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Elevated temperature mechanical properties of hollow flange channel sections

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HIGHLIGHTS

- Conducted elevated temperature tensile tests for welded hollow flange channel sections.
- Elevated temperature mechanical properties were found for flange and web elements.
- Test results did not agree with previous studies and design standards.
- Proposed new elevated temperature mechanical property reduction factors.
- Proposed new elevated temperature stress–strain models.

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ABSTRACT

The fire performance of cold-formed steel members is an important criterion to be verified for their successful use in structural applications. However, lack of clear design guidance on their fire performance has inhibited their usage in buildings. Their elevated temperature mechanical properties, i.e., yield strengths, elastic moduli and stress–strain relationships, are imperative for the fire design. In the past many researchers have proposed elevated temperature mechanical property reduction factors for cold-formed steels, however, large variations exist among them. The LiteSteel Beam (LSB), a hollow flange channel section, is manufactured by a combined cold-forming and electric resistance welding process. Its web, inner and outer flange elements have different yield strengths due to varying levels of cold-working caused by their manufacturing process. Elevated temperature mechanical properties of LSBs are not the same even within their cross-sections. Therefore an experimental study was undertaken to determine the elevated temperature mechanical properties of steel plate elements in LSBs. Elevated temperature tensile tests were performed on web, inner and outer flange specimens taken from LSBs, and their results are presented in this paper including their comparisons with previous studies. Based on the test results and the proposed values from previous studies and fire design standards, suitable predictive equations are proposed for the determination of elevated temperature mechanical properties of LSB web and flange elements. Suitable stress–strain models are also proposed for the plate elements of this cold-formed and welded hollow flange channel section.

1. Introduction

Cold-formed steel members are increasingly used in the construction industry due to their advantages such as versatility in manufacturing, easy transportation, easy erection and dismantlement and high strength to weight ratios. Light gauge steel frames (LSF) used in wall and floor systems are a good example of the use of cold-formed steels. Traditionally conventional lipped channel section studs and joists have been used in these wall and floor systems. Recent research has investigated the use of welded or rivet/screw fastened and cold-formed hollow flange channel sections and shown their superior structural performance in these applications [1,2]. LiteSteel Beam (LSB) was one such hollow flange channel section, commercially produced by an Australian company using a combined cold-forming and electric resistance welding process to form two rectangular hollow flanges as shown in Fig. 1. However, there has not been any research on the fire performance of these cold-formed and welded hollow flange channel sections and these sections have not been used in

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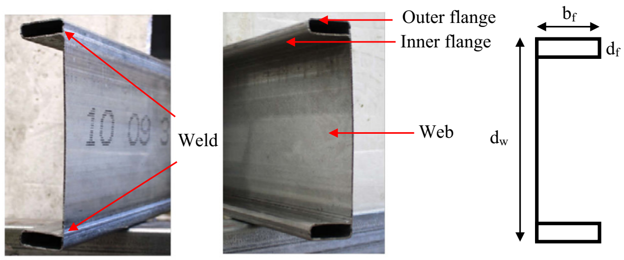

Fig. 1. Welded hollow flange section – LiteSteel Beam (LSB).

applications where fire rating is required. The main reason for this is the unavailability of the elevated temperature mechanical properties of LSB steel plate elements.

Accurate elevated temperature mechanical properties are very important for the development of performance based fire design methods for cold-formed steel structural members [3]. Elastic modulus and yield strength are the important mechanical properties, which degrade with increasing temperatures during fire events. Eurocode 3 Part 1.2 [4] provides the same elevated temperature elastic modulus and yield strength reduction factors for thin hot-rolled (Class 4) and cold-formed steels although their manufacturing processes significantly differ. Dolamune Kankanamge and Mahendran [5] have shown that unlike hot-rolled steels, cold-formed steels lose their strength gained through cold-forming at elevated temperatures. In recent times Dolamune Kankanamge and Mahendran [5], Mecozzi and Zhao [6], Chen and Young [7], Ranawaka and Mahendran [8], Wei and Jihong [9] and Jihong and Wei [10] have conducted detailed experimental studies to determine the elevated temperature mechanical property reduction factors of cold-formed steels. They found that the reduction factors they obtained significantly differed from those given in Eurocode 3 Part 1.2 [4]. Hence they proposed different predictive models for elastic modulus and yield strength reduction factors for cold-formed steels at elevated temperatures based on their experimental studies. Their proposed values even varied largely among them.

