Axial Compression Properties Nonlinear Analysis on Square Double Skin Steel Stub Short Columns Filled with Recycled Concrete

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Abstract. Taking the mixing amount of diatomite calcined and vitrified micro bubbles(VMB) as the main changing parameters, experiment studies the properties of the vitrified micro bubbles recycled concrete blocks; then this paper adopts the finite element software ANSYS to analyze the square double skin steel stub short columns filled with recycled concrete under axial compression. According to the vertical stress distribution, strain and bearing capacity of the steel tube and core concrete, we make a contrastive axial compression properties analysis on the different hollow ratio $\chi(0,0.35)$ and the VMB content(0%,100%,130%) of square double skin steel stub short columns filled with recycled concrete. The result shows that: Compressive strength of VMB recycled concrete increases with the increase of diatomite calcined content, when mixing amount of diatomite calcined is 3%,the compressive strength of 130% VMB content test specimen can reach 32.45 MPa;Because of the inner circular steel tube is setted which strengthening component buckling capacity and improving the ductility of the component, stress distribution of hollow components is more balance than solid components, and their axial displacements decrease by 5.6% compared with the solid components when they reach ultimate bearing capacity; When the hollow ratio is same, ultimate bearing capacity of 130% VMB content test specimen compared with the content is 0% only reduces by about 3.5%; When the VMB content is same, ultimate bearing capacity of hollow components compared with solid components increases by about 2.5%, which reducing weight as well as improving the anti-seismic performance.

1 Introduction

Currently, vitrified micro bubbles(VMB) is widely used as a new sort of environment-friendly and inorganic lightweight insulation materials, which can be used to make VMB recycled concrete when it is added into recycled concrete. Its strength and thermal insulation property can reach the ideal performance that is tested by the experiment[1].Recycled concrete filled square steel tubes (CFST) is the structure style casting recycled concrete into the steel pipe, core concrete bears three directions force due to the restraint of the steel tube, improving the bearing performance and the recycled concrete engineering application value; Besides the same advantages with CFST, concrete filled double-skin steel tube(CFDST)could also expand cross section, with a higher bending rigidity lighter weight and better performance in earthquake resistant and fire resistant. Compared with those

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structural parts in style of SHS outer and SHS inner, SHS outer and CHS inner has better malleability [2-3].

Therefore, by means of experiment this paper studies the properties of VMB recycled concrete blocks,and adopts ANSYS to make an analysis on vertical stress distribution, strain, displacement of steel tube and core concrete and bearing capacity of square double skin steel stub short columns filled with recycled concrete to compare the influence of different hollow ratio and VMB content to the axial compression properties of square double skin steel stub short columns filled with recycled concrete.

2 General situations of the experiment

2.1 The experiment of vitrified micro bubbles recycled concrete

Experiment uses 42.5 ordinary Portland cement; recycled coarse aggregate with a broken jaw crusher whose screening particle size is 5~20mm,bulk density is 1280 kg/m^3 and bibulous rate is 4.8%; sand fineness modulus is 2.9; fly ash uses the original ash from Yanji heating plant, basically reaching the level Ⅱ for fly ash fineness requirements;Jilin linjiang City Tianyuan catalyst co.LTD., production of 325 mesh diatomite calcined, its performance parameters are shown in table 1;Vitrified Micro Bubbles produced by Linghai City Longyan Building Materials Factory,stacking density is 128kg/m^3 whose performance parameters are shown in table 2;poly carboxylic acid high efficiency water reducing agent produced by Yanji Fangsheng Building Materials Company, water reducing rate is 25% or higher, which contains 0.8% of gas composition;mixing water is ordinary tap water.

After trial mixing,eventually water-binder ratio of VMB recycled concrete mixture ratio is 0.45, sand ratio is 30%. Results of each test block of experiment parameters and maintenance of indoor after curing 28d are shown in table 3.

