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Component-based model of fin plate connections exposed to fire-part II: Establishing of the component-based model

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ABSTRACT

To establish a component-based model for a fin plate connection exposed to fire, to be used for the fire resistance analysis of an entire structure, the plate in bearing component was investigated omitting friction in the study reported in the previous companion paper. In this study, the bolt in shear component and fiction component are investigated and a component-based model of fin plate connection is established and verified. Firstly, the threaded bolt in shear component omitting friction is examined; a three-dimensional solid finite element analysis of the parameters affecting the properties of the component is performed - including bolt diameter, plate thickness and temperature. Then a prediction model for the resistance and initial stiffness of the bolt in shear component is proposed and the force-deflection function for the component is established. A finite element analysis of the friction in the lap joint was performed for determining the relationship between the friction component and the plate in bearing component and establishing the component-based model for the fin plate connection. Finally, the component-based model for the fin plate behaviour was employed for simulating the performance of the connection exposed to fire and subjected to complex forces. The simulation result exhibited a satisfactory fit with the results of the 3-D solid finite element simulation, which verified the accuracy of the component-based model. The simulation time also decreased from several days to several seconds.

1. Introduction

The behaviours of the connections and the structure exposed to fire can only be accurately explained by investigating the substructure or the entire structure in which connections are properly considered. The component-based model can be utilized to analyse the fire resistance of an entire structure, which provides a more practical and more economical solution to the fire resistance analysis of an entire structure than fire test and three-dimensional (3-D) solid element analysis. The key to establishing a component-based model of the connections is the understanding of the temperature-related force-deflection relationship of each component, which has not been extensively analysed. In the previous paper, the plate in bearing component of the fin plate connection exposed to fire was investigated omitting friction, a 3-D solid element analysis of the parameters affecting the properties of the component was conducted, a nonlinear force-deflection function of the component was established. In this study, the research is expanded by examining the bolt in shear component and the friction component of the fin plate connection, and eventually establishing a component-based model for the fin plate connection exposed to fire. Firstly, the fully threaded bolt in shear component was analysed omitting friction, a finite element analysis (FEA) of the parameters affecting the properties of the component (bolt diameter, plate thickness and temperature) was conducted, a prediction model for the resistance and initial stiffness of the bolt in shear component was proposed and the force-deflection function of the component was established. Secondly, a FEA of the friction in the lap joint was performed and a component-based model of the fin plate connection was established. Finally, the component-based model of the fin plate connection was applied for simulating the performance of the connection under complex forces during fire exposure, thereby verifying the accuracy and practicability of the component-based model.

2. Parametric analysis of the bolt in shear component

The parameters that affect the bolt in shear component include the bolt diameter, the bolt grade, the bolt material properties and the temperature. The effects of bolt grade and temperature on the bolt in shear component are reflected in the modified properties of the bolt material. Therefore, an analysis of the effect of temperature reveals the effects of these three parameters. Actually, bolts are subjected to shear forces and moments. Different plate thicknesses of the connections result in different lever arms of the shear couple, which may affect the properties of the bolt in shear component. Based on the baseline FEA model in the previous paper, related influencing parameters in the finite analysis

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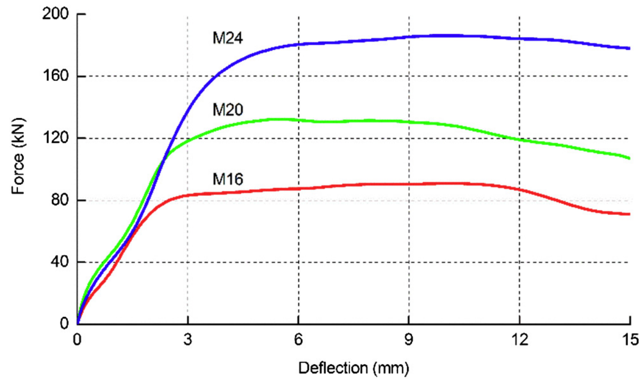

Fig. 1. Effect of bolt diameter on the force-deflection relationship of the bolt in shear component.

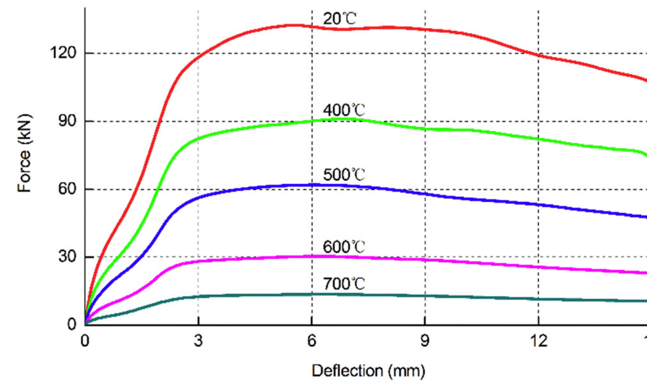

Fig. 3. Force-deflection relationship of the bolt in shear component for different temperatures.

model were modified. The focus of this study is the bolt in shear component. Failure of the lap joint was planned to appear in the bolt. Therefore, the yield strength and the ultimate strength of the materials of the fin plate and the beam plate in the baseline FEA model at ambient temperature and elevated temperatures were both increased to ensure failure of the bolt in shear.