The manufacturing process, level of cold-working and chemical composition of the cold-formed steels used in their experiments varied and these may be the reasons for the different reduction factors. Further, some researchers conducted experiments on specimens taken from cold-formed steel sheets while others took them from cold-formed steel members such as Square Hollow Sections (SHS) and Rectangular Hollow Sections (RHS). This would also have caused the observed differences in the elevated temperature mechanical property reduction factors. Dolamune Kankanamge and Mahendran [5] provide suitable elevated temperature mechanical property reduction factors for both low and high strength cold-formed steels based on tensile tests of coupons taken from steel sheets. They may not be applicable to LSB plate elements as LSBs were made by a combined cold-forming and welding process. Further, previous researchers found that yield strengths obtained at ambient temperature varied significantly when specimens were taken from LSB's web and flange plate elements, and thus elevated temperature tensile tests are imperative to determine the accurate elevated temperature mechanical properties. Therefore elevated temperature tensile tests were conducted on the specimens taken from different locations in LSBs such as web, inner flange and outer flange elements. This paper presents the details of these tensile tests, and the results including the mechanical property reduction factors and stress–strain relationships of LSB plate elements.

2. Experimental investigation

2.1. Test method

There are two types of test methods, steady and transient state methods, which are used to investigate the mechanical properties of cold-formed steels at elevated temperatures. In the steady state tests, the test specimen is heated to a target temperature and once the temperature is uniform in the specimen, a tensile load is applied at a constant rate until failure while maintaining the achieved temperature. On the other hand, in the transient state tests, the test specimen is kept under a target load while the temperature is increased at a specified rate until failure. It has been stated by several researchers that the transient state test method is more realistic since it simulates the real conditions of fire situations including the creep effect [7,11]. The time dependent creep effect is influenced by both the applied load and temperature. This effect can be neglected since both steady and transient state tests are usually completed within an hour and thus undergo limited amount of creep effect. Furthermore, steady state tests are considerably easier to conduct than transient state tests and stress–strain curves can be directly obtained from them. Therefore many researchers have used the steady state test method because of its simplicity and accuracy. In this research study, the steady state test method was adopted to conduct the tensile tests to determine the elevated temperature mechanical properties of web, inner flange (IF) and outer flange (OF) elements of the welded hollow flange channel sections (LSBs). Past research on LSF walls made of conventional channel sections [17,18] have shown that the elevated temperature mechanical properties of steels obtained from steady state tests [5] can be used in the transient state finite element analyses of steel studs by comparing their numerical and full scale fire test results.

2.2. Test specimens

Test specimens were taken from the web, IF and OF elements of two LSBs, 200 × 45 × 15 × 1.6 mm and 150 × 45 × 15 × 1.6 mm. They were prepared in accordance with AS 2291 [12] and their dimensions and shape are shown in Fig. 2. A 10.5 mm diameter hole was provided on both sides in order to fix the specimen to the jaws of the Instron Testing Machine.

Test specimens taken from LSBs were zinc coated and hence the coating of each specimen was removed by immersing them in diluted hydrochloric acid. Following the removal of coating, an average coarse sand paper was used to make the specimen surface rough, which was then cleaned using Ethanol. Test specimen dimensions required for the stress calculations, the base metal thickness and gauge width, were measured using a micrometer. The average base metal thickness of the web, IF and OF elements were found to be 1.53, 1.58 and 1.66 mm, respectively. Following this, two retro-reflective tapes were fixed to the specimen at a gauge length of 50 mm as shown in Fig. 3 in order to measure the strain in the specimen at elevated temperatures.

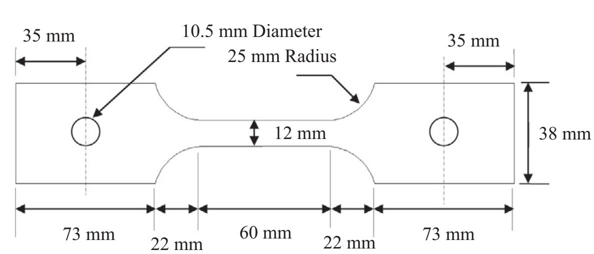

Fig. 2. Tensile specimen and its dimensions.