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Experimental investigation of rubberised concrete-filled double skin square tubular columns under axial compression

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ABSTRACT

Waste tyres are among the largest and most problematic sources of waste in modern society due to their durability and high rate of dumping in landfills. One possible recycling alternative is to incorporate waste tyre rubber as an aggregate replacement in concrete to promote sustainability and utilise the elastic properties of rubber. Rubberised concrete has not reached its full potential because of the decrease in compressive strength and a lack of research to solve such challenge. Recent research suggests that combining rubberised concrete with confinement increases ductility and energy absorption. Specifically, confined rubberised concrete using single skin or double skin square hollow section tubular columns present higher ductility than those made of normal concrete. This study explored experimentally the use of rubberised concrete filled single skin and double skin steel tubes under concentric axial compression. The experimental investigation included changing the confinement of the outer and inner square hollow sections and explored how confinement affected normal concrete compared to rubberised concrete. Four variations of double skin steel tubes with a total of twelve 300 mm long columns of 0%, 15%, and 30% rubber replacement were created and tested concentrically. Three single skin short columns with 0%, 15%, and 30% rubber content were also tested and compared. The compressive strengths were determined theoretically and compared against those measured experimentally. An interesting spring back phenomenon occurred where the infill rubberised concrete moved upwards after testing due to the large confinement of the core and elasticity of the rubber. This study examined the use of rubberised concrete filled double skin steel tubular columns as a promising construction technique for applications such as columns in buildings located in seismic active zones, security bollards and flexible road side barriers.

1. Introduction

1.1. Development of rubberised concrete (RuC)

Currently, waste tyres are among the largest and most problematic sources of waste for modern society due to their durability and high rate of dumping in landfills [1]. In the USA, the total amount of tyre rubber waste is 20.53 million ton/year and as large as 87% of such amount is recycled every year [2]. In Europe, the total amount of tyre rubber waste is 28.92 million ton/year and only 69% of such amount is recycled. In Australia, 50 million tyres are wasted every year [2]. Tyre landfills can be harmful to the environment and surrounding areas by providing a breeding ground for mosquitos, rats and other animals. Additionally, if a fire started in a tyre landfill, it becomes hard to distinguish, and it gives rise to harmful smoke and noxious emissions. Accordingly, waste tyre management and disposal is a major environmental concern in many countries because waste tyres are becoming a significant environmental, health, and aesthetical problem that cannot be easily solved. A disposal alternative is to incorporate tyres into the manufacture of the so called Rubberised Concrete (RuC) as a way to conserve natural resources and reduce the amount of tyres entering landfills. RuC is a relatively new and innovative field of research aiming at providing a sustainable way of disposing tyres as well as complementing concrete properties [3,4]. For example, the partial replacements of sand and cement by rubber enhance the mechanical characteristics of concrete in terms of its fracture properties, ductility, impact and seismic resistances [5–7]. Additionally, Liu et al. [8] found that the ratio of flexural strength to compressive strength of RuC increases relative to normal concrete, indicating that the rubber was better in anti-cracking performance. Furthermore, Liu et al. [8] found that increasing the rubber volume content increases the toughness of the concrete. Hassanli et al. [9] observed that as the rubber content

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Nomenclature

A_c	cross-sectional area of the concrete
$A_{c,no\min al}$	the nominal cross-sectional area of the concrete
A_{si}	cross-sectional area of the inner steel tube
A_{sc}	the cross-sectional areas of the sandwiched concrete following Tao and Han [35]
A_{sc}	the cross-sectional areas of the outer steel tube following Tao and Han [35]
A_{so}	cross-sectional area of the outer steel tube
D	specimen width
$(EI)_e$	the effective elastic flexural stiffness of the member
f_{ck}	the characteristic concrete strength
f_{cu}	the characteristic cube strength of concrete
f_{syi}	yield stress of the inner steel tube
f_{syo}	yield stress of the outer steel tube
KL	the effective length of the member
L	specimen length
r_y	smallest radius of gyration of the cross-section
P_{cr}	the critical buckling load of the column
$P_{i,u}$	the compressive strength of the inner tube computed, Tao and Han [35]
$P_{osc,u}$	the compressive strength of the outer tube with the sandwiched concrete following Tao and Han [35]
$P_{pl,Rd}$	the plastic resistance to axial compression of the concrete-filled column
$P_{pl,Rd,Mod}$	currently modified plastic resistance to axial compression of the RuCFDST column
$P_{theoryConc}$	compressive strength of the sandwiched concrete according to Zhao and Grzebieta [18]
$P_{theorySHS}$	compressive strength of the empty hollow sections according to Zhao and Grzebieta [18]
$P_{ul,EC4}$	compressive strength of the CFDST columns with inner SHSs according to EC4 [16]
$P_{ul,EC4,Mod}$	currently modified compressive strength of the RuCFDST based on EC4 [16]
$P_{ul,Zh}$	compressive strength of the CFDST columns with inner SHSs according to Zhao and Grzebieta [18]
$P_{ul,Tao}$	compressive strength of the CFDST columns with inner SHSs according to Tao and Han [35]
$\overline{\lambda}$	the slenderness parameter of the column
σ_{yf}	the yield stress at the flat portions of the cross-sections
σ_{yc}	the yield stress at corners of the cross-sections
ζ	the confinement factor used in the calculations by Tao and Han [35]
χ	reduction factor calculated by using the European strut curves to account for the overall-buckling
ρ_s	the ratio of the cross-sectional area of the steel tube to that of the concrete core

