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Axial Compression Performance of Reinforced Concrete Columns with glass aggregate

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ملخص البحث

يهدف البحث لأستنتاج تصرف الأعمده الخرسانيه تحت تأثير الأحمال المركزيه عند أستبدال جزء من الركام الكبير (السن) أو الصغير (الرمل) مع الزجاج المعادتدويره من كسر ألواح الزجاج.تم أختبار عدد سبعة أعمده, العينه الأولي تستخدم كمرجع وتم صنعها كلية بأستخدام ركام طبيعي, ثلاث عينات تم استبدال الركام الكبير(السن) بنسب (10,20,30%) بركام ذو تدرج كبير من الزجاج, ثم ثلاث عينات تم استبدال الركام الصغير(الرمل) بنسب (10,20,30%) بركام ذو تدرج كالرمل من الزجاج. نتائج البحث أشارت الي تحسن في المقاومه والممطوليه والصلابه للأعمده التي تم استبدال الركام الكبير(السن) بنسب (10,20,30%) بركام ذو تدرج كبير من الزجاج بينما عند تم استبدال الركام الصغير(الرمل) بنسب (10%, 30) بركام ذو تدرج كالرمل من الزجاج تلاحظ حدوث نقص في المقاومه والصلابه والممطوليه فيما عدا العينه التي تم استبدال نسبة 20% فقد زادت المقاومه بنسبة 25% عن العينه المرجع.

ABSTRACT

The aim of this paper is to investigate the behavior of reinforced concrete (RC) columns under concentric loads when replacing natural aggregates with waste glass aggregates. Seven reinforced concrete columns were performed in this research the first one made totally with natural aggregates as reference specimen, the others made with different replacement percentages of coarse and fine glass aggregate. The percentage replaced with coarse glass aggregate was (10, 20, and 30%) of natural coarse aggregate; the percentage replaced with waste fine glass aggregate was (10, 20, and 30%) of natural fine aggregate. The results of the research show improvement in strength, stiffness, and ductility by replacing natural coarse aggregate with coarse glass aggregate. While replacing natural fine aggregates with fine glass aggregate shows decrease in stiffness and ductility, there was no improvement in strength except when replace by 20% the strength increase by 25%.

Keywords: axial compression; reinforced concrete; glass aggregate; ductility ratio; strength.

INTRODUCTION

In recent years, the use of recycled aggregate has steadily increased in structural researches, especially recycled concrete used as coarse and fine aggregates; there are also a lot of researches on behavior of concrete using waste glass as coarse and fine aggregates. It was found that increasing the incorporation of glass aggregates in concrete leads to a loss of compressive strength (CS) at the same age, but its value still increases over time, as in conventional concrete. Chen et al. [18] and Wang [6] replaced fine natural aggregates (FNA) with fine glass aggregates (FGA) from liquid crystal display (LCDs) and although the CS decreased, within each mixture it increased over time. Sepra et al. [25] replaced fine and coarse natural aggregates with fine and coarse glass aggregates up to 20% replacement ratio; they found that compressive strength was more affected by fine aggregates than by coarse aggregates. This effect can be minimized by using super plasticizers to keep both the workability and the w/c constant in all mixture. However, Limba-chiya [21] demonstrated that for replacement ratios up to 20%, the CS does not change significantly, but it does for higher ratios for bigger aggregates. Park et al. [24] also showed that increasing the replacement of natural aggregates (NA) by glass aggregates (GA) decreases the CS, but there is no linear correlation between CS and GA content. Alhumoud et al. [22] obtained a continuous decrease of CS as the incorporation of CGA increased, but for a 10% ratio, the CS was higher than that of the reference concrete (RC). When replacing coarse aggregates (CA) and fine aggregates (FA) simultaneously, Kou and Poon [19] showed that the CS fell with the ratio of replacement of NA by GA, but it increased with age for each mixture. Alhumoud et al. [22] showed that the replacement of CA led to better results than that of FA, and that the CA + FA option yielded the worst results in terms of CS, except for the 50% replacement ratio, where the FA gave better results than the CA. Park et al.24 suggested that the decrease of CS for greater incorporation ratios of FGA could be due to a loss of adhesion between cement paste and aggregate.

Still very few researches done in structural elements made with concrete containing coarse and fine aggregates, there is some researchers studied shear and flexural of beams[2,3] . But till now no research study column with glass aggregates.

EXPERIMENTAL PROGRAM

Natural sand and crushed stone (NA) had a nominal maximum size of 10 mm. Ordinary Portland Cement (OPC) and tap drinking water were used in this work. The waste glass aggregates (GA) came from Egyptian used glass that produce plates. This glass was collected, screened, washed, and crushed to standard size ranges all of which were used in this research. The w/c ratio was 0.57 and kept constant for all mixtures. In accordance with E.C.P Egyptian Code of Practice for Reinforced Concrete Construction [15] a reference concrete (RC) was produced with a target CS. The mixtures volumetric proportions are given in Table 1. The experimental work was done in reinforced concrete laboratory at Housing Building National Research Center.

