EDITING FOR ACCELERATED FATIGUE TESTING USING STRAIN RANGE AND SWT PARAMETER CRITERIA

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ABSTRACT

The objective of this research was to determine if conventional strain range editing and a new SWT parameter editing technique can be used to accurately edit a variable amplitude strain history to a predetermined damage level. A variable amplitude strain history containing 62 672 reversals was scaled to three peak strain levels and used as three full length histories. These histories were then edited to 50% damage retained levels that omitted more than 99.5% of the original history. Comparison between experimental and calculated lives using smooth uniaxial SAE 1045 steel in the through hardened condition ($R_c = 54$) subjected to full length and edited histories were used to evaluate the two editing techniques. Both the conventional strain range editing and the new SWT parameter editing were successful in editing the predicted damage.

KEYWORDS

Fatigue, variable amplitude, cumulative damage, life prediction, spectrum editing, 1045 steel.

INTRODUCTION

Laboratory structural fatigue testing is performed extensively in all industries. Much of this testing involves simulating field or service loading using lengthy complex variable amplitude histories that may contain many small amplitudes that produce little fatigue damage. These small amplitude cycles are often edited from the histories, using a variety of filtering techniques, in order to produce representative and meaningful yet economical testing. This research examines the use of a conventional strain range based editing model and a new editing model based upon the Smith, Watson, Topper (SWT) parameter using uniaxial smooth specimen through hardened SAE 1045 steel. The SAE Fatigue Design and Evaluation (SAEFDE) committee Log Skidder Bending (LSB) history was selected for use. This history, as shown in Fig. 1, contains 62 672 reversals and was provided in a normalized sequential peak and valley file by the SAEFDE committee. The history was chosen due to the large number of small amplitude cycles and its prior success in previous SAEFDE committee variable amplitude fatigue research.

Conventional strain range editing involves a peak to peak strain range value (or gate) for editing purposes. All strain ranges less than the gate value regardless of mean stress are removed. The SWT parameter editing technique, however, includes the product of strain range and maximum stress for a given cycle. Thus, SWT parameter editing combines strain amplitude and mean stress evaluation in the cycle omission (or gate) criterion. All SWT parameter cycles less than the gate value are removed.

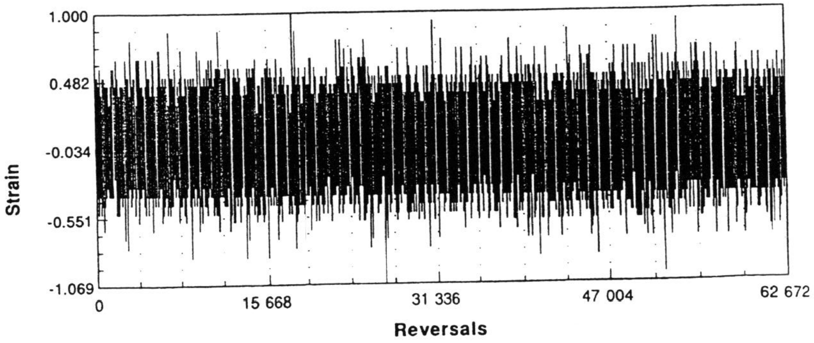

Fig. 1 Normalized LSB strain history

The objective of this research is to determine if the conventional strain range technique and the new SWT parameter technique can be used to accurately edit the LSB history to a predetermined damage level. Smooth cylindrical uniaxial through hardened SAE 1045 steel specimens were used for all testing. Comparisons between calculated and experimental fatigue lives for the complete and edited histories at three different peak strain levels where used to evaluate the editing techniques.

MATERIAL PROPERTIES

The SAE 1045 steel was through hardened by heating and then quenching in oil to form a martensitic microstructure with a Rockwell C (R_c) hardness of approximately 54. The composition is given in Table 1. Monotonic, cyclic and ε-N fatigue properties under fully-reversed strain conditions were obtained from smooth axial specimens using a 6 mm diameter test section with a 12.4 mm gage length. The material properties obtained included the monotonic true stress-true strain relationship, Eq(1),

$$\varepsilon = \left(\frac{\sigma}{E}\right) + \left(\frac{\sigma}{K}\right)^{1/n} \tag{1}$$

the cyclic stress strain relationship, Eq(2),

$$\varepsilon_a = \frac{\sigma_a}{E} + \left(\frac{\sigma_a}{K'}\right)^{1/n'} \tag{2}$$

and the fully-reversed strain-life relationship, Eq(3).

$$\varepsilon_a = \frac{\sigma'_f}{E}\left(2N_f\right)^b + \varepsilon'_f\left(2N_f\right)^c \tag{3}$$

Table 1 - Composition in Weight % for SAE 1045 Steel

C	Si	P	S	Mn	Ni	Cr	Mo	Fe
0.465	0.310	0.016	0.023	0.850	0.040	0.080	0.010	Bal.

