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Application of high strength and ultra-high strength steel tubes in long hybrid compressive members: Experimental and numerical investigation

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ABSTRACT

With the increasing application of high strength steel material in industries, there is a high potentiality for taking advantage of the exceptional load-bearing capacities of this material in construction practice. In the present study, an innovative application for high and ultra-high strength steel material is proposed which enhances the overall behavior of structural elements. The high strength and ultra-high strength steel with nominal tensile strengths of 750 MPa and 1250 MPa, respectively, are proposed to be utilized as tube elements welded to corners of mild steel plates shaping an innovative hybrid section. This section takes advantage of the combined material properties of the two constituting elements in terms of strength, local buckling behavior and ductility. Large-scale tests and numerical analysis have been conducted to compare the behavior of the proposed sections against conventional welded sections. The effect of heat on the material properties of the hybrid section has also been considered. These effects are included in the finite element modeling of innovative columns where numerical outputs have been verified accordingly.

1. Introduction

Due to their unique characteristics such as strength, energy absorption, weight saving etc. high strength (HS) and ultra-high strength (UHS) steel materials are widely used in industrial productions. One of the most wide spread applications of high strength steel has been in automobile manufacturing, for instance its utilization in propeller shafts, suspension parts and doors under impact and crush conditions [1–3]. Accordingly, the unique specifications of high strength steel can be proposed as an exceptional alternative for conventional structural material. The use of this material can lead to a great deal of reduction in the consumed mass and increase the overall load bearing capacity. This is due to the fact that high strength steel and mild steel possess similar weights per equal volume. Published researches can be found on the employment of high strength circular steel tubes in structures and structural elements. Namely, roof structures [4], stub columns consisting of high strength steel tubes under compression and members under bending and tension [5–7], tube joints and welded connections in structural steel hollow sections [8–10] and CFRP strengthened butt-welded ultra-high strength steel tubes [11]. In terms of material properties, fracture-mechanical characterization of high-strength steel tubes adopting numerical and experimental data was done with respect to the specimen geometry and also thermo-mechanical conditioning during the production of tubes [12]. The use of high strength material also leads to longer life span of structure. Specifically, UHS steel material utilized in this study exhibits an increase of 2.5 times of life span than that of mild tubes [13]. The cost effectiveness of high strength material has also thoroughly been studied in previous literature [14,15]. In terms of cost, a comparison among high strength steel tubes and normal steel tubes in realistic possibilities of building columns, considering the strength, stability and stiffness conditions, clearly indicated that using high strength steel in structures is more economic [16].

In compressive loading conditions, HS and UHS tubes experience failure modes due to the brittle behavior of the material as well as global buckling, depending on the geometry and slenderness. In fact the lower ductility of sections consisting only of HS and UHS steel compared to mild steel sections has an undermining effect on the global performance of the whole structure. Therefore, an innovative hybrid section consisting of HS or UHS tubes welded to mild steel plates has been proposed [17] which significantly

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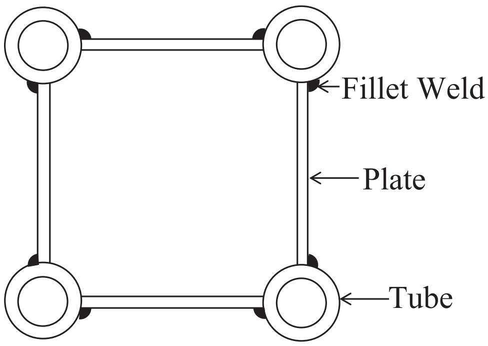
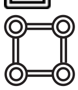
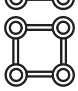
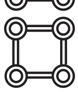
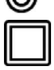
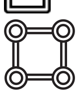
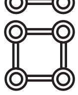
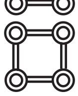


Fig. 1. IFC section geometry.

Table 1
Geometric specifications of test specimens.

