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Improved shear strength design of cold-formed steel connection with single self-piercing rivet

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ABSTRACT

In order to introduce self-piercing rivet (SPR) technique to component connections of thin-walled steel structures, 78 SPR joints were tested to evaluate their quality and the shear strength. Parameters included in this test program were the sheet thickness, and the rivet. Based on test results, the research developed an empirical formula between the combination thicknesses of sheet and rivet length, and proposed quality evaluation standard of SPR connections and a new design method of shear strength. The test results showed that sheet thickness and sheet thickness ratio had a great effect on failure mode, and rivet length was a key factor on shear properties of SPR connections. The proposed quality evolution standard and design calculation method of shear strength in this paper had certain reasonability and reliability.

1. Introduction

At present, to promote the industrial development of residence, low-rise buildings extensively adopted prefabricated cold-formed thin-walled steel structural systems because of its advantages in modular design, industrial production and high-speed assembly [1]. In terms of self-drilling screw, blind rivet, fastener, these are common connections need positioning, drilling, nailing and other process before assembling. Thus using above-mentioned connections may so seriously reduce efficiency of production and will waste an amount of time and money [2,3].

SPR is a common connection method in the automotive and machinery industries, and it has advantages of high strength, high stiffness, efficient installation, and anti-fatigue behavior [4–6]. The forming process of SPR connection involves: (1) positioning the sheets on the clamping device, (2) clamping the connected sheets, (3) exerting pressure to top molds, (4) piercing the top sheet, (5) deformation of rivet and bottom sheet under the action of bottom molds, (6) forming of connection [7]. Fig. 1 illustrates schematic diagram of the forming process of a SPR connection [8].

Most studies on SPR using numerical and testing methods concentrated on process parameters, mechanism of forming, fatigue and mechanic performance. Pickin [9] investigated the effect of die parameters on interlock mechanism (the amount of rivet flaring, interlock length, effective height) of SPR for various thickness aluminum sheets. It was found that the rivet flaring increased with the increase of bottom die diameter and the reduction of die height. Xu [10] presented the influence of rivet length and sheet thickness on the interlock of aluminum alloy joints, and the result showed that the rivet flaring increased with the increase of rivet length and sheet thickness. Fratini and Ruisi [11] researched the formability and forming parameters of hybrid SPR joints made of aluminum alloy composite materials, and further investigated static behavior and failure mechanism of joints. For fatigue performance of SPR joints, the rivet setting pressure is a key process parameters influencing on the static failure load, but it has little effect on fatigue life, which was presented by Fu [12]. Zhao [13] reported on studies of the fretting behavior of SPR joints in titanium sheet materials. The results showed that increasing sheet thickness could improve the fatigue strength of the joints at high load levels but less so at low load level. Zhang [14] aimed to evaluate influence of heat treatment on fatigue performances for self-piercing riveting similar and dissimilar titanium, aluminum and copper alloys were studied. Mechanical properties of single and multiple SPR joints made of aluminum sheets was studied by Xing [15]. Moss [16,17] investigated the structural behavior of SPR connections in G300 and G550 thin sheet steels used in steel framed housing. His research found that the failure modes for SPR connections were similar to those found for screwed or bolted connections, with patterns emerging for the behavior dependent on sheet

