



Cumulative fatigue damage under shot peening treatment

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ABSTRACT

In this paper, fatigue damage accumulation were studied using three methods i.e. Miner, new non-linear model and experimental method. The prediction of fatigue lifetimes based on Miner method are uneconomic and non-conservative respectively. However satisfactory predictions were obtained by applying the non-linear damage rule (present model) for 5052-H34 aluminum alloy. Many shortcomings of the Miner methods are related to their inability to take into account the surface treatment effect.

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Introduction

Fatigue is an important parameter to be considered in the behavior of mechanical components subjected to constant and variable amplitude loading [1]. Variable loading or cumulative damage is usually investigated by testing specimens with a definite number of cycles at one stress level, and then to continue the test at other stress level until failure. In these various stress level tests, the stresses may be either in an increasing or decreasing order or mixed together [2]. In this study a new cumulative fatigue damage model for life predication will presented involving the effects of loading sequences and the surface shot peening treatment.

Fatigue damage accumulation:

Cumulative fatigue damage is an old, but not yet resolved problem [3]. Miner first expressed the concept in a mathematical form as [4],

$$D = \sum \frac{n_i}{N_{fi}} = 1 \quad \text{-----}(1)$$

The proposed non-linear model:

Following the work of Perieira et al [5] and alalkawi et al [6], they suggested the damage due to fatigue for low-high and high-low stress level as:

$$D = \left[\frac{n_i}{N_{fi}} \right]^x \quad \text{-----}(2)$$

Where, (x) is a function of the applied load. In the present work, (x) may be defined as the effect of loading sequences and surface treatment, here the surface treatment is shot peening technique. Equation (2) can be modified to take the form:

$$D = \left[\sum \frac{n_i}{N_{fi}} \right]^x \quad \text{-----}(3)$$

Where (x) represents the effect of loading sequences and shot peening treatment, here (x) may be defined as:

$$x = \frac{\sigma_l}{\sigma_h} \beta \quad \text{-----}(4)$$

Where, β is the inverse slope of the S-N curve, if the test program is low-high, also (x) it could be, $x = \frac{\sigma_h}{\sigma_l} \beta$ when the test

program from high-low. In order to make the predication safe equation can be divided by the value (x) to become:

$$D = \frac{\left[\sum \frac{n_i}{N_{fi}} \right]^x}{x} \quad \text{-----}(5)$$

Experimental work

The chemical composition of aluminum alloy 5052-H34 used was 0.25 Si – 0.31 Fe – 0.027 Cu – 0.014 Mn – 2.41 Mg – 0.02 Zn – 0.23 Cr – 0.1 other - Al. The mechanical properties of this alloy are: (65)HRC, yield strength of 222 MPa, ultimate tensile of 274 MPa. This material was treated with different shot peening time: 10 min, 15 min, 20 min, 25 min, 30 min, all of them with speed of 40 m/s, a distance of 10 mm and pressure 12 bar. The shot used was cast steel (ϕ 0.6 mm) with a coverage of 100% carried out on an rotating-wheel machine (Shot Tumbblast Control Panal model STB-OB). The shots are kept in perfect conditions. The specimens used (Fig. 1) were tested in rotating bending fatigue tests ($R = -1$) at frequency of 50 Hz, at room temperature.

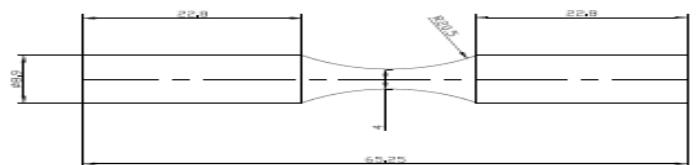


Fig. 1: Rotating bending fatigue testing specimens (all dimensions in mm)

Results and discussion

The experimental constant (A, m) for the S-N curve equations with shot peening time can be shown in table (1). Equation of power law regression is given by (fatigue life formula).

$$\sigma = AN_f^m \quad \text{-----}(6)$$

Where (σ) is the applied stress.

It is well known that the data and the models describing the materials fatigue behavior at constant amplitude loading are not necessarily sufficient to assess their fatigue performance under variable amplitude conditions [7].

