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Experimental investigation and design method for the shear strength of self-piercing rivet connections in thin-walled steel structures

Weiming Yan [a], Zhiqiang Xie [a], Cheng Yu [b,*], Linlin Song [a], Haoxiang He [a]

[a] Beijing Key Laboratory of Earthquake Engineering and Structural Retrofit, Beijing University of Technology, Beijing, China
[b] Department of Engineering Technology, University of North Texas, Denton, TX, United States

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ABSTRACT

The paper presents an experimental investigation on the shear strength of self-piercing rivet connections used in thin-walled steel structures. The test program included specimen variations in the number of rivets in each connection, rivet spacing, end distance, and steel sheet thickness. According to the experimental results, the curve of load-slip, peak load, and failure mechanism for all specimens were analyzed. Parameters of riveting in terms of end distance, spacing, arrangement, length, and thickness difference between connection components were studied on their effects for shearing performances of self-piercing rivet connections. A design method based on the model of transmission dynamics of infectious diseases was proposed for calculating the shear strength of the rivet connections. The strength reduction due to the effect of group rivets was considered in the new method.

1. Introduction

Nowadays, more and more low-rise buildings adopted prefabricated cold-formed thin-walled steel structural systems [1]. In the assembling process of thin-walled structures, connections using blind rivet, clinching, welding or self-drilling screw are commonly employed [2]. The self-drilling screw is the most common type of connection in cold-formed steel structures, however the installation process can be generally complex due to the need for clamping plate, drilling, tightening screws and other steps, which may seriously reduce efficiency of industrial production for components in prefabricated cold-formed thin-walled steel structure [3]. In addition, a large number of experimental studies have found that tilting, shear and pull out of screws are the controlling failure models in cold-formed steel structures. The strength of the cold-formed steel structures is largely dependent on the shear capacity of self-tapping screws [4–5].

In order to improve the fabrication efficiency and structural reliability of cold-formed steel connections, the self-piercing rivet (SPR) technique used in the automotive industry is studied herein on cold-formed thin-walled steel structures. The process of forming SPR connection involves driving a separate rivet component into the layer of the parent metal, piercing and clinching in a single operation [2,6,9]. Schematic diagram of forming a SPR join is illustrated in Fig. 1. SPR has high tensile strength, shear strength, stiffness, and high efficiency in connecting steel sheets of different thickness and mechanical properties.

The previous research on SPR joints has been concentrated on the forming mechanism and fatigue behavior for ductile thick steel plates [8,9,11], the study on SPR connections with thin-walled steel sheets is limited. Mucha and Lennon [2,12] studied various connections using SPRs, self-drilling screws, clinching and blind rivets. They found that SPR gave the highest stiffness and ultimate load among all investigated connection methods. Voelkner [13] suggested that the overall thickness of the connected sheets shall not be >6 mm for SPR connections. Parameter analysis of SPR connections under different combinations of sheet materials was presented in Porcaro et al. [14,15], their results suggested that thickness and material properties of sheets had significant influence on the shear strength. Li and Han [16,17] concluded that the edge distance had effect on dynamic fatigue strength and static behavior of SPR aluminum joints.

Haque et al. [18] developed a simple model for characterizing SPR joints in steel sheets based on experimental results. Lorenzo [19] proposed a shear design formulation of the circular press-joints based on the design rules of blind rivet connections recently introduced in the European standard on cold-formed steel structures [20]. However, because of the different mechanical mechanism between the blind rivet connections and the press-joints, Lorenzo's method was not appropriate for SPR connections. LaBoube et al. [21] showed that the self-drilling screws connection had “Group Effect”, and they developed design equations to reflect the “Group Effect” on the shear strength of cold-formed steel screw connections. The previous research was mainly focused on single rivet connections. The research presented here includes both

* Corresponding author.
E-mail addresses: Yanwm@bjut.edu.cn (W. Yan), xzq198898@163.com (Z. Xie), cheng.yu@unt.edu (C. Yu), 577070636@qq.com (L. Song), hhx7856@163.com (H. He).

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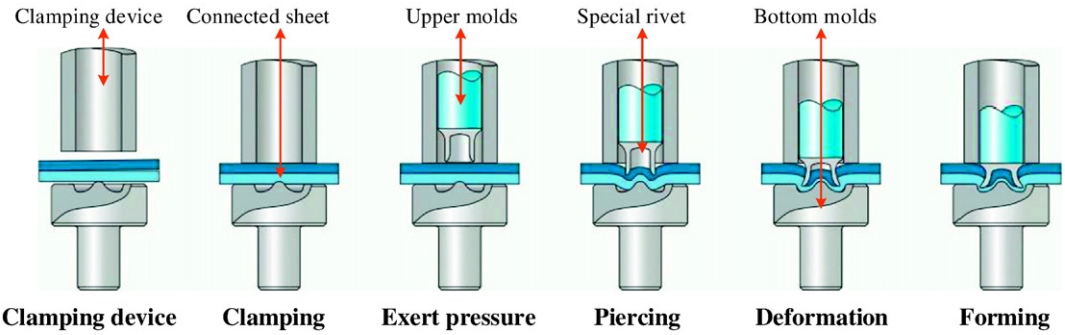

Fig. 1. Schematic diagram of the forming process of a SPR joint [10].

single and multiple SPR connections with cold-formed thin-walled steel. Design methods for shear strength of SPR connections using single and multiple rivets are proposed.