Table 1: MIX DESIGEN PROPORTIONS

	Glass Replacement Volume %						
	Coarse Glass				Fine Glass		
	0%	10%	20%	30%	10%	20%	30%
Water (liter)	200	200	200	200	200	200	200
Cement (kg\m^3)	350	350	350	350	350	350	350
Natural Coarse Aggregate	106	956	850	743	1068	1068	1068
Natural Fine Aggregate (kg\m^3)	712	712	712	712	641	570	498
Coarse Glass Aggregate (kg\m^3)	0.00	112	218	324	0.00	0.00	0.00
Fine Glass Aggregate (kg\m^3)	0.00	0.00	0.00	0.00	71	142	214

The GA was incorporated in concrete as replacement by volume of NA, according to their size (that is, keeping the grading distribution constant in all mixtures. The replacement ratios were determined as a function of the overall volume of fine and coarse aggregates. In terms of glass particle sizes, in some mixtures, only coarse glass aggregate (CGA) in percentage 10, 20, and 30% as in Fig. 1, in others only fine glass aggregates (FGA) in percentage 10,20,30%were used as in Fig. 2.

PREPARATION OF TEST SPECIMENS

The mixer was prepared and pre wetted and the coarse aggregates, fine aggregates, half the water, the cement, and the rest of the water were added, in that order. For compressive strength tests six cubes are prepared and tested on the 28th day, the size of the cubes are 150*150*150 mm.

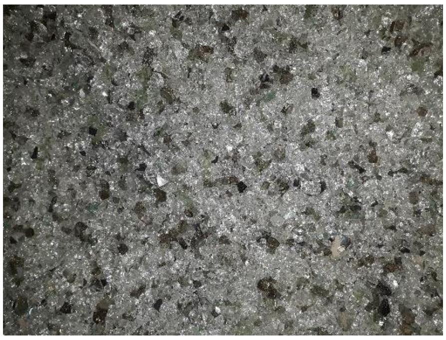


Figure 1. Coarse Glass Aggregates Sample.

Figure 2. Fine Glass Aggregates Sample

DESCRIPTION OF COLUMN SPECIMEN

The experimental investigation was conducted on seven columns divided into two groups first group represent specimens with coarse glass aggregate, the second group includes specimens with fine glass aggregate, The control column with natural aggregate. Classification of column specimens is shown in Table (2).

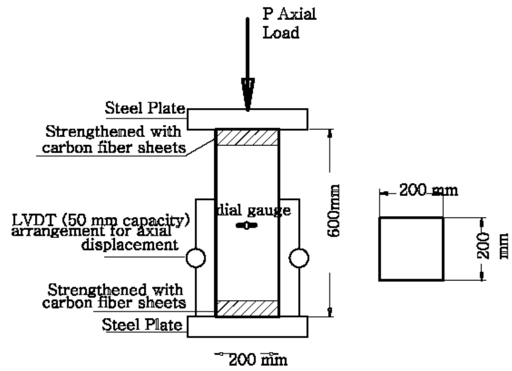
Table 2: CLASSIFICATION OF COLUMN SPECIEMENS

Column ID	**Control**	**Group1**			**Group 2**		
	CR	CC10	CC20	CC30	CF10	CF20	CF30
Aggregates replaced (%)	0	10	20	30	10	20	30
Fine aggregates replaced (%)	0	0	0	0	10	20	30
Coarse aggregates replaced (%)	0	10	20	30	0	0	0

All columns had a square section with a side length 200 mm; the total height of the column was 600 mm as shown in Fig. 3. The actual ultimate concrete strength, f_{cu} was 22.5 MPa· 4 Deformed high-grade steel bars 12 mm diameter with yield strength 360 MPa. were used as longitudinal reinforcement. The Stirrups were 8 mm diameter every 50 mm and made of plain bars with yield strength of 240 MPa. Steel bars were tested and comply with Egyptian Standard Specifications. The details of reinforcement for all column specimens are shown in Fig. 4. The upper and lower stub regions of columns had additional transverse reinforcement and were then strengthened with carbon fiber sheets prior to testing to prevent failure in these regions, as shown in Fig. 3.

TEST PROCEDURE AND INSTRUMENTATION

All columns were loaded concentrically using a 3,000 kN capacity testing system. The specimens were tested under monotonic loading. In the test region, axial displacement was recorded by 50 mm capacity linear variable differential transducers (LVDT) mounted at two faces of the column, as shown in Fig. 3. The applied axial loads were recorded by a load cell attached to the machine. Test was terminated when either a severe column deformation was observed or the applied load dropped suddenly.



