Nigerian Journal of Engineering, Vol. 28, No. 2, August 2021, ISSN (print): 0794 – 4756, ISSN(online):2705-3954.

Nigerian Journal of Engineering,
Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria
journal homepage: www.njeabu.com.ng

Thermal Characteristics of Metakaolin-Blended Hollow Sandcrete Blocks

O. M. Kamiyo

Department of Mechanical Engineering, Faculty of Engineering, University of Lagos, Lagos, Nigeria.
okamiyo@unilag.edu.ng,

Research Article

Abstract

Sand-cement hollow blocks are widely applied in building construction in most countries. Attempt to lower the high costs of the material constituents, as well as the desire to enhance properties, has led to the substitution of the constituents with different admixtures. Adding admixtures to most cementitious materials often affects their thermophysical properties. One of the commonly used admixtures is metakaolin. This study investigates the thermal characteristics of hollow sandcrete blocks produced with metakaolin-blended cement. The replacement of cement with metakaolin is varied up to 30% by volume in a step of 5%. The results show increasing heat transfer rate, heat energy storing capacity and thermal mass with the mekaolin content. Time-response properties such as thermal admittance and thermal effusivity rise while most of the insulating properties reduce with increasing metakaolin substitution. The results show the potential use of metakaolin-based blocks for building applications should be with caution.

Keywords

Metakaolin, cement, admixtures, sandcrete blocks, thermal properties';'.

Article History

Received: – October, 2020
Reviewed: – February, 2021
Accepted: – August, 2021
Published: – August, 2021

1. Introduction

Provision of economical and durable building structures has become imperative in order to provide affordable housing for the Third World countries. In Nigeria especially, over 90% of physical infrastructures are being constructed with hollow sandcrete blocks (Nwaigwe *et al*, 2015). The high and increasing cost of cement has contributed to the non-realization of adequate housing for both urban and rural dwellers in the country. Therefore, development of alternatives to cement as a material has been a desire. For many years, many authors reported effects of adding admixtures to construction materials on the workability, compressible strength and durability of cementitious products (Nimityongskul and Daladar, 1995; Ganesan *et al*., 2008; Adesanya and Raheem, 2009; Seo *et al.*, 2010; Mohammed and Cheeseman, 2011; Oyekan and Kamiyo, 2011; Omoregie, 2013; Sonebi *et al.*, 2013; Muntohar and Rahman, 2014).

Supplementary cementing materials (SCMs) like blast-furnace slag cement, granite fines, fly ashes and metakaolin are finely ground solid materials added to concrete or sandcrete mixtures to make them cheaper, reduce water absorption, make it stronger or improve other properties (Oyekan and Kamiyo, 2008; Vejmelkova *et al.*, 2010; Cassagnabère *et al.*, 2010; Kolovos, 2013; Dojkov *et al.*, 2013; Mo *et al.*, 2017). Metakaolin (MK) is one of the supplementary materials that agrees with ASTM C 618-19 (ASTM, 2019) for pozzolan specifications. Substituting cement with metakaolin is not only to reduce carbon dioxide emission but also to improve the properties of the concrete and sandcrete blocks. Effectiveness of metakaolin as a pozzolan to achieve these purposes has been a subject of research in recent times. Siddique and Klaus (2009) carried out a broad review on the effects of metakaolin on the properties of mortar and concrete. Later, Guneyisi *et al.*, (2008) investigated the effect of metakaolin on water absorption, pore structure, drying shrinkage, the compressive strength of concrete. Srivastava *et al.*, (2012) studied the suitability of silica fume and metakaolin combination in production of concrete. Murali and Scruthee (2012) experimentally investigated the use of metakaolin as a partial replacement substance for cement in concrete. Rezende *et al.*, (2015) studied the effect of metakaolin on the durability of concrete hollow blocks with focus on the degradation caused by driving rain. Kolovos *et al.*, (2016) experimentally investigated the properties of sandcrete mixtures modified with metakaolin and exposed to corrosive environments. Ibrahim and Ocholi (2020) observed improvement in the structural strength of metakaolin-based sandcrete blocks. As observed, most of these investigations have focused on structural benefits of metakaolin as admixture in building components.

Energy consumption of buildings is influenced by the design and materials used to construct the buildings. Therefore, attention is paid to the thermophysical properties of the materials because they significantly determine the heating or cooling load required for comfort in the buildings. Also, upgrading the thermal resistance of external walls and roofs of buildings have generally come to be accepted as part of the efficient measures taken to reduce energy consumption in those buildings. With the common use of metakaolin as admixture in building construction materials, it is therefore necessary to study the thermal properties of such structures. This study therefore investigates the thermal characteristics of sandcrete blocks with up to 30% percentage substitution of cement with metakaolin with the aim of determining its influence on the thermophysical properties of the blocks.

