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Axial compressive strength of welded S460 steel columns at elevated temperatures

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ABSTRACT

This paper presents an investigation on the structural performance of welded S460 steel columns under axial compression at elevated temperatures using finite element analysis. Stub and long columns with box and H-sections were considered. A new stress-strain curve model for S460 steel at elevated temperatures was proposed and adopted to obtain the stress-strain curves for the finite element analysis. A finite element model was developed and verified against the available test data for welded S460 steel columns subject to axial compression at room and elevated temperatures. A parametric study was carried out to generate additional data of the axial compressive strength of box and H-section columns with various cross-section slenderness and column slenderness ratios at elevated temperatures. The obtained numerical results of the column strength were compared with the design predictions using the European and American specifications and the direct strength method by substituting the material properties at elevated temperatures. It was found that the provisions in European and American standards for elevated temperature conditions provide relatively conservative predictions. The direct strength method overestimates the strength of stub columns while accurately predicts the strength of long columns at elevated temperatures. Modifications are proposed for the European and American standards and direct strength method and these modified design rules are recommended to be used to more accurately estimate the design strength for welded S460 steel columns at elevated temperatures.

1. Introduction

The use of high strength steel (HSS) with nominal yield strength over 460 MPa in structural construction brings about considerable advantages over mild steel. By using HSS, lighter structural members with smaller cross-section sizes can be adopted, resulting in the significant material savings and easier handling during construction. Consequently, the transportation and construction costs can be reduced. Besides, the lesser consumption of steel materials also generates higher environmental efficiency. In order to carry out accurate design of HSS structures, extensive research studies have been conducted to determine the behaviour of cold-formed and welded HSS columns under compression at room temperature. The local buckling behaviour and strength of HSS stub columns were investigated in experiments and numerical modelling [1–6] and revised slenderness limits for cross-section classification were proposed [7]. The global buckling resistance of HSS columns was also investigated [4,5,8–11] and suitable buckling curves for the design of HSS columns were also proposed [8–10,12]. However, although great progress in developing room temperature design guidance for HSS columns has been made, the performance of HSS columns under elevated temperature conditions has received much less attention and needs to be thoroughly investigated for designing the structures for the possibility of fire exposure.

The behaviour of BISALLOY 80 high strength steel (with the nominal yield strength of 690 MPa) columns with box and I- sections at elevated temperatures was investigated numerically by Chen and Young [13]. A parametric analysis was performed to determine the temperature effect on the strength of both stub columns with various cross-section slenderness and long columns with different slenderness ratios. The suitability of specifications in European, American and Australian standards and direct strength method [17] for BISALLOY 80 high strength steel columns at elevated temperatures was assessed by comparing the results of the parametric study with those of the column strength predicted based on the standards with the substitution of material properties at elevated temperatures. It was found that European and American specifications and direct strength method could be used to conservatively predict the strength of BISALLOY 80 high strength steel columns at elevated temperatures. Wang and co-workers [19] conducted experiments to investigate the axial compressive strength of welded Q460 steel columns at only two temperatures of

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450 °C and 650 °C and the column specimens with two cross-section sizes were tested. It was found that the axial compressive strength of the columns at 650 °C was significantly lower than that of the columns at 450 °C due to the deterioration of material strength and stiffness with increasing temperatures. However, no systematic study has been conducted to investigate the strength of 460 MPa steel columns at varying elevated temperatures that the structures may experience under fire condition.

In this study, the axial compressive strength of welded S460 steel columns with box and H- sections at elevated temperatures was investigated using finite element analysis. Firstly, a stress-strain model for S460 steel at elevated temperatures was proposed based on the experimental results obtained by Qiang and the co-workers [20] for structural design and analysis. Secondly, a finite element model was initially developed and validated against the test results of the welded S460 steel columns at room and elevated temperature conditions [1,8,9,19,21]. Upon validation of the finite element model, a parametric study was subsequently carried out to determine the strength of welded S460 steel columns with various cross-sectional slenderness and column slenderness ratios at a wide range of elevated temperatures. Finally, the results of finite element analysis were compared with the design strength predictions obtained based on the provisions in European standard [14], American standard [15] and the direct strength method (DSM). Modifications to the European and American standards and DSM are suggested in order to obtain more accurate and safe predictions of the column strength for structural design.