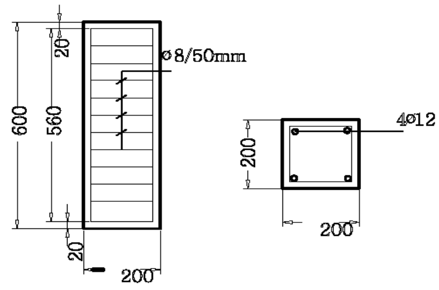


Figure 3. Setup and Concrete Dimensions **Figure 4. Reinforcement Details of Columns**

TEST RESULTS AND DISCUSSIONS

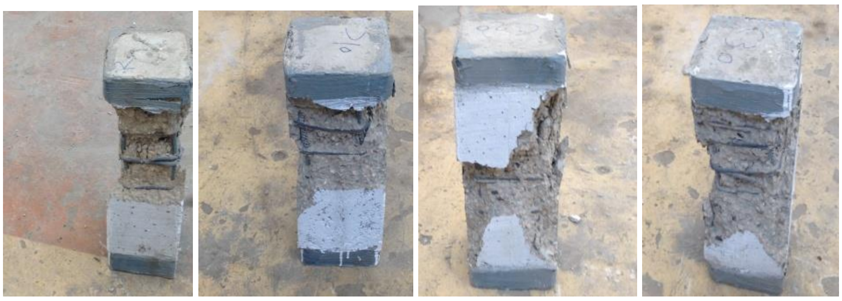
CRACK PROPAGATION AND FAILURE MODE

Initial cracks in the concrete cover typically occurred longitudinally at 75 to 91% of ultimate strength Pn of the column, as given in Table 3. The concrete cover began to spall from the core concrete immediately before the ultimate strength of columns.These observations were independent of the type of the column. However, the loss of concrete cover was more severe in columns with fine glass aggregate than in columns with coarse glass aggregate. The load-carrying capacity of columns primarily depended on the column type. With the increase of axial displacement of a column, the stirrups were gradually opened due to the lateral expansion of core concrete. This eventually caused a severe crushing of the core concrete, resulting in buckling of the longitudinal bars, as shown in Figure5.

AXIAL LOAD VERSUS STRAINS

Figure 6. Shows the axial load-axial strain curves measured from the column specimens. The axial strains were calculated as the ratio of the average displacement obtained from the LVDTs at the faces of columns to the gauge length of the test zone. The initial stiffness of columns was dependent of the type and the amount of glass aggregate. The columns had a higher strength to the axial load capacity of the reference columns. This implied that fine and coarse glass aggregate did not adversely affect the axial load capacity of the columns.

The columns using glass aggregate had a comparable strength to the predictions of the ACI 318-14 provision [10]. The ratios between the measured and predicted axial load capacities ranged from 0.83 to 0.99 for columns with coarse glass aggregate, 0.8 to 0.91 for columns with fine glass aggregate, as given in Table3.



A) CR **B) CC10** **C) CC20** **D) CC30**

E) CF10 **F) CF20** **G) CF30**

Figure 5. Crack propagation and failure modes of columns

The slope of the descending branch of the axial load-strain curve was significantly affected by the type of the glass aggregate, indicating that a more rapid drop of the applied load was observed in columns with fine glass aggregate than in column with coarse glass aggregate. This observation was more notable as the concrete compressive strength increased and as the amount of glass aggregate decreased. This may be attributed to a loss of adhesion between cement paste and aggregates. Overall, it was confirmed that using fine glass aggregate resulted in the sudden drop of the load-transfer capacity of columns. Meanwhile, coarse glass aggregate had an insignificant influence on the slope of the ascending and descending branch of the axial load-strain curves as the stiffness and ductility of specimens were higher than control specimen.

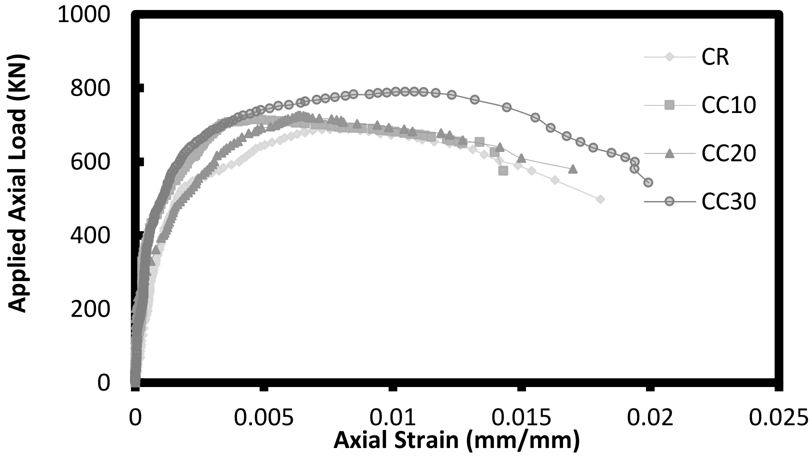


Figure 6a.Axial Strain against Applied Load for control column and columns with coarse glass aggregates

