Uncertainty Evaluation of Tensile Experiment of Welded Joint Based on the Method of GUM
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Abstract. The paper is based on the method of GUM. In this paper, according to the mathematic model of tensile strength, lower yield strength and elongation after break, we analyzed the uncertainty. In the process of analysis, the experimental process is optimized, and the sensitivity coefficient is introduced, which can quantify the contribution degree of each input to the uncertainty. The uncertainty assessment work is more in-depth and more accurate.

Introduction
Along with the development of modern industrial technology, the standardization demand of the test method and experimental technology on the material and structure is higher and higher. Especially the international engineering, more and more foreign Marine engineering company request the laboratory qualification, with which the laboratory can realize the mutual recognition of the results between countries. This need to evaluate the accuracy of the test data and provide experimental method of the uncertainty value. According to the characteristics of mechanical property test of the welded joint, we carry out the uncertainty evaluation of tensile experiment. The data of uncertainty value can ensure the quality of the experimental. In order to obtain this data, the laboratory should consider comprehensively test method, equipment, materials, processes, and many other factors. Through the analysis of the relationship between these factors and the influence degree of the system analysis, we can raise the reasonable assessment data.

Test Process Description
According to the GB/T 228.1-2010, the tensile test conducted in accordance with the following steps. First, the cross-sectional diameter of the sample should be measured with vernier caliper C1. Then we should calculate the original cross-sectional area S0. Using the tensile specimen gage instrument to mark the specimens, and the original gauge length of the specimen is measured by the vernier caliper C1. Installing the sample to the universal testing machine, the sample is stretched at a specified rate until fracture. Then we should measure the break gauge length of the specimen with A vernier caliper C2 and input this data. We can obtain the maximum force Fm, the lower yield force FeL, the tensile strength Rm, the lower yield strength ReL, and we can calculate the break elongation according to the formula. The test is over.

Test Conditions
Equipment
The basic information of equipment using in this paper was as follows.
Table 1. Basic information of equipment.

<table>
<thead>
<tr>
<th>Device name</th>
<th>specifications</th>
<th>minimum resolution</th>
<th>measurement range</th>
<th>expanded uncertainty /maximum tolerance/accuracy level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic universal testing machine</td>
<td>E45.105</td>
<td>0.01KN</td>
<td>0~100KN</td>
<td>Grade 1</td>
</tr>
<tr>
<td>Vernier caliper C1</td>
<td>GL200</td>
<td>0.01mm</td>
<td>0~200mm</td>
<td>±0.01mm</td>
</tr>
<tr>
<td>Vernier caliper C2</td>
<td>GL300</td>
<td>0.01mm</td>
<td>0~300mm</td>
<td>±0.01mm</td>
</tr>
<tr>
<td>Standard dynamometer</td>
<td>/</td>
<td>/</td>
<td>10~100KN</td>
<td>Grade 0.3</td>
</tr>
</tbody>
</table>

Test Environment Conditions (when Applicable)

Temperature: 10-35 °C, humidity: 60%, pressure: 1.013 x 10^5 pa

The Mathematical Model

According to the principle of the tensile test, the mathematical model is set up.

Tensile strength: \[ R_s = \frac{F_m}{S_0} = \frac{4F_m}{\pi d^2} \]

- \( F_m \) - the maximum force, N.
- \( S_0 \) - the original cross-sectional area of sample, mm^2.
- \( d \) - the diameter of the parallel sample, mm.

Yield strength: \[ R_{el} = \frac{F_{el}}{S_0} = \frac{4F_{el}}{\pi d^2} \]

- \( F_{el} \) - the lower yield force, N.
- \( S_0 \) - the original cross-sectional area of sample, mm^2.
- \( d \) - the diameter of the parallel sample, mm.

Break elongation: \[ \Delta = \frac{L_u - L_0}{L_0} = \frac{L_u}{L_0} - 1 \]

- \( \Delta \) - break elongation, %;
- \( L_0 \) - the length of the original gage, mm.
- \( L_u \) - the length of final gage length, mm.

Analysis and Calculate

The Uncertainty of the Diameter and Range of the Sample

The nominal diameter \( d \) of the rod tensile specimen is 10mm, measured with the vernier caliper C1; the original gauge length \( L_0 \) is crossed with the scribe line and measured with the vernier caliper C1. To avoid the correlation between the input quantities, the length of final gage is measured with the vernier caliper C2. The 10 samples were measured under repeated conditions. A total of 10 data were measured. The data are shown in Table 2.

