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DETERMINATION AND DEMARCATION OF FATIGUE CRACK INITIATION PHASE IN ROTATING BENDING CONDITION

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In engineering applications, components often experience cyclic loading and therefore, have crack initiation propagation phase. In this research work experimental demarcation of fatigue crack initiation has been investigated. Initiation phase of fatigue life of Aluminium was determined by using single and two step fatigue loading test on four point rotating bending fatigue testing machine. Experimental data is used to determine the distinction between the initiation and propagation phase. Initiation phase is determined at different stress levels. The obtained results demonstrate the effect of stress level on initiation phase and propagation phase.

Keywords : Fatigue life, Two step loading, S-N curve

1. Introduction

Transverse load applied on a rotating shaft is always under rotating bending fatigue condition and may fail suddenly after a number of cycles. In characterizing the fatigue resistance of a material common practice is to determine experimentally the stress life (S-N curve) for which specimens are tested under constant amplitude, fully reversed loading.

There are several possible methods of determining an S-N curve for a situation where the mean stress is not equal to zero [1].The earlier studies describe that the microscopic crack widen at each subsequent movement of cycle [2]. Earlier experimental work in order to analyze the initiation and propagation of fatigue cracks has been carried out. The crack initiation made in notched specimen is completely different from that in plane bar specimen. Earlier an analysis of multiple two step loading has been investigated by A.J. McEvily [3]. The method is able to predict crack growth behaviour under multiple two step loading. J. Ding et al. [4] found a two parameter fatigue theory to predict small crack growth under combined low and high cycle fatigue loading condition. A step loading of very high cycle fatigue has been investigated by Nicholas [5]. It is also noted that by subjecting a material to periods of cycling in steps of increasing magnitude, it can be made to withstand stress considerably above the primitive fatigue life. A simplified method for estimating the fatigue limit and the fatigue life under two step loading has been analyzed by Takase and Koyama [6]. Fatigue damage in materials is usually characterized by a crack initiation phase and a crack propagation phase. In this research work a model for the demarcation of initiation phase and propagation phase is introduced. In the scope of present work, only an S-N curve has been developed under the application of externally applied loads by using four point rotating bending fatigue testing machine. The experimentation was conducted to investigate crack initiation phase in fatigue life of aluminum under fully reversed stress at constant amplitude under two different loading conditions

2. Experimentation

A round fatigue test specimen of Rolled 6061 T6 Aluminium prepared as per dimensions shown in Fig. 1. Chemical analysis was carried out by using spark emission spectroscope. All the chemical, physical and mechanical properties are mentioned in Table 1 and Table 2. A universal tensile test machine was used to calculate the strength of the material. Four point rotating bending fatigue testing machine Model PQ-6 Jinan Testing Equipment IE Corporation China was used for the determination of fatigue life. Two level tests were performed by applying the loading on a notched specimen from low to high stress level.

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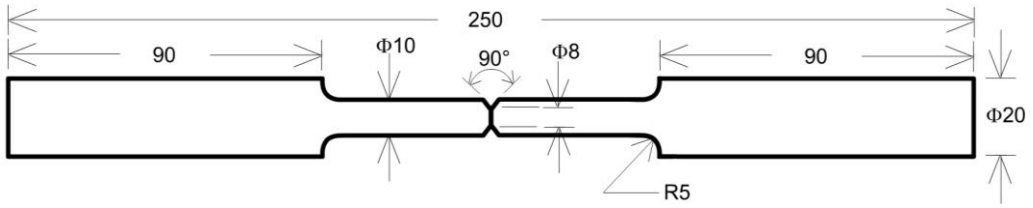

Figure 1. Fatigue Test specimen .

Table 1. %age Chemical Composition of the Aluminium Rolled 6061 T6 Specimen.

Si	Fe	Cu	Mn	Mg	Zn	Ni	Pb	Al
1.55	1.33	0.805	0.11	1.44	10.9	0.12	0.282	83.47

Table 2. Physical and Mechanical Properties of the Aluminium Specimen.

Density (Kg/m^3)	Melting Point (^0C)	Elastic Modulus (GPa)	Poisson's Ratio	Tensile Strength (MPa)	Yield Strength (MPa)
2600-2800	666	68.7	0.33	409.26	346.14

3. Results and Discussions

Different loads were applied on the rotating bending machine of magnitude 4, 5, 6, 7, 8, 9, 10, 15, 20 kg. Stress is calculated by using the relation (1) by simple beam theory.

$$\sigma = 32wl / \Pi d^3 \quad (1)$$

Initiation phase of fatigue life was determined experimentally by single step and two step loading. An analytical equation has been derived to determine the initiation phase of fatigue life for two step loading fatigue test. S-N curve has been drawn. In another series of experiments two step fatigue tests were performed at two stress levels S1 and S2. Lower stress S1 was applied for large fraction of its total life.

It is clear that if total life at lower load, percentage of life for which lower load is applied and percentage of life for which higher load is applied is known then initiation phase of lower load can be determined using relation (2).

