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Corner properties of cold-formed steel sections at elevated temperatures

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Abstract

This paper presents the mechanical properties of the corner parts of cold-formed steel sections at elevated temperatures. Light-gauge structural members are cold-formed which results the mechanical properties of the corner parts being different from the flat parts. However, previous research has focused on the investigation of the corner parts of cold-formed steel sections at normal room temperature and the performance of the corner parts at elevated temperatures is unknown. An appropriate model for fire resistant design of steel structures necessitates a correct representation of mechanical properties of structural steel at elevated temperatures. Therefore, experimental investigation on corner coupon specimens at different temperatures ranged from approximately 20 to 1000 °C was conducted to study the behaviour of the corner parts of cold-formed steel sections at elevated temperatures. Two kinds of corner coupon specimens, namely the inner corner coupon specimens and outer corner coupon specimens having the steel grade of G500 (nominal 0.2% proof stress of 500 MPa) and nominal thickness of 1.9 mm were tested. The test results were compared with the flat coupon specimens taken from the same cold-formed steel sections as the corner coupon specimens. A unified equation to predict the yield strength (0.2% proof stress), elastic modulus, ultimate strength and ultimate strain of the corner parts of cold-formed steel sections at elevated temperatures is thus proposed in this paper. Generally, it is shown that the proposed equation adequately predicts the test results of the corner coupon specimens. Furthermore, stress–strain curves at different temperatures are plotted and a stress–strain model is also proposed for the corner parts of cold-formed steel sections.

Keywords: Cold-formed steel; Corner; Elevated temperatures; Experimental investigation; Fire resistance design; Mechanical properties

1. Introduction

The current design standards of cold-formed steel structures, such as the Australian/New Zealand Standard [1] and North American Specification [2], explicitly permit utilization of the increase in the material properties that result from a cold-forming operation. The mechanical properties of cold-formed steel sections are sometimes substantially different from those of the steel sheet, strip or plate before forming. This is because the cold-forming operation increases the yield point and tensile strength and at the same time decreases the ductility. The percentage increase in tensile strength is much smaller than the increase in yield strength, with a consequent marked reduction in the spread between yield point and tensile strength. Since, the material in the corners of a section is cold-worked to a considerably higher degree than the material in the flat elements, the mechanical properties are different in various parts of the cross section [3]. Light-gauge structural members are cold-formed by a various methods, such as roll-forming and brake-pressing. Large deformations are expected to occur in a section due to the cold-forming operation. The induced deformations at flat parts of the section may be elastic deformations; however, the deformations expected at corner parts of the section are essentially plastic deformations [4]. The changes in the mechanical properties, brought about by cold work are considered as being caused mainly by three phenomena: Strain hardening, the Bauschinger effect, and strain aging [5]. Experimental studies on the mechanical properties of the corner parts of cold-formed steel sections have been reported in the literature [4–7]. However, these research were carried out at normal room temperature and there are no reports on the behaviour of corner properties of cold-formed steel sections at elevated temperatures. Therefore, an experimental investigation on corner coupon specimens at different temperatures ranged from approximately 20 to 1000 °C was conducted to study the behaviour of corner parts of cold-formed steel sections at elevated temperatures.

In this paper, details of the experimental study of the corner parts of cold-formed steel sections at elevated temperatures are presented. The mechanical properties of the corner parts of cold-formed steel at elevated temperatures are reported and compared with those of the flat parts of the same specimens.

