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Preliminary Analysis of Heat Dissipation Pattern in the Recycled Aggregate Concrete Hollow Blocks Using the Finite Element Analysis

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Abstract

The goal of this research is to reduce the need for Air Conditioning (AC) in buildings by limiting temperature dispersion from the exterior to the interior via building envelopes (walls). Hence two different hollow cavity blocks (circular and rectangular shape) have been cast and dimensions were given as per IS2185:2005. The compressive strength experiment for Recycled Aggregate Concrete (RAC) hollow block of two different cavity shapes with distinct substitution percentages of recycled aggregate (0%, 50%, 100%) was carried out by adding 25% coal ash as a replacement to cement. A basic property test of concrete materials is done followed by mix design (IS10262:2019). In this work, we attempt has been made to analyze the heat conduction through cavities in the concrete hollow blocks and circular hollow blocks made of recycled concrete aggregate using the Finite element analysis (FEA). A comparison of the characteristic strength and other properties of circular and rectangular cavities of recycled concrete hollow blocks has been discussed.

Keywords: *Coal Ash, Finite Element Analysis (FEA), Hollow Block, Recycled Concrete Aggregates (RCA).*

1.0 Introduction

The huge demand for infrastructure and construction projects has heightened interest in efficient, cost-effective, and optimal concrete mix design. This creates a challenge and a demand for a more sustainable approach to environmental preservation through resource conservation and reducing the amount of landfill required[1]. The exponential rise in construction and demolition waste, as well as the exhaustive natural resource excavation, wanted for the manufacture of construction supplies have ecologists outraged. One of the most typical building wastes that can be processed is demolished concrete. Concrete recycling was done with environmental preservation in mind. In fact, using recycled concrete as an aggregate in new concrete helped lower costs associated with managing construction and demolition waste while safeguarding natural resources[2]. A study found that recycled aggregate can serve as a bridge between aggregate exigency and supply in India according to research by the Ministry of Urban Development (MoUD), with the housing sector estimating a 55,000 million cubic meter aggregate shortage. One approach to all of these problems is to recycle CDW and use it as an alternative coarse aggregate for concrete. Aggregate recycling may be necessary for the creation of "Recycled Concrete" in the future leading to a shortage of natural resources. The hardened properties of concrete formed with Recycled Coarse Aggregates (RCA) are inferior to those of quartzite, the most widely used aggregate, but not to those of granite, the 2nd largest used aggregate. Therefore,