2.1. Effect of bolt diameter

The bolt diameters in the baseline FEA model were modified to M16, M20 and M24 respectively. Fig. 1 shows the force-deflection relationship curves of the bolt in shear component. With increasing bolt diameters, the resistances of the bolt in shear components—87.6 kN, 132.4 kN and 186.2 kN (their ratio is 1:1.51:2.13)—also gradually increased. The effective areas of the M16, M20 and M24 bolts are 156.7 mm2, 244.8 mm2 and 352.5 mm2 (their ratio is 1:1.56:2.25, which is similar to the ratio of the resistances of the component). Therefore, it is assumed that the resistance of the bolt in shear component is directly proportional to the effective area of the bolt.

2.2. Effect of plate thickness

The thicknesses of the fin plate and the beam web in the baseline FEA model were modified. Fig. 2 shows the force-deflection relationship curves of the bolt in shear component for different plate thickness conditions. Plate thickness exhibited a limited impact on the force-deflection relationship of the bolt in shear component. Although an increase in the plate thickness produced an increase in the lever arm of the shear couple, it also increased the interactions between the bolt nut and the plate and between the bolt head and the plate.

2.3. Effect of temperature

The temperature field in the baseline FEA model was modified. Fig. 3 shows the force-deflection relationship curves of the bolt in shear component for different temperatures. With increasing temperature, the resistance of the bolt in shear component and the initial stiffness of the bolt gradually decreased. Fig. 4 shows the reduction factor of the resistance, which exhibited an acceptable fit with the reduction factor of the ultimate strength of the bolt material. Therefore, it is concluded that the resistance of the bolt in shear component was directly proportional to the ultimate strength of the bolt material.

3. Force-deflection relationship of the bolt in shear component

To describe the relationship between the force sustained by the bolt in shear component and the deformation of the bolt, the Ramberg-Osgood function [1] was adopted to fit the finite element simulation data. The fitting function is expressed as:

$$\Delta_{\text{bolt}} = \frac{F_{\text{v}}}{K_{\text{v},\theta}} + \Omega_{\theta}\left(\frac{F_{\text{v}}}{F_{\text{v},\theta,\text{R}}}\right)^{m_{\theta}} \quad (1)$$

where Δ_{bolt} (mm) represents the deformation of the bolt in shear component; F_{v} (N) represents the force sustained by the bolt in shear component; $K_{\text{v},\theta}$ (N/mm) represents the shear stiffness at the temperature of θ; $F_{\text{v},\theta,\text{R}}$ (N) represents the resistance of the bolt in shear

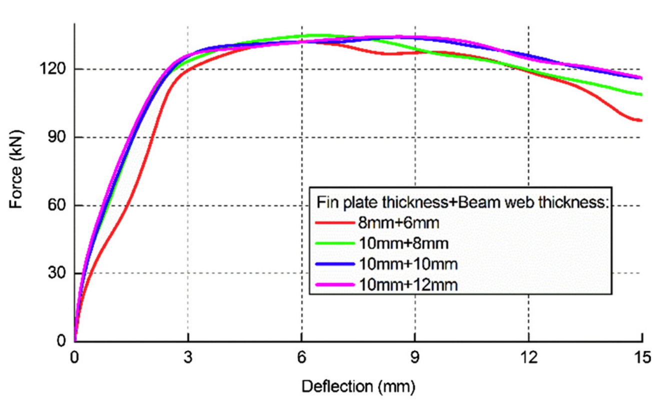

Fig. 2. Effect of plate thickness on the force-deflection relationship of the bolt in shear component.

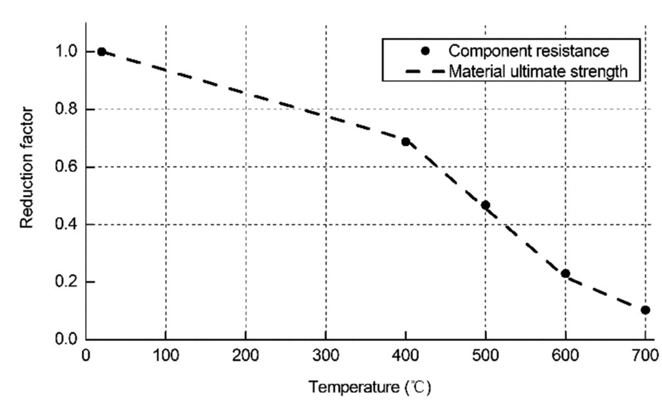

Fig. 4. Reduction factor for the resistance of the bolt in shear component with regard to temperature.