2. Proposed stress-strain curve model

2.1. Stress-strain curve model proposed by other researchers

A stress-strain curve model is given in EN1993-1-2 [14] for temperatures up to 1200 °C and is based on test results on hot-rolled normal strength steel. Schneider and Lange [22] have found that the stress-strain curves for S460 steel predicted using the model in EN1993-1-2 are very different from the curves obtained in experiments. Stress-strain curve models for elevated temperatures were also developed based on the Ramberg–Osgood equation [23] for hot-rolled steel [24], S420 steel [25] and light gauge steel [26]. In these models, the basic form of the Ramberg–Osgood equation for elevated temperatures is given as

$$\varepsilon_T = \frac{f_T}{E_T} + \beta\left(\frac{f_{y,T}}{E_T}\right)\left(\frac{f_T}{f_{y,T}}\right)^n \tag{1}$$

where ε_T is the strain at temperature T °C, f_T is the stress at temperature T °C, $f_{y,T}$ is the yield stress at temperature T °C, E_T is the elastic modulus at temperature T °C. For the coefficients of β and n, different studies provided different values and calculation methods. The stress–strain curves for S460 were predicted using these stress–strain curve models [24–26]. These predicted curves were compared with the curves obtained in experiments which were conducted by Qiang and co-workers [20], as shown in Figs. 1–3 respectively. As can be seen in the figures, the differences between the stress-strain curves predicted using the three proposed models and those from the test results are quite significant. Therefore, using the predicted curves from these models can lead to inaccurate structural analysis and design. An accurate model for S460 steel at elevated temperatures is needed.

2.2. New stress-strain curve model

The prediction of stress-strain curves based on Eq. (1) compares reasonably with the experimental stress-strain relationship in the elastic stage when the stress increases linearly with the increment of strain. However, Eq. (1) provides inaccurate simulation of the stress-strain relationship in the inelastic stage when the stress becomes higher than the proportional limit of the material, as observed in Figs. 1–3. This is

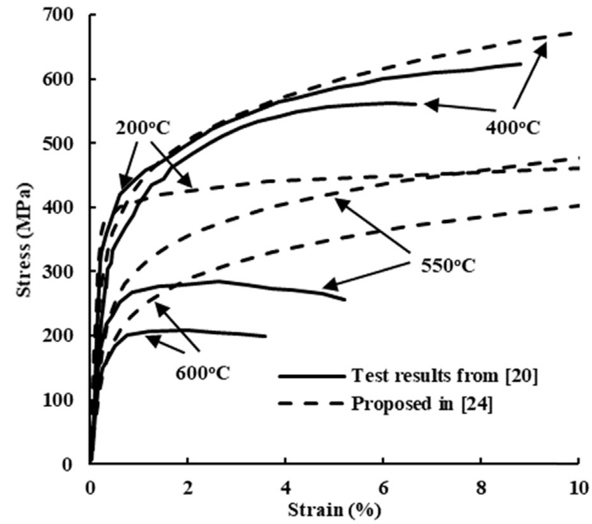

Fig. 1. Comparison of stress-strain curves predicted using the model in [24] with the test results from [20].

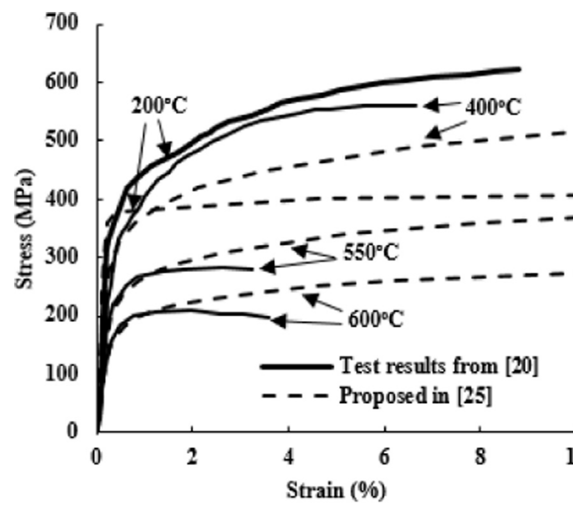

Fig. 2. Comparison of stress-strain curves predicted using the model in [25] with the test results from [20].

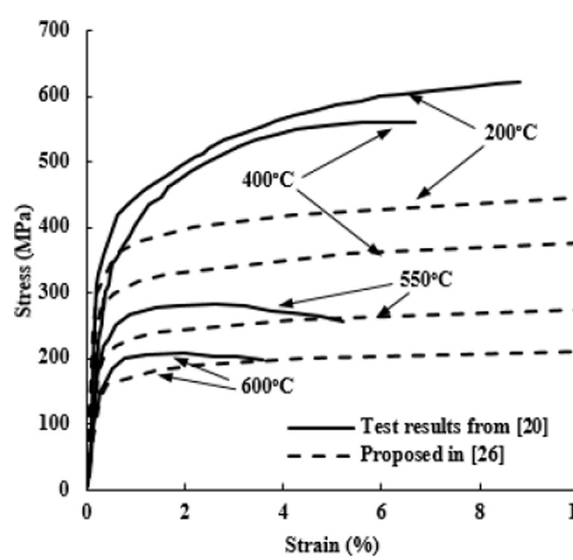

Fig. 3. Comparison of stress-strain curves predicted using the model proposed by Lee and the co-workers [26] with the test results [20].