2. Materials and Methods

The materials used to make the sandcrete blocks are sharp sand (void of impurities), cement (which was partly substituted with metakaolin) and water. In accordance with BS 1377-3 (2018), wet sieve analysis was employed and the results showed that the sand has a value of 2.68 and 2.95 for specific gravity and coefficient of uniformity respectively; with an average moisture content of 0.90 percent. Portland cement with properties complying with international standard BS 12 (1996) and local standard NIS 439 (2000) employed for sandcrete blocks production in Nigeria was adopted. The water used was fresh, tasteless, odourless, colourless and dirt-free. The particle size analysis of the sand used is as presented in Figure 1.

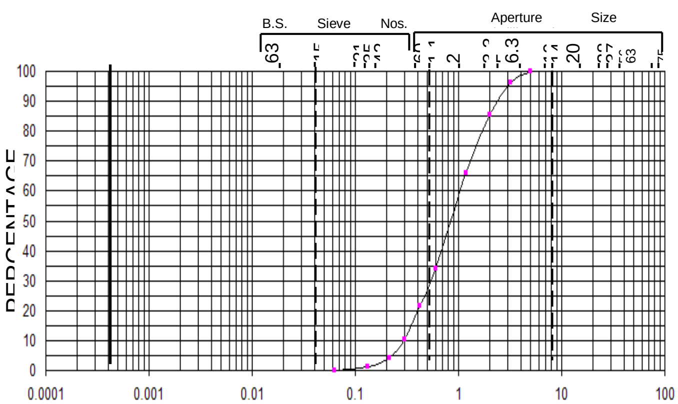


Figure 1 Particle size analysis of the sand

Table 1: Chemical analyses of OPC and Metakaolin

Parameter	OPC (%)	Metakaolin (%)
Silica (SiO_2)	18.26	62.47
Aluminium oxide (Al_2O_3)	4.68	28.68
Ferrous oxide (Fe_2O_3)	0.40	1.56
Calcium oxide (CaO)	66.06	0.06
Magnesium oxide (MgO)	2.13	0.16
Sodium oxide (Na_2O)	0.52	1.44
Potassium oxide (K_2O)	0.49	2.87
Moisture content	0.009	0.000
Loss of Ignition	0.015	1.14
Silica Ratio [SiO_2 /(Al_2O_3 + Fe_2O_3)]	3.594	2.066
Aluminium Ratio [Al_2O_3/ Fe_2O_3]	11.7	17.1
∑ (SiO_2 +Al_2O_3 + Fe_2O_3)	23.34	92.71

The chemical analysis of metakaolin presented in Table 1, has the sum of SiO_2, Al_2O_3 and Fe_2O_3 to be 92.71%. This implies that metakaolin is a good pozzolan as the value is higher than the 70% required as minimum for pozzolan (ASTM C618-19, 2019). The sum value shows metakaolin is a better pozzolan than rice husk ash which has 76% (Kamiyo and Oyekan, 2009) and corn cob ash which has 78% (Adesanya and Raheem, 2009). The oxide composition of the metakaolin-blended cement at various percentages is as shown in Table 2.

Table 2. Oxide contents in the metakaolin-blended cement at various percentages

Oxide Composition	95% OPC 5% MK	90% OPC 10% MK	85% OPC 15% MK	80% OPC 20% MK	75% OPC 25% MK	70% OPC 30% MK
SiO_2	20.47	22.68	24.89	27.10	29.31	31.52
Al_2O_3	5.88	7.08	8.26	9.48	10.68	11.88
Fe_2O_3	0.458	0.516	0.574	0.632	0.690	0.748
CaO	65.61	62.16	58.71	55.26	51.81	48.36

Immersion poker vibrating machine was used to produce the blocks with the average water/cement ratio being 0.6. Standard mix proportion of 1:6 as specified by BS 2028 (1968) is adopted. As shown in Figure 2, the size of the block used is 225mm x 225mm x 450mm; a third of the volume made void. The cement was replaced with metakaolin 5% by volume at a time up to 30%.

