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Full Length Research Paper

Investigation of the short and long weariness breaks for metal combination

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In this study the effect of short and long cracks for brass alloys specimens exposed to bending cyclic load is 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 are 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 are always greater than experimental number of cycles of failure.

Key words: Fatigue, varying loads, short cracks, long cracks, brass alloy.

INTRODUCTION AND SURVEY

The fatigue phenomenon is an important position between others which cause failure for mechanical and engineering parts. Therefore, it is mostly interested in studying the metal failure and evaluating the performance of parts for a long time. Most of the researches are concentrated on fatigue nature and fracture mechanism which begins from creating cracks and its behavior along its growth time until the parts age ended practically because of exposing alternating stresses, thereby causing the failure because of repeated loads, which became a characterized engineering problem with the coming of rotating and reciprocating machines within the industrial revolution in the early period of the ninth century. It is noticed that the metals which are known as ductile metals failed at a range of loads, which is considered safe and the fracture face looks like brittle. Since the fatigue problem has become obsessed for the engineers from the period of the ninth century, it has the wider base of failure in land, aerial and marine vehicles. A great effort is made to know the nature of fatigue problem damage and the ways to cover it and treat it in design. These problems are studied from many points of views and in many levels they vary between studying it with microscopic instruction pictures and analyzing the engineering structure for all its volume. However, many researches have been done in the field of fatigue (Michell, 1978). In the year 1822, Albert recorded in Germany, for the first time, the failure caused by repeated loads and in 1939; the French Poncelet presented the (fatigue) term.

In 1849, the England of Mechanical Engineering Institute discussed the "theory" of how to prove the fatigue, in 1864, Farbairn made first experiments about effects of repeated loads, and 1871, Wohler made first study of fatigue system behavior in railway axles by cyclic bending tests and drawing (stress vs no. of cycles) (S-N) curves and put forward endurance limit idea. Bauschin (1886) noticed change in elastic limit in hysteric cycle of periodic stress and strain, and Ewing and Humfreg (1903) made microscopic study and invalided the old theory and explained that fatigue formed by sliding. In 1940, Baristow noticed the deference in (stress-strain) responses through rotating and he measured hysterical cycle by test of many steps and put forward cyclic rigid and soften idea. Coffin and Manson (1955) studied the periodic thermal loads and fatigue of low cycles and also looked after the plastic strain considering, and in 1963, Paris presented mathematical model of fatigue cracks growth which considered most usable and simple. Perason (1974) made experiments on aluminum material

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and noticed that little cracks had different behaviors than large cracks and could not obey the Paris equation.

The researches continued about cracks and its treatment, in the present time there are many researches about and so much that it could not be restricted. The failure of parts under the effect of repeated load in a specified number of times called fatigue. If the material is exposed to alternating stresses in direction and value then it would fail at stress values much less than yield stress. Sometimes it happens that the parts fail only by varying load value without changing in the direction, Keyser (1986) phenomenon makes the most of failure common types where it reaches about 90% from the failure of parts and engineering structures therefore it was and still a subject for many researchers. In spite of large numbers of researches, there are no full convenient about the microscopic details of starting cracks and growing (Dleter, 1976). The failure of parts because of fatigue depends on three principal parameters could be used to predict the age of parts by number of cycles where the part stand before final failure, these parameters are:

1) The length of crack.
2) The periodic stress.
3) The boundary conditions.

One of the simplest fatigue test is circular section specimens exposed to bending cyclic load, this test applied on a group of standard specimens until its fracture, data taken from it can be drawn as a curve between stress and number of cycles curves (S-N) which gives the fatigue limit, that is a limit for iron metals only and express the stress at which the curve (S-N) became horizontal. For non ferric metals there is endurance limit which means the value of stress hangs on a specified number of cycles of load at the (S-N) curve, if the applied periodic stress is less than a specified level, then it is called simple stress, where no effective of sliding bundle is created. The effective sliding bundle is responsible of creating cracks, the metal exposed to this stress will stay for a non defined period of time therefore all metals have a fatigue limit.

Laird (1947) and Lukas et al. (1972) carried out cyclic stress test where the plastic strain is controlled. They found that the specimens submitted to diagram of plastic strain rate with the age where the failure occur at strain less than (10^{-5}), the deference between the periodic test and stress periodic, in the first test the stress is lower than the first cycle of test and then increasing gradually until saturating limit while the second test the total stresses are applied at the first cycle causing a wide strains, in soft metals from the primary wide strain. In any fatigue analysis for a specified part if the fatigue is low cyclic or high cyclic, then it is important to take into consideration that many parameters affects the fatigue behavior, the low cyclic fatigue usually taken from testing specimens under constant strain condition means that a little number of cycles makes failure because of consuming between strain and number of cycles through which a high plastic occur. In these cases the linear relation between stress and strain dose not exist (Lukas et al., 1972).

