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Post-fire mechanical properties of cold-formed steel hollow sections

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HIGHLIGHTS

- Conducted tests to determine post-fire mechanical properties of cold-formed steel hollow sections.
- Determined post-fire mechanical properties of hollow sections of different grades and thicknesses.
- Test results did not agree with those obtained from previous studies and design standards.
- Proposed suitable equations to predict post-fire mechanical property reduction factors.
- Strength enhancement techniques were proposed for fire damaged hollow sections.

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ABSTRACT

Cold-formed steel hollow sections are extensively used in building construction due to their potential benefits over hot-rolled and open cold-formed steel sections. Their performance in fire is important for successful structural applications while their post-fire residual capacities are also important to assess the extent of their fire damage and reusability with and without strength enhancing techniques. This paper presents the details of an experimental investigation on the post-fire mechanical properties of cold-formed steel hollow sections. Tensile tests were performed on coupons exposed to elevated temperatures varying from 100 to 800 °C and then cooled down to room temperature. These coupons were cut from cold-formed steel square and rectangular hollow sections with varying thicknesses and grades. The results from this investigation provided post-fire stress-strain curves, yield strengths, ultimate strengths and elastic modulus, and their reduction pattern. They show that the post-fire mechanical properties of cold-formed steel hollow sections are different to those of open cold-formed channel and hot-rolled sections. New predictive equations were proposed to determine the post-fire mechanical property reduction factors. Post-fire mechanical properties were also compared with their elevated temperature mechanical properties to evaluate their strength gain after cooling down. This paper also evaluates various strength enhancement techniques for use with fire damaged cold-formed steel hollow sections.

1. Introduction

Steel hollow sections (Fig. 1) are extensively used in buildings as structural members since they possess many significant advantages structurally over equivalent open sections. Two types of steel hollow section are manufactured and used, which are hot-rolled and cold-formed hollow sections. Puthli and Packer [1] recommend the use of cold-formed hollow sections since they perform efficiently if the products comply with the corresponding standards. They also pointed out a few distinctive advantages of cold-formed sections over hot-rolled sections; viz., 26–45% higher tonnage prices for hot-rolled products in Germany, smooth surfaces of cold-formed products, giving aesthetically pleasing appearance, and easier corrosion protection in trusses and welded connections to columns due to their smooth corner radius. Thus in recent times, cold-formed steel hollow sections are increasingly used in comparison with hot-rolled steel sections. In Australia also, fabricators prefer the use of cold-formed hollow sections due to their high strength and cost efficiency. Cold-formed steel hollow sections of Grade 350 and 450 steels (350 and 450 MPa yield strengths) are commonly used in Australia. It should be noted that presently cold-formed steel hollow sections of super high strengths such as 950 MPa are manufactured and used in some European countries.

Fire performance of cold-formed steel hollow sections is an important criterion to be verified during their design stage. The structural fire capacity is important to determine the fire

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Fig. 1. Cold-formed steel hollow sections.

resistance rating of cold-formed steel hollow sections while their residual strength after a fire event is important to assess the structural fire damage and their potential reusability. Fire behaviour of cold-formed steel sections including hollow sections and their elevated temperature mechanical properties had been extensively studied in the past [2–28]. Previous studies [18–28] showed that the elevated temperature mechanical property reduction factors of cold-formed steel hollow sections are different to those of open cold-formed steel sections made of low and high strength steel sheets and hot-rolled steels. Post-fire mechanical properties of hollow sections could also be different to those of open cold-formed steel sections. Therefore, this study investigates the mechanical properties of fire damaged cold-formed steel hollow sections.

