Calculation and Analysis of Heat Transfer Performance of Vitrified Micro-Bead Recycled Concrete Composite Columns Based on ANSYS

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Abstract: In order to make clear the heat transfer performance of vitrified micro-bead recycled concrete composite columns , the effects of different mixing amounts of vitrified micro-bead and calcined diatomite on compressive strength and thermal conductivity of recycled concrete were analyzed by experiments, and the effects of different hollow rates on the heat transfer performance of vitrified micro-bead recycled concrete composite columns were analyzed by combining theoretical calculation and ANSYS analysis. The result shows that: When the mixing amount of vitrified micro-bead is 130% and that of calcined diatomite is 3%, the compressive strength of recycled concrete can reach 32.5MPa, but its heat conductivity is only 0.2443W/(m•k); compared with solid composite members, composite members with hollow ratio is 0.35 have lower heat transfer performance and the average heat transfer coefficient is reduced by 21.3%. The experimental results provide theoretical reference for the application of components in engineering.

1. Introduction

Currently, with the rapid development of green building, vitrified micro-bead (VMB) is widely used as a new sort of environment-friendly and inorganic lightweight insulation materials. In 2007, Zhang Zeping et al. developed VMB load-bearing and insulating concrete that can meet architectural design strength requirements[1]; In 2012, Hu Heping found that durability of VMB load-bearing and insulating concrete is better than ordinary concrete by theoretical study[2]; Sun Heng et al. researched the compressive properties of VMB recycled concrete columns by experiment and analyzed the superiorities by using software when they are used as building palisade structure[3].

Concrete filled double skin square steel tube composite columns(CFDST) has features of high bearing capacity, light weight, earthquake proof, good ductility and fire resistance is widely applied in engineering, but studied on its thermodynamic performance are fewer. In 2015, Zhou Ting et al. took special-shaped column composed of concrete-filled square steel tubes steel residence of Hebei province as research objects to analyze heat-transfer properties of the corner of structure of special-shaped composed columns [4]. Therefore, this article chooses better thermal conductivity and strength VMB recycled concrete used for CFDST as building palisade structure, and selects outside corner of wall whose heat conduction is the most unsubstantial to analyze performance of energy consumption of thermal bridge by theoretical calculation and ANSYS finite element analysis.

2. Vmb Rycycled Concrete

For choosing better thermal conductivity and compressive strength to meet the requirements of engineering design, based on the research results that Research Group has achieved, this article

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selects VMB volume contains compare to the total volume is 100% and 130%, then makes up 6 groups of VMB recycled concrete whose strength grade are C30. 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 1280kg/m3 and bibulous rate is 4.8%; sand fineness modulus is 2.9; the original fly ash is from Yanji Heating Plant, basically reaches the level II for fly ash fineness requirements; 325 mesh calcined diatomite is produced by Jilin Linjiang Tianyuan catalyst co.LT ;VMB is produced by Linghai City Longyan Building Materials Factory, stacking density is 128kg/m3; polycarboxylate superplasticizer is produced by Yanji Fangsheng Building Materials Company, which contains 0.3% of gas composition and its water reducing rate is 25% or higher; mixing water is ordinary tap water. Results of each test block of experiment parameters after curing 28d are shown in Table 1.

Conclusions according to Table 1: when the calcined diatomite content is same, increasing the VMB content, or when the VMB content is same, increasing calcined diatomite content, the compressive strength of concrete presents a trend of increase; with VMB content increasing, the heat conductivity is reducing. RC-130-3 test block 28d compressive strength can reach 32.5MPa, and its heat conductivity is just 0.2443W/(m•k), so we select this mixture ratio of VMB recycled concrete for composite column of building palisade structure.

Table 1. VMB Recycled Concrete Experimental Parameters and Test Results

Specimen number	Material utilization amount/(kg/m^3)								*Compressive strength /MPa*	*heat conductivity /W/(m·k)*
	Cement	Fly ash	*Calcined diatomite*	*Recycled coarse aggregate*	*Sand*	*VMB*	*Water reducer*	*Water*		
RC-100-3	458.2	122.8	18.5	1115	479	128	13.5	270	30.6	0.3610
RC-100-2	464.4	122.8	12.32	1115	479	128	13.5	270	26.9	0.3722
RC-100-0	476.5	122.8	0	1115	479	128	13.5	270	22.6	0.3855
RC-130-3	458.2	122.8	18.5	1115	479	154	13.5	270	32.5	0.2443
RC-130-2	464.3	122.7	12.32	1115	479	154	13.5	270	27.5	0.2652
RC-130-0	476.5	122.7	0	1115	479	154	13.5	270	25.9	0.2556

Note: RC-130-3, RC represents VMB recycled concrete, 130 represents the VMB volume contains compare to the total volume is 130%, 3 represents the calcined diatomite content is 3%, others can be get by the parity of reasoning.

