Test Research on Toughness Evaluation of Long-span Bridge Welded Joint

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Abstract. Aiming at the inherent unavoidable defects of welded joints, a CTOD (Crack Tip Opening Displacement) test was carried out on the E43 steel weld specimen under the fatigue state. The research results provide experimental and calculation basis for the use of bridge steel. In this paper, a CTOD fatigue pre-crack test study was carried out on the welded joint of E43 steel.

1. Introduction
With the rapid development of engineering structure construction in China, people are using more and more materials. Especially metal materials often encounter extreme situations, which are often far below the design performance [1]. Fatigue damage has always been considered as one of the main failure modes of various engineering structures. Since the occurrence of fatigue cracks, the steel structure has been in a stable expansion state, causing frequent failures of the engineering structure [2]. Due to the sudden occurrence of the fracture, it will cause very serious consequences. Toughness is the ability of a material to absorb energy in the process of elasto plastic deformation before fracture, which is a comprehensive expression of strength and plasticity. The toughness of the weld and heat affected zone in the welded joint is often lower than that of the base metal. The thicker the base steel plate is, the more obvious the toughness of the welded joint decreases [3]. At present, the impact test is mainly used to evaluate the toughness of welded steel box girder joints in China, which has great limitations. Firstly, impact toughness is essentially a mechanical quantity to measure the impact resistance of welded joints, which cannot fully reflect the true toughness of welded joints. The brittle fracture of ductile material under triaxial tensile stress is presented. However, the brittle material exhibits ductile failure under triaxial compressive stress. The local sampling of the impact sample changes the stress state of the sample, so the stress state of the original welded joint cannot be simulated. Due to the particularity of its structure form, the long-span steel bridge is a typical welded structure with complex working conditions and large stress concentration. Under the action of external force, welding defects, welding residual stress, and the uneven structure and properties of the joint all lead to brittle fracture. With the continuous increase of bridge span, the steel plate used in steel box girder is getting thicker and thicker, and the problem is prominent. Therefore, it is of great significance to accurately obtain the toughness of steel structure engineering and ensure the safety of steel structure engineering. Extensive experimental studies must be done to identify bridge steels. In addition, the fracture toughness of...
CTOD is a useful tool for evaluating the brittle fracture resistance of steel and welded joints, and an important parameter of brittle fracture behavior can be used to evaluate the brittle fracture resistance of steel.

CTOD (Crack Tip Opening Displacement) refers to the relative distance between two points on the crack tip after the crack material is affected by the opening load. The greater the CTOD, the greater the fracture toughness. However, the smaller the CTOD, the worse the fracture toughness. TOD fracture toughness testing technology is widely used in major developed countries. This paper is based on CTOD (Crack Tip Opening Displacement) test data of six thick steel plates. The purpose of this paper is to study the fracture toughness of thick steel plates and estimate the fracture toughness of engineering structures.

2. Sample and Sample Preparation
Steel plate samples from Dongxiang Bridge in Guangdong were used in this test. According to the British standard BS7448, the three-point bending standard specimen shown in Fig.1. was made.

![Specimen figure](image_url)

Fig. 1. Specimen figure

The base material shall be executed according to BS7448:1991-Part1 "Method for the Determination of $K_{IC}$, Critical CTOD and Critical J Value of Metal Materials", and the welded joints and heat-affected zones shall be executed according to BS7448:1997-Part2 "Method for the Determination of $K_{IC}$, Critical CTOD and Critical J Value of Metal Materials Weld" [4] [5]. At the first, the sample was cut linearly and carried out CTOD test according to the standard, then holes were made on one side of the sample to make the holes in the direction of thickness. Finally, fatigue cracks were generated by JXG-200 high frequency fatigue testing machine, and CTOD values were tested by material testing machine.

3. Test
The experiment was carried out according to British standards. The test is carried out on the computer controlled hydraulic universal material testing machine, and the single sample method is adopted. The CTOD value of E43 steel was measured by three-point bending test. The sample is B-shaped in section. The notch direction is N P direction, where N is perpendicular to the welding direction and P is parallel to the welding direction. After processing, the actual thickness of the standard sample is 38mm. According to the BS7448 standard, the CTOD toughness test of the welded joint of E43 high strength steel is carried out at room temperature. The standard of three-point bending specimen with single prefabricated fatigue crack is introduced in CTOD temperature. The samples were taken from each substrate, the tensile strength of the material was calculated according to BS7448 standard, and the crack opening displacement was derived.

4. CTOD value and fatigue test results and discussion
Fatigue test values are shown in Tab.1. and CTOD values in Tab.2. The fracture information of ductile failure specimens is given.
Tab.1. The fatigue crack growth of H44W

| Specimen’s number | Specimen’s thickness (mm) | Fatigue crack’s propagation extent mean value (mm) |
|-------------------|--------------------------|--------------------------------------------------|
| H44W-1            | 38.00                    | 5.050                                            |
| H44W-2            | 38.00                    | 5.110                                            |
| H44W-3            | 37.95                    | 5.040                                            |

The measured results show that there is a phenomenon of failure danger in the CTOD test of thick steel plates: ductile instability fracture. According to the allowable value of BS7448, the fracture toughness of the structure reaches the standard level. According to the test results given in Tab.1., the CTOD test results of the base metal at room temperature, where $\delta_u$ and $\delta_m$ are respectively the CTOD value of brittle instability and the CTOD value of the maximum load, and the CTOD value of the sample is only related to the elastic component $\delta_e$ and plastic component $\delta_p$. The fracture surface of ductile failure specimen are shown in Fig. 2.

Tab.2. CTOD value of H44W

| Specimen’s number | $\delta_e$ | $\delta_p$ | $\delta_u$ | $\delta_m$ |
|-------------------|------------|------------|------------|------------|
| H44W-1            | 0.134      | 0.777      | —          | 0.911      |
| H44W-2            | 0.15       | 0.75       | —          | 0.900      |
| H44W-3            | 0.153      | 0.766      | —          | 0.919      |

Fig. 2. The fracture surface of ductile failure specimen

5. Conclusion
According to BS7448, CTOD fracture toughness test of thick steel plate joints was carried out at room temperature. The results show that fatigue is the main reason for the failure of the welded joint, and the plastic component $\delta_p$ determines the fracture toughness of the weld, and the specimen shows good fracture toughness at room temperature. The test results provide the basis for ensuring the construction quality of steel box girder of Dongxiang Bridge. It also provides some ideas for improving the welding process.

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