Table 1. Performance of diatomite calcined

Fe$_2$O$_3$ content/%	S$_i$O$_2$ content/%	Specific surface area /(cm^2/g)	Ignition loss /%	Bulk density /(g/cm^3)
≤1.5	≥92	600 thousand	≤0.5	≤0.42

Table 2. Performance of vitrified micro bubbles

Granularity /mm	Density /(kg/m^3)	Heat conductivity coefficient /[W/(m·k)]	Surface vitrified /%	Water absorption /%
0.5~1.5	50~200	0.0284~0.054	≥95	20~50

Conclusions according to table 3:when the diatomite calcined content is same, increasing the VMB content, or when the dosage of VMB is same, increasing dosage of diatomite calcined, the compressive strength of concrete has a trend of increase; when diatomite calcined is 3% and the dosage of VMB is 130%, compressive strength of block reaches 32.45 MPa and its density is just 1942.45 kg/m^3, compared with the ordinary concrete dry apparent density of 2000~2500 kg/m^3, it can achieve reducing building self quality and improving anti-seismic performance.

Table 3. Experimental parameter and test result of VMB recycled concrete

Test specimen number	Material utilization amount/(kg/m^3)								Compressive strength /MPa	Dry density /(kg/m^3)
	Cement	Fly ash	Diatomite calcined	Recycled coarse aggregate	Sand	VMB	water reducer	water		
BRC-0-3	349.11	93.5	14.2	1171.35	504	0	10.38	206	34.5	2118.05
BRC-100-3	458.18	122.6	18.4	1114.95	479.5	127.8	13.51	270	30.8	1969.35
BRC-100-2	464.3	122.6	12.31	1114.95	479.5	127.8	13.51	270	26.49	1965.43

BRC-100-0	476.49	122.6	0	1114.95	479.5	127.8	13.51	270	22.36	1909.12
BRC-130-3	458.19	122.6	18.4	1114.95	479.5	154	13.51	270	32.45	1942.45
BRC-130-2	464.25	122.6	12.31	1114.95	479.5	154	13.51	270	27.56	1910.28
BRC-130-0	476.49	122.6	0	1114.95	479.5	154	13.51	270	25.95	1923.42

Note: BRC-130-3,BRC represents VMB recycled concrete,130 represents the VMB volume contains in the total volume is 130%,3represens that the diatomite calcined content is 3%,others can get by the parity of reasoning.

2.2 Design of test specimens

In order to study CFDST, length of the test specimen must be proper, the specimen's length-width ratio is 3[4].Steel type is Q235,main parameters of test specimen are shown in the table 4, $\chi = D_i/(B-2t)$, $\xi = A_{so}f_y/(A_{co}f_{ck})$, in the formula, A_{so} is the outer steel pipe cross-sectional area, f_y is outer steel pipe yield strength,A_{co} is the area contained by the outer steel tube,f_{ck} is standard value of recycled concrete compressive strength.

Table 4. Test specimen number and main parameters

Test specimen number	B×t×L /(mm³)	Dᵢ×tᵢ /(mm²)	Hollow ratio χ	Confining factor ξ	F_y /(MPa)	F_{cu} /(MPa)	N_{ANSYS} /(kN)
S-K1-0	180×2.5×540	——		0.5891		34.5	1110
S-K1-100	180×2.5×540	——	0	0.6599		30.8	1008
S-K1-130	180×2.5×540	——		0.6265	235	32.45	1061
S-K2-0	180×2.5×540	62×2.5		0.5891		34.5	1126
S-K2-100	180×2.5×540	62×2.5	0.35	0.6599		30.8	1041
S-K2-130	180×2.5×540	62×2.5		0.6265		32.45	1090

Note: All the specimens'diatomite calcined content of recycled concrete are 3%;K1and K2 represent hollow ratios of test specimens are 0 and 0.35; 0,100,130 mean VMB content accounted for 0%,100% and 130% of the total concrete volume.

3 Establishment of the finite element model

3.1 The selection of element types

Steel uses the Solid45 element to simulate, E_s=2.06×10⁵MPa, V_s=0.3;Concrete uses the Solid65 element to simulate, elastic modulus is calculated by recycled concrete elastic modulus formulas that is put forward by the reference [5], V_t=0.2.

$$E_C = \frac{10^5}{2.2 + 34.7/\text{fcu}} / (0.2811\delta + 1.065) \tag{1}$$

In the folumar: δrepresents the replacement rate of recycled coarse aggregates, f_{cu} is the cube compressive strength of recycled concrete.
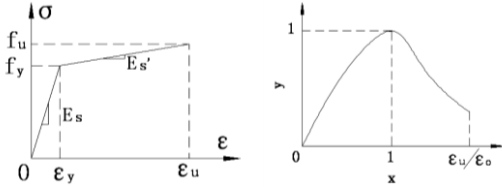
3.2 Constitutive relations of materials
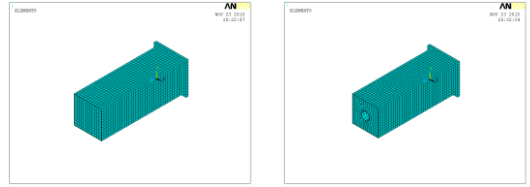
(1)Constitutive relation of steel

The steel uses dual linear kinematic hardening model (BKIN), which is shown in the figure 1 (a).