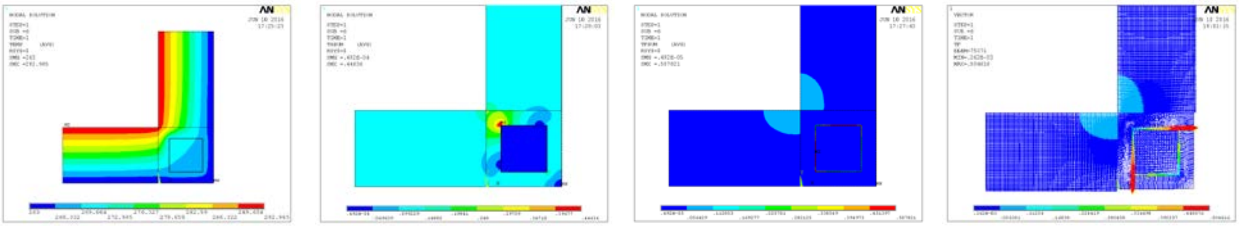
3. Finite Element Modeling and Analysis

This article adopts the finite element ANSYS to do steady state thermal analysis and solves the heat transfer properties of RC filled double skin square steel tube composite columns, and uses ANSYS to make sure the changing of parameters such as the outer wall corner temperature, thermal gradient, heat flow rate, heat flow density due to stable thermal load.

3.1. Finite Element Modeling

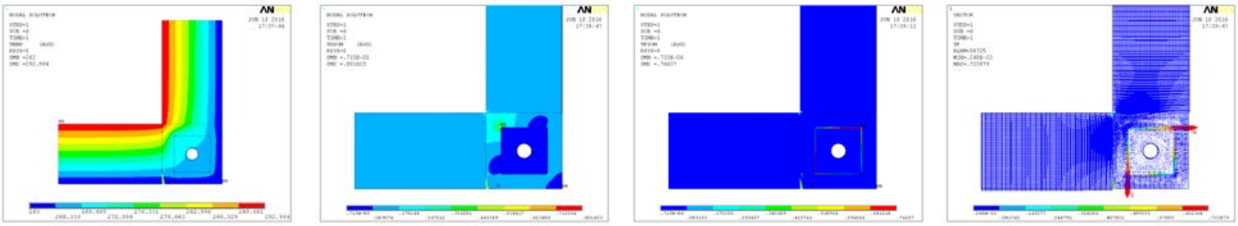
Materials and dimensions of the wall. The hollow rates of RC filled double skin square steel tube are 0 and 0.35, the section size of steel tube is 160mm×160mm×2.5mm,core concrete is ordinary concrete and VMB recycled concrete, outer pillars is surrounded by the fireproof material whose thick is 50 mm, the wall uses composite insulation block. According to the refs.[5], the influence scope of lateral heat dissipation is 1.5 or 2 times size of the wall thickness, so length of the wall is 450mm.

The heat conductivity of materials and the boundary conditions. The construction steel λ=58.2W/(m•k), concrete λ=1.28W/(m•k)[6], Thick type fireproofing coatings λ=0.1W/(m•k)[4]. Indoor air temperature Ti=293k, outdoor air temperature To=263k; The inner surface heat transfer coefficient αi=8.7W/(m2•k), the outer surface heat transfer coefficient αo=23W/(m2•k).



(a) Temperature field nephogram (b) Temperature gradient nephogram (c) Heat flux nephogram (d) Heat flux vector nephogram

Figure 1. Steady state thermal analysis of outside corner of the wall of ordinary concrete filled square steel tube



(a) Temperature field nephogram (b) Temperature gradient nephogram (c) Heat flux nephogram (d) Heat flux vector nephogram

Figure 2. Steady state thermal analysis of outside corner of the wall of RC filled double skin square steel tube

3.2. ANSYS Analysis

The unit type is SOLID55, and we use parameters above to make models and solve, then we get the temperature field, temperature gradient, heat flux and heat flux vector nephogram of outside corner of the wall, we select the analysis results of outside corner of wall of ordinary concrete filled square steel tube and RC filled double skin square steel tube, as shown in Figure 1, 2.