The material properties are given in Table 2. Cyclic and fatigue data in the "standard fit" column were obtained as per ASTM E606 standard and data in the "property fit" column were obtained using an approach developed by Yan etal. (1992). This fitting procedure was developed by them to better represent the actual ε-N data and to better represent extropolated variable amplitude fatigue damage at longer lives. The "property fit" values were used in all fatigue calculations and editing techniques.

FULL LENGTH LSB HISTORY TESTS

The LSB history shown in Fig. 1 contains 62 672 reversals and was used for all full length-variable strain amplitude testing. The history was scaled to three peak strain levels of 0.0096, 0.0065, and 0.00545 for testing. These three levels were selected based upon analytical predictions to provide a range of fatigue life of 19, 111 and 282 blocks respectively. These predicted fatigue lives were obtained utilizing LiFst software, the property-fit data of Table 2, rainflow counting, Palmgren-Miner linear damage rule and the SWT mean stress model, Eq(4).

$$\sigma_{\max}\varepsilon_a = \frac{\left(\sigma'_f\right)^2}{E}\left(2N_f\right)^{2b} + \sigma'_f\varepsilon'_f\left(2N_f\right)^{b+c} \tag{4}$$

The 3D cycle histogram showing cycles, strain range and mean strain for the 0.0065 peak strain level with the full LSB history is shown in Fig. 2. Cycle histograms for the other two peak strain levels would appear identical to Fig. 2 except for magnitude changes. Figure 2 shows the large number of small amplitude cycles present in the full length LSB history, as well as indicating the overall history to be generally centered about the zero mean strain level. The damage plot for the 0.0065 peak strain level full length LSB history is shown in Fig. 3, which shows the amount of theoretical damage per block and the responsible cycles. The many small cycles are responsible for a very small amount of damage. They were found to make up about 90% of the full scale LSB histories while causing less than 10% of the theoretical damage.

Table 2 SAE 1045 Through Hardened Properties

Monotonic			
Hardness,	R_c	54	
Young's Modulus,	E (GPa)	203.3	
0.2% Offset Yield Strength,	S_y (MPa)	1606	
Ultimate Tensile Strength,	S_u (MPa)	2039	
% Elongation at Fracture,		5.5	
% Reduction in Area at Fracture,		8	
True Fracture Ductility,	ε_f	0.083	
Strain Hardening Coefficient,	K (MPa)	2976	
Strain Hardening Exponent,	n	0.099	
Cyclic/Fatigue		**Standard Fit**	**Property Fit**
Cyclic Strength Coefficient,	K' (MPa)	5252	4438
Cyclic Strength Exponent,	n'	0.189	0.170
Fatigue Strength Coefficient,	σ'_f (MPa)	4786	5684
Fatigue Strength Exponent,	b	-0.154	-0.170
Fatigue Ductility Coefficient,	ε'_f	0.209	0.081
Fatigue Ductility Exponent,	c	-0.714	-0.633

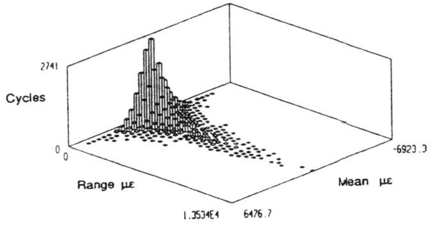

Fig. 2 Cycle histrogram for the 0.0065 peak strain level full length LSB history

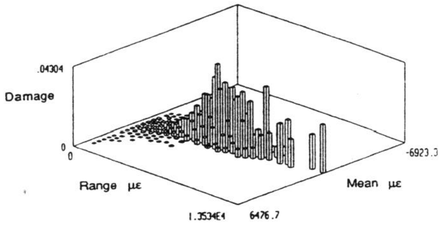

Fig. 3 Damage plot for the 0.0065 peak strain level full length LSB history

Two 6 mm diameter uniaxial specimens were tested at each of the three peak strain levels using the full LSB history. Scatter factors for a given peak strain ranged from 1 to 3 with more scatter at the lower peak strain level. The average experimental fatigue lives were less than the calculated fatigue lives by a factor of about two for each peak strain level. This factor of two, although unconservative, is still very reasonable and acceptable.

