Study on concrete using waste materials by partial replacement of aggregates to reduce global warming gases

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Abstract

The climate change due to global warming is one of the greatest environmental issues we face now. The green house gases including CO_2 are released during cement and steel manufacturing process. In order to reduce the amount of green house gases, an attempt has been made to reuse the waste materials along with concrete in construction industries. In recent years, attempts have been made to increase the utilization of fly ash, quarry dust, granite and construction and demolition debris to partially replace the use of fine aggregate and coarse aggregate in concrete are gathering momentum. This paper presents information on fly ash, granite and quarry dust based concrete, material and the mixture proportions, the manufacturing process, and the influence of various parameters on the properties of fresh and hardened concrete with plain concrete and partial replacement of fine aggregate by fly-ash and quarry dust and coarse aggregate by granite and C & D debris concrete. The column specimens were tested under axial compression to investigate the effects of waste materials. Since the materials used were locally available waste materials, a detailed characterization was planned. In this paper, an attempt was made to utilize the waste materials by effectively recycling and filling in steel tubular circular columns with recycled aggregate concrete instead of conventional concrete. An empirical equation for calculating the design load carrying capacity of the composite column was developed using the experimental results. The test results were compared with the international codes and new theoretical models were suggested for the design. In this paper, experimental and analytical investigations were carried out to study the strength and behaviour of CFST columns over the entire range of loading. The ultimate loads and behaviour of CFST were compared with those of the hollow steel tube columns. From these elaborative experimental and analytical investigations that were done, it is concluded that out of all the waste materials used, the contribution of C & D debris and quarry dust are significant. The remaining materials that include fly-ash and granite are reasonably contributed in the performance enhancement under axial loading conditions. Finally, it is concluded that materials recovered from various waste stream are suitable to be used as secondary aggregates in concrete. The advantage of using such waste materials provides generally a low cost construction than using virgin aggregates and the elimination of the need for waste disposal in landfills. Utilization of these waste materials in concrete leads to an effective solid waste management technique and will also be cost effective. The exploitation of available natural resources and raw materials required for the construction industries can also be reduced which in turn reduces the release of green house gases which causes global warming.

Keywords: Fly-ash, recycled aggregate concrete, granite, waste management, global warming.

Introduction

Steel members have the advantages of high tensile strength and ductility, while concrete members have the advantages of high compressive strength and stiffness. Composite members combine steel and concrete, resulting in a member that has the beneficial qualities of both materials. The two main types of composite column are the steel-reinforcement concrete column (Fig. 1), which consists of a steel section encased in reinforced or unreinforced concrete, and the concrete-filled steel tubular (CFST) columns (Fig. 2), which consists of a steel tube filled with concrete. CFST columns have many advantages over steel-reinforcement concrete columns. Although CFST columns are suitable for all tall buildings in high seismic regions, their use has been limited due to a lack of information about the true strength and the inelastic behaviour of CFST members. Due to the traditional separation between structural steel and reinforced concrete design, the procedure for the designing CFST column using the American concrete institute's (ACI) code is quite different from the Load and resistance factor design (LRFD) method suggested by the American institute of steel construction's (AISC).

Notation

D-outside diameter of column
t-wall thickness of steel tube
N_{EC4}- ultimate axial load of composite column
$N_{ACI/AS}$- ultimate squash load
As-area of steel tube
Ac-area of concrete
f_{cc}-characteristics cube compressive strength of concrete
f_{cy}-cylinder compressive strength of concrete (0.8 times of f_{cc})
η_1-co-efficient of confinement for concrete
η_2-co-efficient of confinement for steel

Past research: Experimental research on CFST columns has been ongoing worldwide for many decades, with significant contribution having been made particularly by researchers in Australia, Europe and Asia. The vast majority of these experiments have been on moderate scale specimens (less than 200 mm in dia.) using normal and high-strength concrete. Neogi *et al.* (1969) investigated numerically the elasto-plastic behaviour of pin-ended, CFST columns loaded either concentrically or eccentrically about one axis. It was assumed complete interaction between the steel and concrete, triaxial and biaxial effects were not considered. Eighteen eccentric loaded columns were tested, in order to compare the experimental results with the numerical solutions. The conclusions were that there was a good agreement between the experimental and theoretical behaviour of columns with L/D ratios greater than 15, inferred that triaxial effects were small for such columns. Where for columns with smaller L/D ratios, it showed some gain in strength due to triaxial effect. A series of tests had been carried out by (O'Shea & Bridge, 1996) on the behaviour of circular thin-walled steel tubes. The tubes had diameter to thickness D/t ranging between 55 and 200. The tests included; bare steel tubes, tubes with un-bonded concrete with only the steel section loaded, tubes with concrete in filled with the steel and concrete loaded simultaneously and tubes with the concrete infill loaded alone. The test strengths were compared to strength models in design standards and specification. The results from the tests showed that the concrete infill for the thin-walled circular steel tubes has little effects on the local buckling strength of the steel tubes.