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when natural aggregate is completely replaced with RCA, Construction and Demolition Waste (CDW) is able to create concrete up to 30 MPa fck[3]. The RCA can be 100% replaced in place of Natural Coarse Aggregates (NCA) in concrete without compromising the fresh properties or strength of M20-grade concrete[4]. Studies conducted on use of Coal Ash (CA) in place of Portland cement and natural sand in concrete showed that adding CA to concrete reduced slump and CA has reduced compressive strength at 7 days with considerable improvement after 28 days[5]. The benefits of various insulated-frittage hollow blocks, such as their lightweight, excellent insulating performance, high surface quality, and enhanced hole rate have all been highlighted. The practical test on the heat transfer coefficient of hollow shale block walls shows their exceptional self-insulating qualities when compared to other wall materials[6]. According to previous research studies, implementing policies to reduce energy use and the need for air conditioning could result in savings of up to 500 MW of generating capacity annually[7]. MATLAB analysis on the impact of groves on heat transfer through traditional and interlocking block findings demonstrated that the interlocking blocks with 4 groves significantly decreased the thermal conductivity. On the other hand, thermal conductivity was unaffected by expanding the cavity count beyond four[8]. A study on the geometric configuration for hollow concrete blocks the heat transfer using the finite element method was carried out for 23 models that have various arrangements of hollow concrete block cavities, taking convection and radiation inside the hollow area into consideration. The findings showed that 51% void ratio concrete block could have its average inner surface temperature lowered by 7.18 ^{0}C[9]. There were numerous, interrelated factors that affected how much heat was transferred through the hollow blocks. Heat flux through the hollow area by radiation and convection was decreased by narrowing the cavities (in a heat flux-parallel manner). Enhancing the hollow ratio tends to reduce the amount of heat that is transferred by conduction through the block's solid portions. Fewer cavities tend to significantly lessen the amount of heat that is conveyed by way of convection and radiation inside the cavities[10]. Among the three rectangular cavity blocks considered in the study, the conventional block's thermal conductivity (K) is 1.33 W/m-K[11]. 11.8% less thermal conductivity has been noticed in concrete with ground recycled aggregate combined with 50% mixed recycled aggregate when compared to concrete with natural aggregate[12]. The thermal conductivity of surface dry condition concrete block is decreased by 3.9% when 25% of the cement composition is replaced by coal bottom ash[13]. The effect of void types on the low thermal feature and heat barrier efficiency of a small hollow concrete block was found that when the void rate is constant, the thermal resistivity property of rectangular grooves is better than the thermal performance of elliptical, circular, parallelogram, and triangle grooves. When the void percentage is unchanged, the three-cavity or four-cavity block performs well in terms of thermal barrier[14]. To enhance their thermal properties, wall blocks were tested. For lowering heat transfer rates, hollow blocks' ideal cavity size and shapes were taken into consideration[15,16]. It was discovered that rearranging the block cavities could increase thermal resistance by up to 17.65%. These new technologies of replacing natural aggregates with recycled concrete aggregates would reduce 30.5% energy consumption per ton of aggregates[17]. Recycling C&D waste instead of dumping it in a landfill would prevent at least 4.92 kg of CO_2 equivalent emissions from being released into the atmosphere and save 0.30 m^2 of organic land[18]. An experimental examination of drying shrinkage in concrete composed of recycled concrete aggregates, both with and without the addition of a superplasticizer, revealed that the recycled concrete mixtures displayed a shrinkage level of up to 0.09%. This value surpasses the maximum allowable percentage as specified in IS2185. Additionally, the rate of shrinkage in samples containing superplasticizers was higher[19]. Grade A hollow masonry units with adequate characteristic strength can be made using recycled aggregates and coal ash, which reduces environmental impact by 30% and reduces energy use by 1%[20]. Construction practices in India have a significant impact on the country's environment, society, and economy. As a result, sustainable development must be practiced. Waste reduction, industrial recycling, efficient energy use, environmentally friendly approaches, and environmental resource conservation are all instances of sustainable growth[21].

2.0 Methodology

According to IS2185 (2005)[22], a hollow concrete block with a characteristic strength of 5MPa and a block density greater than 1500 kg/m3 is required for use in

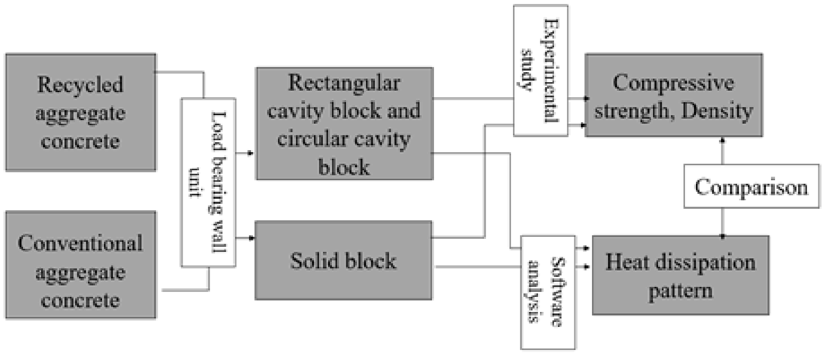

Figure 1. Methodology flow chart.

the construction of load-bearing walls. An investigation into the use of recycled coarse aggregate by 50% and 100% as a replacement for natural aggregates and 25% coal ash as a replacement for cement in the rectangular cavity and circular cavity blocks has been experimented. The dimensions of the block are 500x100x100 with 25mm bed thickness, the hollow cavity size being 200X50mm and the diameter being 50mm in the case of the RCB (rectangular cavity block) and CCB (circular cavity block), respectively. For the Indian building circumstance, R2 and C2 (100% RCA; 25%CA) can be used in construction as load-bearing hollow blocks.