EDITED LSB HISTORY TESTS

The strain range and SWT parameter editing techniques were used with nCode® software to edit the full LSB history to 50% retained damage for each of the three reference peak stain levels. This resulted in a retained history for strain range gate editing of 276, 204 and 204 reversals for the 0.0096, 0.0065 and 0.00545 peak strain levels respectively. The analogous retained history for the SWT parameter gate editing was 250, 186 and 170 reversals. Each of these six edited histories consisted of less than 0.5% of the original LSB history. This demonstrates that a very small percentage of a variable amplitude history can be responsible for fully one half of the damage. The edited histories for the 0.0065 peak strain level for strain range and SWT parameter editing are shown in Figures 4 and 5 respectively. The corresponding edited 3D cycle histograms for the 0.0065 peak strain level are shown in Figures 6 and 7. These figures show the significant removal of smaller strain ranges. They also show different resulting histories for strain-range and SWT parameter editing techniques. Damage plots for the 0.0065 peak strain level with the strain range and SWT parameter editing techniques are shown if Figures 8 and 9 respectively. The damage distribution is different for the two methods, but both show well distributed damage within the significantly reduced cycles.

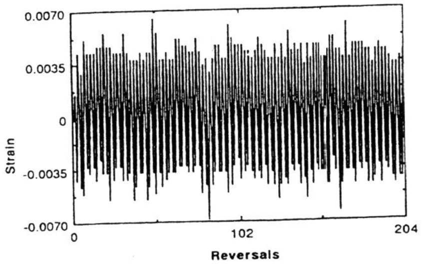

Fig. 4 Strain range edited 50% damage 0.0065 peak strain level LSB history

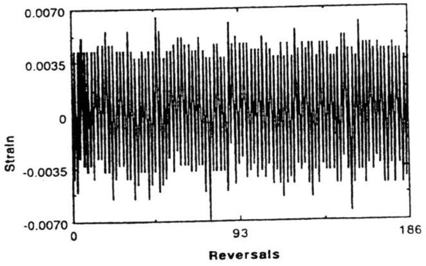

Fig. 5 SWT parameter edited 50% damage 0.0065 peak strain level LSB history

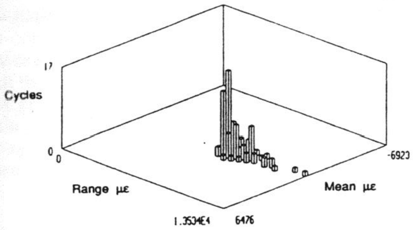

Fig. 6 Cycle histogram 50% damage retained strain range edited 0.0065 peak strain level LSB history

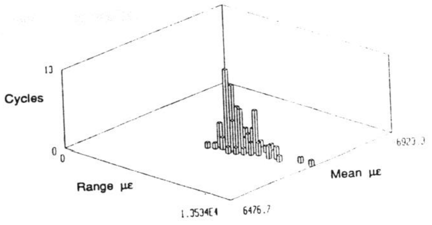

Fig. 7 Cycle histogram for 50% damage retained SWT parameter edited 0.0065 peak strain level LSB history

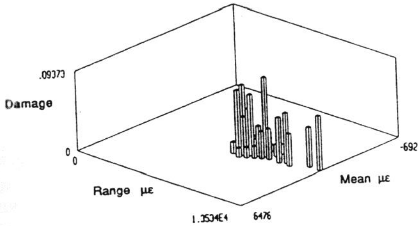

Fig. 8 Damage plot for 50% damage retained strain range edited 0.0065 peak strain level LSB history

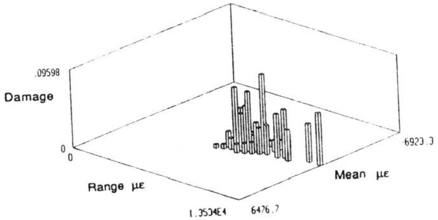

Fig. 9 Damage plot for 50% damage retained SWT parameter edited 0.0065 peak strain level LSB history

