STUDY OF WELDING LINE UNRIPPING TEST OF METAL BELLOWS

Zhongbin Tang\(^{1(*)}\), Yulong Li\(^{1}\), Tao Suo\(^{1}\), Qiong Deng\(^{1}\)

\(^{1}\)School of Aeronautics, Northwestern Polytechnical University, Xi’an, Shaanxi, 710072, China
\(^{(*)}\)Email: tangzhongbin@nwpu.edu.cn

ABSTRACT

Metal bellows, as a functional structure in elastic sensor, heat expansion element, medium isolator, airproof component, et al., have been widely used in modern industry, such as machinery, metallurgy, aerospace and electronics. A critical problem for metal bellows is the failure of the welding material, which may lead to the device invalidation and catastrophic results. The welding lines of metal bellows usually work under cyclic stress state, and the welding quality affects directly the reliability of the working element. In this study, the unripping tests of the welding lines of metal bellows were investigated experimentally at room temperature (25ºC) and -196ºC. The geometry, grips as well as sampling of the specimen from metal bellow were all carefully designed. Results show that the fracture modes as well as the average failure loads are identical for both low-temperature and room temperature tests. Moreover, there is no significant difference between specimens from different bellow layers. An analysis on the experimental results shows that the distribution of the average failure loads obeys Weibull distribution, and the scattering of data is smaller for the low temperature tests and the outer samples.

Keywords: unripping test, metal bellows, welding line, Weibull distribution.

INTRODUCTION

In defense and civilian industries, metal bellows are used to store gas and hydraulic fuel, or be key control components. Therefore, its capacity, compression ratio, safety, credibility as well as long-term stability are very important (Liang, 2008). Since the welding lines of the metal bellows always work under cyclic loading, the quality of welding lines directly affects the metal bellows’ reliability (Situ, 2006). The study on mechanical properties of welding affected zone and the strength of the welding line is an essential issue for the safety and reliability design of metal bellows.

At present, the research on the welding line’s strength are focuses on the tearing test of the large thickness steel plate, e.g. T-welded joints and fillet welded joints (Dai, 2007). The study on welding line’s strength of thin films is rarely reported. In this study, the unripping tests of the welding lines of metal bellows were investigated experimentally at room temperature (25ºC) and -196ºC respectively.

EXPERIMENTAL PROCEDURE

Fig.1 shows the schematic of a typical metal bellows. Due to the limit size of the metal bellows, a T-shape specimen was used to measure the unripping behavior of the metal bellow.
(as shown in Fig.2). According to the shape of the metal bellows, the unripped specimens were sampled from metal bellow as shown in Fig. 3. To ensure the quality of the sample, the samples are fabricated using a low speed wire-cut electric discharge machine (LSWEDM). It should be pointed out that the specimens with the number of 1 to 6 are taken from the outer welding layer No. 1, 2, 4, 5 and 8, and specimens with the number of 7 to 12 are taken from the inner welding layer No. 1, 2, 4, 5 and 8. At the same layer, six specimens were prepared.

![Diagram of metal bellows](image)

**Fig. 1 - Schemes of the metal below**

To test its unripping behavior, two grip ends of the T-shape specimen was bent to 90° to ensure the grip ends to be vertical to the welding layer, as shown in Fig. 4. Then each of grip ends was attached to a clam which can be fixed directly to the test machine (see in Fig. 5). If tensile load vertical to the welding layer of specimen is applied, unripping property can be achieved successfully. Fig. 5 shows the unripping test apparatus where an enlarged view of cooling system is shown on the right corner. During experiments, liquid nitrogen is spayed on the surface of specimen via the cooling apparatus and the sample can be unripped at the temperature of -196°C. Though the unripping test, the maximum failure loads of the specimen are obtained.

![Unripping test apparatus](image)

**Fig. 4 - Diagram showing the unripping test apparatus**

**Fig. 5 - Unripping test apparatus showing the cooling system**

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RESULTS AND DISCUSSION

(1) Failure load

To obtain the failure load per unit length, the measured failure loads of the unripping tests were normalized. Fig. 6 and 7 show the failure load distribution of unit weld length at room and low temperature respectively. It can be seen from Fig. 6 that at room temperature the minimum failure load per unit weld length for the samples taken from the outer weld layer is 5.5N/mm, and the maximum is 13.0N/mm. However, for the samples taken from the inner weld layer, the minimum failure load per unit length is 7.5N/mm, and the maximum is 16.5N/mm. At low temperature, for the samples taken from the outer weld layer, the minimum and maximum failure load per unit weld length are 6.0 and 12.5N/mm respectively, while for the samples taken from the inner weld layer the minimum failure load per unit weld length is 6.5N/mm, and the maximum is 13.0N/mm. If comparing experimental results for specimen taken from different region but tested at the same temperature, it can be found that at whatever room or low temperature the failure loads for the specimen taken from inner weld layer is larger than that taken from the inner layer. Meanwhile, with the reduction in temperature, the failure load increases slightly.