From Figure 1, 2 (a), temperature field of composite column outside corner of the wall distributes uniformly, links smoothly to the outside corner of the wall, that is to say the temperature distribution in thermal bridge section is good; From Figure 1, 2 (b), the range of temperature gradient distribution of ordinary concrete filled square steel tube of composite column outside corner of the wall is larger than RC filled double skin square steel tube, which means that its thermal bridge influences on the wall is larger; from Figure 1, 2 (c) and (d), in addition to the heat flux density of composite column plate part is larger, the others are all smaller, but for the heat flux of inside corner of the wall, thermal insulation properties of RC filled double skin square steel tube are obviously better than ordinary concrete filled square steel tube.

4. Energy Consumption of Thermal Bridge Calculation

In the steady state thermal analysis, heat transfer coefficient K means when both sides air temperature difference of building palisade structure is 1K or 1℃, the value of heat crosses 1m2 in one hour, its unit is W/(m2·K), therefor, heat transfer coefficient can be response of the energy consumption of structure.

4.1. Heat Transfer Coefficient of the Wall

According to refs. [6], calculation formula of a single material thermal resistance R is R=δ/λ, in the formula, unit of δ is m, which represents thickness of material layer. Heat transfer resistance formula of building palisade structure is R0=Ri+R+Re, in the formula, Ri is heat exchange resistance of interior surface, R is building enclosure thermal resistance, Re is heat exchange resistance of outside surface. The average heat transfer coefficient K0 of the wall is K0=1/R0. Heat transfer coefficient K0 of the new composite insulation block wall is 0.46W/(m2·K) [7], which meets the cold region 65% of building energy efficiency design standards[8].

4.2. Average Heat Transfer Coefficient of Composite Column after Considering the Thermal Bridge

Average heat transfer resistance of building palisade structure made up by more than two kinds of material is:

$$\overline{R}=\left[\frac{F_0}{\frac{F_1}{\mathrm{r}_1}+\frac{F_2}{\mathrm{r}_2}+\cdots+\frac{F_n}{\mathrm{r}_n}}-\left(R_1+\mathrm{R}_e\right)\right]\varphi \qquad □ □ □$$

In the formula: F0 represents the total heat transfer surface area that is perpendicular to the direction of heat; F1, F2……Fn represents each heat transfer section is parallel to the direction of heat, as shown in Figure 3; r1, r2……rn represents heat transfer resistance of each heat transfer surface; Ri is heat exchange resistance of interior surface, Ri= 0.11(m2•K/W); Re is heat exchange resistance of outside surface, Re= 0.04(m2•K/W); φ is correction factor, φ=1.

Thermal bridge models of RC filled double skin square steel tube composite columns have symmetry, so we select half of the model and divide heat transfer section is parallel to the direction of heat, as shown in Figure 4(a) and (b).

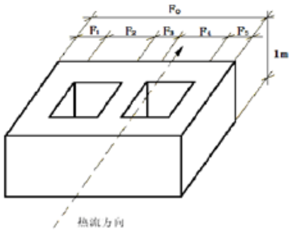


Figure 3. Each heat transfer section is parallel to the direction of heat

We calculate each heat transfer resistance of RC filled double skin square steel tube composite columns by using the methods mentioned above:

r1=1/0.46=2.17 m2•K/W

r2=0.04+0.05/2/0.1+0.21/0.1=2.39 m2•K/W

r3=0.04+0.05/0.1+0.16/58.2=0.54 m2•K/W

r4=0.04+0.05/0.1+0.107/0.2443+0.053/2/0.2443=1.191 m2•K/W

r5=0.04+0.05/0.1+0.053/0.2443+0.054/58.2=0.758 m2•K/W

r6=0.04+0.05/0.1+0.053/0.2443+0.0025/58.2+0.18=0.938 m2•K/W

r7=0.04+0.05/0.1+0.05/2/0.2443=0.648 m2•K/W

r8=0.04+0.05/2/0.1=0.29 m2•K/W

Each area parallel to the direction of heat is:

