Fatigue Performance of T-joint with Complete Weld Details

Xi Liu, Qingyu Meng, Can Wang and Song Huang
Jiangsu XCMG Construction Machinery Research Institute Ltd. Xuzhou, J S 221004, China
Email: 435398417@qq.com

Abstract. The fatigue properties of T-joint of Q345 steel commonly used in construction machinery are studied. The fatigue life of T-joint with complete weld details is analyzed by nominal stress method and the equivalent structural stress method respectively, and compared with the test results. The results show that under the condition of stress ratio R=0.5, the fatigue crack of T-joint with complete weld details often occurs at the weld root of the arc extinguishing and propagate along the weld throat. In production, arc extinguishing should be avoided in key parts. The nominal stress method used to predict the fatigue life of T-joints with complete weld details is dangerous, while the fatigue life of T-joint analyzed by the equivalent structural stress method is basically consistent with the test results.

1. Introduction
T-joint is a typical joint type in welded structures. It is widely used in ships, vehicles, bridge tunnels and other industrial fields. Due to the change of the section form, the stress concentration factor is high. Under cyclic loading, the fatigue fracture often occurs [1].

At present, there are many researches on the fatigue performance of T-joint, but the main object is the fatigue performance of the T-joint eliminated the arc striking and arc extinguishing [2-3]. However, the arc striking and arc extinguishing exist objectively in the actual welding engineering structure, and fatigue cracking often occurs in these parts. At present, the S-N curves given in the fatigue standards of welded structures are mainly based on the fatigue test of joints eliminated the arc-striking and arc extinguishing, and the results may be inaccurate.

Therefore, it is of great significance to study the fatigue performance of welded joint with complete weld details. In this paper, the fatigue test of T-joint with complete weld details is carried out. The nominal stress method and the equivalent structural stress method are used to predict the fatigue life of the T-joint, and compared with the test results to provide a theoretical reference for the selection of fatigue analysis methods for T-joint with complete weld details.

2. Test Method

2.1. Test Materials and Joint Forms
The test material is Q345 steel, the mechanical properties are shown in Table 1. The T-joint form is adopted, and the geometry and dimensions are shown in Figure 1. The welding material is ER50-6 with diameter 1.2mm, and the welding method is gas metal arc welding. The welding process parameters are shown in Table 2. The samples retain the complete weld details, including arc striking and arc extinguishing.
Table 1. Mechanical Properties of Q345

| Material | Tensile/MPa | Yield/MPa | Elongation/% |
|----------|-------------|-----------|--------------|
| Q345     | 495         | 396       | 28           |

Table 2. Welding Process Parameters

| Voltage /V | Current /A | Velocity /mm.min⁻¹ | Gas-flow rate/L.min⁻¹ |
|------------|------------|---------------------|-----------------------|
| 24         | 225-235    | 320                 | 15-25                 |

Figure 1. Geometrical Characteristic of Specimen

2.2. Test Method

The test equipment is GPS-200 electromagnetic resonance high frequency fatigue testing machine. The maximum average load is ±200kN, and the maximum alternating load is 100kN. The frequency range is 80–250Hz and the loading error is within ±1%. The fatigue test is carried out under constant amplitude load. The applied load type is pressure-pressure load, and the stress ratio is R=0.5. For the loading form of the T-joint, a special test tool is designed and manufactured. The tooling is fixed on the three-point bending fixture, and the fatigue specimen is fixed on the tooling by bolts, as shown in picture 2.

Figure 2. Fatigue Testing Machine

3. Test Results

The fatigue test results of T-joint specimens with complete weld details are shown in Table 3. The test data are processed according to the statistical method specified by the International Welding Society, and the S-N curves are fitted to 50% survival rate and 95% survival rate respectively, as shown in Figure 3. The conditional fatigue strength of the T-joint with complete weld details at 2×10⁶ cycle is shown in Table 4.
Figure 3. S-N Curve of T-joints

Table 3. Fatigue Testing Results

| Number | Stress amplitude /MPa | Fatigue life /10^6 | Fracture position |
|--------|-----------------------|--------------------|-------------------|
| 1      | 32.33                 | 5.07               | Weld root         |
| 2      | 36.72                 | 1.61               | Weld root         |
| 3      | 42.53                 | 2.13               | Weld root         |
| 4      | 49.76                 | 0.78               | Weld root         |
| 5      | 54.58                 | 0.62               | Weld root         |
| 6      | 58.48                 | 0.62               | Weld root         |
| 7      | 62.95                 | 0.35               | Weld root         |
| 8      | 41.97                 | 2.14               | Weld root         |
| 9      | 47.21                 | 2.02               | Weld root         |
| 10     | 49.83                 | 0.96               | Weld root         |
| 11     | 52.46                 | 0.84               | Weld root         |
| 12     | 51.75                 | 0.90               | Weld root         |
| 13     | 57.7                  | 0.64               | Weld root         |
| 14     | 57.42                 | 1.07               | Weld root         |
| 15     | 49.76                 | 0.66               | Weld root         |
| 16     | 51.04                 | 0.74               | Weld root         |
| 17     | 53.88                 | 0.64               | Weld root         |
| 18     | 48.49                 | 1.49               | Weld root         |
| 19     | 44.8                  | 1.75               | Weld root         |

Table 4. Fatigue Strength of T-joint

| Specimen type | a       | b        | Δσ2×10^6/MPa |
|---------------|---------|----------|-------------|
| T             | 3.07494 | -0.2297  | 42.42       |

Figure 4. A Typical Crack Location of T-joint
The test results show that the fatigue specimens of T-joint with complete weld details cracking at the arc extinguishing position. To observe the inner-crack propagation of the joint, the wire-cutting is used to sample at the crack initiation location of the joint as shown in Figure 4. The fatigue crack growth from the weld root through the weld throat to the surface of the weld until it breaks.