Since dispersity of experimental data can be found from Fig. 6 and 7, the Weibull distribution was also employed in this work (Zhang, 1996 and You, 2009). Fig. 8 shows the Weibull distribution of average unit failure load obtained for specimens taken from both inner and outer weld layer. It can be seen from Fig.8 that at whatever room and low temperature, the unit failure loads for both outer and inner weld layer specimen obey the Weibull distribution. The shape and scale parameter of Weibull distribution can be obtained from Fig. 8, and the results are shown in Table 1. It can be seen from Table.1 that the Weibull distribution function modulus of unit failure loads \((m)\) for the outer weld layer is larger than that for the inner weld layer, leading to smaller dispersion of the unit failure loads for outer weld layer. If comparing the Weibull distribution parameters for specimens tested at room and low temperature, the Weibull distribution function modulus of the unit failure loads increases with reduction in temperature, leading to smaller dispersion of the unit failure loads when the specimen is tested at low temperature. It can also been observed from Table 1 that the difference between the characteristic value \(f_0\) and the average unit failure loads (average \(f/d\)) is very small, indicating the reliability of the Weibull distribution function.
Fig. 6 - The failure loads per unit weld length at room temperature

Fig. 7 - The failure loads per unit weld length at low temperature

Fig. 8 - The Weibull distribution of the unit failure loads
Table 1 - The Weibull distribution parameters of the unit failure loads

<table>
<thead>
<tr>
<th>Weibull Distribution parameters</th>
<th>Outer weld layers samples</th>
<th>Inner weld layers samples</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Room temperature</td>
<td>Low temperature</td>
</tr>
<tr>
<td>[m]</td>
<td>6.163</td>
<td>6.479</td>
</tr>
<tr>
<td>[f_0 (N / mm)]</td>
<td>9.590</td>
<td>9.766</td>
</tr>
<tr>
<td>Average [f/d] (N/mm)</td>
<td>9.057</td>
<td>9.116</td>
</tr>
</tbody>
</table>

(2) Failure mode

It should be pointed out that post-test observation of failed specimen show that all specimens failed at the weld layer and the rupture surface of the outer and inner weld layer is almost same. Fig. 9 shows the typical rupture surface of the outer weld layer tested at room and low temperature respectively from which near no difference can be observed. That is, the temperature influence is not obvious. The region contained in the box corresponds to the weld region while the region outside is non-welded surface. It can be seen from Fig. 9 that the rupture surface close to the non-welded region is much rougher than the other region. Since rougher rupture surface means more energy is needed before failure, the fact that rougher rupture surface is observed in the region close to non-welded region indicates this region bears most of applied load and therefore failure initiates. After the complete separation of this region, crack propagates quickly, leading to smooth rupture surface for which less energy is required.

CONCLUSIONS

In this work, an unripping test method was proposed to investigate the unripping resistance of a kind of metal bellow at temperatures of room temperature and -196°C repetively. Through the unripping test, the following conclusions are obtained:

(1) If comparing the experimental results at low temperature and room temperature, the failure mode has no significant difference. The failure mode is welding layer unripped. The average unit unripped loads are almost the same.
(2) The average unit failure load of the inner weld layer is slightly larger if compared with the outer weld layer.

(3) At whatever room and low temperature, the unit failure loads for both outer and inner weld layer specimen obey the Weibull distribution. The Weibull distribution function modulus of unit failure loads for the outer weld layer is larger than that for the inner weld layer, leading to smaller dispersion of the unit failure loads for outer weld layer. Meanwhile, the Weibull distribution function modulus of the unit failure loads increases with reduction in temperature, leading to smaller dispersion of the unit failure loads when the specimen is tested at low temperature.

(4) Rougher rupture surface appearing at the region close to non-welded region indicates this region bears applied load mainly, leading to crack initiation.

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REFERENCES