N_1= No. of cycles for which higher load was applied

Nf_1= Total fatigue life at higher load

N_2= No. of cycles for which lower load was applied

Nf_2= Total fatigue life at lower load

x = Fraction of total life for which lower load was applied

y = Fraction of total life for which higher load was applied.

Z = Fraction of lower load during which crack is in propagation phase

$$xN_{f2} = N_{i2} + zN_{p2}$$

$$z = 1 - y$$

$$yN_{f1} = yN_{p1}$$

$$N_{i1} = 0$$

$$xN_{f2} = N_{i2} + (1 - y)\, N_{p2}$$

$$xN_{f2} = N_{i2} + (1 - y)(N_{f2} - N_{i2})$$

$$N_{i2} = \frac{N_{f2}(x + y - 1)}{y} \quad (2)$$

In experimentation different loads were applied gradually and their corresponding number of cycles has been determined. These results have been tabulated in Table 3. For Single step loading average data have been incorporated for 10 specimens whereas for the two step loading, 21 specimens were tested and experimentation

Table 3. Results of Single Step Fatigue Loading Test at k_t= 2.45.

S. No	Load(Kg)	Load(N) W=mg	$\sigma = 32wl/\Pi d^3$	S=σ*Kt	No. of Cycles
1	20	196	195.06	477.897	1400
2	15	147	146.22	358.239	6200
3	12	117.6	116.98	286.601	32400
4	10	98	62.39	152.8555	38600
5	9	88.2	87.73	214.9385	50400
6	8	78.4	49.91	122.2795	52340
7	7	68.6	43.67	106.9915	54800
8	6	58.8	37.43	91.7035	58900
9	5	49	31.19	76.4155	110500
10	4	39.2	2.34	5.733	180200

Table 4. Two Step Fatigue Loading Test Readings.

Test No.	S2(kg)	S1(kg)	Nf2	Nf1	N2	N1
01	4	10	180200	38600	151300	17600
02	5	10	110500	38600	86200	18150
03	6	10	58900	38600	39500	18200
04	7	10	54800	38600	33900	17800
05	8	10	52340	38600	24600	21500
06	9	10	50400	38600	17200	22800
07	10	15	38600	6200	15300	2300

repeated thrice for validation. The average values have been incorporated in Table 3 and Table 4. In two step loading the experimentations were performed on two different loads S1(higher value of load) and S2 (lower value of load) for a particular specimen. Accordingly by using these values, fatigue life for lower and higher loads (Nf2 & Nf1) and further the total number of cycles (N1 & N2) for the two different loading conditions have been determined.

Low load was applied for more than half of its total life; Crack in specimen was in propagation phase when load was changed from low to high. When high load was applied, in many cases specimen breaks after few hundred cycles that was an indication of the fact that much life out of total life has already been consumed. Before applying the high load reading was recorded. The name given to this reading is N2.

After fracture, reading was recorded for which high load was applied that was N1.

As load increased the total life was decreased. At high load much of the life is consumed in propagating a crack, initiation phase and complete in a short time. But the case is reversed for low loading in which much of the life out of total life is consumed in initiating a crack. After initiation, crack will propagate very rapidly. Hence fraction of total life for which crack is in initiation phase is more in case of low loading.

Two step fatigue loading readings have been tabulated in Table 4. Initiation life for each step has been calculated and shown in Table 5 and summary of results is reflected in Table 6. Figure 2

Table 5. Calculation for Initiation Life in Two Steps Loading.

Test No.	$x = \frac{N_2}{N_{f2}}$	$y = \frac{N_1}{N_{f1}}$	N_{f2}	$x + y - 1$	$N_{i2} = \frac{N_{f2}\ x + y - 1}{y}$	$\frac{N_{i2}}{N_{f2}}$
01	0.84	0.66	180200	0.5	136500	75.74%
02	0.78	0.68	110500	0.46	74750	67.64 %
03	0.67	0.68	58900	0.35	30320	51.54 %
04	0.62	0.66	54800	0.28	23260	42.44%
05	0.47	0.81	52340	0.28	18100	54.38 %
06	0.39	0.86	50400	0.25	14800	22.96 %
07	0.58	0.48	26400	0.06	3300	12.50 %

Table 6. Summary of Results.