Kilpatrick *et al.* (1997) examined the applicability of the Eurocode 4 for design of CFSTs which use high-strength concrete and compare 146 columns from six different investigations with EC4. The concrete strength of columns ranged from 23 to 103 MPa. The mean ratio of measured/predicted column strength was 1.10 with a standard deviation of 0.13. The EC4 safely predicted the failure load in 73% of the column analyzed. Brauns (1998) stated that the effect of confinement exists at high stress level when structural steel acts in tension and concrete in compression and that the ultimate limit state material strength was not attained for all parts simultaneously. In his study, the basis of constitutive relationships for material components, the stress state in composite columns was determined taking into account the dependence of the modulus of elasticity and Poisson's ratio on the stress level in concrete.

O'Shea and Bridge (2000) tried to estimate the strength of CFSTs under different loading condition with small eccentricities. All the specimens were short with a length-to-diameter ratio of 3.5 and a diameter thickness ratio between 60 and 220. The internal concrete had a compressive strength of 50, 80 and 120 MPa. From those experiments O'Shea and Bridge concluded that the degree of confinement offered by a thin-walled circular steel tube to the internal concrete is dependent upon the loading condition. The greatest concrete confinement occurs for axially loaded thin-walled steel with only the concrete loaded and the steel tube used as pure circumferential restraints. EC4 has been shown to provide the best method for estimating the strength of circular CFSTs with the concrete and steel loaded simultaneously. For axially loaded thin-walled steel tubes, local buckling of the steel tube does not occur if there is sufficient bond between the steel and concrete. For concrete strength up to 80 MPa, EC4 can be used with no reduction for local buckling. For concrete strength in excess 80 MPa, EC4 can still be used but with no enhancement of the internal concrete confinement and no reduction in the steel strength from local buckling and biaxial effects from confinement. Thin-walled circular axial compression and moment can be designed using the EC4 with no reduction for local buckling.

Fig. 1. Concrete encased composite columns.

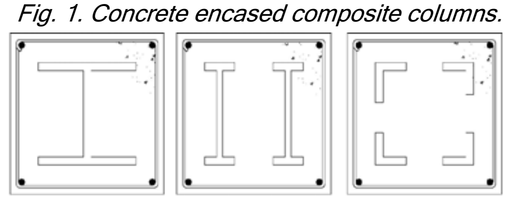
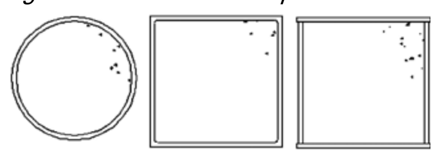


Fig. 2. Concrete filled composite columns.



Experiments

A total of eighteen specimens of circular (designated C) sections were tested for this study. All specimens were tested with strength of concrete as 20 MPa and a D/t ratio 23.78. The columns were 76.1 mm in diameter and 300, 600 and 900 mm in length. The column specimens were classified into six different groups. Each group consists of six specimens filled with plain concrete (designated P), partial replacement of fine aggregate by 10% fly-ash (designated FA) and 40% quarry dust (designated QD) and coarse aggregates by 25% granite (designated G) and 25% construction and demolition debris (designated CD). The rest of the column specimens were tested as hollow sections for comparison (designated H). All the specimen properties are given in Table 1. All the specimens were fabricated from circular hollow steel tube and filled with five types of concrete. The average values of yield strength and ultimate tensile strength for the steel tube were found to be 260 and 320 MPa respectively. In the present experimental work, the parameters of the test specimens are the size of specimen, strength of concrete and L/D ratio of columns. In order to prevent

Table 1. Specimen properties.

