Durability Assessments of Motorcycle Handlebars

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ABSTRACT

To investigate fatigue failure of motorcycle handlebars, fatigue analysis and durability experiments are conducted in this study. The finite element software, MSC.Nastran, was used to obtain the stress distribution of a handlebar subject to loadings in various directions. The results of FEM analysis were compared with those of static test to obtain optimum applied loading direction in the durability test. The strain history of the handlebar was measured when a motorcycle traveled on the Belgium (Pave) Road. The applied loading history in the durability test was obtained with remote parameter control technique. Three methods including “traditional S-N approach”, “BS 5400 approach” and “BS 5400 with Gurney thickness modification approach” were used to analyze the fatigue life of the handlebars. Rainflow cycle counting method and Miner’s damage accumulation rule were applied. FEM results show that when the loading angle of the actuator is 26° from the horizontal, a crack is produced where the handle was welded to the main pipe. This coincides with the test result in full vehicle simulation. The traditional S-N approach and BS 5400 standard approach cannot give a satisfactory result for fatigue life prediction. On the other hand, the BS 5400 standard with the Gurney thickness modified approach gives a satisfactory result. The difference between the predicted results and the experimental results was within an acceptable range of 2.5 times. It means the BS 5400 standard with the Gurney thickness modified approach could be used to assess the durability of motorcycle handlebars.

INTRODUCTION

Motorcycle industry is one of the important industries in Taiwan. Fatigue cracks of motorcycle structures are sometimes found to initiate at welded regions during structural development. It is necessary to understand what fatigue analysis approach is suitable for this product. Fatigue design methodologies for metallic components have been traditionally based on the stress-life (S-N) approach [1, 2]. This approach works well for designs involving long life. There are reams of data available for almost any variation in surface finish, load configuration, environment, and so on.

Welded structures are often subject to fatigue problems. There are many reasons for the reduced fatigue strength in welded structures such as global stress concentration, residual stresses, weld flaws and heat affected zone. A statistical analysis of fatigue tests on steel welded structures have been conducted in 1972 [3], and led to the development of fatigue design, which is now incorporated in many standards. The BS 5400 standard [4] is used to predict the fatigue life of welded structures, and has been developed over many years. When the thickness effect was considered, the damage model was modified by Gurney [5]. In addition, there are other standards specified S-N curves of welded joints such as AASHTO [6], AISC [7], API RP2A [8], AREA [9], AWS: PT9 [10] and ARSEM [11]. The purpose of this study is to find out a suitable durability analysis approach for motorcycle handlebars. The procedure consists of finite element analysis, field data acquisition, road simulation, durability test and fatigue life prediction. Three methods including “traditional S-N approach”, “BS 5400 approach” and “BS 5400 with the Gurney thickness modification approach”, were used to analyze the fatigue life of the handlebars. In order to validate this methodology, four levels of loading histories in the
durability tests on real motorcycle handlebars were performed.

THEORY

Fatigue life of a welded joint may be influenced by geometric shape, material property, residual stresses and weld defects, etc. Since the complexities, its fatigue design is much difficult than non-welded metals.

BS 5400: part 10 standard formulated by British Standards Institute was developed to assess fatigue life of steel, concrete and composite bridges. There are nine classes of welded details categorized as per load type, location of potential crack initiation and weld geometry, etc. They are called: class B, class C, class D, class E, class F, class F2, class G, class S, and class W, respectively. In references [12, 13], the method for classification of welded details according to this standard has been rearranged and tabulated in a convenient form with corresponding schemes and legends that show these data in a clear and concise format.

The parameters describing mean S-N curve and standard deviation of each class are listed in BS 5400 standard for design reference. Therefore, it can provide the prediction of fatigue life with various failure probabilities.

When \( N_f \leq 10^7 \), the correlation between fatigue life and nominal stress is:

\[
\log N_f = \log K - z \sigma - m \log S_n
\]  
(1)

where

- \( N_f \): fatigue life,
- \( K \): constant relating to the mean-line of the statistical analysis results,
- \( z \): number of standard deviations below the mean-line,
- \( \sigma \): standard deviation of \( \log N_f \),
- \( m \): inverse slope of mean-line \( \log S - \log N \) curve,
- \( S_n \): nominal stress.

When \( N_f > 10^7 \), the equation is:

\[
\log N_f = \log K - z \sigma - (m + 2) \log S_n
\]  
(2)

Gurney [13] modified equation (1) and (2) to consider thickness effect. The modified equations are as follow:

When \( N_f \leq 10^7 \),

\[
\log N_f = \log K - z \sigma - m \log \frac{S_n}{(22)^{0.25}}
\]  
(3)

\[
\log N_f = \log K - z \sigma - (m + 2) \log \frac{S_n}{(22)^{0.25}}
\]  
(4)

For comparison, the S-N curve of base metal is estimated. Endurance limit is 0.5 times the ultimate strength, and alternating stress level corresponding to a life of 1000 cycles is 0.9 times the ultimate strength.