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Nomenclature

a, b, c	coefficients for proposed unified equation;
A_{cm}	cross section area of corner coupon specimen obtained using the first method;
A_{cw}	cross section area of corner coupon specimen obtained using the second method;
B	width of the cross sectional area of corner coupon specimen;
E_{normal}	elastic modulus at normal room temperature;
E_T	elastic modulus at temperature T (°C);
$E_{y,T}$	elastic modulus at yield strength at temperature T (°C);
f_T	stress at temperature T (°C);
$f_{u,normal}$	ultimate strength at normal room temperature;
$f_{u,T}$	ultimate strength at temperature T (°C);
$f_{y,normal}$	yield strength (0.2% proof stress) at normal room temperature;
$f_{y,T}$	yield strength (0.2% proof stress) at temperature T (°C);
h	depth of the inside surface curvature of corner coupon specimen;
k	strength coefficient;
L	length of the inside surface curvature of corner coupon specimen;
L_c	length of the parts taken from the corner coupon specimen within the gauge length;
n	strain–hardening exponent and coefficient for proposed unified equation;
n_T	coefficient for proposed stress–strain equation;
m_T	coefficient for proposed stress–strain equation;
r	radius of the inside surface curvature of corner coupon specimen;
t	basic metal thickness;
T	value of temperature;
M_c	mass of the parts taken from the corner coupon specimen within the gauge length;
α	angle of the inside surface curvature of corner coupon specimen;
σ'	true stress;
σ_{yc}	yield strength of corner coupon specimen;
$\sigma_{yc\text{-}predicted}$	yield strength of corner coupon specimen predicted by equation;
$\sigma_{yc\text{-}test}$	yield strength of corner coupon specimen obtained from the tests;
ε'	true strain;
ε_T	strain at temperature T (°C);
$\varepsilon_{f,normal}$	total elongation at normal room temperature;
ε_f	total elongation;
$\varepsilon_{f,T}$	total elongation at temperature T (°C);
$\varepsilon_{u,normal}$	strain corresponding to ultimate strength at normal room temperature;
$\varepsilon_{u,T}$	strain corresponding to ultimate strength at temperature T (°C);
$\varepsilon_{y,T}$	strain corresponding to yield strength at temperature T (°C);
ρ	density of the test cold-formed steel material.

A unified equation for the reduction factors of the elastic modulus, yield strength, ultimate strength and ultimate strain of the corner parts of cold-formed steel sections at elevated temperatures is proposed. In addition, equations for the complete stress–strain curves at different temperatures are also proposed for the corner parts of cold-formed steel sections.

2. Experimental investigation

2.1. Test device

The tensile testing machine used in this study was an MTS 810 Universal testing machine of 100 kN capacity. The heating device was an MTS Model 653 high temperature furnace with a maximum temperature of 1400 °C. The furnace was controlled by an MTS model 409.83 temperature controller. An MTS Model 632.53F-11 of axial extensometer was used to measure the strain of the middle part of the coupon specimens. Details of the test devices were present in Chen and Young [8].

2.2. Test specimen

Two kinds of corner coupon specimens, namely the inner corner coupon specimens and outer corner specimens, were tested in this study. The flat coupon specimens were presented in Chen and Young [8]. The two kinds of corner coupon specimens were taken from the same cold-formed steel sections as the flat coupon specimens, as shown in Fig. 1(a). The dimension of the corner coupon specimens was identical to the flat coupon specimens and were prepared in accordance

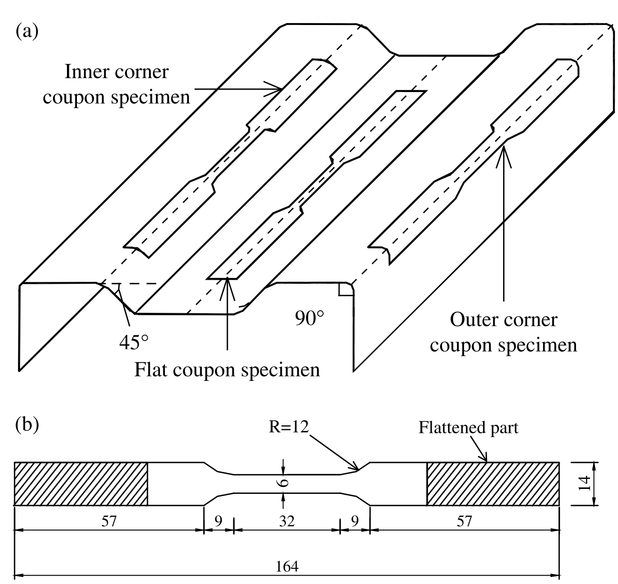

Fig. 1. Coupon specimens.