Rubberized concrete filled steel tube

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Abstract: One of the solution to reduce tire waste is by incorporating rubber as fine aggregate replacement, producing a rubberized concrete. This type of concrete generally has lower compressive strength, however, could potentially be used as structural application due to its inherent ductility. This study explored the application of rubberized concrete filled steel tube (RCFST) as structural member. A review of available literature has indicated the lack of experimental data for RCFST. Hence, an experimental study was conducted for circular composite columns with different thicknesses, 2.75mm, 4mm and 5mm, where each were filled with (a) normal concrete and (b) rubberized concrete with 10% fine aggregate replacement. The behaviour of RCFST was studied in terms of strength and ductility under axial compression load. From material testing, it was found that the compressive strength of rubberized concrete was approximately 30% less than that of the normal concrete. However, the axial load capacity of RCFST was only 1.4% to 6.6% less than the control samples (CFST). It was also found that the RCFST possesses some ductility and could be used for structures undergoing vibrations and seismic loads. As the overall behaviour of RCFST is comparable with the control CFST, rubberized concrete has the potential to be used as a filler material in steel tube to form composite column.

1. Introduction
The disposal of scrap tires is very difficult and poses environmental issues, hence reusing them will be a better alternative. One of the ways to reuse the tires is by incorporating crumb rubber as construction material. However, its application is limited due to its reduction in strength when added in structural member as aggregate replacement. In order to tap in the potential of the material, its application must be ensured that the reduction in strength would not affect the overall efficiency of the structure. With that, the application of the material as rubberized concrete filled steel tube (RCFST) were explored. Concrete filled steel tube (CFST) is a composite structure which consists of steel tube filled with concrete mix. Uses of composite structures are common worldwide, attributed to their superior properties in term of buckling and confinement[1], [2].

1.1 Concrete filled steel tube
CFST columns have been increasingly used especially in high-rise buildings. The infilled concrete increases the buckling load of the steel tube, while the steel provides confinement to the concrete core, improving its strength and ductility[2], [3]. The use of this composite structure reduces the labour and material costs during the construction process as the steel tube serves as permanent formwork during concrete casting[1], [2], [4], [5]. The main disadvantage of the CFST column is that the steel tube is
exposed, leading to lower fire resistance compared to concrete-encased steel columns. The different properties of components of CFST lead to different dilation and this will initiate different initial elastic stage under compression[6][2]. Contemporary with development of the steel manufacturing, engineers use thinner tubes that are made from high-strength steel rather than thicker tubes made of normal strength steel to produce the CFST column[7].

1.2 Rubberized concrete
Tire waste in the form of crumb rubber can be mixed with concrete creating a homogeneous mix called rubberized concrete[8], [9]. Incorporation of rubber in the concrete mix could improve the elastic behavior and toughness as well as decrease the brittleness of concrete[10]. However, the compressive strength and modulus of elasticity of the rubberized concrete reduces in comparison to the normal concrete[11]. Many studies showed that replacing the course aggregate with crumb rubber resulted to larger decay in compressive and flexural strengths, while replacement of 25% fine aggregate with rubber decreases the flexural strength by 4.5%[12]. Additionally, it was found that the optimum percentage of replacement of rubber aggregates can be up to 15%. Rubberized concrete could be an ideal material for energy absorption under impact or seismic loads, however, its use is not recommended in structural elements where high strength is required. The use of scrap tires in structure engineering is currently uncommon as it is attributed to decreasing in strength when mixed with concrete[13].

Limited researches on RCFT have been conducted in recent years. The cyclic behaviour of short CFST and RCFST columns. It was observed that the increase in the rubber particle content up to 15% leads to a decrease in the cyclic strength and stiffness of the columns due to the lower compressive strength[7]. It was also discovered that the circular sections exhibit better performance in terms of ductility compared to square and rectangular columns. Additionally, the rubberized concrete is recommended to be used in seismic areas, where ductility and energy dissipation are essential requirements. Experimental push-out tests have been conducted[14] on RCFST, with up to 30% of rubber as fine aggregate replacement. Similar results were obtained in terms of compressive strength, stiffness and ductility.

