

Finite Element Analysis about Compressive Strength and Heat Transfer Coefficient of New Composite Insulation Block

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Abstract. In north China, exterior insulation technology is adopted, brings a series of problems such as the lives of outer insulation material and building are different. A new composite insulation block has been put forward to solve these problems. The compressive strength and heat transfer coefficient of normal concrete composite insulation block (NC-190) was analyzed by ANSYS. Its simulation error is less than 10%. It can reflect the real working state. With this method, we forecast the compressive strength and heat transfer coefficient of recycled concrete composite insulation block (RC-190) with 100% recycled aggregate replacement ration. Its compressive strength 5.54MPa meets the non-load-bearing blocks' strength requirements according to "Technical Specification for Concrete Small-Sized Hollow Block Masonry Buildings". Its heat transfer coefficient 0.585W/(m²·k) meets the thermal insulation requirements of external wall in Yanji City (shape coefficient less than 0.3) according to "The Civil Building Energy-Saving Design Standard".

Introduction

With the rapid development of Chinese construction industry, construction waste emissions are also increasing year by year, which affects the further development of the national economy seriously. At the same time, Chinese building energy-saving standard has been increased to 65% [1], energy-saving requirements become higher and higher. Most blocks just extend the heat transfer path, can't solve the thermal bridge problem fundamentally [2]. In north China, people adopt exterior insulation technology, which brings a series of problems such as the lives of the outer EPS insulation material and building are not the same.

To solve the problems mentioned above, Wang studied the heat transfer coefficient (HTC) and compressive strength (CS) of NC-190 [1]. On this basis, this paper researches CS and HTC of NC-190 by ANSYS, analyzes the error of simulation values to test values, forecasts CS and HTC of RC-190, studying the feasibility of using finite element analysis method to guide later tests and engineering application.

Test of compressive strength

We used P.O 42.5 ordinary Portland cement produced by Jilin Yatai Group. The fineness modulus of fine sand is 2.8 and its size is 0.25~3mm. For every concrete layer is only 30mm thick, we used crushed stone with size 5~10mm [3].

Figure 1 shows the 3d model diagram of the new composite insulation block. It is composed by three layers of concrete and two layers of thermal insulation material. The two inner concrete layers are main force structure, connected by concrete bar and plastic bar. The outer concrete layer is decorative layer, connected by plastic bar only with the main body. Figure 2 shows its three view drawings. Table 1 shows the 28d compressive strength.

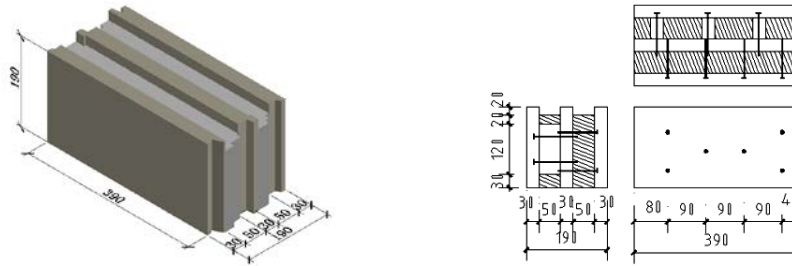


Fig. 1 The 3d model diagram of block Fig. 2 The three view drawings of block

Table 1: The compressive strength test of concrete blocks

No.	Cubic compressive strength (MPa)	Block compressive strength (MPa)	Block average compressive strength (MPa)
1		6.59	
2	24.5	6.64	6.63
3		6.67	

Thermal performance

50 NC-190 blocks are commissioned for testing in construction engineering quality test center of Jilin Province. Based on GB/T 13475-2008[4], HTC of blocks is $0.418\text{W}/(\text{m}^2\cdot\text{k}) < 0.6\text{W}/(\text{m}^2\cdot\text{k})$, meeting the requirements of thermal insulation for building external wall in Yanji City (shape coefficient ≤ 0.3) according to “The Civil Building Energy-Saving Design Standard”[5].