Reference Columns	Outer Dia D (mm)	Thickness t (mm)	D/t	Length L (mm)	L/D	Steel Strength f_y (Mpa)	Concrete cube strength f_{cu} (Mpa)
C1-H	76.1	3.2	23.78	300	3.94	260	NA
C2-P	76.1	3.2	23.78	300	3.94	260	25.03
C3-FA	76.1	3.2	23.78	300	3.94	260	22.75
C4-QD	76.1	3.2	23.78	300	3.94	260	24.47
C5-G	76.1	3.2	23.78	300	3.94	260	23.26
C6-CD	76.1	3.2	23.78	300	3.94	260	28.14
C7-H	76.1	3.2	23.78	600	7.88	260	NA
C8-P	76.1	3.2	23.78	600	7.88	260	25.03
C9-FA	76.1	3.2	23.78	600	7.88	260	22.75
C10-QD	76.1	3.2	23.78	600	7.88	260	24.47
C11-G	76.1	3.2	23.78	600	7.88	260	23.26
C12-CD	76.1	3.2	23.78	600	7.88	260	28.14
C13-H	76.1	3.2	23.78	900	11.8	260	NA
C14-P	76.1	3.2	23.78	900	11.8	260	25.03
C15-FA	76.1	3.2	23.78	900	11.8	260	22.75
C16-QD	76.1	3.2	23.78	900	11.8	260	24.47
C17-G	76.1	3.2	23.78	900	11.8	260	23.26
C18-CD	76.1	3.2	23.78	900	11.8	260	28.14

Table 2. Concrete properties.

Type of Concrete	f_{ck} (MPa)*	f_{cr} (MPa)*	f_{ct} (MPa)*
Conventional concrete	25.03	3.06	2.26
Partial replacement of fine aggregate by fly-ash 10 %	22.75	3.19	2.44
Partial replacement of fine aggregate by quarry dust 40 %	24.47	3.50	2.53
Partial replacement of coarse aggregate by granite 25 %	23.76	3.07	2.35
Partial replacement of coarse aggregate by C&D debris 25%	28.14	3.17	2.82

* average of three cubes, prisms and cylinders respectively

Table 3. Comparison of load carrying capacity with existing.

Ref. Columns	N_{test} (kN)	N_{Ec4} (kN)	$N_{ACI/AS}$ (kN)	N_{test}/N_{Ec4}	$N_{test}/N_{ACI/AS}$	Modified $N_{ACI/AS}$ (kN)	N_{test}/Modified $N_{ACI/AS}$
C1-H	258.50	NA	NA	NA	NA	NA	NA
C2-P	417.30	342.10	255.48	1.219	1.633	289.87	1.438
C3-FA	316.50	335.78	249.57	0.943	1.268	280.82	1.128
C4-QD	438.50	340.39	254.04	1.288	1.726	287.65	1.526
C5-G	330.50	337.34	250.90	0.979	1.317	282.85	1.170
C6-CD	402.85	350.53	263.56	1.149	1.528	302.21	1.331
C7-H	248.60	NA	NA	NA	NA	NA	NA
C8-P	361.50	287.59	255.48	1.257	1.415	289.87	1.245
C9-FA	294.35	281.29	249.57	1.046	1.181	280.82	1.050
C10-QD	387.45	285.91	254.04	1.355	1.523	287.65	1.348
C11-G	301.90	282.70	250.90	1.068	1.203	282.85	1.067
C12-CD	392.60	295.67	263.56	1.328	1.499	302.21	1.298
C13-H	189.10	NA	NA	NA	NA	NA	NA
C14-P	284.65	266.73	255.48	1.067	1.113	289.87	0.979
C15-FA	260.35	259.76	249.57	1.002	1.040	280.82	0.928
C16-QD	301.40	265.02	254.04	1.137	1.185	287.65	1.048
C17-G	280.55	261.32	250.90	1.074	1.116	282.85	0.993
C18-CD	315.50	276.23	263.56	1.143	1.197	302.21	1.043

Table 4. Values of k for different L/D ratio.

L/D ratio	4	5	6	7	8	9	10	11	12
k factor	1.50	1.45	1.40	1.35	1.30	1.25	1.20	1.15	1.10

Table 5. Comparison of test results with proposed equation.