Test No.	Load (kg)	Initiation phase (Percentage of total life)
1	4	75.74
2	5	67.64
3	6	51.54
4	7	42.44
5	8	54.38
6	9	22.96
7	10	12.50

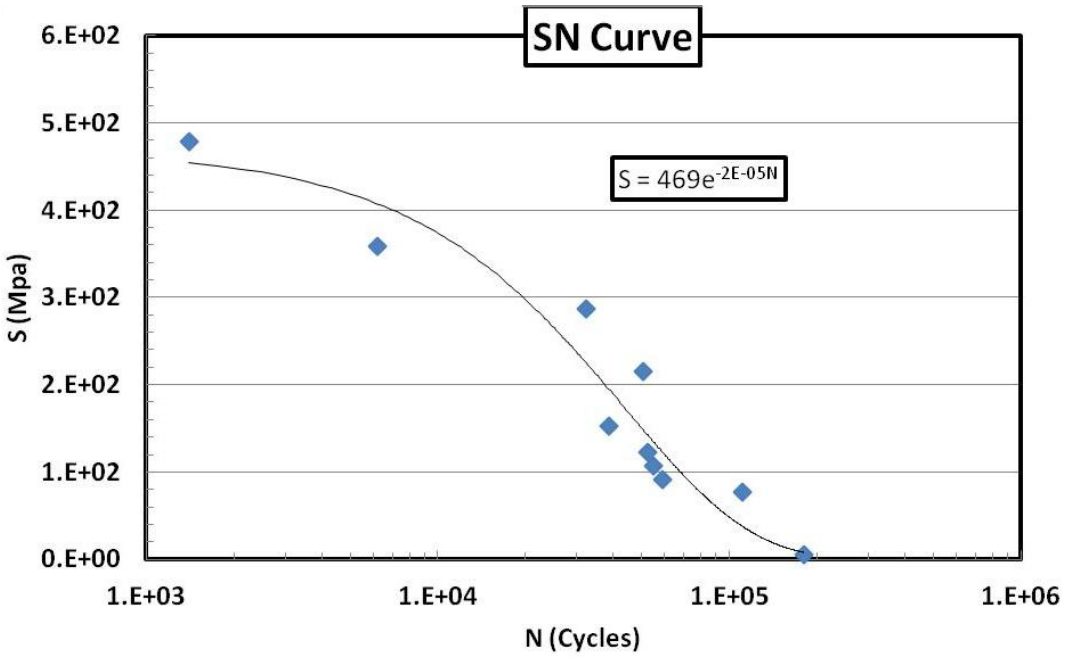

Figure 2. S N Curve of Tested Specimens.

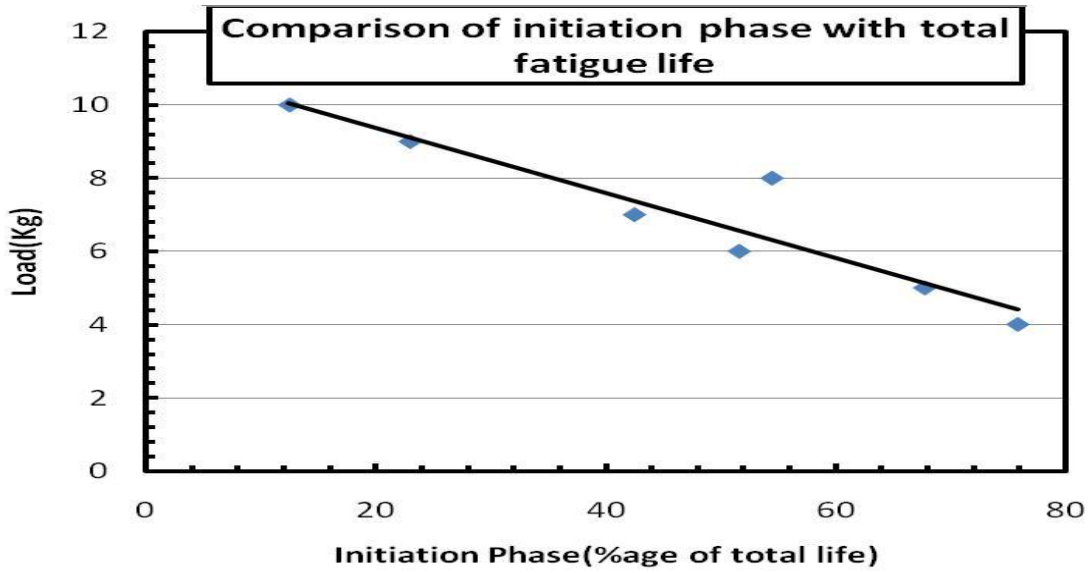

Figure 3. Comparison of Initiation Phase with Total Fatigue Life .

shows S-N diagram of the tested specimen which indicate overall trend of the aluminum specimen under fatigue loading.

Figure 3 shows that with the increase of stress level initiation phase will decrease and vice versa. In this experimental work, different pairs of loads were selected. In the pair of lower load and higher load, fatigue crack initiation for lower load was determined by using the relation described above. It is observed that at higher load crack will initiate very early.

5. Conclusion

Fatigue life and crack initiation under two step loading have been determined. It was observed that the considered aluminium alloy fractured in low cycle fatigue region under the subjected loading condition, In two step loading condition, at higher stresses the initiation life decreases in accordance with the decreasing fatigue life as expected. With the presence of notch, fatigue strength is reduced and accordingly fatigue life also reduces. Most of the specimens had fractured from the point where notch was present which is the expected normal behaviour. The further research can be carried out on, forged and heat treated specimens machined in various directions.

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