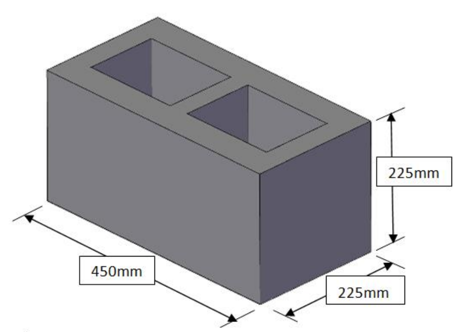


Figure 2: Standard size of a sandcrete block

In the production of the blocks, the materials were turned with hands several times till uniform colour and consistency are attained. Then water is added to the mix and turned again till good adhesion is ensured. The mixture is rammed into the moulds of the vibrating machine and compacted. The blocks were then placed on pallets in several rows and covered throughout the curing period. On daily basis, they were watered in order to keep them wet throughout the period. The condition of the laboratory where the experiment was performed was 27 ± 2^0C dry-bulb temperature and relative humidity of 50 ± 5%.

3. Results and Discussion

Adding admixtures to most cementitious materials often affects their thermophysical properties. (Kamiyo and Oyekan, 2009; Bentz *et al.*, 2011; Kamiyo and Oyekan, 2011). The properties of the blocks investigated in this study for percentage change in the volume of metakaolin are the primary properties, viz., the thermal conductivity (k), and the specific heat capacity (c). Since these quantities are density-dependent, the density of the blocks is also presented. Time-response thermal properties considered are thermal diffusivity (α), thermal effusivity (*e*) and thermal admittance (h_a). Insulation related properties investigated include thermal conductance (C-value), thermal resistivity (r_t), thermal resistance (R-value) and thermal insulance (i_t). The variations of these properties with % substitution of metakaolin are as shown in Figures 3, 4 and 5.

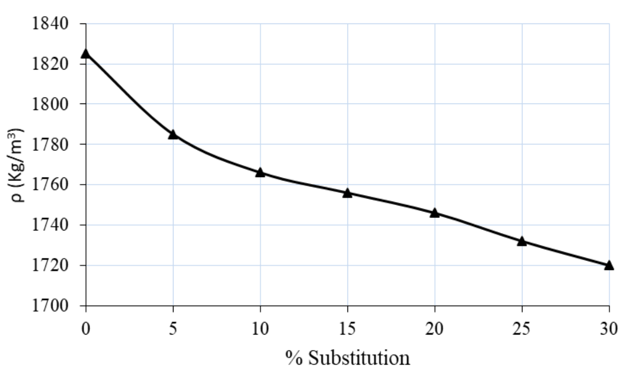
Using the guarded hot plate box, the thermal conductivity of the blocks was determined according to ASTM C177-19 (ASTM, 2019). The determination of the specific heat capacity of the sandcrete blocks was through the adiabatic calorimetric technique. To ensure the results were as accurate as possible, necessary precautions were taken.

3.1 Effect of metakaolin substitution on the primary properties

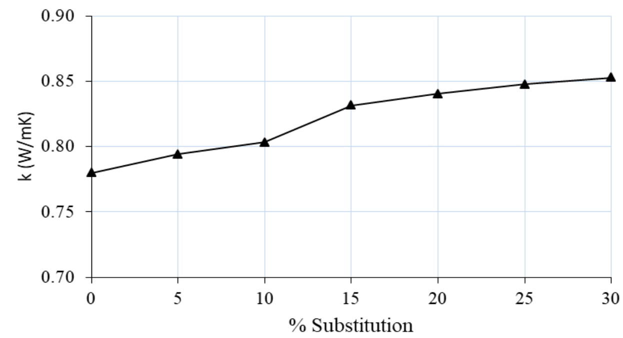
The effect of metakaolin substitution on the primary properties of the cement such as density, thermal conductivity and specific heat capacity are analysed.

3.1.1 Density (ρ)

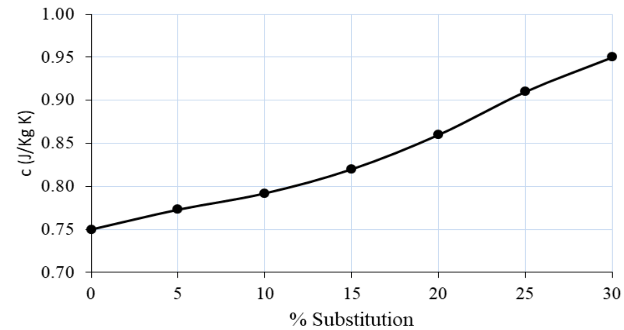
The replacement of part of cement with metakaolin has reducing effect on the density of the sandcrete blocks as shown in Figure 3(a). The value of the density of the block is found to reduce at a rate of 0.6% for every 5% substitution of cement with metakaolin. The density of the block with 30% substitution is 6% less than that of the control (0%). According to ASHRAE (2005), change in the density of a block has effect on its thermal properties.