To investigate the thermal performance preparation of models of hollow blocks and solid blocks followed by the method of 1-D steady state heat flow simulations based on the Finite Element Analysis (FEA). The discrepancy in temperature difference in the interior surfaces of different concrete mix blocks at varied outside temperatures has been studied. The methodology flow chart of the study is shown in Figure 1.

3.0 Results

3.1 Mix Design and Block Manufacturing

The materials employed in this study comprise M-sand, natural coarse aggregate, recycled coarse aggregate (with a size less than 6mm), OPC 53 grade cement, and coal ash. The mix design for hollow concrete blocks adheres to the guidelines outlined in IS 10262(2019)[23]. The Recycled Coarse Aggregate (RCA) is procured from a construction and demolition waste recycling facility situated near Chikkajala, Bengaluru. Coal bottom ash is derived from the incineration of coal at a clay brick manufacturing

Figure 2. Preparation of RCB.

Figure 3. Preparation of CCB.

unit. Before conducting the mix design and casting process using molds measuring 500*100*100mm, a specific gravity and water absorption test is performed on all materials. A concrete mix ratio of 1:1.5:2 for target strength of 30 N/mm^2 is obtained as per 1S10262 (2019) which is followed in casting RCB and CCB with varying percentage of Recycled Coarse Aggregates (RCA) and

Coal Ash (CA). Table 1 enlists the basic property test results of cavity block materials. Rectangular hollow section and circular section concrete hollow blocks cast are shown in Figure 2 and Figure 3. The bed thickness of 25mm in both blocks, face shell thickness, web thickness of the hollow blocks, is given as per the IS2185 (part 1) 2005 code.

Six concrete cavity blocks have been casted and the proportions of the concrete in two different cavity blocks is provided in Table 2. Void ratio of RCB is 1.42 and CCB is 0.882.

Table 1. Basic material property test results

Concrete Materials	Specific Gravity	Water Absorption (%)
M Sand	2.61	8.1
RCA (Fine)	2.44	4.74
Natural Coarse (NCA)	2.54	<1
RCA (Coarse)	2.24	6.38
OPC 53 Grade Cement	2.97	NA
Coal Ash	2.41	NA

Table 2. Material quantity for mix, W/C=0.55

RCB	CCB	Material quantity for mix design for W/C=0.55	Concrete type
Rc	Cc	100%cement: 100%NA: M sand	Conventional concrete
R1	C1	25%CA+75%cement: 50%RCA+50%NA: Msand	Recycled concrete
R2	C2	25%CA+75%cement: 100%RCA: Msand	

3.2 Compressive Strength and Density of CCB, RCB, and Conventional Solid Block

Due to the hollow area which reduces the overall design strength cavity blocks have not reached their intended mix design target strength. CCB has increased its compressive strength relative to RCB due to its low void ratio. For 100% RCA and 25% coal ash supplements for natural coarse aggregates and cement respectively, about

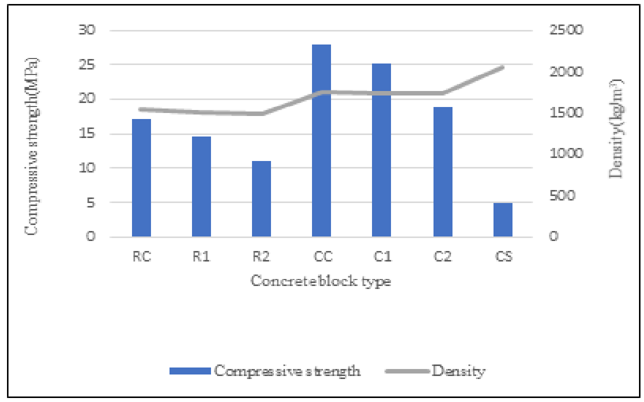

Figure 4. Compressive strength (fck) and density of varied concrete composition and cavity block.