“Thermal Design Code for Civil Buildings” (GB50176-93) [6] gives the following thermal resistance calculation equation:

i) A single material layer thermal resistance is calculated according to the following equation:

$$R = \frac{\delta}{\lambda} \quad (1)$$

R-The thermal resistance of material layer ($\text{m}^2\cdot\text{K}/\text{W}$);

δ -The thickness of material layer (m);

λ -The thermal conductivity of materials [$\text{W}/(\text{m}\cdot\text{K})$], it should be used according to the provisions of the specification appendix and table note.

ii) Multilayer building envelope thermal resistance is calculated according to the following equation:

$$R = R_1 + R_2 + \dots + R_n \quad (2)$$

$R_1 + R_2 + \dots + R_n$ -The thermal resistance of material layers ($\text{m}^2\cdot\text{K}/\text{W}$).

iii) For heterogeneous retaining structure composed of two or more materials, the average thermal resistance is calculated according to the following equation (Figure 3 is the thermal calculation chart):

$$\bar{R} = \left[\frac{F_0}{\frac{F_1}{R_{0,1}} + \frac{F_2}{R_{0,2}} + \dots + \frac{F_n}{R_{0,n}}} - (R_i + R_e) \right] \varphi \quad (3)$$

\bar{R} -Average thermal resistance ($\text{m}^2\cdot\text{K}/\text{W}$);

F_0 -The total heat transfer area perpendicular to the direction of heat flow (m^2);

$F_1, F_2 \dots F_n$ -The heat transfer areas parallel to the direction of heat flow (m^2);

$R_{0,1}, R_{0,2} \dots R_{0,n}$ -The thermal resistances of each heat transfer area ($\text{m}^2\cdot\text{K}/\text{W}$);

R_i -The inner surface heat transfer resistance, values $0.11(\text{m}^2\cdot\text{K}/\text{W})$;

R_e -The Outer surface heat transfer resistance, values $0.4(\text{m}^2\cdot\text{K}/\text{W})$;

φ -Correction factor, it should be used according to the provisions of the specification appendix.

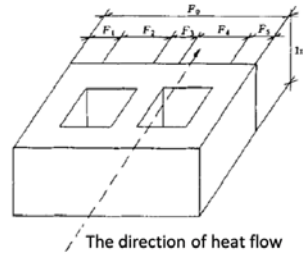


Fig. 3: The thermal calculation chart

iv) The heat transfer resistance of building envelope is calculated according to the following equation:

$$R_0 = R_i + R + R_e \quad (4)$$

R_0 -The heat transfer resistance of building envelope ($\text{m}^2 \cdot \text{K}/\text{W}$);

R -Thermal resistance of building envelope ($\text{m}^2 \cdot \text{K}/\text{W}$).

The specification states the thermal conductivity of normal concrete (NC) is $1.74\text{W}/(\text{m}^2 \cdot \text{K})$, polystyrene insulation board is $0.042\text{W}/(\text{m}^2 \cdot \text{K})$. Because the insulation board has compression and moisture absorption effect as a laminate in the concrete, its thermal conductivity should be multiplied by a correction factor 1.2, its value is $0.05\text{W}/(\text{m}^2 \cdot \text{k})$. Increasing 15mm thick mortar layer inside the block, its thermal conductivity is $0.93\text{W}/(\text{m}^2 \cdot \text{k})$. The thermal conductivity of recycled concrete (RC) is $1.48\text{W}/(\text{m}^2 \cdot \text{k})$, 85% of the normal concrete [7]. For easy calculation, the block is decomposed into two sections (shown in Figure 4). The end section (no concrete bar) accounts for 36.8% and the middle section (with concrete bar) accounts for 63.2%. Table 2 shows calculation results.