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Nomenclature

C_p	correction factor.
C_ϕ	Calibration coefficient (1.52 for LRFD).
d	diameter of rivet (mm).
d_r	residual bottom thickness (mm).
d_w	diameter of rivet head (mm).
D	diameter of die (mm).
D_t	diameter of deformed rivet (mm).
f	tensile strength of the sheet material for Yan (MPa) [8].
f_{y1}	yield strength of sheet in contact with rivet head (MPa).
f_{y2}	yield strength of sheet in contact with rivet tail (MPa).
f_u	tensile strength of parent material for European code (Mpa) [34].
F_{1max}	shear strength of SPR connections proposed by Yan (kN) [8].
F_b	strength of bearing failure of the blind rivet connections adopted by European code (kN) [34].
F_{LS}	shear strength of SPR connections proposed by Haque (kN) [36].
F_m	mean value of fabrication factor.
h	height of the die pip (mm).
h_0	height of rivet head (mm).
H	die depth (mm).
i	interlock length (mm).
L	rivet length (mm).
M_m	mean value of material factor.
P_m	mean value of professional factor (1.0 for tested component).
P_s	the design value of shear strength of SPR connections (kN).
P_u	average maximum force (kN).
s	amount of rivet flaring (mm).
t	the thickness of thinner sheet (mm).
t_1	the top sheet thickness (mm).
t_2	the bottom sheet thickness (mm).
t_e	effective thickness of bottom sheet (mm).
T	the thickness of thicker sheet (mm).
V_F	coefficient of variation of fabrication factor.
V_P	coefficient of variation of test results.
V_Q	coefficient of variation of load factor (0.21 for LRFD).
V_M	coefficient of variation of material factor.
α	calculated coefficient for European code [34].
α_{s1}	calculated coefficient for the rivet tail pulled out from the bottom sheet failure.
α_{s2}	calculated coefficient for the rivet head pulled out from the top sheet failure.
α_{LS}	calculated coefficient for Haque [36].
β_o	target reliability index (3.5 for connections for LRFD).
γ_M	partial factor for resistance of the connection.
ξ	coefficient of correction considering length of rivet having effect on shear strength.
σ_t	yield strength of the sheet material for Haque (MPa) [36].
Ω	the safety factor for ASD design.
ϕ	the resistance factors for LRFD design.

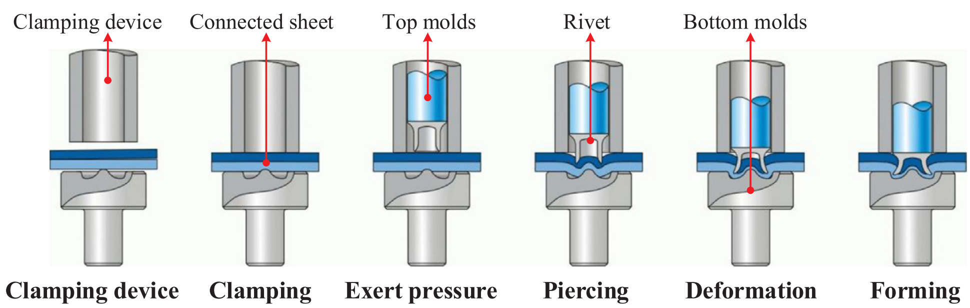

Fig. 1. Schematic diagram of the forming process of a SPR connection [8].

thickness combinations. Meanwhile, the further investigation is required into the observed failure modes for other connection geometries and different grades of steel.

There are many scholars who had previously analyzed influencing factors of shear strength of SPR joints made of aluminum alloy materials. Fu and Xu [18,19] concluded that parameters including hardness, length and diameter had great effect on the strength and quality of SPR joints. Sun [20] indicated that rivet length was a major influence on shear performance. They concluded that the shear strength showed 3.7 kN and 5.3 kN respectively when 6-mm and 6.5-mm long rivets were used to join sheets (1.6-mm + 2.0-mm). Zhao and Calabrese [21,22] found that sheet thickness had an effect on joint's strength and fatigue life. In addition, shear strength and failure mode were determined by top thinner sheet. Li [23] reported the effect of side/edge distance on quality and strength of SPR joint connecting 2 mm AA5754 to 2 mm AA5754. It was concluded that end distance over 11.5 mm had minimal effect on joints. Li [24] researched that an innovative method was used to modify the local surface of the top sheet around the rivet piercing location with different impression tools and garnet particles to study the influence of local frictions on rivet inserting process, joint features and static lap shear strength. The results showed that the local surface textures on the aluminum sheet did not have significant influence on the rivet inserting process. However, it could slightly change the joint features, especially the rivet head height, but overall this influence was not significant. Yan [8] did a pilot study on the shear strength of SPR connections used in cold-formed steel sheets, they proposed a design method based on the model of transmission dynamics of infectious diseases for the shear strength of SPR connections. However, the design method in Yan [8] was only applicable to the rivet rail pull-out failure, did not apply to the rivet head pull-over failure.

In summary, researches on SPR joints mainly considered about sheet material of great ductility such as aluminum, magnesium, cuprum and other materials. However, for SPR connections made of cold-formed steel sheets with lower ductility and higher hardness, there is uncertain of the mechanical mechanism and property in the structural steel field. Since there are lots of influencing factors (materials, rivet character- is-