Eleven smooth 6mm diameter uniaxial specimens were tested with the 50% damage retained histories. Six specimens were used with the strain range edited peak levels and five specimens were used with the SWT parameter edited peak levels. Thus, one to three tests were performed for a given peak strain editing procedure. Scatter factors for duplicate or triplicate tests ranged between 1 and 2 which was similar to the scatter in the full length LSB tests. Fatigue life calculations were performed for each of the test conditions using the same software/procedures as for the full LSB history. As with the full length LSB histories, the edited average experimental fatigue lives were less than the calculated fatigue lives by a factor of about two for each peak strain level. This indicates that editing the LSB history using either the strain range or SWT parameter techniques did not affect the small unconservative relationship between experimental and calculated fatigue lives. Calculated fatigue lives in blocks versus experimental fatigue lives in blocks for all tests are shown in Fig. 10. The solid 45° line represents exact calculated versus experimental correlation, while the dashed lines represent a factor of ±2.

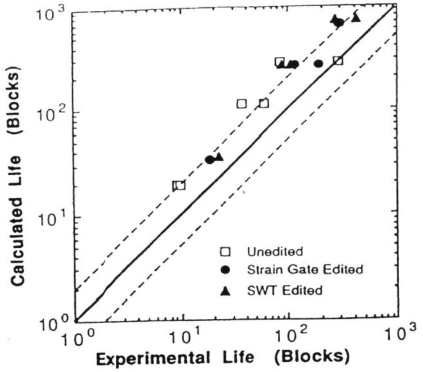

Fig. 10 Correlation of calculated and experimental fatigue lives for original and edited LSB histories

DISCUSSION OF RESULTS

The percent damage retained using the LSB history versus percent maximum strain range gate value or percent maximum SWT parameter gate value is shown in Figures 11 and 12 respectively. The slope of the curves in both figures is steepest between the 20 and 80% damage retained levels. This implies that possible errors in the edit gate value or editing technique have the maximum detectability in this region. The 50% damage retained level fell within the steepest slope region. Additionally, the theoretical fatigue life of an LSB history edited to 50% retained damage provides a factor of two difference in expected life which provides an adequate difference for comparisons with experimental fatigue lives. This also eliminated more than 99.5% of the reversals.

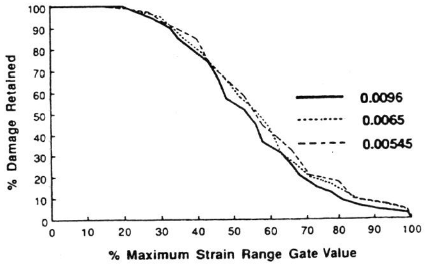

Fig. 11 Percent damage retained for the LSB history versus percent maximum strain-range gate value

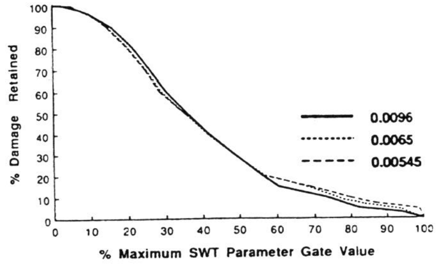

Fig. 12 Percent damage retained for the LSB history versus percent maximum SWT parameter gate value.

Comparing the calculated and experimental fatigue lives given in Fig. 10 for a given condition, a non-conservative factor of about 2 was found to exist between both the edited and non-edited histories. This indicates that both editing techniques removed the predicted amount of damage from the LSB histories for all peak strain levels. Also both editing procedures using 50% retained damage resulted in fatigue lives that were about double the non-edited fatigue lives for a given peak strain level. Thus both the conventional strain range gate and the new SWT parameter 50% damage retained editing procedures with this through hardened SAE 1045 steel were very successful.

SUMMARY AND CONCLUSIONS

1. Use of the local strain approach incorporating SWT mean stress correction with low cycle fatigue properties, rainflow counting and the linear damage rule resulted in unconservative room temperature smooth specimen uniaxial fatigue life predictions by a factor of about two. This is a small acceptable difference.

2. The new SWT parameter editing technique edits a variable amplitude history based upon strain amplitude and mean stress, while the conventional strain range editing technique involves only the strain amplitude. Both editing techniques successfully edited the predicted amount of damage from the LSB history. The SWT parameter editing technique, however, removed more cycles and thus may be more efficient.

3. Based upon percent damage retained as a function of percent maximum editing gate value, both editing techniques can be used to edit from small to large numbers of cycles.

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