Required data in the fatigue analysis include:

(a) Load history: nominal stress history (= Young’s modulus \( x \) nominal strain history).
(b) Class of welded detail.
(c) Thickness of weld joint.
(d) Material properties (S-N curve).
(e) Probability of failure (= 50% in this study).

METHODS

With respect to durability tests and analyses, the major procedures are as follows:

1. Target Component and Target Road

The vehicle for this study was a 150c.c. scooter type of motorcycle. We selected motorcycle handlebar as the target component (shown in Figure 1) and Belgium (Pave) road of the proving ground in ARTC (Automotive Research and Testing Center in Taiwan) as the target road (shown in Figure 2).

Figure 1. The target component of durability test (the motorcycle handlebar).
2. Stress Analysis

The geometry and dimensions of the target handlebar are employed to construct a computer model. MSC.Nastran finite element software was adopted to carry out the stress and strain analysis and to find out possible failure locations. In addition, the results of FEM were compared with those of full vehicle road simulation durability test to obtain optimum applied loading direction in the durability test with single actuator.

3. Data Acquisition of Field Test

With the help of FEM analysis, the areas of stress concentration were pointed out. Then rosette gauges were installed on the motorcycle handlebar at the critical locations to determine the maximum principal stress direction, as exemplified in Figure 3.

The motorcycle was driven on the Belgium (Pave) road at a speed of 30 km/h, as shown in Figure 4. Data recorder (IMC-CRONOS) was mounted at a suitable location on the test vehicle. Sampling rate was 1 kHz. The strain histories of the handlebar were measured and the acquired data were edited to ensure that the quality of data was good and free from spikes, noise, etc.

4. Road simulation

Fixtures required for the durability test were designed and manufactured. The field strain history was reproduced in the laboratory with a remote parameter control technique, in order to obtain the applied loading history with single servo hydraulic actuator in the durability test. The controller for this simulation test was IST-8800 and the software was RS-SPiDAR. The diagram of the force input is shown in Figure 5. The optimum loading angle of actuator was analyzed by FEM analysis. From pilot fatigue analysis, the fatigue life of original (1x magnification) strain history would be up to 800 hours. Therefore, the original field strain history was edited to four higher strain levels (3x, 3.5x, 4x and 4.5x), and we obtained the corresponding load histories by remote parameter control technique [14, 15, 16].

5. Durability Test

Four levels of loading histories obtained from road simulation were applied in the durability test. Inspection was performed periodically to find whether crack was initiated. The test duration was shortened to within an acceptable range of 48 hours.
6. Evaluation of Fatigue Life

In S-N fatigue analysis, the nominal stress history is obtained by the strain history multiplying Young’s modulus. Rainflow cycle counting method [17, 18] and Miner’s damage accumulation rule [19] were used to perform this evaluation. The analysis steps are as follows:

Step 1: For the traditional S-N approach, enter the estimated stress-life curves. While for the BS 5400 approach, enter the class, thickness and probability of failure of the welded joint in order to determine the stress-life curves.

Step 2: Make a cycle counting for stress history and derive the damage of each counted stress cycle corresponding to the stress-life curve which is given from step 1, then find the fatigue life of the welded joint by damage accumulation.

RESULTS AND DISCUSSION

The location of potential crack initiation and the angle of force input in the durability test were examined firstly. Then fatigue lives of experimental test and three fatigue life assessment methods were compared.

1. Analysis of Loading Angle and Fracture Location:

At the beginning of the experiment, it was noticed that the angle of force input for the servo hydraulic actuator was related to the fracture locations. For this reason, finite element software was applied to analyze the stress distribution and possible fracture locations of motorcycle handlebar and compared with the experimental results of previous full vehicle durability test. The input parameters: Young’s modulus = 210,000 MPa, Poisson’s ratio = 0.3, 2D shell element type, thickness 2.3 mm, boundary condition - load exerted at the ends of motorcycle handlebar.

When the servo hydraulic actuator applied a force downward at an angle of 26° from the horizontal (this angle was measurement from the rider’s hand and the horizontal under practical riding condition), the crack was produced in the welded region (area A), where the handle was welded to the main pipe (as shown in Figure 6). The result of finite element analysis also showed that area 2 is one of higher stress-concentrated areas (as shown in Figure 7), and this area would crack first due to the welded effect.

If the angle of force input was increased to 36° from the horizontal, the result of finite element analysis also showed that, there were three higher stress-concentrated areas (as shown in Figure 8). The actual cracks would initiate at the welded region - area B (as shown in Figure 9).

Figure 6. Fracture location of motorcycle handlebar at durability test (loading angle 26°).

Figure 7. Stress distribution of the motorcycle handlebar (loading angle 26°).

Figure 8. Stress distribution of the motorcycle handlebar (loading angle 36°).
2. Evaluation of Fatigue Life

Since fracture locations along the handlebar will probably occur near the welded region, the welded effect must be considered when performing the fatigue life prediction. For 1-magnification strain history, the signals obtained from the target road were too small, and the duration of experiment would be as high as up to 800 hours. On the other hand, according to the ultimate strength of the material, the reasonable range of magnification on the durability test would be under or equal to 4.0x. If the magnification is 4.5 or higher, the maximum stress of loading history would be higher than ultimate strength, it would be unreasonable for the accelerated durability test. Therefore, the 3 ~ 4.5 times magnification strain history were used to perform durability tests.