(2)Constitutive relation of concrete

As CFST, the interaction between steel tube and concrete makes the working performance of the core concrete complicate.Therefore, the paper uses theory[6] that core recycled concrete stress-strain relationship model, as shown in figure 1 (b).

| (a) Constitutive relation of steel | (b)Constitutive relation of concrete | (a) Solid concrete filled steel tube | (b) Concrete-filled double skin steel tube |

Figure 1. Material stress-strain relations   **Figure 2.** Finite element model

3.3 Modeling and Meshing

Regardless of slip between core concrete and steel tube, we add 15mm rigid plate in order to prevent the phenomenon of stress concentration on both ends of pillars.Quality of meshing directly affects the precision and speed of calculation, so hexahedron unit division side length of solid45 and solid65 are 15 mm. As shown in figure 2.

3.4 Control of Convergence

(1) Loading and boundary conditions

We add axial load on the upper plate,which generated by the rigid plate into uniformly distributed load on the model, at the same time we add x, y, z three directions of displacement constraints on the column bottom plate.

(2) Concrete crush Settings

The open crack of concrete shear transfer coefficient and closed joint shear transfer coefficient are respectively set as 0.35 and 0.9 , axial tensile strength is 3 MPa, close the concrete crush option.

(3) Nonlinear analysis options

Open the large deformation of static analysis and the automatic time step length, number of substeps is set as 200 , maximum equilibrium iteration times is set as 40, the Newton - Laposen (N - R method) is used to solve and convergence tolerance is set as 0.05.

4 Calculated result analysis of finite element

Post-processing function of ANSYS is used to study stress, strain and displacement fringe of specimen S-K1-0, S-K2-0 and specimen S-K1-130, S-K2-130 .

4.1 Stress analysis of test specimens

As shown in figure 3(a),(b)and(c),von Mises stress nephogram of the solid components in the square steel tube corner distributes complexly and the value of stress is the maximum;von Mises stress of the core concrete stress is approximately elliptic constraint zone, the middle is larger than the side of constraint and load; The axial stress of steel from the load and constraint transits to the middle and distributes unevenly;In figure 4(a),(b)and(c),outer steel tube axial stress distribution of hollow components transits smoothly,the setting of inner steel stub makes the stress distribution more evenly; The end of load core concrete axial stress is bigger;Axial stress distribution of inner steel tube is larger near the middle of the component.
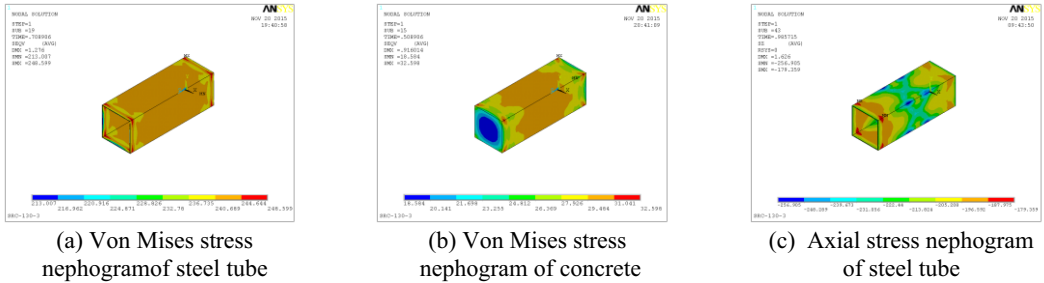

| (a) Von Mises stress nephogramof steel tube | (b) Von Mises stress nephogram of concrete | (c) Axial stress nephogram of steel tube |

