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Mechanical behavior of recycled aggregate concrete-filled steel tube stub columns after exposure to elevated temperatures

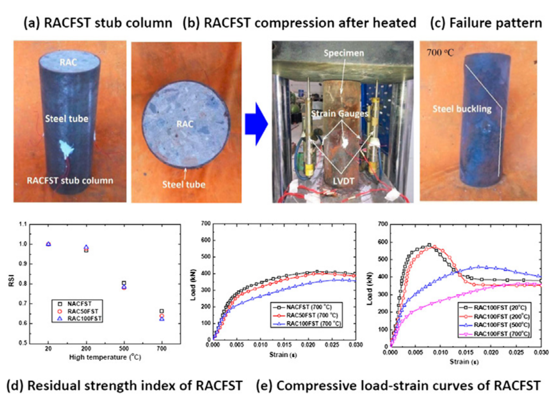
Wengui Li [a,*], Zhiyu Luo [a,b], Zhong Tao [c], Wen Hui Duan [d], Surendra P. Shah [e]

[a] *Centre for Built Infrastructure Research, School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NSW 2007, Australia*
[b] *College of Civil Engineering, Hunan University, Changsha, Hunan 410082, China*
[c] *Centre for Infrastructure Engineering, Western Sydney University, Penrith, NSW 2751, Australia*
[d] *Department of Civil Engineering, Monash University, Clayton, VIC 3800, Australia*
[e] *Center for Advanced Cement-Based Materials (ACBM), Northwestern University, Evanston, IL 60208, USA*

HIGHLIGHTS

- The heated RACFST stub columns manifested local outward folding and buckling.
- The ductility of RACFST stub columns increased with the increase in high temperature.
- The compressive strength declined dramatically heated by high temperatures of 500 °C and 700 °C.
- The elastic modulus of RACFST decreased linearly with the increase in high temperature.
- The RACFST stub columns showed higher peak strain than that of the corresponding NACFST column.

GRAPHICAL ABSTRACT



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ABSTRACT

The compressive mechanical behaviors of recycled aggregate concrete-filled steel tube (RACFST) stub columns after exposure to elevated temperatures were experimentally investigated in this study. The RACFST stub columns incorporating different recycled coarse aggregate (RCA) replacement ratios of 0, 50% and 100% were heated under elevated temperatures of 200 °C, 500 °C, and 700 °C. The results show that the compressive strength and elastic modulus of RACFST columns were relatively inferior to those of the corresponding natural aggregate concrete-filled steel tube (NACFST) columns after exposure to the same elevated temperatures, and the degradations became more pronounced with increasing RCA replacement ratio and higher temperature. This phenomenon might be attributed to the lower resistance of recycled aggregate concrete (RAC) than natural aggregate concrete (NAC) when was exposed to elevated temperatures. However, after elevated temperature exposure, the peak strain of RACFST stub column was relatively higher than that of the NACFST counterpart. Degradation regression formulas of mechanical properties and deformation behaviors of RACFST stub columns after exposure to elevated temperatures were proposed and agreed well with the experimental results.

* Corresponding author.
E-mail address: wengui.li@uts.edu.au (W. Li).

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Nomenclature

A_c	cross-sectional area of concrete, mm^2
A_s	cross-sectional area of steel, mm^2
$E_s(0)$	elastic modulus of the NACFST stub column, N/mm^2
$E_s(r)$	elastic modulus of RACFST stub column with different RCA replacement ratio, N/mm^2
$E_s(20)$	elastic modulus of specimens at room temperature of 20 °C, N/mm^2
$E_s(T)$	elastic modulus of specimens after exposed to temperature T, N/mm^2
f_y	yield strength of steel, N/mm^2
f_{ck}	characteristic concrete compressive strength (0.67 f_{cu} for normal strength of concrete, N/mm^2
K_e	residual elastic modulus ratio
$K_{e,c}$	calculated residual elastic modulus ratio
$K_{e,e}$	experimental residual elastic modulus ratio
$RCAK_e$	RCA elastic modulus ratio
$RCAK_\varepsilon$	RCA residual peak strain ratio
K_ε	residual peak strain ratio
$K_{\varepsilon r,c}$	calculated residual peak strain ratio
$K_{\varepsilon,e}$	experimental residual elastic modulus ratio
$N_u(0)$	load capacity of NACFST, kN
$N_u(r)$	load capacity of RACFST stub column with different RCA replacement ratio r, kN
$N_u(20)$	compressive strength of NACFST stub column at room temperatures of 20 °C, kN
$N_u(T)$	strength of NACFST stub column after exposed to high temperature T, kN
RCARSI	RCA residual strength index
RSI	residual strength index
RSI_c	calculated residual strength index
RSI_{rc}	calculated residual strength index by modified formula
RSI_e	experiment residual strength index
T	high temperature, °C
r	RCA replacement ratio
$\varepsilon(0)$	peak strain of the NACFST stub column
$\varepsilon(r)$	peak strain of RACFST stub column with RCA replacement ratio r
$\varepsilon(20)$	peak strain of RACFST at room temperature of 20 °C
$\varepsilon(T)$	peak strain of RACFST after exposed to high temperature T
ξ	confinement factor

