications of this Brass are Copper: **-** 70 percent.

Zinc: **-** 30 percent.

This Brass was purchased in the form of rod of diameter 19mm and length of 190mm.

Alloy	Modulus of Elasticity, E (GPa)	Onset of 1st yield $\sigma_{critical}$ (MPa)	Yield stress, $\sigma_{0.2}$(MPa)
Cu-70%,Zn-30%	110	47	96.3

Brass has higher malleability than Bronze or Zinc. The relatively low melting point of 900°C to 940°C ,depending on composition and its flow characteristic make it a relatively easy to cast. The density of Brass is approximately 8.4 to 8.73g/cm^3.

3.3.3 THE HARDNESS TEST

Hardness may be defined as resistant of metal to plastic deformation (usually) by indentation. Hardness is one of the most basic mechanical properties of engineering materials. Hardness test is practical and provide a quick assessment and the result can be used as a good indicator for material selections. The main source of error with indentation tests is the strain hardening effect of the process.

However, it has been experimentally determined through "strain less hardness tests" that the effect is minimal with smaller indentations. Surface finish of the part and the indenter do not have an effect on the hardness measurement, as long as the indentation is large compared to the surface roughness. This proves to be useful when measuring the hardness of practical surfaces. The indentation techniques used in experiment involve Brinell hardness test.

The Brinell hardness number (BHN) is expressed as the load P divided by the surface area of the indentation. This is expressed by the formula,

$$BHN = \frac{P}{\pi \times D \times .5 \times \left(D - \sqrt{(D^2 - d^2)}\right)}$$

Where, P = is the applied load (kg).
D =is the diameter of the steel ball (mm).
d =is the diameter of the indentation (mm).

Generally, the metal surface should be flat without oxide scales or debris because these will Significantly affect the hardness values obtained. A good sampling size due to large steel ball diameter is advantageous for materials with highly different microstructures or micro structural heterogeneity. Scratches or surface roughness have very small effects on the hardness values measured

Fig: 3.3.3.1- A Brinell hardness testing machine**.**

Figure 3.3.3.2 –Brass specimen indentation after Brinel hardness test.

3.3.4 Annealing

The machined and polished specimens were then annealed in groups of 5 in a furnace at temperature of 490*c and constant temperature is maintained for 1 hour. And then cooling was in control atmosphere of furnace for the three days

Figure 3.3.4.1-Muffle furnace

Figure 3.3.4.2-Annealine fatigue test pieces of brass materials

3.3.5 Groove

The machined and polished specimens were then a groove of 1mm is made at neck of 5 test pieces. Introduction of groove in specimens act as stress raisers.

Figure 3.3.5.1 –Groove (1mm) fatigue test pieces of brass materials

3.3.6 Corrosive

Corrosive environment have negative effects on fatigue properties of the materials as they accelerate faster rates of both fatigue initiation and propagation. Corrosion attack was obtained by immersion of specimens in an salt water for 14 days in order to investigate the effect of corrosion on the fatigue-life of the material. The corrosion agent was a solution of NaCl with a PH close to 6.5-6.8 and solution concentration of 38%.Fatigue test at a revolution of 2800 R.P.M at room temperature and without environment humidity control was carried out on the pre-corroded and non-corroded specimens in order to investigate the corrosion effect on the fatigue life .Humidity has a negligible effect on fatigue life .The relative humidity (19.5% to **100%)** has only a negligible effect

Figure 3.3.6.1 –Corroded fatigue test pieces of brass material

3.4 Test Procedure

3.4.1 First of all tensile test is done for determining the mechanical properties of Brass materials, such as strength, ductility, elastic modulus, Poisson’s ratio and percentage reduction in area. The tension test first requires the preparation of a test specimen, as shown in Fig.3.4.1 & 3.4.2. The specimen is prepared generally according to specifications. Typically, the specimen has an original gage. Length (*lo)* generally 50mm (2 in.) and a cross-sectional area (*A)*, usually with a diameter of 15 mm (0.578 in.).It is mounted in the jaws of a tension-testing machine equipped with various accessories and controls so that the specimen can be tested at different load and rates of deformation.