Specimen cross-section	Specimen label	Length (mm)	Design Slenderness ratio
	S-MT1	1000	27.1
	S-HST1	1000	27.1
	S-UHST1	1000	27.1
	WB-1	1000	8.2
	IFC-MT1	1000	6.3
	IFC-HST1	1000	6.3
	IFC-UHST1	1000	6.3
	S-MT2	2000	54.2
	S-HST2	2000	54.2
	S-UHST2	2000	54.2
	WB-2	1000	16.3
	IFC-MT2	2000	12.6
	IFC-HST2	2000	12.6
	IFC-UHST2	2000	12.6

enhances the compressive capabilities of high strength steel material in terms of both strength and ductility. In this section type, high strength steel tubes are welded to the corners of mild steel plates. The closed geometry of the proposed section consisting of circular tubes exhibits exceptional performance under compression in terms of local buckling [15]. The behavior of short lengths of these innovative sections was investigated under various conditions such as fire [18–20]. This study looks into the behavior of higher lengths of columns and the effect of section configuration on the overall ductility of hybrid columns.

As opposed to cold-formed material elements [21], when it comes to hybrid sections, welding has a significant effect on the material properties and behavior in the vicinity of weld, known as the heat affected zone (HAZ). Several research works are available investigating the effect of heat and high temperatures on steel [22–27] and specifically welding on high strength and ultra-high strength tube materials [28–30]. Properties of the material located at various distances from weld in fabricated sections consisting of high strength and ultra-high strength steel tubes have been derived with respect to the tube manufacturing process, type of welding and post-welding conditions [31].

The present research work, as opposed to previous literature available on this specific section focusing only on stub columns, experimentally investigates the behavior of long innovative specimens fabricated from HS or UHS steel tubes and mild steel plates under static compression. The load-bearing performance of high strength and ultra-high strength steel tube in the compressive behavior is investigated and compared to mild steel tubes. The effect of welding on each of the column constitutive elements have been taken into consideration to understand the detailed structural characteristics of the proposed high strength section. This has also led to achieving a robust and precise numerical finite element model.

2. Specimen specifications

2.1. Geometric specifications

The hybrid fabricated column section welded from steel plates and tubes is shown in Fig. 1. The plate elements used for innovative fabricated columns are Grade 250 mild steel with nominal width of 210 mm and thickness of 3 mm. Tubes with nominal outer diameter of 76.1 mm and thickness of 3.2 mm are used having three different material properties. In total, 14 specimens are tested in different lengths of one and two meters including individual tubes, conventional welded box columns and the hybrid fabricated columns. Individual tubes have similar sections used in the hybrid column in terms of geometry. Likewise, the width and thickness of the plates incorporated in the conventional box section are equal to those of plates used in the innovative hybrid section. Geometric specifications of all test specimens are shown in Table 1. As for specimen labeling, **S** represents **s**ingle tube, **WB** represents conventional **w**elded **b**ox and **IFC** shows the initials of **i**nnovative **f**abricated **c**olumn. The letters that come after the dash indicated the material type of the tube where **m**ild steel **t**ube, **h**igh **s**trength **t**ube and **u**ltra-**h**igh **s**trength **t**ube are represented by **MT**, **HST** and **UHST**, respectively. The number at the end of each specimen label refers to the length of column. Effective design slenderness ratios are also calculated for each column by dividing the ratio of design effective length to radius of gyration. Considering the end boundary conditions of fixed at both ends of columns a coefficient of 0.7 is applied.

2.2. Fabrication, welding and imperfections

In the proposed fabricated section, fillet weld is used to connect the plates and tubes to each other. This welding configuration is more convenient in terms of cost and performing only on the outside of column [15]. The welding wire is 2.4 mm of the category AWS A5.9 ER2209. Type of welding is gas tungsten arc welding (G.T.A.W) with a 0.2% proof stress and tensile strength equal to 560–620 MPa and 800–835 MPa, respectively. This type of arc welding leads to consistence weld thickness throughout the length of column as opposed to other welding types such as metal inert gas (MIG) welding which helps to have a more consistent behavior in the column. The rate of welding for all fabrications is in a range of 75–95 mm/min and the gas used is 99.9% argon gas. All welding methods used are in compliance with AS/NZS1554.7:2006 [32].

The existence of imperfections has a direct effect on the compressive behavior of members and provisions are made in design