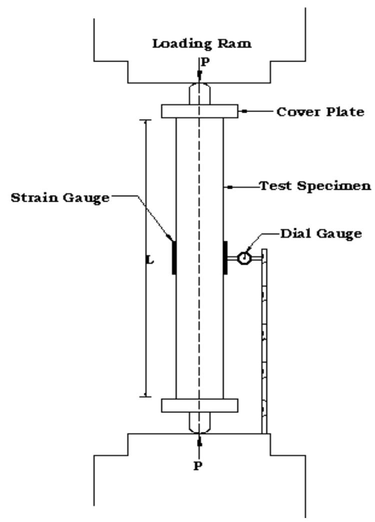
Outer Dia	Thick	L/D	Test result	ACI/AS	Proposed eqn. (1)
75 mm	3 mm	12.0	264.4 kN	240.07 kN	264.08 kN
114 mm	4 mm	7.15	588.8 kN	427.92 kN	577.65 kN
90 mm	4 mm	3.89	599.2 kN	370.86 kN	556.30 kN

the steel hollow column section from local buckling, ACI required the width-to-thickness (B/t) ratio of the steel hollow section not greater than the following limit: for 76.1 mm dia the B/t is 23.78 < $\sqrt{(3Es/f_y)}$ = 48.04. The concrete mix was obtained using the following dosages: 3.75 kN/m^3 of Portland cement, 5.23 kN/m^3 of sand, 11.62 kN/m^3 of coarse aggregate with maximum size 12 mm, and 0.192 m^3 of water. Fly-ash (waste from Mettur Thermal plant), quarry dust (waste from crusher), granite (waste pieces from granite industries) and C&D debris (construction & demolition debris) by weight basis are taken. In order to characterize the mechanical behaviour of concrete, three cubic, three prismatic and three cylindrical specimens were prepared from each concrete and tested. The mean values of the strength related properties of concrete at an age of 28 days are summarized in Table 2.

Test setup and procedure

All the tests were carried out in an Electronic UTM of a capacity 1000 kN. The columns were hinged at both ends and axial compressive load applied as shown in Fig. 3. A pre-load of about 5 kN was applied to hold the specimen upright. Dial gauges were used to measure the lateral and longitudinal deformations of the columns. The load was applied in small increments of 20 kN. At each load increment, the deflection at centre was recorded. All specimens were loaded up to failure.

Fig. 3. Test set up of concrete filled steel tubular column in UTM.



Comparison with Eurocode 4 (EC4), ACI 318-95 (ACI) and Australian standards AS 3600 & AS 4100 (AS)

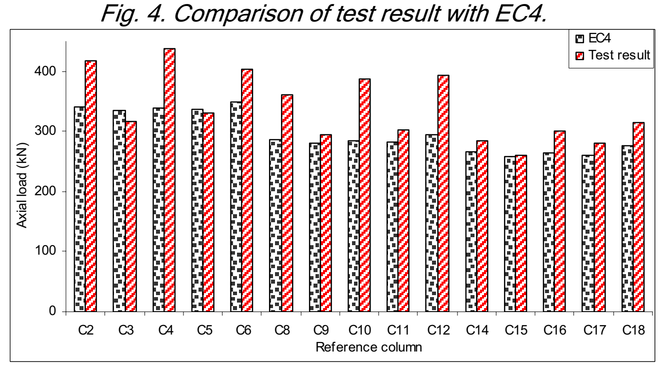
EC4 is the most recently completed international standard in composite construction. EC4 covers concrete-encased and partially encased steel sections and concrete-filled sections with or without reinforcement. EC4 uses limit state concepts to achieve the aims of serviceability and safety by applying partial safety factor to load and material properties. EC4 is the only code that treats the effects of long-term loading separately. The ultimate axial force of a column is $N_{EC4} = A_s f_y \eta_2 + A_c f_{cc} (1+ \eta_1 (t f_y / D f_{cy}))$. The ACI and AS use the same formula for calculating the squash load. Neither code takes into consideration the concrete confinement. The limiting thickness of steel tube to prevent local buckling is based on achieving yield stress in a hollow steel tube under monotonic axial loading which is not a necessary requirement for an in-filled composite column.

The squash load is determined by $N_{ACI/AS} = 0.85 A_c f_{cc} + A_s f_y$. Detailed comparisons of load carrying capacity of composite columns are presented in Table 3. For the first set of specimens having small L/D ratio (3.94) is the increase in value of N_{test} ranges from 22 to 70%. Where as in the case of second set of specimens with L/D ratio of 7.88 the N_{test} values increases ranges from 18 to 58% and the third set of specimens with large L/D ratio (11.8) the N_{test} values increases ranges from 37 to 67%. Hence the strength of infill concrete and L/D ratio influences the critical load carrying capacity. The N_{EC4}, and N_{test} loads of various infill concrete materials is presented in Fig 4. It is observed that the EC4 equation provides a good prediction of load carrying capacity of concrete filled composite column. But a comparison with ACI/AS codal equation shows that the equation under estimates the critical load carrying capacity of columns varying up to 4 to 72%. This observation were also made by researchers (Giakoumelis & Lam, 2004) hence they proposed a modified equation as $N_{ACI/AS} = 1.3 A_c f_{cc} + A_s f_y$. Fig. 5 shows the comparison of test results with ACI/AS and the modified ACI/AS equation.