Figure 3. S-K1-0 CFST stress nephogram

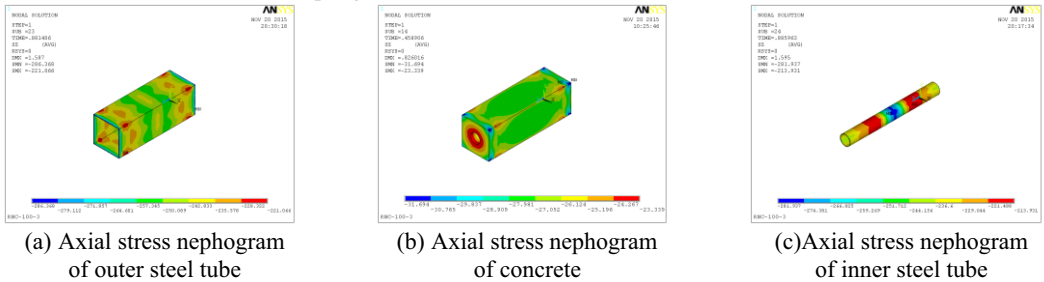| (a) Axial stress nephogram of outer steel tube | (b) Axial stress nephogram of concrete | (c)Axial stress nephogram of inner steel tube |

Figure 4. S-K2-0 CFDST stress nephogram

4.2 Strain and displacement analysis of test specimens

Figure 5 is the strain and displacement nephogram of specimen S - K1-130 and S - K2-130 that have arrived the ultimate bearing capacity. As shown in figure 5 (a) and (b), axial strain of the components corner in the load and constraint is apparently greater than other regions, especially the middle is apparently greater than its adjacent areas, local buckling occurres, axial displacement is 1.7mm; as shown in figure 5 (c) and (d), hollow components appear the local buckling,but do not change apparently in the middle, which indicats the inner steel tube can prevent or delay local buckling of the components,axial displacement is 1.605 mm that decreases by 5.6% compared with the solid components,setting of inner steel tube enhances the deformation capacity and improves the ductility.
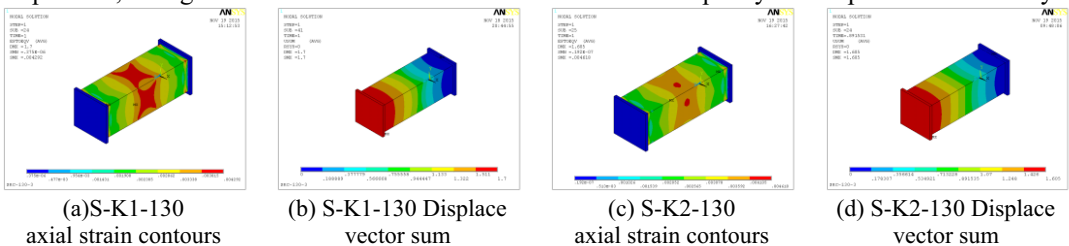

| (a)S-K1-130 axial strain contours | (b) S-K1-130 Displace vector sum | (c) S-K2-130 axial strain contours | (d) S-K2-130 Displace vector sum |

Figure 5. Component stress and displacement nephogram

4.3 Ultimate bearing capacity analysis of test specimens

The ultimate bearing capacity of 6 different hollow rates and VMB content of CFDST are shown in table 3, results of ANSYS analysis are following: When the hollow ratio is same, the ultimate bearing capacity of 130% VMB component compared with content is 0% only reduces by 3.5%; When VMB content is same,though CFDST have reduced the amount of concrete,because of the inner steel tube,compared with solid components ,their ultimate bearing capacity increase by about 2.5%, which reducing weight and enhancing the anti-seismic performance of components.

5 Conclusions

(1)When the diatomite calcined content is same,with the increase of vitrified micro bubbles content, or when the vitrified micro bubbles content is same,with the increase of diatomite calcined content, compressive strength of recycled concrete shows a trend of increase; When diatomite calcined content is 3% and vitrified micro bubbles content is 130%,compressive strength of block can reach 32.45 MPa, and its density is just 1942.45 kg/m^3;

(2)Due to the inner steel tube setting of hollow components, the stress distribution is more evenly compared with solid components,their axial displacemen decreases by 5.6% when they reach ultimate bearing capacity,which improving the buckling performance of the component and the component defor-mation ability and increasing the ductility of components;

(3)When the hollow ratio is same, the ultimate bearing capacity of 130% VMB component compared with content is 0% only reduces by 3.5%; When VMB content is same,though CFDST have reduced the amount of concrete,because of the inner steel tube,compared with solid components ,their ultimate bearing capacity increase by about 2.5%, which reducing weight and enhancing the anti-seismic performance of components.

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