2. Experimental work
This research was carried out to investigate the behavior of rubberized concrete filled steel tube (RCFST) columns against axial compression load. Two different concrete mixes were considered: (i) normal concrete (NC), mix A and (ii) rubberized concrete mix by replacing 10% fine aggregate with crumb rubber, mix B.

2.1 Concrete types
Ordinary Portland Cement (OPC) was used, classified as type I according to ASTM standard. The crumb rubber in this study act as fine aggregate replacement by 10% with sizes between 1mm to 4mm. The crumb rubber was treated using NaOH solution, to improve the bond between rubber and surrounding concrete. In order to obtain the compressive strength of concrete, three standard cylinders and three cubes made for each mix were prepared, cured and tested after 28 days. Mix A is the control mix producing normal concrete, while Mix B is the rubberized concrete.

2.2 Preparation of CFST columns
The steel tube sections were of 150mm in diameter and 330mm in length (Figure 1). A square steel plate (250x250x10mm) was welded at the bottom of steel tube as its base. For each mix, three steel tubes with thicknesses of 2.75mm, 4mm and 5mm were prepared, as detailed in Table 1. The rusts inside and outside of the tubes were cleaned to ensure proper bonding between the concrete and steel. The specimens were casted and compacted accordingly. Finally, they were cured by covering the exposed surface by wet gunny sack to prevent moisture loss.
Figure 1. Dimensions of the specimens, (a) side view and (b) plan view

Table 1. Details of specimens

| Specimens | Mix | t (mm) | D (mm) | L (mm) |
|-----------|-----|--------|--------|--------|
| A-2.75    | A   | 2.75   | 150    | 330    |
| A-4       | A   | 4      |        |        |
| A-5       | A   | 5      |        |        |
| B-2.75    | B   | 2.75   |        |        |
| B-4       | B   | 4      |        |        |
| B-5       | B   | 5      |        |        |

2.3 Test procedures and instrumentations

Compression machine with the capacity of 3000kN was used to test the six specimens. The surface was grinded to ensure a uniformly distributed load throughout the whole cross-section of the specimen. The setup of the specimen is shown in Figure 2. The compressive load was applied in 60kN increment until it reaches 65% of the calculated axial load capacity. Beyond that, the incremental load was reduced to 30kN and applied until failure of the specimen.

Two linear variable differential transducers (LVDTs) were placed between the top and bottom clamping plates to measure the axial displacement of the specimens. A pair of strain gauges were placed on each tube in longitudinal and horizontal directions to measure the strain at the middle of the section.

Figure 2. Experimental setup of the compression test for specimens
3. Results and discussions

3.1 Material testing
To study the mechanical properties of the concrete mixes, three cylinders (100mm diameter and 200mm length) and three cubes (100x100mm) were prepared for each mix. The results of compressive strength and modulus of elasticity for the normal and rubberized concrete are shown in Table 2. It was observed that the replacement of 10% fine aggregate by crumb rubber reduced the compressive strength by more than 20%. Similarly, the modulus of elasticity of mix B is 30% lower compared to the control mix. The result of material testing is very similar to the findings found by other researchers[11][12].

| Mix | Rubber content (%) | $f_{cu}$ (MPa) | $f'_{c}$ (MPa) | $E_c$ (MPa) |
|-----|--------------------|----------------|----------------|--------------|
| A   | 0                  | 36             | 26             | 25           |
| B   | 10                 | 28             | 18             | 17.8         |

Tensile coupons tests were conducted to obtain the material properties of the circular steel tubes. The steel was of mild strength, with yield strength ($f_y$) of 226MPa, ultimate strength ($f_u$) of 314MPa and maximum tensile strain of 0.1.