(a) density



(b) thermal conductivity



(c) specific heat capacity

Figure 3. Variation of primary properties against percentage substitution

3.1.2 Thermal Conductivity (k)

Thermal conductivity of a material indicates the rate at which the material permits heat to flow through it. In Figure 3(b), it is observed that the value of the thermal conductivity marginally increases with the quantity of metakaolin added. The k value for the block with 30% metakaolin substitution is just 9% higher than that of the control (0%). The higher k value obtained for the block is as a result of the finer metakaolin particles filling the pores that were hitherto present within the initial sand-cement mix; since the thermal conductivity of air is less than that of metakaolin. The higher heat transfer rate will increase the cooling/heating load in the building space which is undesirable as it will increase the capacity and hence the cost and energy consumption of the mechanical equipment required for comfort.

3.1.3 Specific heat capacity

The variation of the specific heat capacity against percentage metakaolin substitution, Figure 3(c), indicates that the value of the specific heat capacity of the block change slightly for every additional 5 percent of metakaolin. For example, specific heat capacity for 10% substitution is just 0.019 KJ/kg.K higher than that of 5% substitution. It is observed that blocks with metakaolin have higher heat energy storing capacity and therefore higher thermal mass than those without it. In summer time, these modified sandcrete blocks loses heat stored during the day slowly, thereby extending the need for air cooling required to maintain thermal comfort within a building. The high value of specific heat capacity indicates higher thermal mass; a building property desired in cold climate. In relation to density, Figure 3(c) shows that the specific heat capacity of blocks made with metakaolin-blended cement increases as density decreases. This in agreement with the observation of Oktay *et al*., (2015).

3.2 Effect of metakaolin substitution on the time-response related properties

Similarly, the effect metakaolin substitution on the time-response related properties such as thermal diffusivity, effusivity and admittance is equally analysed.

3.2.1 Thermal diffusivity (α)

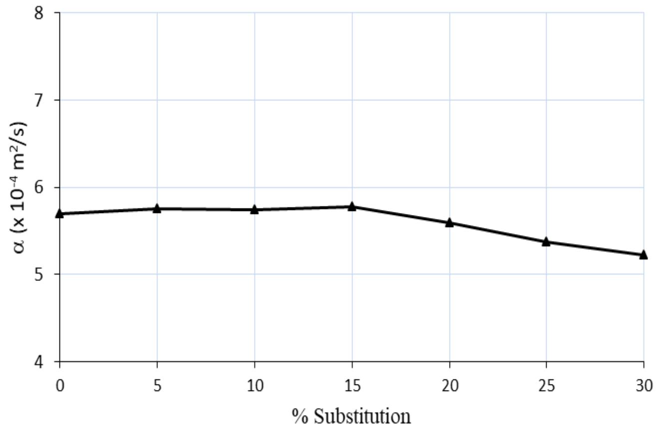
Thermal diffusivity of a material is a measure of how quickly the material respond to changes in temperature when exposed to a fluctuating thermal environment. It characterises unsteady heat diffusion within the material. That implies, when the thermal diffusivity of the block is high, its temperature will quickly adjust to that of its environment. In Figure 4(a), the variation in value of thermal diffusivity is affected by the slightly upward changes in values of specific heat capacity and thermal conductivity, balanced by the downward changes in the values of the density. As a result, it marginally increases and then reduces as the percentage metakaolin substitution increases. This effect implies that the blocks with lower percentage of metakaolin content will adjust its temperature more quickly or, in comparison with the control block , will permit heat flow through it more rapidly. But with increasing percentage of metakaolin in the block, leading to reducing thermal diffusivity, the rate of heat flow through it will be slower and heat storage capacity will be larger.

3.2.2 Thermal effusivity (e)

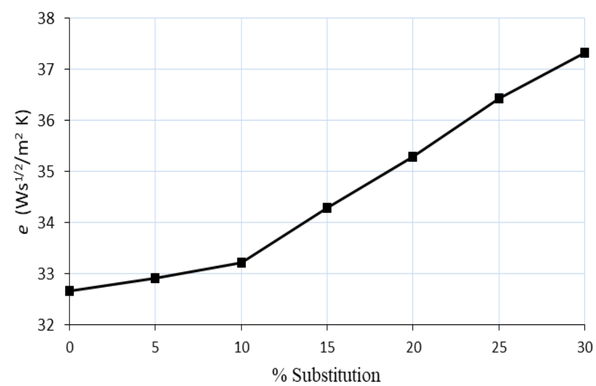
Thermal effusivity, sometimes referred to as the heat penetration coefficient, is the rate at which a material absorbs or dissipates heat. It brings up the feeling of ‘warm’ or ‘cold’ when the material is touched. In Figure 4(b), the thermal effusivity increases with metakaolin content. From the plot, for up to 10% substitution of metakaolin, the increase is very marginal. But thereafter, there was a noticeable increase. The thermal effusivity value for the 30% metakaolin block is 14% higher than that of the 0% sandcrete block. The higher value of thermal effusivity of the metakaolin-blended block increases its ability to conduct heat into or out of the building space faster.

