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Experimental investigation of cold-formed stainless steel tubular T-joints

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Abstract

This paper describes a test program on a wide range of cold-formed stainless steel welded tubular T-joints fabricated from square and rectangular hollow section brace and chord members. A total of 22 tests was performed. High strength stainless steel (duplex and high strength austenitic) and normal strength stainless steel (AISI 304) specimens were tested. The tests were performed by supporting the chord member of the specimen along its entire length with the pure concentrated force applied to the chord face by the brace member. The ratio of brace width to chord width (β) of the specimens varied from 0.5 to 1.0 so that failure modes of chord face failure and chord side wall failure were observed. The test results were compared with the design procedures in the Australian/New Zealand Standard for stainless steel structures, CIDECT and Eurocode design rules for carbon steel structures. It is shown that the design strengths predicted by the current design specifications are conservative for the test specimens calculated using the 0.1%, 0.2%, 0.5% and 1.0% proof stresses as the yield stresses. The 0.2% proof stress is comparatively more reasonable to predict the design strengths of stainless steel welded tubular T-joints for both ultimate limit state and serviceability limit state. In this study, it is shown that the ultimate limit state controls rather than the serviceability limit state for most of the test specimens.

Keywords: Cold-formed stainless steel; High strength; Rectangular hollow section; Square hollow section; Tubular structures

1. Introduction

Cold-formed stainless steel tubular connections are being used increasingly for architectural and structural purposes in recent years. This is due to the aesthetic appearance, high corrosion resistance, ductility property, improved fire resistance and ease of maintenance as well as ease of construction of stainless steel structural members. Typical applications of stainless steel include frameworks in corrosive environments and truss girders in atriums, facade structures in office buildings, offshore platform, canopy structures, wall cladding, and other roof structures.

The use of stainless steel as primary structural components is rather limited due to its high material cost and a lack of research in this area. The current design rules for stainless steel tubular connections are mainly based on carbon steel sections. However, the mechanical properties of stainless steel sections are clearly different from those of carbon steel sections. Stainless steel sections have a rounded stress-strain curve with no yield plateau and low proportional limit stress compared to carbon steel sections. Hence, the stainless steel material is not being fully utilized. To facilitate the use of stainless steel tubular structures, design guidelines should be prepared for stainless steel tubular hollow sections to offset its higher material costs through efficient design.

The experimental investigation of the static strength of welded tubular T-joints made of cold-formed carbon steel rectangular hollow sections (RHS) was carried out by Kato and Nishiyama [1]. Three dominating failure modes as web crippling of chord members, flexural failure of chord flanges and local buckling of brace members were clearly identified. Test results were compared with yield-line theory and the possible adaptation limit was clarified. A few specimens was fabricated from stress-relieved rectangular

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Nomenclature

A_0	cross-sectional area of chord member
A_1	cross-sectional area of brace member
b_0	overall width of chord member
b_1	overall width of brace member
b_e, b_{eff}	effective width of brace member
COV	coefficient of variation
E	Young's modulus of elasticity obtained from longitudinal tensile coupon test
f_b, f_k	chord side wall flexural buckling stress
f_{y0}	yield stress of chord member
f_{y1}	yield stress of brace member
$f(n)$, k_n	parameters account for the influence of compression chord longitudinal stress
g	gap between the flat end of the brace and the chord flange
G	nominal root gap
h_0	overall depth of chord member
h_1	overall depth of brace member
L_0	overall length of chord member
L_1	overall length of brace member
N	axial compression load
N_1	design strength
N_{1n}	nominal strength
N_f	failure load
N_{max}	maximum test strength (peak load)
$N_{1\%b_0}$	test strength at the deformation of $1\%b_0$
$N_{3\%b_0}$	test strength at the deformation of $3\%b_0$
$N_{1n\sigma0.1}$	nominal strength calculated using CIDECT rules based on $\sigma_{0.1}$
$N_{1n\sigma0.2}$	nominal strength calculated using CIDECT rules based on $\sigma_{0.2}$
$N_{1n\sigma0.5}$	nominal strength calculated using CIDECT rules based on $\sigma_{0.5}$
$N_{1n\sigma1.0}$	nominal strength calculated using CIDECT rules based on $\sigma_{1.0}$
N_s	test serviceability strength
r_0	inner corner radius of chord member
r_1	inner corner radius of brace member
R_0	outer corner radius of chord member
t_0	overall thickness of chord member
t_1	overall thickness of brace member
u	chord flange indentation
v	chord web deflection
w	weld size
w'	weld size for full width joint
α	imperfection factor
β	brace to chord width ratio (b_1/b_0)
γ_{M5}	partial safety factor
τ	brace to chord thickness ratio (t_1/t_0)
2γ	chord width to thickness ratio (b_0/t_0)
η	brace depth to chord width ratio (h_1/b_0)
θ_1	inclined angle between brace and chord member
ε_f	elongation after fracture based on a gauge length of 50 mm
σ_p	tensile proportional limit stress
σ_u	static ultimate tensile stress
$\sigma_{0.1}$	static 0.1% tensile proof stress
$\sigma_{0.2}$	static 0.2% tensile proof stress
$\sigma_{0.5}$	static 0.5% tensile proof stress
$\sigma_{1.0}$	static 1.0% tensile proof stress
ϕ	resistance factor for tubular joints
Δ_{max}	deformation corresponding to the maximum test strength

hollow section members and the strength was compared with that of corresponding cold-formed specimens. It was shown that the effect of cold-working or residual stresses on the joint strength can be negligible. In 1991, a test program on cold-formed carbon steel tubular T-joints fabricated from square and rectangular hollow sections (SHS and RHS) subjected to combined bending and concentrated force was conducted by Zhao and Hancock [2]. The chord member was simply supported with the concentrated force applied at the center of the member. The member length was varied in order to determine the interaction relationship between bending moment and concentrated force. Tests under pure moment and pure concentrated force were performed for control purposes. In addition, the thickness of the chord member sections was varied so as to produce a range of section slenderness and failure modes from buckling to yielding. The test results were compared with the design procedures in the American Specification [3], Australian Standard [4], CIDECT [5], as well as the plastic mechanism models. In 1998, four planar trusses comprising of welded T-joints and four isolated welded T-joints fabricated from cold-formed carbon steel square and rectangular hollow sections (SHS and RHS) were tested by Nayak and Bhattacharyya [6]. All the tests were performed in three stages. Firstly, the trusses were tested under loading to explore the exact behavior of the welded tubular T-joints in a structure. Secondly, two isolated T-joints were tested with the brace member under direct compression and the chord member supported throughout without any preloading, to isolate the local effect of the chord member. In the third case, the other two isolated T-joints were tested with compression to chord member and tension to brace member simultaneously, to study the joint under combined actions. The strain values at some strategic locations were measured with the load increment for all three cases to obtain relationship between load and strain. It should be noted that there is little research being carried out on cold-formed stainless steel tubular T-joints.

Design rules for carbon steel tubular joints are available in the Comité International pour le Développement et l'Étude de la Construction Tubulaire (CIDECT) Monograph No. 6 [7]. The Eurocode 3 part 1.8 [8] provides