3.2 Compression test of CFST columns
Table 3 shows the result of the maximum axial load capacity of the specimens with different mix designs and thicknesses. From the experiment, it was found that the axial load capacity is directly related to the thickness of steel tube, where the capacity increased with increasing thickness. As expected, since the compressive strength ($f'c$) of the control concrete (mix A) was higher than the rubberized concrete (mix B), the maximum axial load capacities for all CFST specimens were higher than the RCFT. However, the reduction in the maximum axial load capacities of the RCFT were only 1.4% to 6.6% of the control, whereas the reduction in $f'c$ of mix B was up to 30% of mix A.

As steel thickness increase from 2.75mm to 4mm, the axial load capacity increases by approximately 15% while when thickness increase from 4mm to 5mm, the axial load capacity increase by about 25% for both mixes. This shows that the axial strength of composite columns is governed by the steel thickness, due to the relative difference between the concrete and steel compressive strengths. In addition, the effect of confinement is found to be greater for rubberized concrete, as the axial load capacity of RCFT is comparable to the control CFST.

| Specimens | Thickness (mm) | Max load capacity (kN) |
|-----------|----------------|------------------------|
| A-2.75    | 2.75           | 1173                   |
| B-2.75    |                | 1136                   |
| A-4       | 4              | 1350                   |
| B-4       |                | 1261                   |
| A-5       | 5              | 1666                   |
| B-5       |                | 1642                   |

3.3 Vertical strain
Figure 3 compares the results of axial load versus vertical strain for the control CFST and RCFST with similar thickness. The results can be analysed in terms of axial load and vertical strain capacities, and
the stiffness of the specimens. Generally, the overall behavior of load versus vertical strain for all specimens were found to be very similar. As the thickness of the steel tube increases from 2.75mm to 5mm, the maximum vertical strain in the control CFST was found to be increasing, indicating that the specimen becomes more ductile. Similar trend was observed in the RCFST except for specimen B-4 (Figure 3(b)), possibly due to error in the strain gauge.

The maximum vertical strains in the RCFST for thickness of 2.75mm and 5mm were slightly higher than the control CFST, indicating the possibility of the slightly ductile behavior of rubberized concrete compared to normal concrete. Based on Figure 3(a), the stiffness of the specimen B-2.75 decreases beyond 400kN, however, this was not observed in specimen B-5. This implies that steel tubes with small thickness is affected more by the infilled concrete compared to those with higher thickness.

![Graphs showing load versus vertical strain for different thicknesses](image1)

**Figure 3.** Axial load versus vertical strain curves for the specimens with thicknesses of (a) 2.75mm, (b) 4mm and (c) 5mm

### 3.4 Failure mode

Figure 4 depicts the failure of tested specimens with different mixes and thicknesses. All six composite columns exhibited local buckling at the top and mid-height, and some specimens also experiences local buckling at its bottom end. Large distortion was observed in specimen B-5, where very prominent buckling can be seen both at the top and bottom ends. This shows that the rubberized concrete has some ductility and allows significant deformation before crushing.
The experimental results were also compared with the theoretical calculation for compressive strength of composite columns based on Eurocode 4 (2004), as shown in Equation (1).

\[ N_{pl,Rd} = \frac{A_a \eta_2 f_y}{\gamma_a} + \frac{A_c f_{ck}}{\gamma_c} \left[ 1 + \eta_1 \left( \frac{t}{d} \right) \frac{f_y}{f_{ck}} \right] \]  

where \( A_a \) and \( A_c \) are the cross-sectional areas of steel and concrete sections respectively, \( f_y \) is the yield strength of the steel, \( f_{ck} \) is the characteristic compressive strength of the concrete, \( \gamma_a \) and \( \gamma_c \) are the partial safety factor, taken as 1.0, \( t \) is the thickness of the section, \( d \) is the outer diameter, and \( \eta_1 \) and \( \eta_2 \) are factors taking into account the concrete enhancement and hoop stress effects. For centrally loaded stocky column, \( \eta_1 \) is taken as 4.9 and \( \eta_2 \) as 0.75. At the ultimate load capacity, the value of \( f_y \) in the first term is replaced by \( f_u \) (ultimate strength), as given in Equation (2).