3.2.3 Thermal admittance (h_a)

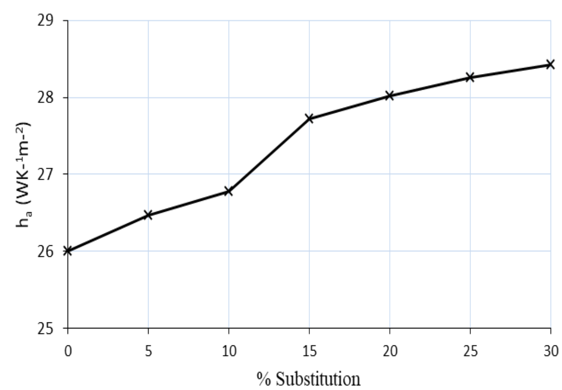
The measure of a material’s ability to absorb or release heat quickly to its environment in response to a cyclic change in temperature of the environment is called thermal admittance. For the metakaolin-blended sandcrete blocks considered, Figure 4(c) shows a steady increase in the thermal admittance with the percentage metakaolin substitution. At a constant block thickness, the thermal admittance increases at the same rate as the thermal conductivity of the block.



(a) thermal diffusivity



(b) thermal effusivity



(c) thermal admittance

Figure 4.Variation of time-response related properties with percentage substitution

3.3 Effect of metakaolin substitution on the insulation related properties

The effect of metakaolin substitution on the insulation related properties comprising of thermal conductance, resistivity, resistance and insulance is also studied.

3.3.1 Thermal conductance (C-value)

When a wall is at different surface temperatures, a measure of the ability of the wall to allow heat to flow through it from the hot surface to its cold surface is referred to as thermal conductance. For a material, the higher the thermal conductance, the higher the heat flow. Figure 5(a) shows the variation of the thermal conductance with percentage substitution of metakaolin. When 5% metakaolin substitutes the cement, the thermal conductance of the block increased to 0.913W/K; an increase of just 1.4% from that of the control. Additional 5% metakaolin substituted increased the C-value by 1.8%. The increase is consistently gradual until it reaches 0.98W/K; an increase of 9% from that of the control. This implies there will be an increase in heat flow through the walls of the space built with the blocks; hence, an increase in the building cooling load during the day but faster rate of losing heat to outer space during the night.

3.3.2 Thermal resistivity (r_t)

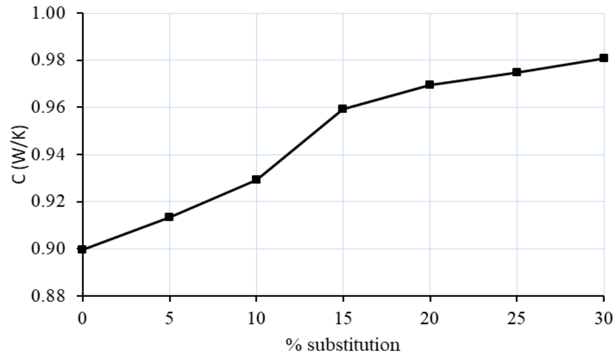
As the percentage substitution increases, a steady decrease is observed in Figure 5(b) for the thermal resistivity of the sandcrete blocks. When 5% metakaolin substitutes the cement, the thermal resistivity of the metakaolin block decreases to 1.2591km/W (a decrease of 1.8%) from that of the control at 1.2821km/W. At 10% metakaolin content, the thermal resistivity value decreased by 1.2%. It reduces to 1.1727km/W at 30% metakaolin substitution below that of the control which is 9.3%. Being the reciprocal of the thermal conductivity, it shows that the ability of the block to resist heat flow through it becomes weakened as the metakaolin content increases. This implies that sandcrete blocks with metakaolin cannot be used as external walls for enclosures requiring heat conservation especially for human comfort in either cold or hot weather.

