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Damage analysis of FRP/steel composite plates using acoustic emission

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Abstract

Fibre-reinforced plastic (FRP)/steel composite is gaining momentum in civil engineering for repair, permanent formwork and external reinforcement. It is of vital importance to research the damage propagation of the new composite under loading. In this paper, we prepared four identical specimens of FRP/steel composite plates to conduct our test. Two of the specimens were under uniaxial loading, and the other two were under cyclic uniaxial loading. During the test, we monitored the specimens by acoustic emission (AE). AE is a suitable method to monitor the damage process of composite material because of its nondestructive and real-time features. In this study, we used a sentry function to assess the damage process of the specimens that were under uniaxial loading and calculated the index of damage (ID) and the modified index of damage (MID) to analyse the damage of the specimens that were under cyclic uniaxial loading.

Keywords: Acoustic emission; Composite plates; Sentry function; Index of damage

Introduction

Composite materials have been a heavily investigated research topic in several fields, and significant progress has been made in composite research. FRP is a new material with good mechanical properties, such as high strength of extension, low density, good corrosion resistance and anti-fatigue [1]. The high strength of extension and low density indicate that the material has a high specific strength, which will lead to low self-weight. With these advantages, FRP has been widely used in structural repair and strengthening [2—5]. However, FRP also has shortcomings, including high brittleness and a high price. Steel performs well in ductility, but it has high self-weight and is easily corroded. Therefore, we can combine these two materials in the structure to benefit from their advantages and hide their defects.

FRP and steel composite has been use in a wide range of applications in civil engineering because of its good performance. The applications of FRP and steel composite include some important components—FRP/steel composite bars and FRP/steel confined concrete. FRP/steel composite bars avoid the corrosion of the

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rebar and improve the anti-fatigue performance of structure because of the high specific strength and good corrosion resistance of FRP [6–8]. Due to the high extension strength and the high elasticity modulus, FRP/steel confined concrete can control the expansion of concrete effectively to improve the compressive strength of the columns [9,10].

As FRP/steel composite becomes widely used, the monitoring of its damage is also becoming more important. To monitor this composite, acoustic emission (AE) is a good choice. AE is a non-destructive (NDT) monitoring method that is widely used in engineering [11]. Compared with other NDT methods, AE is usually applied during loading, whereas most others are applied before or after loading, which makes AE more convenient for monitoring the damage process of structures [12]. During the monitoring, the AE system can record parameters of the source signals that can be used for further research, such as the amplitude, counts, rise time, duration, average frequency and energy. In recent years, some researchers have developed data processing methods for the AE parameters.

Sentry functions have been successfully used to study the damage progression and fracture energy release rate of composite laminates [13]. This technique combines the cumulative AE energy with the strain energy of the material rather than analysing the AE and mechanical information separately. Sentry function have found their value in estimating the residual strength and studying the damage characteristics of composite materials [14]. However, few studies have applied sentry functions to investigate FRP/steel composite. The index of damage (ID) was proposed based on the relation between the cumulative AE energy and plastic strain energy of the specimens [15,16]. The ID is calculated by the cumulative energy at any moment during the test divided by the cumulative energy when the structure member experiences the maximum allowable damage. This method is well-suited to assess the damage of structure members that are under cyclic loading because it can perform quantitative analysis of the damage of the structure members rather than qualitative analysis. The cumulative AE energy when the structure members experience the maximum allowable damage cannot be obtained in practical applications, which limits its application in the field. To solve this problem, we use a modified index of damage (MID), which will be discussed later in this paper. In this study, we analyse the damage of specimens under uniaxial loading with a sentry function and assess the damage of specimens under cyclic uniaxial loading with the ID and MID values.

Experimental procedure

Test specimens preparation

Four identical FRP/steel composite plates were produced to conduct our test. The FRP/steel composite plates used the sandwich form with both faces of the steel plates were pasted with a layer of FRP sheet. The shape and size of the specimens are shown in Fig. 1. The composite plates were produced by the hand lay-up method. The preparation of the FRP/steel composite plates is as follows: (1) wipe off the oil stain and dust of the steel plates surfaces with alcohol. (2) Polish the steel plates, remove the rust, and treat the surface of steel plate by roughening. (3) The FRP sheets must be tailored to the designed size, impregnated with resin, and then bonded to the processed steel plates and the excessive resin extruded as much as possible. (4) To prevent the FRP of the end socket from fracturing in the tensile process, we place an aluminium strengthening sheet on the end socket according to *Test method for tensile properties of oriented fibre reinforced plastics*, *GB/T 3354-1999*.

Material characteristics

The CFRP cloth in the test is UT70-30 CFRP (300 g/mm^2), which was produced by *TORAY INDUSTRIES INC*. The type of tackiness agent is JGN-T structural adhesive, which was produced by *Dalian KAIHUA New Engineering Technology Co*., *LTD*. The adopted type of steel plates is 16 Mn with a thickness of 3.05 mm. The parameters of the materials are listed in Table 1. In the table, the parameters of the steel were obtained through tensile test, and the parameters of other materials were provided by the manufacturers.

Experimental procedure

The FRP/steel composite specimens were set on an electronic universal testing machine, which was manufactured by *Jinan Shidai Shijin Test Machine Co*., *LTD*, and then the uniaxial tensile test was conducted. An AE transducer was placed in the middle part of the specimen and then linked to AE monitoring system via preamplifier. An extensometer was also placed on the specimen to conduct deformation measurements. The arrangement of the specimen, the transducer, and the extensometer is shown in Fig. 2. The AE monitoring system is a MISTRAS-2001, produced by Physics Acoustic Corporation. The threshold of the AE signals was set at 45 dB, the main amplifier gain was set at