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Flexural behaviour of steel hollow sections filled with concrete that contains OPBC as coarse aggregate

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ABSTRACT

Oil-palm-boiler clinker (OPBC) is an agricultural waste from the palm oil industry and is considered a serious threat to the environment. Moreover, the high consumption of concrete as a construction material results in a continuous demand for natural aggregates, thereby negatively affecting the environment. Thus, channeling OPBC waste materials into the concrete industry aids in promoting the use of a sustainable and lightweight member. This research presents a novel sustainable composite beam that uses an OPBC as a replacement of the natural coarse aggregate. Flexural behaviour of steel tubes infilled with conventional and OPBC concretes were investigated. The results showed that the ductility, flexural stiffness and structural efficiency were higher in the OPBC concrete filled steel tube (CFST) than conventional CFST by 15%, 12% and 20%, respectively. Furthermore, in comparison to conventional CFST, the 10% less self-weight in OPBC CFST will significantly reduce the construction cost of the material. Conclusively, the utilisation of OPBC as infill material for CFSTs will solve disposal problem, preserve natural resources, reduce environmental pollution and will make the structural system sustainable.

1. Introduction

Solid waste products that originate from various industries require a proper management and disposal to ensure a healthy and clean environment. The agricultural industry in Malaysia is developing rapidly and progressively to support the economy of the country. Approximately 80 million dry solid biomass wastes have been reportedly yielded in 2010 only and are still expected to reach 110 million by 2020 [1, 2]. The Malaysian palm oil industry is the second largest palm oil industry with a share of 42% of the global palm oil and with more than half a million employees [3, 4]. A substantial amount of oil palm wastes is generated, and the problem of waste overload is created whilst this industry becomes large and wide. This problem tends to burden operators with disposal difficulties and escalates the operating cost [5]. Various types of solid wastes, such as palm fibre, oil palm shell, oil-palm-boiler clinker (OPBC) and empty fruit branches, are produced at the end of palm oil processing stages. An OPBC is a waste material obtained by burning off solid wastes during the palm oil extraction [6]. Most of the OPBCs are used to cover potholes on roads within the vicinity of plantation areas, thereby affecting the environment directly [7]; this result is the reason for oil palm industries being known for their extensive negative environmental impacts in most countries [8]. Therefore, utilizing the agricultural waste in the construction industry will be a smart measure because this effort will reduce the damage caused by the agricultural industry to the environment. OPBCs are lightweight waste materials that have been successfully utilized in the past for sustainable and lightweight composite members. The OPBC concrete behaves differently from other types of lightweight concrete and can be designed for high grades and ductility [9, 10]. In the past decade, many researchers have shown that OPBC can be used as a coarse aggregate in concrete [11, 12]. In addition, using the OPBC is a smart effort for sustaining a green environment because OPBC has a low density and can be used in the construction industry to produce lightweight concrete. Hence, using the OPBC as the coarse aggregate in concrete rather than using natural aggregate can be a favourable strategy for improving the cost and sustainability of a structure.

Concrete-filled steel tubes (CFST) were used for the first time in 1870 for bridges in Great Britain. Gardner and Jacobson conducted an

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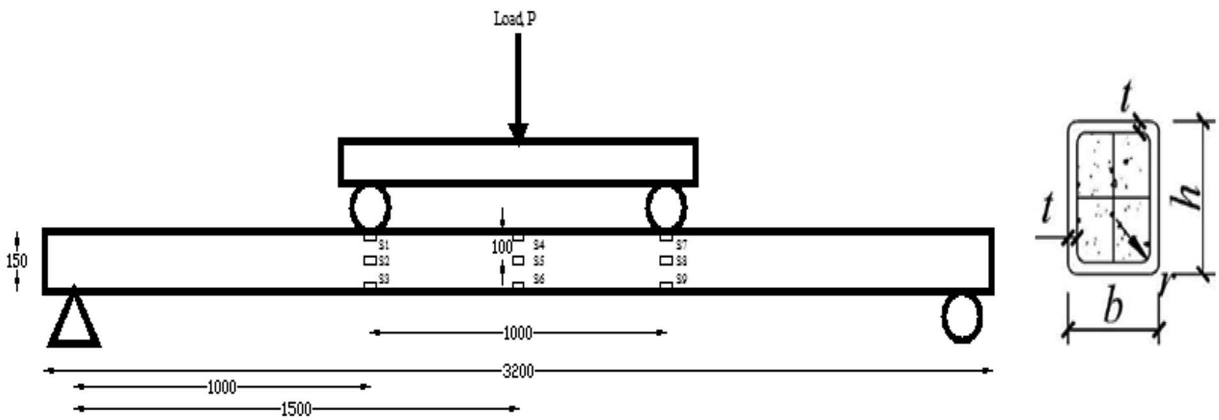

Fig. 1. Test setup and location of strain gauges (all units in mm).