\[ N_{pl,Rd} = \frac{A_a \eta_2 f_u}{\gamma_a} + \frac{A_c f_{ck}}{\gamma_c} \left[ 1 + \eta_1 \left( \frac{t}{d} \right) \frac{f_y}{f_{ck}} \right] \]  

The comparison between the experimental and theoretical axial load capacities is shown in Table 4. The theoretical axial load capacity in Eurocode 8 gives a conservative (safe) values for the control CFST, with the differences ranging from 3% to 10%. However, the theoretical ultimate load capacity for the rubberized concrete mixes were highly under-predicted especially for the thicknesses of 2.75mm and 5mm, by 6% to 20%. The possible reason is that the concrete strengths (\( f'_c \)) were less than 20MPa, falling below the range at which, the equations were developed for. However, it is also possible that the effect of confinement is different in rubberized concrete compared to the normal concrete, which is observed from the large differences observed in \( f'_c \) and ultimate axial load capacity of RCFST. A thorough study is needed to observe and quantify the possible effect of confinement for rubberized concrete for a more accurate determination of strength.
Table 4. Comparison between the ultimate load capacity from experiment and theory (EC4)

| Specimen | Exp. (kN) (a) | Theory (kN) (b) | (b)/(a) |
|----------|---------------|-----------------|---------|
| A-2.75   | 1173          | 1059            | 0.903   |
| A-4      | 1350          | 1311            | 0.971   |
| A-5      | 1666          | 1505            | 0.903   |
| B-2.75   | 1136          | 928             | 0.817   |
| B-4      | 1261          | 1185            | 0.940   |
| B-5      | 1642          | 1382            | 0.841   |

5. Conclusions
Experimental work has been conducted on six steel tubes with different thicknesses, filled with normal (CFST) and rubberized concrete (RCFST) to investigate the load capacity and ductility under compression. By replacing 10% of fine aggregate with rubber, the compressive strength ($f'_c$) and modulus of elasticity ($E_c$) of rubberized concrete was reduced by up to 30% compared to the normal concrete. However, the reduction in the maximum axial load capacities of the RCFT were only 1.4% to 6.6% of the control (CFST). This indicates that the axial strength of composite columns is governed by the steel thickness, due to the relative difference between the concrete and steel compressive strengths. In addition, the effect of confinement is found to be greater for rubberized concrete, as the axial load capacity of RCFT is comparable to the control CFST. The theoretical equation for ultimate compressive strength based on Eurocode 4 is highly underestimated for the RCFST, indicating the possible effect of confinement in rubberized concrete that is different from normal concrete.

Based on the load-vertical strain results, it was found that the general behavior of CFST and RCFST is very similar, indicating that rubberized concrete could be used to fill the steel tubes, producing composite structure. As the steel thickness increases (from 2.75mm to 5mm), the maximum vertical strain of the RCFST was found to be slightly higher than the control CFST, indicating the possibility of a more ductile behavior of rubberized concrete compared to normal concrete.

Due to the comparable behavior between CFST and RCFST, it can be concluded that rubberized concrete has the potential to be used as a filler material in steel tube to form composite column. The rubberized concrete possesses additional ductility that could be utilized for structures undergoing vibration or seismic load. However, more study should be undertaken in terms of its long-term durability before this material could be used as load bearing structural elements.

Acknowledgements
The work described in this paper was part of dissertation of “Rubberized concrete filled steel tube”, and it was funded and carried out in Universiti Putra Malaysia. The assistance of the laboratory staff is gratefully acknowledged.

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