Figure.3.4.1- Specimen mounted on the jaws of Tensile testing machine

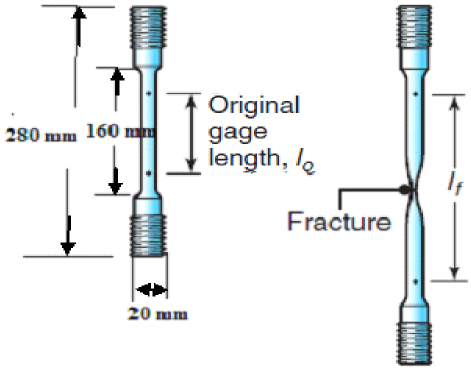


Figure.3.4.2- Tensile test specimen dimension

3.4.2 For conducting fatigue tests measure dimensions of brass specimens provided as shown in Fig.8 and record in tables 3 . The distance from the load end to the minimum diameter of the specimen is 99 mm, the bending stress; σ can be calculated the bending stress for a load *P* (N) is shown in equation 5 Bending stress,

$$\sigma = \frac{MY}{I}$$

Where, M = Moment of N mm (= Pl)
I = Moment of inertia in mm (Π×D^^{4}/64)
Y = Extreme fiber distance (D/2)
Putting all the values in the above equation reduces to the form, we get

$$\sigma = \frac{32 \times P \times 9.81 \times 99}{\pi \times D^3}$$

Where P is load in Newton
D is Diameter of the specimen in mm

3.4.3 Conduct the fatigue test at room temperature using the fatigue testing machine.
3.4.4The fixing of test bar in the fatigue testing machine is done as follows. The nut is unscrewed and the clamping sleeve is removed. If necessary shaft is held tight by the fork operated by means of a lever at the front of the machine. The cover is raised, the weight holder is unhooked by means of the handle and the bearing housing with the bearing is removed. The test bar is inserted in the sleeve which is placed in its position and fixed loosely by nut.
3.4.5 Fit one end of the specimen to a motor and fit the other end to a bearing hung with a known weight, indicating the stress applied to the specimen.
3.4.6 The revolution counter is set at zero and weights corresponding to the desired load are placed on the weight holder.
3.4.7 Care should be taken that the load should not be supplied when the bar is stationary since deformation exercising has an adverse effect on the result.
3.4.8 Start the motor to rotate the specimen at a constant speed. The revolution counter is used to record the number of cycles to which the specimen fails. Record the result in table 3.
3.4.9 Change the weights used and follow the experiment in 3.4.2. Again, record the results in tables 3.
3.4.9 Construct the S-N curves of the Brass specimens.
3.4.10 Investigate fracture surfaces of broken fatigue specimen and sketch the result in tables 3.
3.5.11 Same above fatigue test process is repeated for the Annealed specimens, Groove specimens and Corroded specimens. Again, record the results in tables 3.

S.NO	Specimen diameter (mm)	Cross-sectional areas (mm^2)	Weight (kg)	Maximum stress (MPa)	No of cycles under normal condition	No of cycles after annealing process	No of cycles after making grooves (1mm)	No of cycles after corrosion
Specimen 1	10	78.5	33	327.6	0	0	0	0
Specimen 2	10	78.5	18	178.15	30000	13000	18000	25000
Specimen 3	10	78.5	15	148.386	140000	70000	43000	132000
Specimen 4	10	78.5	13	128.61	400000	300000	260000	430000
Specimen 5	10	78.5	10	98.95	1200000	800000	692000	1110000

IV. RESULT AND DISCUSSION

4.1 THE TENSION TEST

Original dimension
Diameter = 15mm
Gauge length = 50mm
Yield point = 2Ton
Maximum load = 5.8Ton
Breaking load = 4.5Ton
Final dimension
Reducing diameter = 7.6mm
Gauge Length=2mm

Sr. no.	Load (Ton)	Extension (mm)
1.	0.4	4.5
2.	0.8	9.0
3.	1.2	14.0
4.	1.6	22.0
5.	2.0	32.0