early research on using the CFSTs in the late 1960's [13]. The use of CFST has increased in the last three decades, especially in high-rise buildings [14] and bridges [15], given its unique properties, such as high fire resistance and construction efficiency. Moreover, different types of CFST members have been introduced recently, including reinforced CFST [16], concrete-filled stainless steel tubes [17], concrete-filled double skin tubes [18] and stiffened CFSTs [19], to improve the structural efficiency (SE) and performance of CFSTs. All these studies have presented a primary objective of using new alloys or changing the configuration of CFST members to enhance their structural performance. Several researchers have even attempted to use different types of concrete to enhance the SE of CFSTs because most of the volume of CFST consists of concrete. For example, ultra-high-strength, recycled aggregate and lightweight aggregate concrete (as infill materials for CFSTs) have been used to improve the structural performance of CFSTs [20–24]. Moreover, it conserves the natural resources and reduces the dead load of the structure [25].

Several researchers evaluated the effect of different lightweight aggregate concretes on the behaviour of the CFST members under axial load [26–28]. However, limited literature is available on the behaviour of lightweight CFSTs that are subjected to flexural loads. Hunaiti [29] performed four tests to evaluate the behaviour of a pumice lightweight aggregate in CFSTs under the flexural load. It was found that the lightweight aggregate can be used to enhance the properties of hollow steel tubes. Nakamura et al. [30] compared the behaviour of a circular lightweight aggregate-filled concrete with normal CFST by maintaining the compressive strength of concrete constant and concluded that the bending strength of both specimens is the same. The use of OPBC in structural-reinforced composite members has also been studied in the last few years [31, 32]. However, as per authors' knowledge, no research has been conducted to evaluate the flexural behaviour of OPBC CFST (OCFST). Hence, in this research, the flexural performance of OCFST was evaluated and compared with steel tubes filled with conventional concrete (NCFST). Experimental results were used to check the applicability of analytical models available in the literature for the NCFST. The experimental results were also used to check the accuracy of different design codes for designing OCFST. Notably, the unique behaviour of an OPBC concrete (low self-weight and adequate strength) can be used in seismically active areas and for constructing sustainable and economical structures because the OPBC is a waste without any current use.

Table 1
Dimensions of the tested specimens.

Type of infilled concrete	Specimen No.	Height, h (mm)	Width, b (mm)	Thickness, t (mm)
OPBC	1	200.2	100.1	5.99
	2	200.4	100.1	6.01
	3	199.8	100.8	5.99
NMC	4	199.7	99.9	5.99
	5	200.3	100.2	6.02
	6	200.9	100.5	6.01

2. Experimental investigation

2.1. Test specimen

Six CFST beams were prepared. These CFST beams were divided into two groups, namely, specimens filled with normal mix concrete (NCFST) and specimens filled with OPBC concrete (OCFST). The compressive strength of both types of concrete was kept same to obtain a favourable comparison. The length of all specimens was maintained at 3200 mm whilst the nominal depth, width and thickness of the steel tube for all the specimens were 200 mm, 100 mm and 6 mm, respectively. The D/t ratios of the specimens were set to 33.33 to avoid the local buckling of the CFST beams. The details and dimensions of the steel tubes measured by using a Vernier calliper are displayed in Fig. 1 and Table 1, respectively.

2.1.1. Steel tube

The steel tubes in all specimens were cold formed from steel plates by press bending and seam welding. The tubes were obtained from a 12 m length of hollow rectangular steel tube. Tensile tests were performed on steel coupons obtained from the original tubes. A 0.2% proof stress was adopted for cold-formed steel tubes, as recommended in a previous study [33]. The stress–strain curves for three coupon tests are plotted in Fig. 2. The measured yield strength, ultimate strength, elastic modulus and maximum elongation were determined to be 394 MPa, 458 MPa, 201.3 GPa and 29%, respectively.

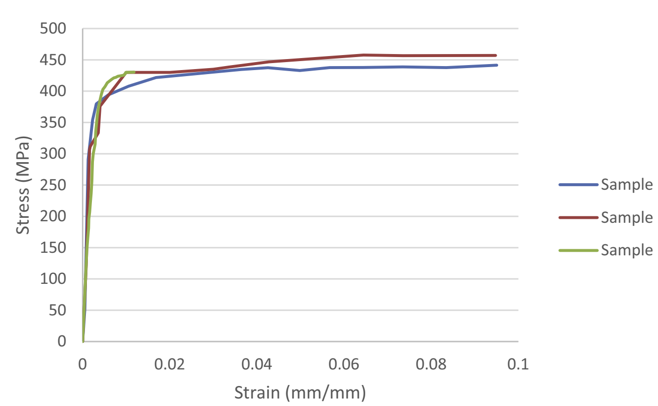

Fig. 2. Stress–strain curves for tensile coupon tests.