Three methods including "traditional S-N approach", "BS 5400 approach" and "BS 5400 with the Gurney thickness modification approach" were used to predict the fatigue lives of the handlebars for four levels of loading history in the durability test. The response strain histories are shown in Figure 11. A portion of original and response strain histories (3x magnification) reproduced by remote parameter control technique is shown in Figure 12. The error between R.M.S. strains of target and response history is only 1.29%. The other results of road simulation are summarized in Table 1. Results of tensile tests for motorcycle handlebar are: ultimate strength = 539.5 MPa, yield strength = 512.0 MPa, elongation = 15.9% and these data are shown in Table 2. The estimated S-N curve of JIS 25C carbon steel use for motorcycle handlebar is shown in Figure 13. The welded detail was classified as G class according to BS 5400: Part 10 standard (as shown in Figure 14). Parameters describing S-N curve of G class detail are $K = 0.57 \times 10^{12}$, $\sigma = 0.662$ and $m = 3.0$, respectively. The mean fatigue life is predicted with $z = 1$ in this study.

Table 3 lists the fatigue lives of durability test and three theoretical methods (1 block = 77 seconds). The predicted results of the traditional S-N approach are far higher than the experimental results (more than 50 times). It means that the influence of weld on the fatigue life is important. The results of BS 5400 approach are also lower than those of experiment. This is because the original information for BS 5400 standard was obtained from the weld joints of 22 mm thickness. When the thickness decreases, the stress state of the specimen tend to be plane stress and lead to a conservative prediction of fatigue life. On the other hand, the BS 5400 with Gurney thickness modification approach (thickness of 2.3 mm) gives a satisfactory result. The differences between results of prediction and experiment are within an acceptable range of 2.5 times. It means that the third approach can assess the durability of motorcycle handlebar satisfactorily.
Figure 12. A portion of the original and reproduced 3x strain history.

Figure 13. Estimated stress–life curve of JIS S25C steel.

Figure 14. The fracture location at welded region and the G class of BS 5400 standard. (Classification of details is from Ref. [4])

CONCLUSION
The durability test and analysis are presented in this study. The optimum loading angle in the durability test for the Belgium road is 26°. Three methods including “traditional S-N approach”, “BS 5400 approach” and “BS 5400 standard with the Gurney thickness modification approach” were used to analyze the fatigue life of the handlebars. In order to validate this methodology, four levels of loading histories were applied in durability tests on real motorcycle handlebars.

A satisfactory agreement is found between the results of the durability test and the prediction of “BS 5400 standard with the Gurney thickness modification approach”. The difference between the results of experiment and prediction is within an acceptable range of 2.5 times. It means that the “BS 5400 standard with the Gurney thickness modified approach” is suitable to assess the durability of motorcycle handlebars. In the future, this approach could be applied to the durability assessment for weldments of automobiles.

Table 1. Results of road simulation.

<table>
<thead>
<tr>
<th>Number of Magnification of Strain History</th>
<th>Target (R.M.S.)</th>
<th>Response (R.M.S.)</th>
<th>Error (%)</th>
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<tbody>
<tr>
<td>3</td>
<td>279.2</td>
<td>275.6</td>
<td>1.29</td>
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<tr>
<td>3.5</td>
<td>325.7</td>
<td>321.3</td>
<td>1.35</td>
</tr>
<tr>
<td>4</td>
<td>372.2</td>
<td>366.9</td>
<td>1.42</td>
</tr>
<tr>
<td>4.5</td>
<td>418.8</td>
<td>412.5</td>
<td>1.50</td>
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Note: R.M.S. (root mean square)
Table 2. Summary of tensile properties.

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Ultimate Strength (MPa)</th>
<th>Yield Strength (MPa)</th>
<th>Elongation (%)</th>
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<tr>
<td>1</td>
<td>537.9</td>
<td>506.8</td>
<td>14.8</td>
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<tr>
<td>2</td>
<td>532.5</td>
<td>507.4</td>
<td>17.0</td>
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<tr>
<td>3</td>
<td>548.2</td>
<td>521.7</td>
<td>15.8</td>
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<tr>
<td>Average</td>
<td>539.5</td>
<td>512.0</td>
<td>15.9</td>
</tr>
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Table 3. Comparison of the fatigue life for motorcycle handlebar.

<table>
<thead>
<tr>
<th>Strain History (Number of Magnification)</th>
<th>Fatigue Life (blocks)</th>
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<tbody>
<tr>
<td></td>
<td>Experiment</td>
</tr>
<tr>
<td>1</td>
<td>—</td>
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<tr>
<td>2</td>
<td>—</td>
</tr>
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<td>4</td>
<td>395</td>
</tr>
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<td>4.5</td>
<td>129</td>
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REFERENCES


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