The high cycle fatigue required a large number of cycles and the failure caused from participation between stress and strain, and number of cycles but in this type of fatigue no yield or micro plastic deformation therefore the normal elastic relationship between stress and strain could be applied. Many researches concentrated their effort on determining average growth of fatigue crack where the old theories depended on one mathematical model to describe growth process beginning from existing of crack till failure happens and in the last two decades the researches concentrated on formulating two mathematical models for crack growth based on the idea that cracks divided with respect to its behavior to two types, the first classified as a short crack from crack volume which approach usually to average grain volume or the length of sliding beam and its usually not exceed the diameter of some grains.

Morkovin and Moore (1944) in these cracks the microscopic instruction affects so much on average growth and its called short microscopic cracks (Lipson and Juvinall, 1963). Either when the cracks are wider than the previously mentioned then the average growth is not affected by the microscopic instruction of metal, it is called micro way cracks the classic method for showing data of the crack growth by drawing the relation (log/log) between average crack growth (da/dN) and the rate of stress intensity change (k). In other researches given, it may be a mathematical model that explains crack growth behavior in the two long and short types, where the deference behavior between them is clear, and where the short cracks started to slow down quickly till it came to a stop. The most researches which had been concentrated on the short cracks because of its big important in modification of the age mechanical parts and the creation speed and growth compared with the long types. From these researchers, the short crack behavior is studied and obtained the mathematical models; Hobson (1982) studied the short cracks growth of aluminum 7075-T6 alloy:

For short crack

$$\frac{da}{dN} = 1.64 * 10^{-34} (D - a)(\sigma)^{11.141} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

For long crack

$$\frac{da}{dN} = 1.04 * 10^{-4} a - 1.68 * 10^{-9} \quad (2)$$

and Hobson (1985) studied short cracks growth in steel of medium carbon:

Table 1. Chemical composition: (A) used alloy and (B) standard ASM alloy.

	Cu	Zn	Pb	Fe	Ni	Mg	Tin
A	-	29	0.100	0.01	0.03	0.04	
B	-	29.5-29.7	0-0.03	0.017-0.02	0.01-0.023		0.018-0.02

Table 2. Mechanical properties of: (A) used alloy and (B) standard ASM alloy.

	Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	Reduction in area (%)
A	64	296.9	72.5	76.5
B	76.4- 191.6	267.6-397.2	46.5-67.2	

$$\frac{da}{dN} = 1.64 * 10^{-34} (D - a)(\sigma)^{11.141} \quad \text{....................} (3)$$

Jassim (1988) studied the accumulation of fatigue damage under combined load:

$$\frac{da}{dN} = 2.76053 * 10^{-36} \sigma^{13.68} a \quad \text{..................} (4)$$

In our research the experimental and theoretical investigation are done for brass alloy which is exposed to alternating loads and evaluation the short and long cracks.

EXPERIMENTAL PART

The first step, the material selection is Brass (70/30) metal with number (C26000) from copper alloys according to ASM classifications. Table 1 shows the chemical composition for the material used in this research which includes ASM standard chemical composition. The second step is the heat treatment of all specimens under (750°C) for two hours after that they are cooled quickly in air. Then the tensile test is done by two types of devices so two standard models of tensile manufactured specimens are obtained, the first type chose on (Amsler type fm 2720), tensile test device where the specimen is (A 8*40 Dim 50125), the second model taken by three specimens which are manufactured and tested by (instron 1195) device which has maximum load (100 kN), the results of tests for the two types are coincident approximately and they are shown in Table 2 which also explained the mechanical properties for standard material according to (ASM) (Morkorin and Moore, 1944). Rigidity had been tested by Brinell test (HB), with applying a constant load (15.625 kg) by a steel ball (2.5 mm) diameter, the diameter of the resulted crack was between (0.72 to 0.73) then from tables of rigidity test type (Wolpert) the rigidity was (37HB).

The specimens used in fatigue test are the standard specimens of the rotating and bending device (Schenck-Punn Rotary, Bending Machine), all specimens are manufactured by using computer lathe (CNC) type (G+F).

RESULTS AND DISCUSSIONS

Five specimens are used experimentally by applying variable load in deferent arrangement with varying the sequence of these loads as shown in Table 3, it is noticed that;

1) In spite of the load sequence and values, for the same loads, the number of cycles of failure are deferent as in specimens 4 and 5.
2) The specimens 1 and 3, the deference can be seen in number of failure cycles between them because of changing load values as in case of loads 450 to 250 kg; this proves that decreasing the applying load cause the obviously increasing in the age.
3) Applying high loads in the beginning then at the end which gives almost smaller number specimen's age.