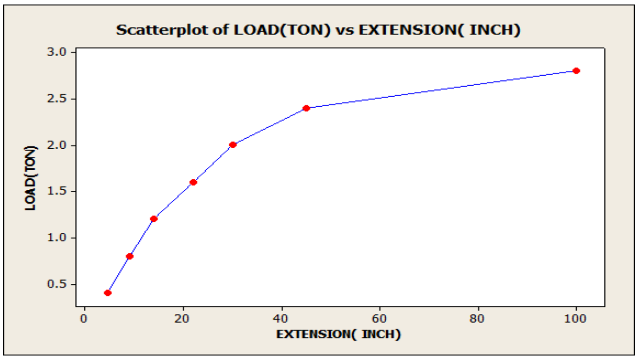
Table 1:- load v/s extension for Brass material on tensile test.

- Yield point =19952.75N
- Maximum load = 57862.99 N
- Breaking load = 44893.69N
- Original area = 176.71 mm^2
- Final area = 45.36 mm^2

(1) Yield strength = 112.91 N/mm^2
(2) Ultimate tensile strength =327.44N/mm^2
(3) Breaking stress =254.05N/mm^2
(4) % Elongation =15%
(5) % Reduction area =73.4%
(6) True fracture stress =989.61 N/mm^2
(7) True strain at fracture =1.36
(8) Engineering strain at fracture
Є= ln(1 + e)   Є - Engineering strain
Exp(e) = (1 + e)   e- Conventional strain
Exp(1.36) = (1+e)
e = 2.896 (conventional strain)

- Poisson ratio (µ) = 0.3096
- True fracture strain, with change in area = 1.36
- True fracture strain in change in length

In this case, the fracture strain determined from length value is incorrect because Necking Produces a very non-uniform strain along the length of the specimen.



GRAPH 1 - Relation between LOAD (TON) and EXTENSION (INCH)

4.2 BRINELL HARDNESS TEST **DATA**

TABLE 2: BRINELL HARDNESS TEST

"D" diameter of steel ball (mm).	**"d" average Measured Diameter (mm).**	**"W" is load on indenter in (kg).**	**BHN NO**
10	3.52	1000	99.5
10	4.0	1000	76.3

$$BHN = \frac{P}{\pi \times D \times .5 \times \left(D - \sqrt{(D^2 - d^2)}\right)}$$

Where, P = is the applied load (kg).

D =is the diameter of the steel ball (mm).

d =is the diameter of the indentation (mm

(a)P=1000kg, D=10mm, d=3.52mm

$$BHN = \frac{1000}{\pi \times 10 \times .5 \times \left(10 - \sqrt{(10^2 - 3.52^2)}\right)} = 99.5$$

(b)P=1000kg, D=10mm, d=4.0mm

$$BHN = \frac{1000}{\pi \times 10 \times .5 \times \left(10 - \sqrt{(10^2 - 4.0^2)}\right)} = 76.3$$