3.3.3 Thermal resistance (R)

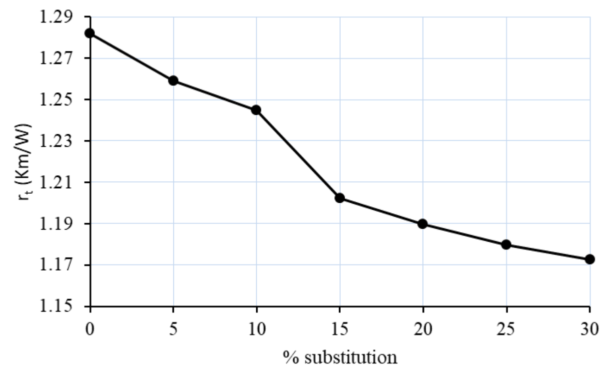
Thermal resistance is the reciprocal of the block's thermal conductance. In Figure 5(c), at 5% metakaolin substitution, the thermal resistance of the sand-cement block reduced by 1.6%. Further gradual drops were observed as percentage substitution of metakaolin in the block is increased. At 30 percent substitution, the block's resistance to heat flow drops to 1.02 K/W; equivalent to about 9% reduction. This means that for every 5% substitution of cement with metakaolin and approximating a linear relationship, the metakaolin block loses its ability to resist heat flow averagely by 1.5%.

3.3.4 Thermal insulance (i_t)

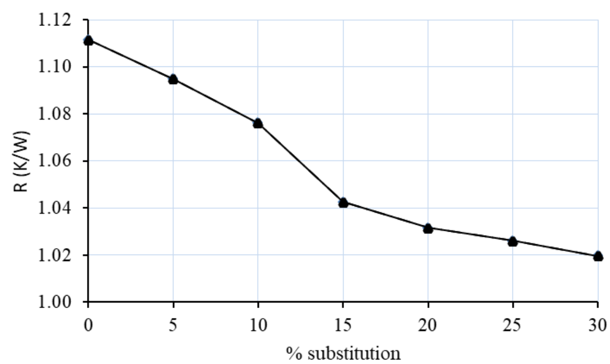
Figure 5(d) shows the variation of thermal insulance with the percentage increase in metakaolin content. In a direct inverse to the thermal admittance, the thermal insulance decreases as the metakaolin content increases. The thermal insulance of 0.0385 Km^2/W for the 0% block reduced to 0.0352 Km^2/W at 30% metakaolin substitution; indicating 9.4 % reduction. Therefore, the difference in value of thermal insulance for every 5% metakaolin substitution is averagely about 1.6%. The result shows that the substitution of metakaolin with cement weakens the insulating power of sandcrete blocks.



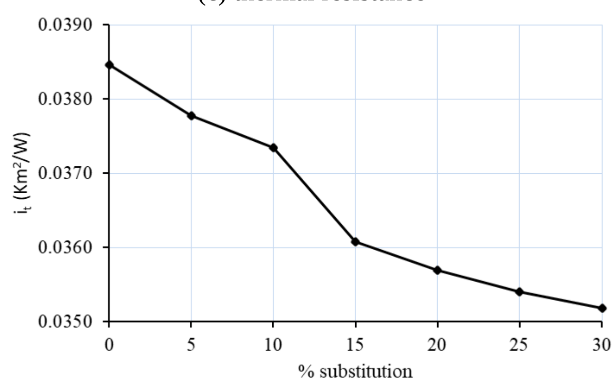
(a) thermal conductance



(b) thermal resistivity



(c) thermal resistance



(d) thermal insulance

Figure 5. Variation of insulation-related properties with percentage substitution

3.4 Case study

Heat transfer characteristics of a building's materials have been of immense importance in the estimate of the heating/cooling load required to determine the capacity of mechanical equipment required to maintain suitable condition within the building, either for human and animal comfort or industrial process. In order to determine the effect of the changes in the thermal properties of sandcrete blocks due to metakaolin substitution on the heating/cooling load, the percentage of heat transfer through walls of a bungalow assumed built with metakaolin-based sandcrete blocks and to be air-conditioned, as shown in Figure 6, was estimated.

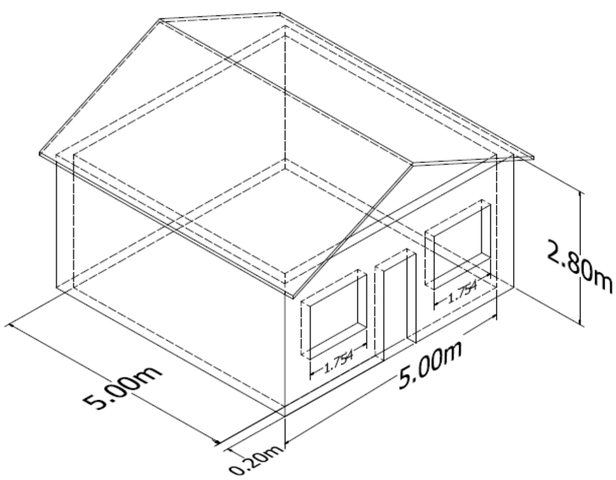


Figure 6: An air-conditioned bungalow

According to ASHRAE (2005), the heat conducted into a building through the outer walls could be about forty percent of the total load required to cool the space. In Figure 7, the changes in the building load within an annual cycle for every 5% substitution of metakaolin in the block is presented.