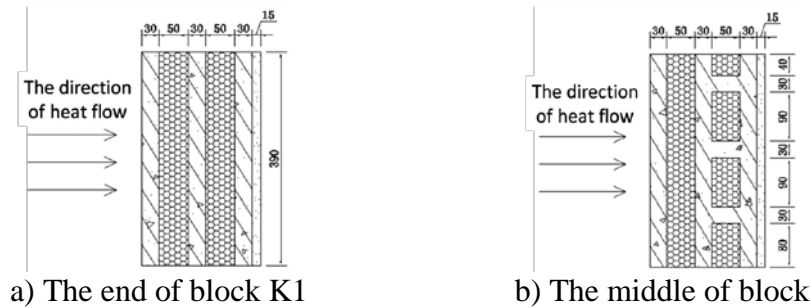


Fig. 4: The calculation diagram of resolution block

Table 2: The heat transfer coefficient of blocks

Type	End section ($\text{m}^2 \cdot \text{K}/\text{W}$)	Middle section ($\text{m}^2 \cdot \text{K}/\text{W}$)	Total [$\text{W}/(\text{m}^2 \cdot \text{k})$]
NC-190	2.218	1.608	0.559
RC-190	2.227	1.619	0.556

Finite element simulation analysis

Compressive strength simulation. Insulation boards don't participate in force basically, so neglecting insulation boards when modeling. Concrete is simulated by SOLID65 element. NC elastic modulus is according to the initial slope value of stress-strain curve. Poisson's ratio is 0.2, uniaxial tensile strength is 1.54MPa, transfer coefficient for opened crack is 0.35, transfer coefficient for closed crack is 1.0, close crush switch [8]. NC constitutive relation is according to the Sargin equation (5). The strength grade of RC is the same as NC. And its rising period of constitutive relation curve ($\varepsilon \leq \varepsilon_0$) is according to the Sargin equation (5), the down period ($\varepsilon_0 < \varepsilon \leq \varepsilon_{cu}$) is according to the literature [9], refers to equation (6). Other physical parameters are the same as NC.

$$\sigma = k_3 f_c \frac{A(\varepsilon / \varepsilon_0) + (D-1)(\varepsilon / \varepsilon_0)^2}{1 + (A-2)(\varepsilon / \varepsilon_0) + D(\varepsilon / \varepsilon_0)^2} \quad (5)$$

In equation, $k_3=1$, $f_c=13.4$, $A=1.7388$, $D=0.5$, $\varepsilon_0=0.002$

$$\sigma = f_c \frac{\varepsilon / \varepsilon_0}{b(\varepsilon / \varepsilon_0 - 1)^2 + \varepsilon / \varepsilon_0} \quad (6)$$

The relation between b and recycled aggregate replacement ratio r refers to equation (7):

$$b = 0.8(7.6483r + 1.142) \quad (7)$$

Plastic bars are simulated by LINK8 element, its elastic modulus value is 28.3GPa, Poisson's ratio is 0.4, yield stress is 55MPa, hardening slope is 5000.

Figure 5 and Figure 6 show the 3d model block and meshing situation. Figure 7 shows the von Mises stress of blocks.

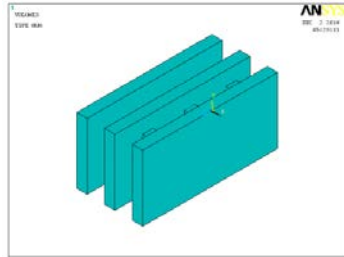


Fig. 5: The 3d model of block

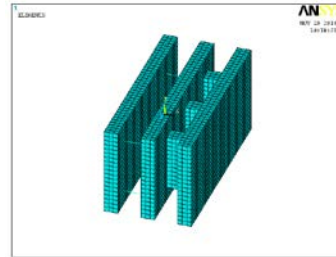
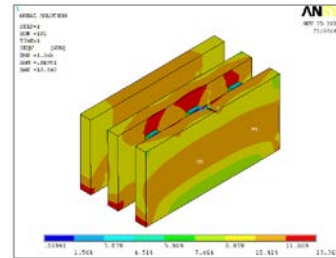
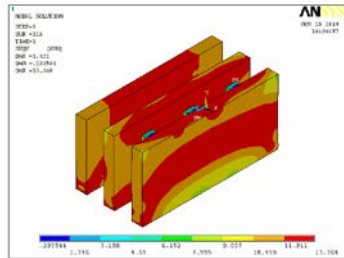