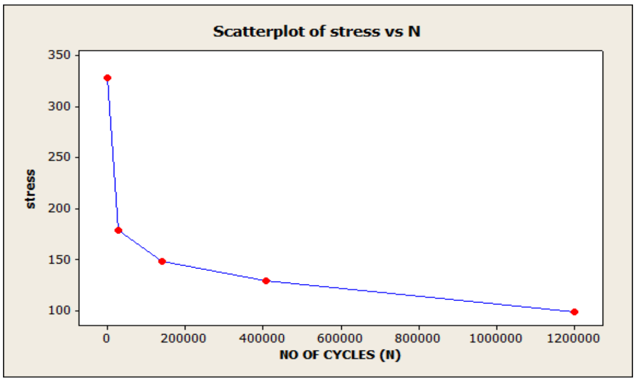
4.3 FATIGUE TEST DATA

Table 3: Fatigue data of Brass specimens

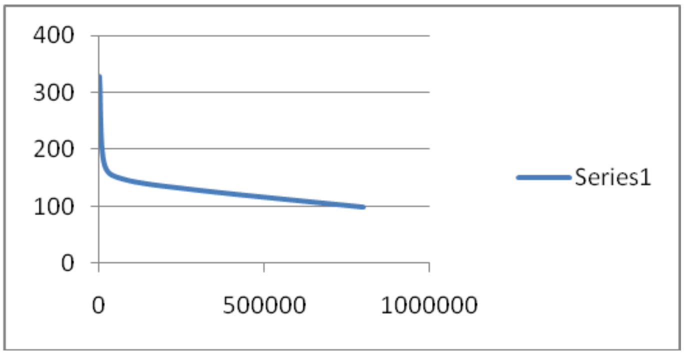
Experimental data from the curve-fitted results were tabulated, and graphs are plotted as follows:-

- Stress v/s No of cycle for general normal condition
- Stress v/s No of cycle for annealed condition
- Stress v/s No of cycle for rough surfaces
- Stress v/s No of cycle for corrosion surfaces
- Stress v/s No of cycle for all conditions

The effect of various factors on the fatigue-life of the Brass materials will be investigated with the help of graphs.

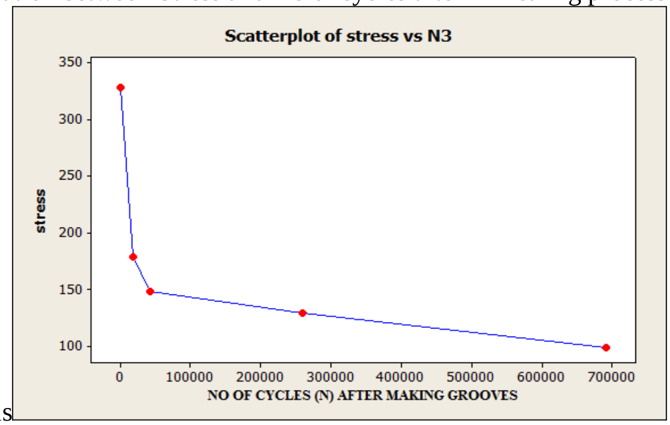


GRAPH 2 - Relation between Stress and No of cycles under Normal condition of the specimens Where N is No of cycles under Normal condition of the specimen under Normal condition of the specimens



No of cycle (N2) after annealing process

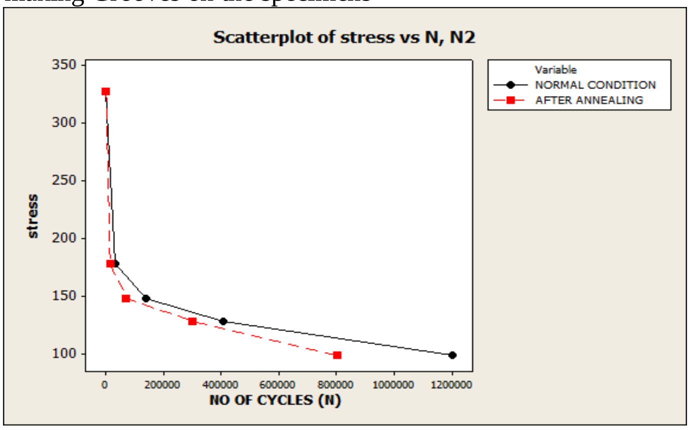
GRAPH 3 **-** Relation between Stress and No of cycles after Annealing process of the specimens



GRAPH 4 **-** Relation between Stress and No of cycles after making Grooves on the specimens

Where

N3 is No of cycles after making Grooves on the specimens

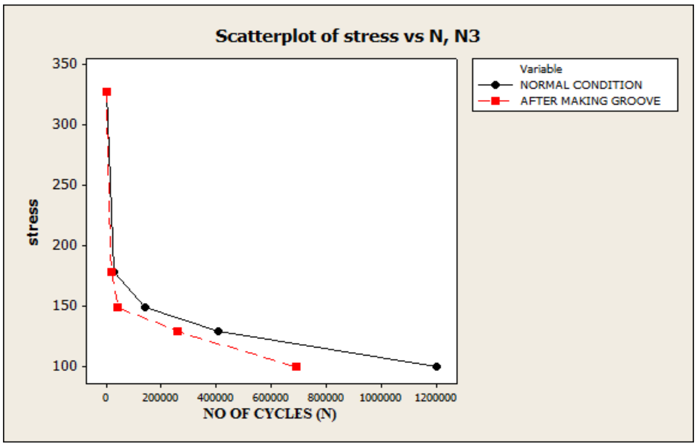


GRAPH 5 **-** Relation between Stress and No of cycles under Normal condition and after Annealing process condition