32% loss in CCB fck and 35% loss in RCB fck has been observed compared to conventional CCB and RCB. Due to the lower specific gravity and high porosity of RCA and coal ash, recycled concrete cavity blocks have a lower density than conventional concrete. Solid Concrete Block (CS) composed of asbestos, natural aggregates being used as a load-bearing element, is tested for comparison with the proposed recycled concrete hollow block. Variation in density and compressive strength of different composition concrete mixtures and cavity shape is shown in Figure 4.

3.3 One-dimensional Heat Flow Simulation in a Different Block

The CATIA Modelling software is used to build the Concrete block model, this model is imported to ANSYS 19.2 version to analyze the temperature distribution defining the boundary condition for steady-state thermal analysis. Considering the outside temperature ranging from 25°C to 45°C and the heat transfer coefficient of the inner wall surface is set based on Newton's law of conduction at 10 W/m^2 °C. Simulation has been performed under various temperatures under different thermal conductivity on different geometry concrete blocks. This indicates the heat flux is not uniform for concrete blocks with circular holes as compared with hollow blocks. The temperature difference between the inner surface (T4), the outer surface (T0) and at different cross-sections (T2,T3) of the hollow block at different ambient temperatures is shown in Figures 5-7.

Considering the ambient temperature of 25 ^{0}C (Figure 5), the lowest inside surface temperature observed is

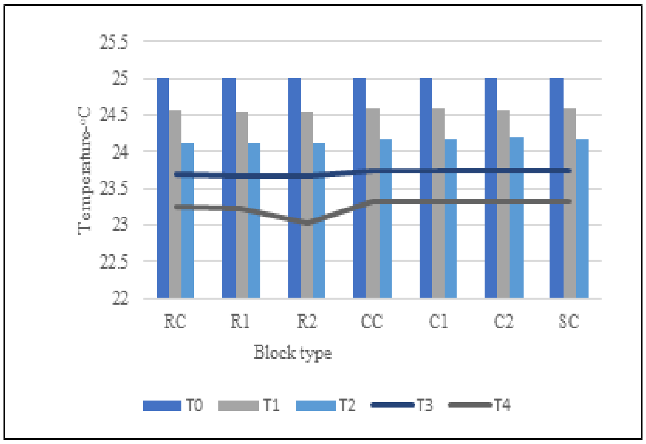

Figure 5. The temperature gradient in different cavity blocks at ambient 25°C.

23 ^{0}C in the rectangular cavity block (R2). Comparing the temperature gradient in a solid block and circular hole cavity block, the solid block has poor thermal insulation, since the maximum temperature difference between inside and outside surface temperature is less than 2 ^{0}C.

For the ambient temperature of 35 ^{0}C, the variation in inside temperature between R2 and C2 is negligible. However, the lowest inside surface temperature observed is 28.8 ^{0}C in the rectangular cavity block (R2). For 35^{0}C outside temperature solid block inner surface would experience 30^{0}C.