4. Analysis and Discussion

Due to the fatigue failure position of the T-joint with complete weld details is at the weld root, the hot spot stress method cannot be used for fatigue evaluation. In order to investigate the accuracy and applicability of different fatigue analysis methods for the fatigue evaluation of T-joints with complete weld details, the nominal stress method and the equivalent structural stress method are respectively used to evaluate the fatigue of the T-joints with complete weld details, and the results are compared with the fatigue test results.

4.1. The Nominal Stress Method

According to the BS7608 standard [4], the fatigue analysis of the T-joint with complete weld details is carried out. According to the joint type and bearing type, the corresponding joint type number is 7.9 in the BS7608 standard, and the corresponding nominal stress level is G, and the corresponding parameters of the G-class S-N curve as shown in Table 5. The median and the normal fatigue S-N curves of the G-class are designed and compared with the fatigue test results of the T-joints, as shown in Figure 6.

| Class | C0       | LgC0   | m  | STD   |
|-------|----------|--------|-----|-------|
| G     | 5.656E11 | 11.7526| 3.0 | 0.1793|

Table 5. The S-N Parameters of Class G

As shown in Figure 6, the fatigue test results of the T-joints are lower than the S-N curve of the corresponding joint in the BS7608 standard. So, if the T-joints with complete weld details are predicted using the standard S-N curve, the predicted life is higher than the actual life, and the prediction is dangerous. This shows that the S-N curve in the BS7608 standard is not applicable to T-joints with complete weld details in actual production.

4.2. The Equivalent Structural Stress Method

The fatigue analysis of the T-joint with complete weld details is carried out by the equivalent structural stress method [5-6]. First, the finite element model is established using solid185 unit and the grid size is 4mm. Second, the vertical plate and the bottom plate are only coupled at the root of the weld and the rest of the parts are not coupled in order to establish boundary conditions that match the test conditions and simulate the connection between the actual vertical plate and the bottom plate at the same time.
As shown in Figure 9, the equivalent structural stress in the three failure modes is calculated. Figure 10 shows that the distribution of the equivalent structural stress along the weld direction in three failure modes of the T-joint. It can be seen that the maximum equivalent structural stress appears in the root failure mode and is located at the end of the weld, which is consistent with the actual fatigue test results.

The equivalent structural stress of all T-joints with complete weld details is calculated and compared with the main S-N curve [7] of the root failure, as shown in Figure 11. It can be seen that the test results are basically locate near the median of the main S-N curve. Therefore, the equivalent structural stress method used for fatigue design or prediction of the T-joints with complete weld details that are common in mechanical structures is relatively safe and reliable.
5. Conclusions

(1) Fatigue test is carried out for T-joints with complete weld details. The failure mode is the root cracking at the arc extinguishing position. Therefore, it is recommended to use arc-striking plates or avoid arc extinguishing appearing at key positions for important bearing joints;

(2) The nominal stress method and the equivalent structural stress method are respectively used to evaluate the fatigue life of T-joint with complete weld details. The results show that the failure mode and predicted life of the T-joint obtained by the equivalent structural stress method are consistent with the test results. However, the predicted life obtained by the nominal stress method is quite higher and different from the test results.

(3) In practical applications, it is dangerous to use the nominal stress method for fatigue analysis of T-joint in the case of fatigue cracking at the arc-striking or arc-extinguishing position. It is recommended to use the equivalent structural stress method for life prediction and fatigue design of T-joint with complete weld details.

6. References

[1] Huo L X. 2000 China machine press (Fracture and Assessment of Welded Structure) p 15
[2] Andrea C, Roberto B and Hans J H 2005 International Journal of Fatigue vol 27 (Fatigue growth of a surface crack in a welded T-joint) p 59-69
[3] Darko F, Heikki R and Jani R 2011 International Journal of Fatigue vol 33 (Fatigue assessment of laserstake-welded T-joints) p 102-114
[4] British Standards Institution 2014 Guide to fatigue design and assessment of steel products p 1-139
[5] Dong P 2001 International Journal of Fatigue vol 26 (A Structural Stress Definition and Numerical Implementation for Fatigue Analysis of Welded Joints) p 865–876
[6] Dong P, Hong J K and Osage D 2002 Master S-N curve method for fatigue evaluation of welded Components
[7] Jeong K H 2013 Journal of Offshore Mechanics and Arctic Engineering vol 135 (Evaluation of Weld Root Failure Using Battelle Structural Stress Method) 021404-1-7