Where

N is No of cycles under Normal condition

N2 is No of cycles after Annealing process condition

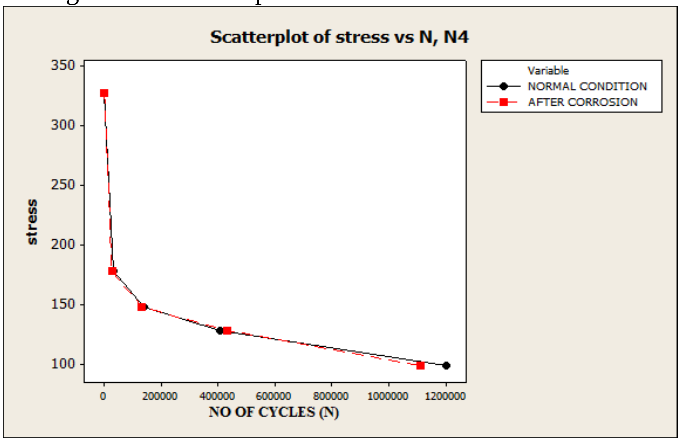


GRAPH 6 - Relation between Stress and No of cycles under Normal condition and after making Groove on the specimens

Where

N is No of cycles under Normal condition

N3 is No of cycles after making Groove on the specimens

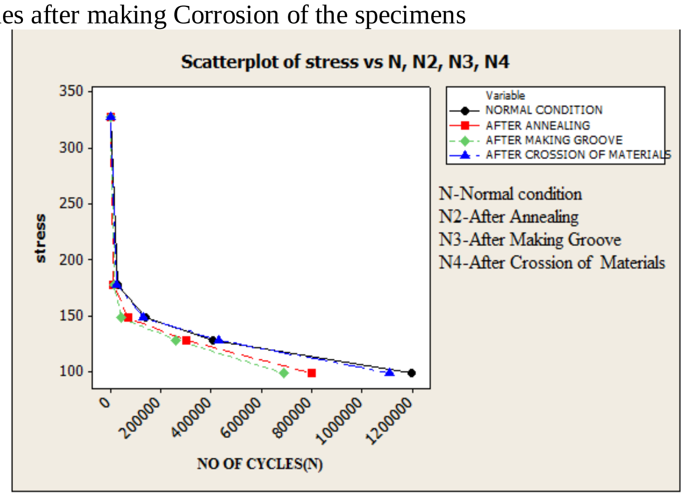


GRAPH 7 - Relation between Stress and No of cycles under Normal condition and after Corrosion of the specimens

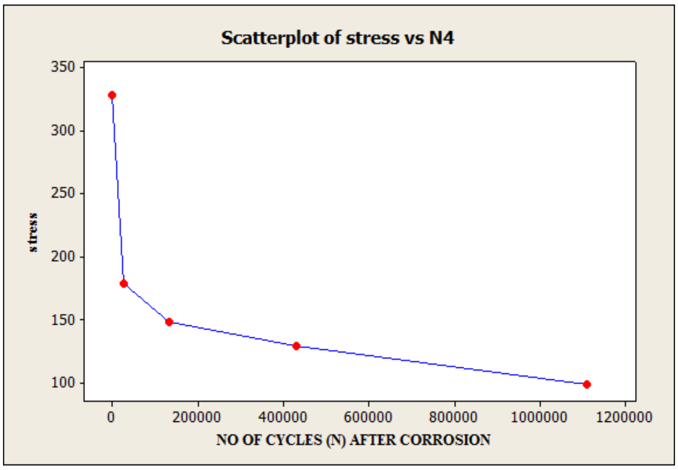
Where

N is No of cycles under Normal condition

N3 is No of cycles after making Corrosion of the specimens



GRAPH 8 - Relation between Stress and No of cycles effects of various factors on the fatigue life of the Brass materials