Figure 7 shows the temperature gradient along with the X –direction. Considering the ambient temperature of 45 ^{0}C, the lowest inside surface temperature observed is 30 ^{0}C in the rectangular cavity block (R2) and 30.8^{0}C in

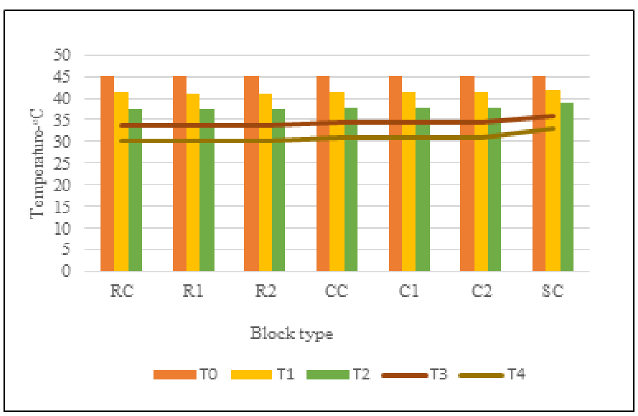

Figure 6. The temperature gradient in different cavity blocks at ambient 35 °C.

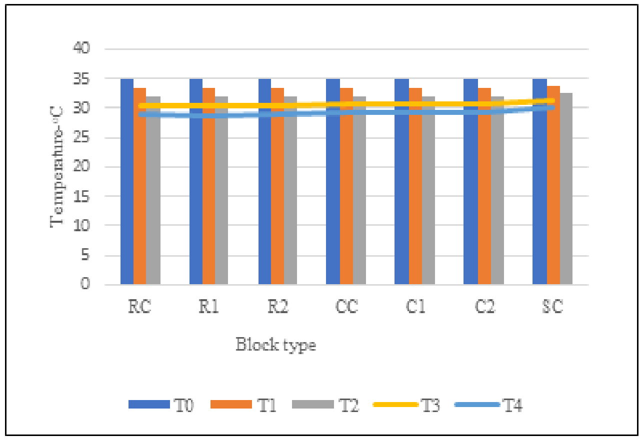

Figure 7. The temperature gradient in different cavity blocks at ambient 45 °C.

circular cavity block (C2). For 45^{0}C outside temperature solid block inner surface would experience 33^{0}C.

The temperature distributions at different locations across the thickness of the bricks under steady state one dimensional is observed that with an increase in the outside temperature, the inside temperature of the bricks increases. However, of all the bricks studied it is observed that rectangular cavities have a predominant effect on the heat transfer characteristics compared with other wall units.

3.4 Heat Dissipation Pattern

From the above-observed temperature gradient analysis R2 and C2 are stated to experience the lowest inner surface temperature compared to the remaining concrete blocks. Heat flow pattern in R2, C2, and solid block as shown

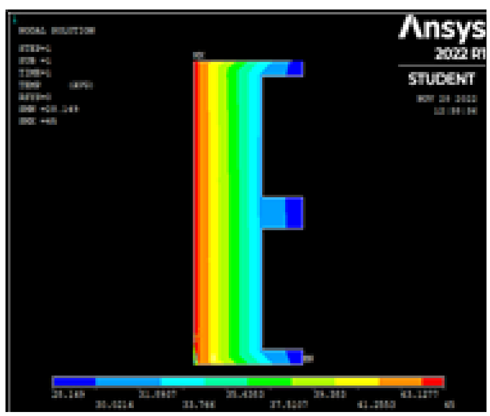

Figure 8. RCB heat flux.

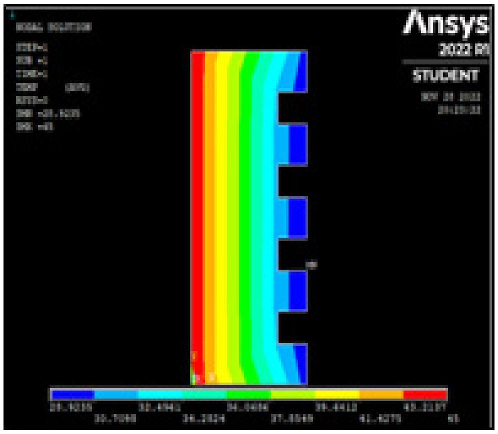

Figure 9. CCB heat flux.