Fig. 6: The meshing situation



a) NC-190 b) RC-190

Fig. 7: The von Mises stress nephograms of two kinds of blocks

Figure 7 shows that the node stress distribution of the two types of concrete blocks are similar, because of the constitutive relation difference between NC and RC, the recycled aggregates have internal defects, leading to CS value of RC-190 block low. The result is consistent with actual status. This increase of three concrete bars improves the integrity of block, makes stress distribution of the main stress part more homogeneous, increasing CS of block, Table 3 shows the test value and ANSYS simulation value.

Table 3: The compressive strength of blocks

Type	Test values (MPa)	Simulation values (MPa)	Error r
NC-190	6.63	6.17	6.9 %
RC-190	-	5.54	-

Table 3 shows the simulation value 6.17MPa is smaller than test value 6.63MPa, which is more secure, ANSYS simulation error is within 10%. The predicted CS of RC-190 is 5.54MPa, meeting the non-load-bearing blocks' strength requirements according to "Technical Specification for Concrete Small-Sized Hollow Block Masonry Buildings" [10].

Thermal performance simulation. This paper simulates NC-190 and RC-190 separately and makes the following assumptions: It simplifies three dimensional component to two dimensional plane to solve; for boundary conditions, it supposes that the block and adjacent blocks are without heat exchange; block is in a steady temperature field, illustrated as the steady state heat conduction problem; concrete of blocks is in a good contact with the insulation board, the temperature in the contact surface is the same.

PLANE55 element is used for steady state thermal analysis, the outside temperature of the block is 263k, the inside temperature is 308k, air convection coefficient takes 2.5, other thermal

parameters are the same as the former, without regard to the influence of plastic bars to thermal performance.