GRAPH 5 – Relation Stress and No of cycles after Corrosion of the specimens
Where
N4 is No of cycles after Corrosion of the specimens

4.4 MICROSTRUCTURE EXAMINATION

After the fatigue tests were completed, one from each batch was selected. Cracking proceed along grain boundaries type with some semicircular shaped cracks. The slip is present only at the surface as shown in the figures

Fig – Scanning Electron Microscope (SEM).

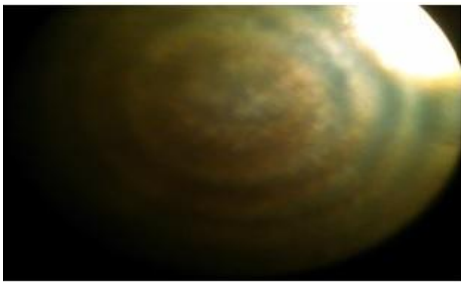


Figure 1- Fracture fatigue specimen Normal condition surface under microscope

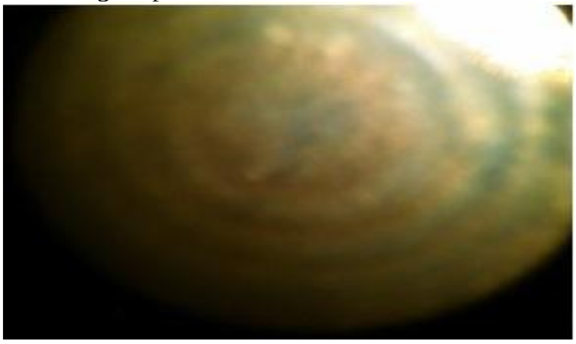


Figure 2- Fracture fatigue specimen Anneal condition surface under microscope

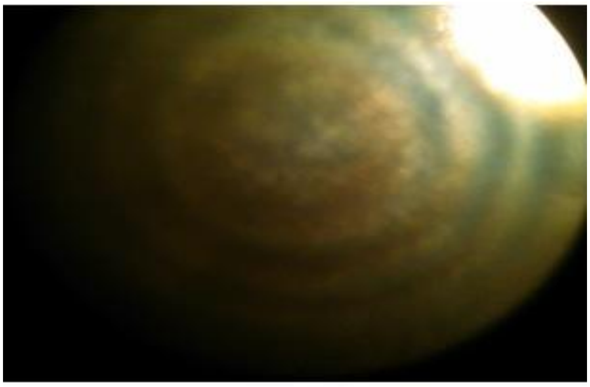


Figure 3- Fracture Groove fatigue specimen surface under microscope

Figure 4- Fracture fatigue specimen Corroded condition surface under microscope

V. CONCLUSION

Detailed experimental investigations on the various factors which influence the fatigue-life on the brass materials have been presented in this paper. From the results it is evident that the Annealing has a significant influence on the surface hardness due to which hardness decrease and ductility increase which leads to decrease in fatigue-life of the materials.

Groove in a specimen under uniaxial loads introduces three effects:

I. There is an increase of stress at the root of the groove
II. A stress gradient is set up from the root of the groove in towards the center of the specimen.
III. Triaaxial state of stress is produced.

The above three effects leads to decrease the fatigue-life of the materials .One of the best ways of minimizing fatigue failure is by the reduction of avoidable stress raisers through careful design and the prevention of accidental stress raisers by careful machining and fabrication.

Corrosive environment produce pitting of metal surfaces. The pitting act as notch which leads to stress raiser and have negative effects on fatigue properties of the materials as they accelerate faster rates of both fatigue initiation and propagation which leads to decrease in fatigue life of the materials. Humidity has a negligible effect on fatigue life .The relative humidity (19.5% to 100%) has only a negligible effect

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