Calculations

The mathematical model of smooth specimens is found from (S-N) curves and it is:

$$\sigma = 684.51 Nf^{-0.11797} \quad \text{.........................} \quad (5)$$

From Equation 5 it can be found that, σ_{equ} for each specimen, the results are demonstrated in Table 4. The results for long and short cracks growth in brass material with smooth specimens are:

For short cracks

$$\frac{da}{dN} = 6.931 * 10^{-19} \sigma^{7.895} (D - a)^{-0.48} \quad \text{.................} \quad (6)$$

For long cracks

$$\frac{da}{dN} = 9.8514 * 10^{-21} \sigma^{7.5} a^{0.47} \quad \text{.......................} \quad (7)$$

Integrating short cracks equation, yields:

$$\int_{0}^{Ns} (6.931 * 10^{-19} \sigma^{7.895}) dN = \int_{R_{MAX}}^{D} (D - a)^{0.48} da \quad \text{...........} \quad (8)$$

Table 3. No. of cycles results.

Sample number	Applied load (kg/mm^2)	Number of cycles
1	300	105
	350	105
	400	105
	450	50000
		Nf = 350000
2	300	105
	350	105
	400	105
	450	50000
		Nf = 350000
3	300	105
	350	105
	250	105
	450	$3.2*10^5$
		Nf = $6.2*10^5$
4	400	105
	350	$1.4*10^5$
		Nf = $2.4*10^5$
5	400	105
	350	105
	300	810000
		Nf = 1010000

Table 4. Value of σ_{equ} .

Spe. No.	Nf (cycle)	σ_{equ} (MPa)
1	350000	151.826
2	350000	151.826
3	$6.2*10^5$	141.9
4	$2.4*10^5$	158.74
5	1010000	134

And it can be found:

$$Ns = 9.7458 * 10^{17} \sigma^{-7.895} (D - R_{MAX})^{1.48} \ldots\ldots\ldots \quad (9)$$

Where: Rmax is maximum value of roughness of specimen surface after brightening, Ns is number of cycles.

Rmax taken 1.9 µm and D = 623 µm

Where: D is failure of grain diameter of specimen material and when integrating the long cracks equation, yields:

$$\int_{Ns}^{Nf} dN = \int_{D}^{af} (9.8514*10^{-21}\sigma^{-7.5}a^{-0.47})da \ldots\ldots\ldots \quad (10)$$

and it can be gotten as:

$$NL = 1.8523*10^{20}\sigma^{-7.5}(af^{0.53} - D^{0.53})\ldots\ldots \quad (11)$$

Where: NL is the number of cycles for long cracks, NL= Nf – Ns, af is failure diameter of specimen = d/2 (taken af = 3350 µm), d is specimen diameter.

Table 5. Theoretical and experimental results.

Experimental Nf cycles	Theoretical Nf cycles	Number of cycles of long cracks (NL)	Number of cycles of short cracks (Ns)	Specimen number
350000	431759	352149	79610	1
350000	431759	352149	79610	2
$6.2*10^5$	720496	584729	135767	3
$2.4*10^5$	308171	252159	56012	4
1010000	1111943	898538	213405	5

Some cases takes (af = d) where the crack growth is high in final step of fatigue. Table 5 shows the summary of results for theoretical and experimental investigation. From Table 4 it can be shown that:

1) It could be noticed that specimen with average of short crack growth having short age, it could be noticed that the calculated Ns values were minimum for short aged specimens, this confirm the importance of short crack growth average which changed to long cracks. The short cracks growth which varies affected by presence of scratches on the specimens' surface, had great effect on determining it's age (Ns) also we noticed that the number of cycles for long cracks growth at failure were smaller than short aged specimens. This confirm that the quick growth of cracks followed by quick growth of long cracks.

2) In determining the theoretical (Ns) values and comparing it with experimental, it can be noticed that the values taken from equations are always greater than experimental number of cycles of failure.

The increasing in value is reasonable for all results it depends on their equation in determining the age of failure under fatigue effect in good way for brass exposed to variable loads and good safety factor.

Conclusions

The fatigue analysis of brass alloy under alternating loads are obtained theoretically and experimentally, it can be concluded that decreasing in the applied load increasing obviously the age and applying high loads in the beginning then at the end given almost smaller number of specimen age. This confirms that the quick growth of short cracks followed by quick growth of long cracks, that the values taken from the theoretical equations are always greater than experimental number of cycles of failure.

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