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Fatigue Performance of T-joint with Complete Weld Details

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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 extinguishingexist 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.

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Table 1. Mechanical Properties of Q345Table 2 Welding Process Parameters

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

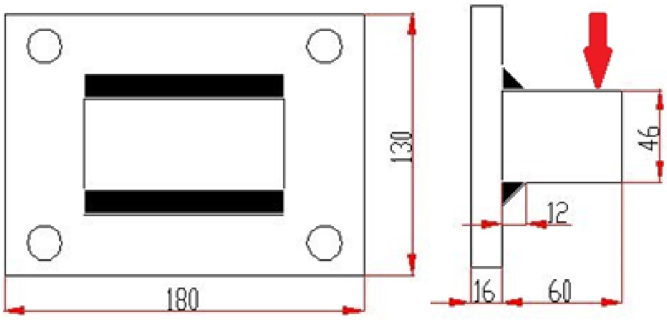

Figure 1. Geometrical Characteristic of Specimen

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 80~250Hzand 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 Figure3. The conditional fatigue strength of the T-joint with complete weld details at 2×106 cycle is shown in Table 4.

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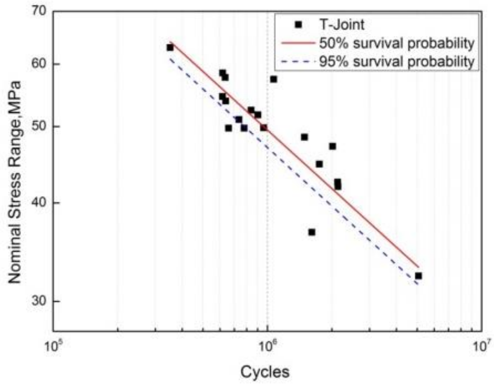

Figure 3. S-N Curve of T-joints

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	$\Delta\sigma 2\times10^6$/MPa
T	3.07494	-0.2297	42.42

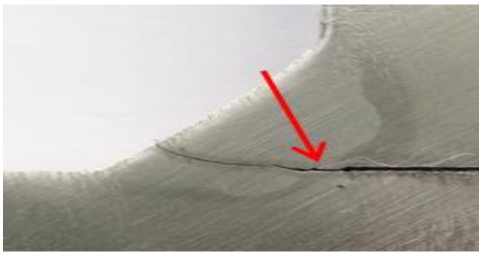

Figure 4. A Typical Crack Location of T-joint

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 andthe normal fatigue S-N curves of the G-classare designed and compared with the fatigue test results of the T-joints, as shown in Figure 6.

Table 5. The S-N Parameters of Class G

Class	C0	LgC0	m	STD
G	5.656E11	11.7526	3.0	0.1793

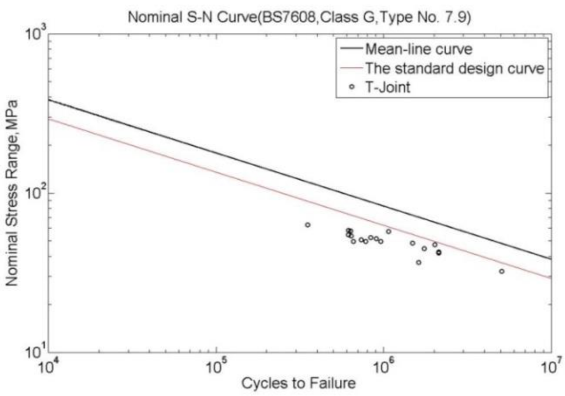

Figure 5. Comparison between S-N Curve (BS7608, Class G) and Test Results of T-joint

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 weldand 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.

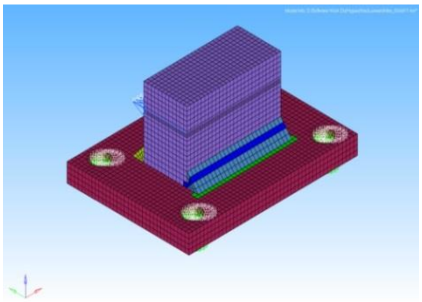

Figure 6. The Finite Model of T-joint

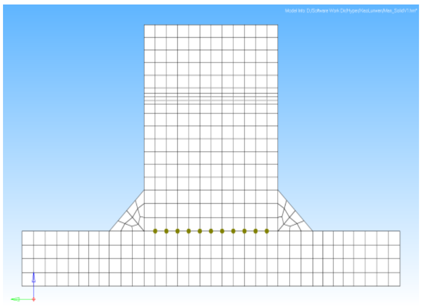

Figure 7. Details of the Nodes Coupling of T-joint

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.

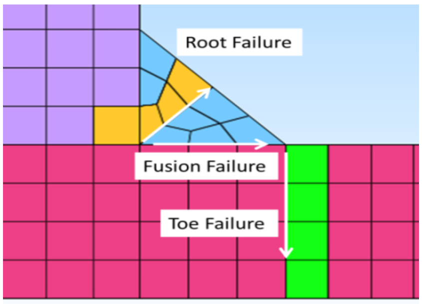

Figure 8. Three Failure Modes of T-joint

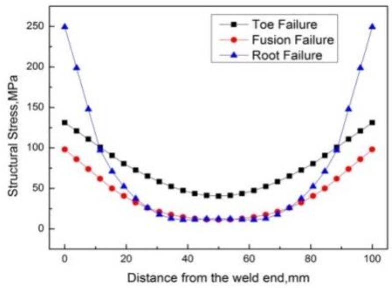

Figure 9. The Comparison of Structure Stress Based on Different Failure Modes

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.

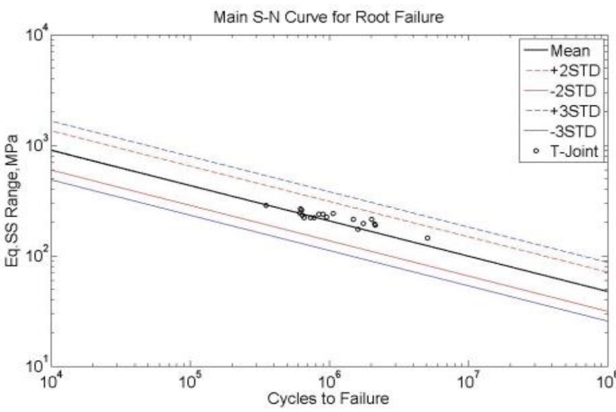

Figure 10. Comparison between Master S-N Curve (for root failure) and Test Results of T-joint

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 thatthe 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

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