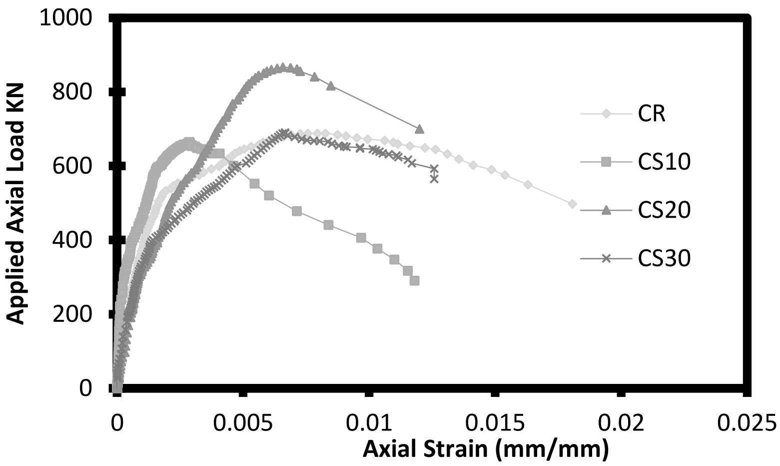


Figure 6b. Axial Strain against Applied Load for control column and columns with fine glass aggregates.

Figure 6. Axial Strain against Applied Load

DUCTILITY RATIO AND STIFFNESS

The axial ductility of RC columns is of the parameter to investigate the performance of the specimens under different load conditions. The axial ductility of RC columns is commonly evaluated using a ductility ratio μ, as defined in equation (1). [14, 23]

$$\mu = \varepsilon 85/0.004 \quad (1)$$

where ε85 is the strain value corresponding to 85% of the ultimate strength on the descending branch of the axial load- strain curve of columns. It is clear that columns with coarse glass aggregates had higher ductility than control column. While columns with fine glass aggregates had lower ductility values.

Table 3—SUMMARY OF TEST RESULTS AND COMPARISONS WITH PREDICTED AXIAL LOAD CAPACITY OF ACI 318-14

specimen	Test results						Prediction	
	compressive strength f_{cu} MPa	P_{cr} KN	P_n KN	εy	ε80	Ductility μ80	(P_n) ACI,KN	(P_n)EXP /(P_n)ACI
CR	23	533	688	0.004	0.0163	4.07	747.6	0.92
CC10	27	592	713	0.004	0.0143	3.57	855.1	0.83
CC20	25	548	724	0.004	0.017	4.25	801.4	0.99
CC30	25	576	799	0.004	0.0173	4.32	801.4	0.96
CS10	26	568	665	0.004	0.006	1.5	828.2	0.803
CS20	27	778	867	0.004	0.012	3.0	855.1	0.91
CS30	25	560	691	0.004	0.0125	3.1	801.4	0.86

CONCLUSIONS

The axial behavior of reinforced concrete columns was tested to explore the significance and limitation of the glass aggregate as an alternative to the conventional normal aggregate. The present experimental investigation would benefit further from the flexural deformation capacity of columns subjected to axial and lateral loads. From the

axial column tests, the following conclusions were drawn:
1. The ultimate strength of column with(10,20,30%) of coarse glass aggregate were higher than reference column by (3.5,5,15%)respectively , while columns with (10%) of fine glass aggregate reduced by 3% but increased for percentages (20,30%) of fine glass aggregates by (23,0.5%). It is clear that there is homogeneity for columns with coarse glass aggregates.
2. Most of the test columns had a slightly lower axial load capacity than the nominal predictions obtained from the ACI 318-14 equation.
3. The descending branch of the axial load-strain curve of columns dropped more rapidly in columns with fine glass aggregates than in columns with coarse glass aggregates, which resulted in a higher ductility ratio column with coarse glass aggregates than in columns with fine glass aggregates.

In summary, the columns with coarse glass aggregates have much better overall performance than the column with fine glass aggregates in enhancing the axial ductility of columns and preventing the premature buckling of longitudinal reinforcements. It is preferable to use coarse ones; but if it is planned to use fine aggregates super plasticizers should be used to maintain the workability.

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