increases, the compressive strain capacity of the members increases. Also, they found that adding rubber to concrete increases the viscous damping ratio and kinetic energy [9].

1.2. Methods used to enhance the mechanical properties of the RuC

Despite of the above mentioned advantages, the RuC are characterised by a significant reduction in its compressive, tensile and flexural strengths [3,5,10]. Experimental testing [3] showed that the lower workability of the RuC, caused by loss of adherence between the surface of rubber particles and the cement, is one reason of such lower strengths. Therefore, several investigations [11–14] were undertaken to improve the workability of the RuC, from which it has been found that the NaOH pre-treatment of rubber increases the adhesion of rubber to cement paste and hence it improves the mechanical properties of the RuC. Another important reason to the lower strengths of the RuC is the Poisson's ratio of rubber which is twice that of concrete and the Young's modulus which is about 1/3 that of concrete [10]. According to Youssf et al. [10], this leads to large relative deformations between rubber and concrete leading to early cracking. Additionally, there are high internal tensile stresses perpendicular to the direction of the compression load attributable to the low modulus of elasticity of the rubber particles [10]. This insight by Youssf et al. [10] leads to the importance of understanding confinement of rubber concrete as a way of reducing stress

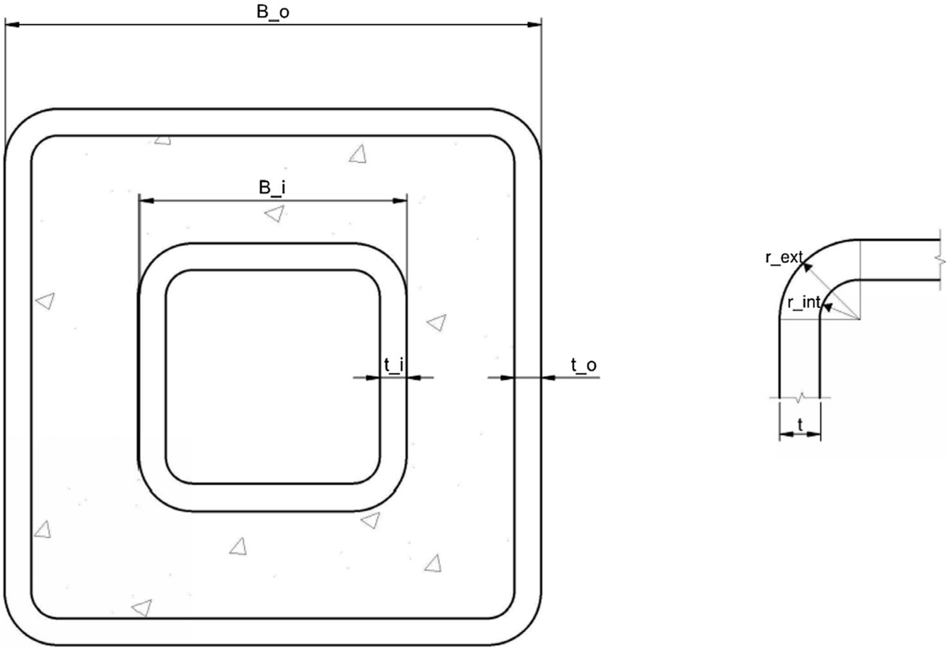

Fig. 1. Cross-section of square CFDST columns.