In this research project, a standard uniaxial shear test method was designed for specimens of single and multiple SPR connections made of cold-formed thin-walled steel sheets. Parameters in terms of end distance, number, spacing, arrangement, thickness difference between connected components and loading rate were studied on their effects for shear strength of SPR connections. Based on the transmission dynamics of infectious diseases model (SIR model), a mechanical model of single riveting was established, and then a formula of shear strength for multiple SPR connections considering the group reduction effect was developed. The research results will provide a design reference and experimental data resource for the application of SPR in the construction industry.

2. Experimental investigation

2.1. The test specimens

SPR originated in Germany has become a common connection type in the automobile industry. However its application in the field of structural engineering is limited. SPR connection is currently fabricated using proprietary rivets and machines. EPRESS SYSTEMS (SHENZHEN) LTD is currently the only SPR manufacturer in China. In this paper, all the test specimens were provided by this manufacturer.

Galvanized cold-formed thin-wall steel was used in all samples. All tested samples were single shear connections consisted of two thin-walled steel sheets. The sheets were 200 mm long × 60 mm wide (Fig. 2a). Five different sheet thicknesses were investigated: 0.8-mm, 1.0-mm, 1.2-mm, 1.5-mm and 2.0-mm thick steel. Various rivet sizes were studied in the test program including diameters (d), length (h), and width (b) (Fig. 2b). The SPRs were made of high hardness of alloy steel, and its grade and dimensions are shown in Table 1. Tensile tests were performed on Zwick/Roell Z050 testing machine equipped with the automatic extensometer, and testing machine capacity was 50 kN (Fig. 3a). The extensometer had a travel distance of 10 mm which allowed the measurement of the elastic and plastic slip in the connections (Fig. 3b). The gauge length which the elongation was measured is 100 mm. The grips were pin connected to the testing machine,

Table 1
Grade and dimensions for SPR.

Length (mm)	Width (mm)	Diameters (mm)	Hardness (HRC)	Elastic modulus (Gpa)
4.0	7.6	5.3	40	201
4.5	7.6	5.3	45	209
5.0	7.6	5.3	44	204
5.5	7.6	5.3	46	211
6.0	7.6	5.3	42	208

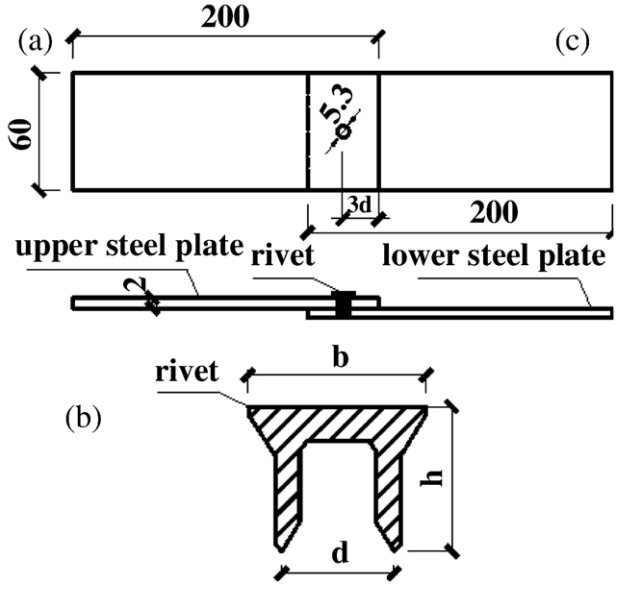

Fig. 2. Dimensions of shear specimens: a) connected sheets, b) cross-section of SPR.

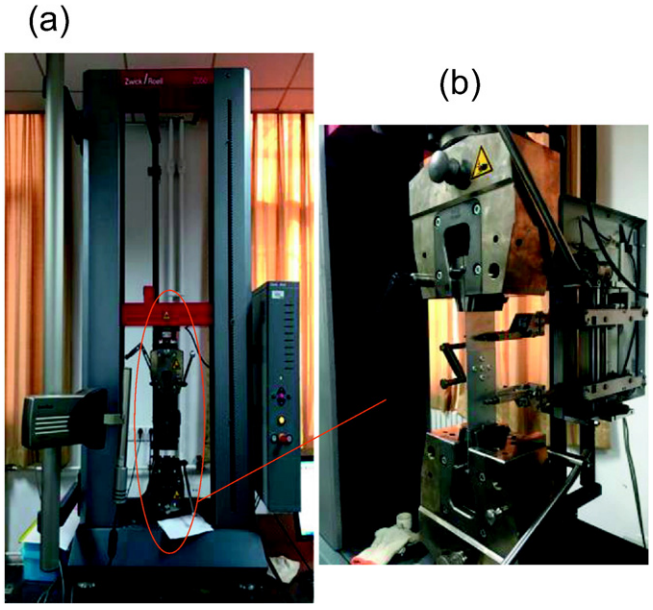

Fig. 3. Test set-up: a) testing machine, b) close-up of test specimen.