Table 1: basic S-N curve equations

SPT (min)	A	m	S – N curve equation
Zero	691.83	-0.1243	$\sigma_f = 691.83 N_f^{-0.1243}$
10	753.328	-0.12315	$\sigma_f = 753.32 N_f^{-0.12315}$
15	640.73	-0.1177	$\sigma_f = 640.73 N_f^{-0.1177}$
20	624.05	-0.1204	$\sigma_f = 624.05 N_f^{-0.1204}$
25	568.64	-0.11528	$\sigma_f = 568.64 N_f^{-0.11528}$
30	472.121	-0.104	$\sigma_f = 472.121 N_f^{-0.104}$

In the present study and in order to be as close as possible to the reality of loading in service, the cumulative fatigue damage tests have been conducted for two-steps program low-high and high-low for the conditions mentioned in table (2).

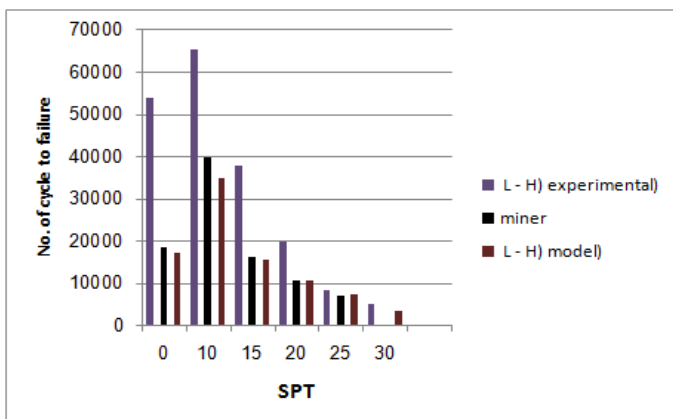
Table 2: Cumulative fatigue damage results

SPT	Specimen No.	Loading program	Applied stress	N_f
0	F1	L – H	165 – 220	54000
	F2	H – L	220 – 165	29600
10	F3	L – H	165 – 220	65300
	F4	H – L	220 – 165	34000
15	F5	L – H	165 – 200	38000
	F6	H – L	200 – 165	21800
20	F7	L – H	165 – 200	19700
	F8	H – L	200 – 165	11600
25	F9	L – H	165 – 200	8200
	F10	H – L	200 – 165	3300
30	F11	L – H	165 – 200	4800
	F12	H – L	200 – 165	1200

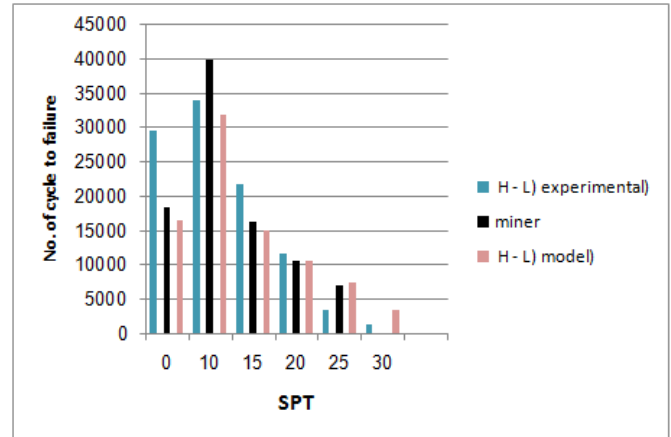
The theoretical cumulative damage according to Miner rule was used to calculate the fatigue life based on Miner rule and to compare it with the experimental and the new model results as shown in table 3.

Table 3: Comparison between fatigue lives predications

SPT min.	Loading program	N_f cycle Miner	N_f cycle experimental	N_f cycle Model
0	L – H	18329	54000	17322
	H – L		29600	16578
10	L – H	39965	65300	35165
	H – L		34000	31833
15	L – H	16191	38000	15517
	H – L		21800	15011
20	L – H	10562	19700	10510
	H – L		11600	10469
25	L – H	6984	8200	7204
	H – L		3300	7380
30	L – H	2905	4800	3199
	H – L		1200	3448

**Fig. 2: The Low-High cumulative fatigue life prediction for three methods**

It is clear that the predication of fatigue lifetime by using the new model gave slightly below the experimental data because it was taken into account the effect of shot peening while the Miner method gave overestimate prediction on fatigue lives because the Miner method does not take the effect of loading sequence (Low-High and High-Low tests) into consideration [3], and shot peening process do not contribute to fatigue damage [8].

**Fig. 3: The High-Low cumulative fatigue life prediction for three methods**

Conclusions:

1. The obtained results from the present model are in good agreement with the experimental results.
2. The comparison between the experimental results and Miner method clearly indicate that the Miner method does not give accurate and reliable prediction for fatigue lives.

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