$$F_0=\frac{0.45+0.81}{2}\times 0.26=0.164\mathrm{m}^2$$

F1 = 0.26×0.45=0.117 m2

$$F_2=\frac{0.21+0.26}{2}\times 0.05=0.012\mathrm{m}^2$$

F3 = 0.21×0.0025=0.0005 m2

$$F_4=\frac{0.05+0.105+0.21}{2}\times 0.053=0.009\mathrm{m}^2$$

$$F5 = 0.025 \times 0.157 = 0.0004 \text{ m2}$$

$$F_6 = \frac{0.103+0.157}{2} \times (0.054 - 0.0025) = 0.007\text{m}^2$$

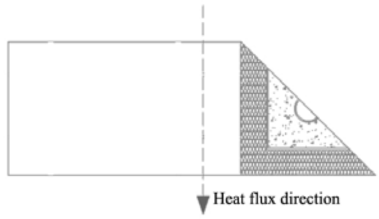
$$F_7 = \frac{0.05+0.103}{2} \times 0.053 = 0.004\text{m}^2$$

$$F8 = 1/2 \times 0.052 = 0.0013 \text{ m2}$$

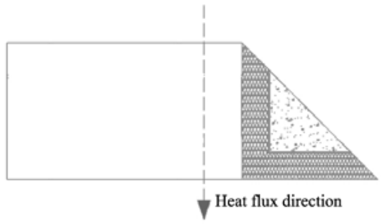
Given the values to formula (1), we can work out the average heat transfer resistance R1 after considering the thermal bridge of composite columns, which is 1.898 m2·k/W, so the average heat transfer coefficient K1 after considering the thermal bridge of composite columns is:

$$K_1 = \frac{1}{R_1} = \frac{1}{1.886} = 0.53W/(m^2 \cdot \text{k})$$

We can work out the average heat transfer coefficient of solid ordinary concrete and solid VMB recycled concrete composite columns after considering the thermal bridge, calculations are shown in Table 2.



(a) Heat transfer section of hollow composite column



(b) Heat transfer section of solid composite column

Figure 4. Heat transfer 1/2 section is parallel to the direction of heat

The energy equilibrium equation of steady state thermal analysis is:

$$[K]\{T\} = \{Q\} \tag{2}$$

In the formula: [K] represents conductance matrix;{T}represents temperature grads vector;{Q}represents heat flux density vector.

ANSYS can automatically combined with material attribute to define the boundary conditions, and generate [K], {T}and{Q}to solve; referencing definitionof whole heat transfer coefficient in refs. [9], we work out ANSYS analyzed values and compare them with calculated values, the results are shown in Table 2.

Known from Table 2, calculated values and ANSYS analyzed values of the average heat transfer coefficient of solid VMB recycled concrete composite columns after considering the thermal bridge are less than solid ordinary concrete composite columns, and increase by 23.9%~36.9% compared with 0.46W/(m2•k) that is average heat transfer coefficient of single wall; calculated values and ANSYS analyzed values of the average heat transfer coefficient of hollow VMB recycled concrete composite columns after considering the thermal bridge are less than solid VMB recycled concrete composite columns, and only increase by 15.2%~23.9% compared with 0.46W/(m2•k) that is average heat transfer coefficient of single wall; it is showing that used as bearing and palisade structure of buildings, although RC filled double skin square steel tube composite columns increase the average heat transfer coefficient of the wall, which increasing the energy consumption of thermal bridge, their effect degree compared with ordinary concrete filled square steel tube is decreasing by 21.3%.

Table 2. Average heat transfer coefficients of ANSYS analysis values and theoretical calculation values

Type	Solid ordinary concrete [W/(m^2•k)]	Solid VMB recycled concrete [W/(m^2•k)]	Hollow VMB recycled concrete [W/(m^2•k)]
ANSYS analyzed values	0.74	0.63	0.57
Theoretical calculation values	0.66	0.57	0.53

5. Conclusions

When the calcined diatomite content is same, increasing the VMB content, or when the VMB content is same, increasing calcined diatomite content, the compressive strength of concrete presents a trend of increase; with VMB content increasing, the heat conductivity is reducing. RC-130-3 test block 28d compressive strengthcan reach 32.5MPa, and its heat conductivity is just 0.2443W/(m·k).

ANSYS analyzed values of different hollow ratios and concretes composite columns show that temperature distribution of composite column outside corner of the wall is distinct and homogeneous, links smoothly to the outside corner of the wall; thermal insulation properties of RC filled double skin square steel tube are obviously better than ordinary concrete filled square steel tube.

By ANSYS analyzing and calculating the average heat transfer coefficient of composite columns after considering the thermal bridge, we make clear that when we use RC filled double skin square steel tube composite columns as bearing and palisade structure of buildings, they influence feebly on energy consumption of external wall, and their average heat transfer coefficient compared with ordinary concrete filled square steel tube is decreasing by 21.3%, which provides certain reference for applying in practical engineering in the future.

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