Table 2. Test measurement data.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_0 )</td>
<td>49.24</td>
<td>50.51</td>
<td>48.17</td>
<td>49.45</td>
<td>50.37</td>
<td>50.48</td>
<td>50.68</td>
<td>50.36</td>
<td>50.46</td>
<td>50.76</td>
<td>50.05</td>
</tr>
<tr>
<td>( L_u )</td>
<td>63.23</td>
<td>64.37</td>
<td>65.23</td>
<td>63.36</td>
<td>65.16</td>
<td>64.18</td>
<td>64.33</td>
<td>64.23</td>
<td>64.91</td>
<td>62.9</td>
<td>64.19</td>
</tr>
<tr>
<td>( R_m )</td>
<td>552</td>
<td>579</td>
<td>580</td>
<td>571</td>
<td>552</td>
<td>557</td>
<td>554</td>
<td>564</td>
<td>564</td>
<td>540</td>
<td>561</td>
</tr>
<tr>
<td>( ReL )</td>
<td>404</td>
<td>424</td>
<td>446</td>
<td>414</td>
<td>415</td>
<td>412</td>
<td>409</td>
<td>416</td>
<td>409</td>
<td>402</td>
<td>415</td>
</tr>
</tbody>
</table>

(1) Class A standard uncertainty assessment
1) measurement repeatability of the original diameter of the sample \( u_1(d) \)

According to the Bessel formula, the standard uncertainty component of \( d \) can be available from Table 1. \( u_1(d) = 0.076 \) mm

2) measurement repeatability of the original gauge length \( u_1(L_0) \)

According to the Bessel formula, the standard uncertainty component of \( L_0 \) is calculated from the data in Table 1. \( u_1(L_0) = 0.831 \) mm

3) measurement repeatability of the final gage length \( u_1(L_u) \)

According to the Bessel formula, the standard uncertainty component of \( L_u \) is calculated from the data in Table 1. \( u_1(L_u) = 0.8075 \) mm

(2) Class B standard uncertainty assessment

1) Measurement error of vernier caliper \( C_1 \) and \( C_2 \)

The original diameter \( d \) and the original gauge length \( L_0 \) are measured with the vernier caliper \( C_1 \).

The caliper is qualified by Metrology Bureau. And its indication error given by the certificate is 0.01 mm. The probability of occurrence of the specimen is in the uniform distribution. The standard uncertainty can be assessed by class B method, \( k \) is 3.

\[
u_2^2(L_0) = \frac{\alpha}{\sqrt{3}} = 0.003 \text{ mm}
\]

2) Measurement error of vernier caliper \( C_2 \)

The length of final gage \( L_u \) is measured with the vernier caliper \( C_2 \), the measuring range of which is 0 ~ 300 mm. The caliper is qualified by Metrology Bureau too, and the indication error is 0.01 mm. It is also subject to uniform distribution, so \( k \) is \( \sqrt{3} \).

\[
u_2^2(L_u) = \frac{\alpha}{\sqrt{3}} = 0.003 \text{ mm}
\]

(3) The synthesis of standard uncertainty

1) Synthetic uncertainty of the original diameter \( u(d) \)

Because \( u_1(d) \) and \( u_2(d) \) are independent, the synthesis of standard uncertainty of the original diameter is according to the following formula.

\[
u(d) = \sqrt{u_1^2(d) + u_2^2(d)} = 0.076 \text{ mm}
\]

2) Synthetic uncertainty of the final gage length \( u(L_u) \)

Similarly, because \( u_1(L_u) \) and \( u_2(L_u) \) are independent, the synthesis of standard uncertainty of the final gage length is according to the following formula.

\[
u(L_u) = \sqrt{u_1^2(L_u) + u_2^2(L_u)} = 0.831 \text{ mm}
\]

3) Synthetic uncertainty of the original gauge length \( u(L_0) \)

The original standard gauge distance \( u_1(L_0) \) and \( u_2(L_0) \) are independent, so the synthesis of standard uncertainty of the original gage length is according to the following formula.

\[
u(L_0) = \sqrt{u_1^2(L_0) + u_2^2(L_0)} = 0.8075 \text{ mm}
\]

The Uncertainty of the Test Force \( u(F) \)

(1) Relative Standard Uncertainty of indication error of Universal testing machine

100 kN electronic universal testing machine is used. Its indication error is ± 1.0 %, and the probability appearing in the interval [-1.0% ~ + 1.0%] is uniform. Therefore, \( k \) is \( \sqrt{3} \), when we use the B class assessment.

the relative standard uncertainty of lower yield strength \( (R_{el}) \) caused by the indication error of
machine, $u_{rel}(F_{el}) = \frac{a}{\sqrt{3}} = \frac{1.0\%}{\sqrt{3}} = 0.577\%$

Similarly, the relative standard uncertainty of the tensile strength ($R_m$) caused by the indication error of machine, $u_{rel}(F_{cm}) = \frac{a}{\sqrt{3}} = \frac{1.0\%}{\sqrt{3}} = 0.577\%$

(2) Relative Standard Uncertainty introduced by standard dynamometers

The test machine is calibrated by means of a Class 0.3 standard dynamometer. Its uncertainty is 0.3\% and the confidence factor is 2. Therefore, the relative standard uncertainty of the class B is as follow: $u_{rel}(F_{cl}) = \frac{U}{k} = \frac{0.3\%}{2} = 0.15\%$