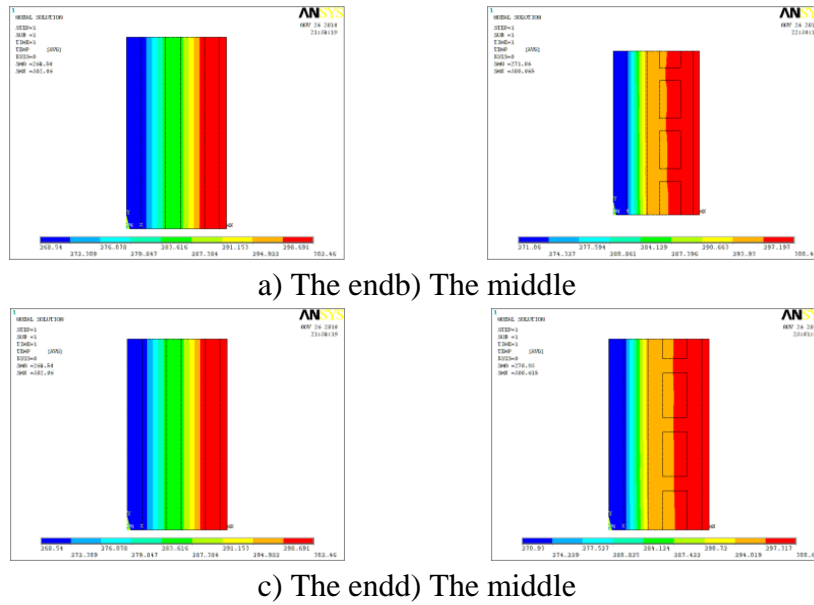


Fig. 8: The temperature field of normal (a-b) and recycled (c-d) concrete block

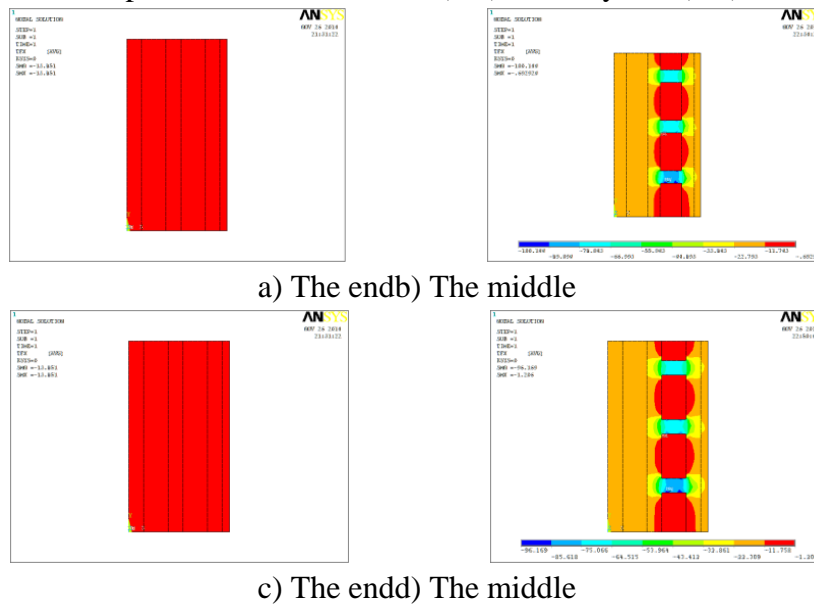


Fig. 9: The thermal flux of normal (a-b) and recycled (c-d) concrete block

Figure 8 shows that two kinds of concrete temperature field distributions are the same and the outer insulation board plays a better thermal insulation performance, blocking multiple temperature gradients. Concrete bars make the heat preservation effect of inner thermal insulation layer reduced. In Figure 9, the thermal flux distributions are also the same. The uniform distribution of materials makes thermal flux consistent in the end section. In the middle section, the thermal conductivity of concrete is much larger than Insulation board, so most of heat flows through the concrete bars.

Combined with ANSYS analysis results, we used the energy equilibrium equation of steady state thermal analysis (8) to calculate HTC of blocks shown in Table 4 [11].

$$[K]\{T\} = \{Q\} \quad (8)$$

In equation: [K]-Transmission matrix; {T}-Temperature gradient vector; {Q}-Heat flux vector.

Table 4: The heat transfer coefficient of blocks

Type	Test values [W/(m ² ·k)]	Calculation values [W/(m ² ·k)]	Simulation values [W/(m ² ·k)]
NC-190	0.418	0.559	0.593
RC-190	-	0.556	0.585

Table 4 shows that HTC calculation value and simulation value of NC-190 are both smaller than its test value, it can reflect block thermal performance accurately. HTC of RC-190 $0.585\text{W}/(\text{m}^2\cdot\text{k})$ is smaller than NC-190 $0.593\text{W}/(\text{m}^2\cdot\text{k})$ because of RC's lower thermal conductivity, its heat preservation effect has been increased for 1.3%. Recycled aggregate has internal micro cracks, which make the porosity of recycled concrete much larger, reduce the thermal conductivity, improve the heat transfer resistance, obtaining better heat preservation effect.

Conclusions

Using ANSYS to make nonlinear analysis on CS of NC-190, its simulation value is smaller than test value, error within 10%. It can reflect block's stressful situations accurately. Making theoretical analysis and finite element numerical analysis on the thermal performance of NC-190, its HTC calculation value and simulation value are both smaller than its test value, meeting the requirements of exterior wall thermal insulation in northeast China.

Using ANSYS to predict CS and HTC of RC-190 block, its stressful situation is similar to NC-190 and its CS 5.54MPa is a little lower than NC-190's 6.17MPa , meeting the requirements of strength grade for non-bearing block. The distribution about temperature field and thermal flux of RC-190 and NC-190 is similar. HTC of RC-190 is only $0.585\text{W}/(\text{m}^2\cdot\text{k})$, its insulation effect has been increased for 1.3%.

The simulation values of CS and HTC is similar to test values. The way of using ANSYS to predict CS and HTC of blocks can be for reference and its CS and HTC can satisfy the requirements of corresponding specifications. It has certain research value and practical significance to use recycled aggregates to produce new composite insulation blocks.

Acknowledgements

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