1. Introduction

After demolition of old concrete buildings and the occurrence of natural disasters like earthquakes and hurricanes, much solid waste concrete is generated, usually associated with serious environmental problems. Reprocessing the waste concrete into recycled aggregates is an ideal way of solving the environmental problem and can also conserve natural aggregate resources. However, the promotion of recycled aggregate concrete (RAC) is restricted by its relatively poorer mechanical properties than those of natural aggregate concrete (NAC) [1,2]. To promote the usage of recycled coarse aggregate (RCA) and improve the mechanical strength and stiffness of RAC, Konno et al. [3] recommended confining RAC within steel tubes. Then the concept of rAC-filled steel tubes (RACFST) was developed by subsequent researchers.

The mechanical performances of RACFST have been explored in several studies [4,5]. Results have showed that, due to the confinement effect of steel tube, compared with corresponding plain RAC, the axial compressive strength and deformation of the RACFST were significantly improved. Studies of uniaxial mechanical behavior, creep, and flexural strength have indicated that the performance of RACFST is inferior to that of the corresponding NAC-filled steel tubular (NACFST) columns [6–9], but RACFST exhibits a really efficient way of reducing the adverse impact on the natural environment caused by the defects of RCA, and it is feasible and safe to use RACFST columns in structural engineering applications. Up to now, few studies have investigated the mechanical behaviors of RACFST columns after exposure to fire or elevated temperatures.

Fire is a frequently occurring disaster, and is one of the most serious threats to buildings. Understanding the fire resistance of RACFST is essential for its safe usage in building structures. Studies of the fire resistance of NACFST columns have been conducted by many researchers. For example, Han et al. [10,11] investigated the compressive and flexural behavior of NAC-filled steel tubes after exposure to iSO-834 standard fire [12]. Abbas et al. [13] experimentally studied the effect of cooling regimes on performance of fire damaged NACFST columns. Jiang et al. [14] explored the mechanical behavior of post-fire NACFST column subjected to biaxial force and bending. Dinh et al. [15] proposed a finite element analysis model for studying the effects of steel type and cross-section shape on the fire resistance of NACFST columns. Using a three-dimensional finite element model, Yao et al. [16] analyzed the performance of fire-exposed NACFST stub columns under different heating conditions. Moreover, some design standards exist to guide practical design for the fire resistance of NACFST columns [17,18]. However, limited studies on the fire resistance of RACFST columns have been reported. Only Yang et al. [19] investigated the mechanical behavior of RACFSTs after exposure to elevated temperatures of 300 °C, 600 °C and 800 °C. Formulas evaluating the strength ratio and elastic modulus ratio for NACFSTs were used for RACFST specimens. It is concluded that the predictions of residual strength and residual elastic modulus of RACFST from these formulas used for fire-damaged NACFST columns before are lower than experimental results. In contrast to the extensive research into NACFST columns, the limited existing research is insufficient to reflect the fire resistance of RACFST columns. Furthermore, more accurate formulas are needed and higher temperature ranges should be adopted.

In this study, the compressive mechanical behaviors of RACFST stub columns were investigated after exposure to high temperatures of 200 °C, 500 °C and 700 °C. The effect of RCA replacement ratios of 0, 50%, and 100% on the mechanical behaviors of the RACFST stub columns after exposure to elevated temperatures was also analyzed. Degradation regression formulas are proposed for the mechanical behaviors of RACFST stub columns including compressive strength, elastic modulus, and peak strain after exposure to elevated temperatures. The values calculated by the modified formulas agreed well with the experimental results. The associated findings can provide useful insights into the assessment and retrofitting of fire-damaged RACFST structures. The experimental work also can provide a very good basis for conducting future theoretical analysis on the post-fire behavior of RACFST columns.