Similarly, $u_{rel}(F_{cm}) = \frac{U}{k} = \frac{0.3\%}{2} = 0.15\%$

(3) The synthesis of standard uncertainty

First, we synthesize the relative standard uncertainty. The electronic universal testing machine and the standard dynamometer have nothing to do with each other, so as to, they are independent, so the synthetic relative standard is as follow:

$$u_{rel}(F_{cl}) = \sqrt{u_{rel}(F_{el})^2 + u_{rel}(F_{cm})^2} = 0.5768\%$$

Similarly, $u_{rel}(F_{cm}) = \sqrt{u_{rel}(F_{cm})^2 + u_{rel}(F_{cm})^2} = 0.5768\%$

The standard uncertainty for substituting data is as follows.

$u(F_{el}) = 415.19 \times 77.1 \times 0.5768\% = 184.263$N

$u(F_{cm}) = 561.2 \times 77.1 \times 0.5768\% = 249.804$N

The Standard Uncertainty Caused by the Numerical Correction

GB/T228-2010 standard stipulates: " The numerical correction of the test results should be in accordance with the requirements of the relevant product standards. If there are not specified specific requirements, the test results should be revised in accordance with the following requirements:

1) strength performance repair about 1MPa;
2) yield point elongation repair to about 0.1\%, other elongation and elongation after breaking repair to about 0.5\%;
3) Section shrinkage is reduced to about 1\%.

In this paper, the specific requirements are not specified. Therefore, the revision should be carried out in accordance with the requirements of the standard, which must introduce uncertainty. And we can use Class B to assess it.

$u_{rel}(F_{cl}) = 0.29 \delta_e = 0.29$ MPa

$u_{rel}(F_{cm}) = 0.29 \delta_e = 0.29$ MPa

$u_{rel}(A) = 0.29 \delta_s = 0.145\%$

Calculation of Synthetic Standard Uncertainty

According to the mathematical model of tensile strength, lower yield strength and elongation at break, the sensitivity coefficient of each input is calculated as follows:

$$c_{F_{el}} = \frac{\partial R_{el}}{\partial F_{el}} = \frac{4}{\pi l^2} = 0.01297, \quad c_{d_{el}} = \frac{\partial R_{el}}{\partial d} = \frac{-8F_{el}}{d^3} = -3.413, \quad c_{A} = \frac{\partial R_{cm}}{\partial d} = \frac{-4}{\pi l^2} = 0.01297$$
\( c_{d,m} = \frac{\partial R_m}{\partial d} = \frac{8F}{d^2} = -4.613, \quad c_{L_0} = \frac{\partial A}{\partial L_0} = \frac{1}{L_0} = 0.01998, \quad c_{L_0} = \frac{\partial A}{\partial L_0} = -L_0 = 0.02562 \)

The uncertainty introduced by the test force, the original diameter, the measurement of the original gauge and the final gauge, the numerical correction are independent of each other. Therefore, the synthetic standard uncertainty can be obtained from the mathematical model as follows:

\[
\begin{align*}
\sigma_e^2 (R_{cl}) &= \sqrt{c^2_{F_{cl}} \times u^2 (F_{cl}) + c^2_{d_{cl}} \times u^2 (d) + u^2_{\text{rou}} (F_{cl})} = 2.8 \\
\sigma_e^2 (R_m) &= \sqrt{c^2_{F_m} \times u^2 (F_m) + c^2_{d_m} \times u^2 (d) + u^2_{\text{rou}} (F_m)} = 3.5 \text{ MPa} \\
\sigma_e^2 (A) &= \sqrt{c^2_{L_0} \times u^2 (L_0) + c^2_{L_0} \times u^2 (L_0) + u^2_{\text{rou}} (A)} = 2.7\%
\end{align*}
\]

The Expansion of Uncertainty

Take the confidence level \( p = 0.95 \), take the coefficient \( k = 2 \). The extended uncertainty is:

\[
\begin{align*}
U (R_{cl}) &= 2 \times 2.8 = 5.6 \text{ MPa} \\
U (R_m) &= 2 \times 3.5 = 7.0 \text{ MPa} \\
U (A) &= 2 \times 2.7\% = 5.4\%
\end{align*}
\]

Conclusion

(1) Through analyzing the uncertainty of the tensile experiment, the experiment process was optimized. Two calipers were used to measure the length of the original gauge length and the final gauge length, which can avoid the strong correlation problem, and greatly simplify the difficulty of assessing the uncertainty of the elongation at break.

(2) In this paper, we transformed the uncertainty caused by impact factors to the associated input, which made our work clearer.

(3) By introducing the sensitivity coefficient, we can quantify the contribution degree of the input to the uncertainty, so that the uncertainty assessment became more in-depth and more accurate.

References