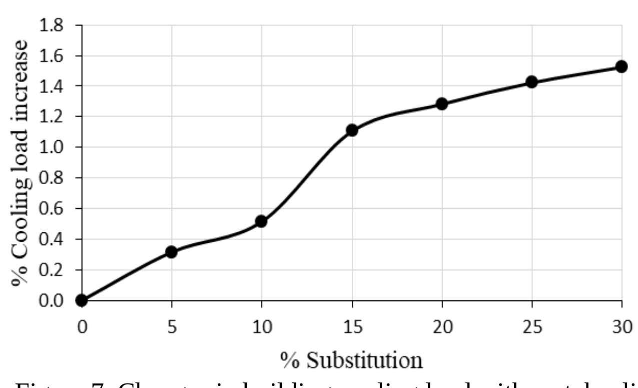


Figure 7. Changes in building cooling load with metakaolin substitution

From the plot, the percentage cooling load increases progressively as the metakaolin content increases. 5% substitution of metakaolin leads to increase of just 0.32%. But at 30%, it increases to 1.52% more than when the control block is used. This increase is better appreciated when multiple large buildings are involved. This is unlike rice-husk-ask-based sandcrete blocks reported by Oyekan and Kamiyo (2011) that the cooling load decreases with percentage substitution.

4. Conclusion

Tests have been conducted to examine the effects of metakaolin on the thermal characteristics of sandcrete blocks when used to partially replace Ordinary Portland Cement. It can be drawn from the analysis of the results that the primary properties, viz, the specific heat capacity and the thermal conductivity of the blocks increase with increasing metakaolin replacement. For the time-response properties, thermal effusivity and thermal admittance increase but thermal diffusivity decreases at higher percentage metakaolin replacement. Thermal resistivity, thermal resistance and thermal insulance, that are insulation related, increase with percentage decrease in metakaolin while thermal conductance increases.

For a building with metakaolin-based blocks, the cooling load will increase with metakaolin content. The practical significance of these results on the thermal characteristics of the sand-cement-metakaolin blocks investigated is the invaluable information revealed to building professionals engaged in the design and analysis of building structures. As suggested by previous investigators (Murali and Scruthee, 2012; Ibrahim and Ocholi, 2020) on the structural advantages of employing metakaolin-based blocks in building construction, the results of this investigation show there is need for caution. Such blocks should rather be used for partitions rather than external walls.

References

Adesanya D.A., Raheem A.A., (2009) Development of corn cob ash blended cement. Construction and Building Materials, Vol.23, 347-352.

ASHRAE (2005) ASHRAE Handbook: Fundamentals SI edition, USA.

ASTM International (2019) Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. ASTM C618-19, USA.

ASTM International (2019) Standard test method for steady-state heat flux measurements and thermal transmission properties by means of the guarded-hot-plate apparatus. ASTM C177-19, USA.

Bentz D. P., Peltz. M. A., Dura´N. H. A., Valdez P. and Jua´Rez C.A. (2011) Thermal properties of high-volume fly ash mortars and concretes. Journal of Building Physics, Vol. 34, No.3, 263–275.

British Standards Institution; (1968) Specification for precast concrete blocks, BS 2028. London.

British Standards Institution; (1996) Specification for Portland cement, BS 12. London.

British Standards Institution; (2018) Determination of particle size distribution – wet sieving method, BS 1377-3. London.

Cassagnabère F., Mouret M., Escaidelas G., Broilliard P., Bertrand A., (2010) Metakaolin a solution for the precast industry to limit the clinker content in concrete: mechanical aspects. *Construction and Buildings Materials*, Vol. 24, Issue 7, 1109-1118.

Dojkov I., Stoyanov S., Ninov J., Petrov B., (2013) On the consumption of lime by metakaolin, fly ash and kaolin in model systems. Journal of Chemical Technology and Metallurgy, Vol.48, 54-60.

Ganesan, K, Rajagopal K, Thangavel K. (2008) Rice husk ash blended cement: assessment of optimal level of replacement for strength and permeability properties of concrete. Construction and Building Materials, Vol.22, 1675-1683.

Guneyisi, E., Gesoğlu M., Mermerdas K., (2008) Improving strength, drying shrinkage, and pore structure of concrete using metakaolin. Materials and Structures, Vol. 41, 937–949.

Ibrahim, M. and Ocholi, A. (2020) Effect of partial replacement of cement with metakaolin on the durability of hollow sandcrete blocks. Nigerian Journal of Engineering, Vol.27, No.1, 6-11.