Test results and discussions

The tests were conducted on 18 specimens with different L/D ratio of 3.94 ≈ 4.0, 7.88 ≈ 8.0 & 11.8 ≈ 12.0 and also with infilling of plain concrete and partial replacement of fine aggregate by flyash & quarry dust and coarse aggregate by granite and C&D debris. The test results were given in fig. 4 & 5. Fig. 4 & 5 compares the relationship between compressive strength of concrete to strength of column predicted by EC4, ACI/AS, modified ACI/AS and experimental test results. From the Fig. 4 and Table 3 it was observed that EC4 and ACI/AS under estimate the strength of column but modified ACI/AS is well correlating with experimental results (L/D=12) and hence $N_{ACI/AS} = 1.3 A_c f_{cc} + A_s f_y$ is applicable for steel tubular section in-filled with concrete. Also, it was noticed that all the codal provisions under estimating the strength of column about 5-40%. It is found that, when L/D ratio reduces, the predicted strength also reduces.

Fig. 4. Comparison of test result with EC4.



In EC4 code, the difference between predicted and actual strength is 5-25% only because the slenderness effect has been considered. But in ACI/AS, the difference is upto 40% because there is no consideration for slenderness effect or L/D ratio. Hence this equation may be hold good for L/D > 12 some factor should be multiplied with the existing ACI/As equation to predict the exact strength.

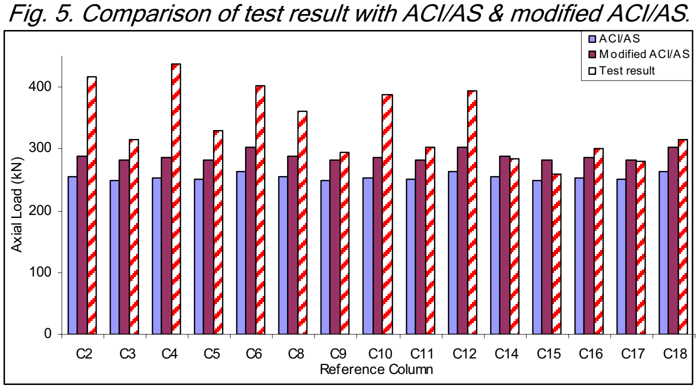
In this study, from experimental results, a factor **k** is suggested for different L/D ratios and the values of **k** are tabulated below in Table 4. Now the equation is slightly modified by multiplying a factor **'k'**.

The proposed equation for short column is

$N_{ACI/AS} = \mathbf{k}\,[0.85\, A_c\, f_{cc} + A_s\, f_y]$ ------- (1)

To evaluate the proposed equation three columns of different dimensions have been tested and compared with predicted results and the results are tabulated (Table 5). From Table 5 it was found that proposed equation gives almost same strength obtained by experimental result.

Fig. 5. Comparison of test result with ACI/AS & modified ACI/AS.



Conclusions

The results obtained from the tests on composite columns presented in this paper allow the following conclusions to be drawn.

- ❖ The predicted axial strengths using EC4 were maximum of 26% lower than the results obtained from experiments (C10).
- ❖ The predicted axial strengths using ACI/AS were maximum of 42% lower than the results obtained from experiments (C4).
- ❖ ACI/AS equation gives better results for long columns of L/D > 12.
- ❖ For L/D < 12, modified equation is proposed with the multiplying factor **'k'**.
- ❖ **k** values are suggested for different L/D ratio varying from 4 to 12.
- ❖ The strength of steel tubular columns in-filled with concrete is about 150 to 162 % of hollow columns.
- ❖ The strength of CFSTs with partial replacement of fine and coarse aggregate by waste materials is almost same as that of plain concrete.
- ❖ The strength of partial replacement of quarry dust as fine aggregate and C&D debris as coarse aggregate in CFST columns is more than that of plain concrete.
- ❖ Excellent prediction was achieved for C9, C11, C14 - C18 CFST columns, with N_{test}/modified $N_{ACI/AS}$ ratio around unity.

From the above conclusions, it is evident that the waste materials like flyash, quarry dust, C&D debris can be used in construction which reduces the use of virgin materials. This in turn helps in reducing the releasing of green house gases due to man made activities. This may possibly helps us to reduce the global warming to a considerable extent.

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