Fire damaged steel structures can be repaired and renovated in most of the cases as steels possess higher residual strength after cooling down from elevated temperatures. According to Kirby [29], fire damaged steel members can be mainly categorised into three groups: Category 1 – members slightly damaged by a fire which have no or slight deformations, Category 2 – members deformed but could be straightened if economically justified, Category 3 – members severely deformed. In most cases, Category 2 and 3 members could be replaced. However, to re-use them with minimum repair and with less cost, it is important to establish the strength data of steel sections after cooling down. Visual inspection and non-destructive testing are inadequate to determine the extent of damage, and destructive testing is needed where possible samples are extracted and tested. In this case, the maximum temperature steel was exposed to during the fire accident can be found if the post-fire mechanical property data are available. Such data can also be used as an input to determine the temperature development history during fire and the residual structural capacity of the other structural and non-structural members of the fire damaged buildings by coupled thermal and structural analyses. Based on this information suitable modifications can be proposed to regain the lost strength of the damaged members, i.e., adding stiffeners or carbon fibre reinforced polymer (CFRP) sheets around the members. This would allow repair instead of demolishing the fire damaged buildings. Since cold-formed steel hollow sections are increasingly used at present, it is imperative to know their residual capacities after a fire in order to assess the extent of fire damage and reusability of structures if built from such sections. For this purpose, their post-fire mechanical properties are important.

In the past only a few investigations [30–32] have been performed on the post-fire mechanical properties of steel members. Gunalan and Mahendran [30] conducted tensile tests on specimens obtained from low and high strength cold-formed steel sheets to determine their post-fire mechanical properties. Qiang et al. [31] also conducted an experimental study of high strength S460 and S690 steels. They proposed predictive equations to predict the post-fire mechanical property reduction factors, but they varied among themselves. Their applicability to the commonly used cold-formed steel hollow sections is questionable as it was found that the elevated temperature mechanical property reduction factors of cold-formed steel hollow sections are different to those of open cold-formed steel sections [4]. Therefore, it is necessary to conduct an experimental study to accurately determine the post-fire mechanical property reduction factors of cold-formed steel hollow sections.

At first, this paper reviews the elevated temperature and post-fire mechanical property reduction factors of different cold-formed steel sections available in the literature and design standards. After highlighting the importance of determining the post-fire mechanical properties, this paper presents the experimental study performed to investigate such post-fire mechanical properties of high strength cold-formed steel hollow sections including the details of test specimens and test procedure. Test specimens were heated from temperatures ranging from 100 to 800 °C and then cooled down to room temperature. The stress-strain curves were obtained and the yield strength, ultimate strength, and elastic modulus were then determined. Using these test results, suitable mechanical property reduction factor models were proposed to determine the fire residual strengths of cold-formed steel hollow sections and are presented in this paper. The proposed models are then compared with the other available models for cold-formed steel sections. Also, the residual strength gains of the hollow sections after fire were also evaluated by comparing the post-fire and elevated temperature mechanical property reduction factors. Potential strength enhancement techniques for fire damaged cold-formed steel hollow sections are also evaluated and presented in this paper.

2. Review of the elevated and post-fire mechanical properties of cold-formed steels

Fire behaviour of different types of cold-formed steel section including both open and hollow sections has been extensively investigated in the past through experimental and numerical studies [2–17]. Since determining the actual elevated temperature mechanical properties is imperative to accurately predict the fire behaviour of cold-formed steel sections, many studies focused on measuring the elevated temperature mechanical properties of cold-formed steels [18–28]. Based on the test results, they proposed suitable equations to determine the elevated temperature mechanical property reduction factors for cold-formed steels. Predictive equations were also developed to derive elevated temperature stress-strain curves along with yield strength, ultimate strength and elastic modulus reduction factor models. Fig. 2 (a) and (b) present the elevated temperature yield strength and elastic modulus models proposed in various studies. As evident from these figures, there are large differences between their elevated temperature yield strength and elastic modulus reduction factors.

The possible reasons for the variations in the elevated temperature mechanical property reduction factors are: the differences in chemical composition, test method used, thickness and grade of steel, manufacturing process and technology of cold-formed steels (press braking or roll forming). Qiang et al.'s [31] experimental study showed that the obtained elevated temperature reduction factors varied based on the test method used, i.e., steady and transient state test methods. In Kankanagme and Mahendran's [19]