Kamiyo O.M., Oyekan G.L., (2009) The thermal and hygrothermal properties of sandcrete blocks containing rice husk ash. Journal of Engineering Research, Vol. 14, No. 3, 40-51.

Kamiyo O.M., Oyekan G.L., (2011) Thermal, hygrothermal and Structural properties of sandcrete blocks produced with coconut husk ash blended cement, Journal of Engineering Research, Vol.16, No.3, 80-89.

Kolovos K.G., Asteris P. G., Tsivilis S., (2016) Properties of sandcrete mixtures modified with metakaolin. European Journal of Environmental and Civil Engineering, Vol. 20, No.1, 18–37.

Kolovos K. G., Asteris P. G., Cotsovos D. M., Badogiannis, E., Tsivilis, S. (2013) Mechanical properties of soilcrete mixtures modified with metakaolin. Construction and Building Materials, Vol.47, 1026–1036.

Mo K.H., Ling T.C., Alengaram U.J., Yap S.P., Yuen C.W., (2017) Overview of supplementary cementitious materials usage in lightweight aggregate concrete. Construction and Building Materials, Vol.139, 403–418.

Mohammed B., Cheeseman C. R., (2011) Use of oil drill cuttings as an alternative raw material in sandcrete blocks. Waste and Biomass Valorization, Vol. 2, 373–380.

Muntohar A. S., Rahman M. E., (2014) Light weight masonry block from oil palm kernel shell. Construction and Building Materials, Vol.54, 477–484.

Murali G., Scruthee P., (2012) Experimental study of concrete with metakaolin as partial replacement of cement. International Journal Emerging Trends in Engineering and Development, Vol. 4, No.2, 344-348.

Nimityongskul P., Daladar T.U., (1995) Use of coconut husk ash, corn ash and peanut shell ash as cement replacement. Journal of Ferrocement. Vol.25, No.1, 35-44.

Nwaigwe D.N., Ogwu E.A., Ugonna M.C., Atakpu O.D., Edom v .A., (2015) Evaluation of the Quality of Hand Moulded Sandcrete Block in Owerri. Journal of Sustainable Development Studies, Vol. 8, No. 2, 251-254.

Oktay H., Yumrutaş R., Akpolat A., (2015) Mechanical and thermophysical properties of lightweight aggregate concretes. Construction and Building Materials, Vol. 96, 217-225.

Omoregie A., (2013) Optimum compressive strength of hardened sandcrete building blocks with steel chips. Buildings, Vol.3, 205–219.

Oyekan G. L., Kamiyo O. M., (2011) A Study On The Engineering Properties Of Sandcrete Blocks Produced With Rice Husk Ash Blended Cement. Journal of Engineering and Technology Research, Vol. 3, No.3, 88-89.

Oyekan G.L., Kamiyo O.M., (2008) Effects of granite fines on the structural and hygrothermal properties of sandcrete blocks. Journal of Engineering and Applied Science, Vol. 3, No. 9, 735-741.

Rezende, M. L., Barbosa do Nascimento, J.W., Neves, G., Ferreira, H.C., (2015) The effect of metakaolin on the durability of concrete hollow blocks used in masonry: evaluation of degradation caused by driving rain. Rem: Revista Escola de *Minas.* Vol.68, No.1, 21-27.

Seo T., Lee M., Choi C., Ohno Y., (2010) Properties of drying shrinkage cracking of concrete containing fly ash as partial replacement of fine aggregate. Magazine of Concrete Research, Vol.62, 427–433.

Siddique R., Klaus J., (2009) Influence of metakaolin on the properties of mortar and concrete: A review. *Applied Clay Science*, Vol. 43, 392-400.

Sonebi M., Lachemi M., Hossain K. M. A., (2013) Optimisation of rheological parameters and mechanical properties of superplasticised cement grouts containing metakaolin and viscosity modifying admixture. Construction and Building Materials, Vol. 38, 126–138.

Srivastava V., Kumar R., Agarwal V.C., Mehta P.K., (2012) Effect of silica fume and metakaolin combination on concrete. International Journal of Civil and Structural Engineering, Vol.2, No.3, 893-900.

Standards Organisation of Nigeria (2000) Standard for cement, NIS 439, Lagos.

Vejmelkova E. M., Pavlikova M., Keppert M., Kersner Z., Rovnanikova P., Ondracek M., Sedlmajer M., Cerny R., (2010) High performance concrete with czech metakaolin: Experimental analysis of strength, toughness and durability characteristics. Construction and Building Materials, Vol.24, Issue 8, 1404–1411.