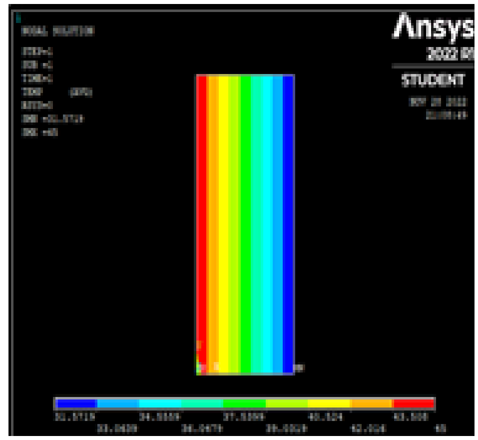

Figure 10. Solid block heat flux.

in Figures 8-10. The temperature distribution across the thickness of the block for both solid and cutouts of the different geometry for an ambient temperature of 45 °C is shown below. It is observed that cavity blocks exhibit better-insulating properties than solid concrete blocks which is reflected in terms of dropping the temperature of the inside surface of the bricks for all conditions due to their density and other propagation of the block. Further, it is observed that bricks with rectangular cutouts exhibit better heat dissipating capabilities when compared with circular cut out and the natural solid block moving to the higher convective heat transfer. This can be attributed to the enhanced surface area of geometry.

Walls in the buildings are extremely high heat transfer areas. The interior and exterior surface temperatures of the wall affect the heat gains and losses in buildings. These factors make it clear that walls are crucial in lowering a building's energy use[24]. Based on some study results, lowering the air conditioning by just one degree Celsius can reduce electricity use by about 6%[25]. Improving thermal insulation properties is an important step toward achieving sustainable structures. Decreased heat loss in buildings lowers energy consumption and hence refrigeration and heating costs reduces[26].

4.0 Discussions

Without a doubt, the building's construction components have a significant impact on the reduction of energy use linked with the building. It is emphasized that the thermal capability of the hollow brick can be enhanced to lower the building's energy demand. Additionally, recycled concrete hollow blocks are lighter compare to conventional concrete hollow blocks which are beneficial in terms of faster construction, less material usage, and energy efficiency. Hollow blocks have more air pockets than solid blocks, making it less effective conductors of heat. In the case of R2 and C2, the heat transfer average distance will decrease with a decrease in concrete density, causing lower thermal conductivity. This is due to fewer particles overall in the material and hence there is less mass of material to conduct heat through. Improvements in thermal insulation have an impact on sustainability as a result of lower energy use. FEM analysis results on conventional bricks showed that raising the overall cavities significantly improved thermal insulation by reducing heat flow into the. building. A large thermal resistance is observed in RCB than in CCB.

5.0 Conclusions

- The findings of this study suggest that recycled aggregate concrete can effectively meet the strength for being used in framed structures, even if it exhibits lesser strength compared to conventional aggregate concrete. In the context of hollow block production, it is feasible to replace a portion of the natural materials with coal ash, up to a maximum of 25%, and Recycled Concrete Aggregate (RCA), up to 100%, without compromising the desired compressive strengths of 13MPa (R2) and 18MPa (C2).
- Compared to conventional mix, recycled aggregate-coal ash blocks are slightly lower

denser due to porosity and lesser unit weight than conventional mixture.

- Recycled concrete rectangular cavity block has excellent insulating property when compared with circular cavity and solid blocks.
- For the ambient temperature of 45 °C, the inner surface of the solid block is experiencing 34.55 °C, C4 is emitting 32.49 °C and R4 is 31.89 °C. Temperature variation of 2 °C in C2 and 2.7 °C in R2 is dissipated which is more than a conventional solid block.
- Since recycled aggregate and coal ash has better thermal insulation property than natural materials, additionally using these recycled-waste materials in producing hollow block would give thermal comfort by insulating the building to a minimum of 3 °C.

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