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Activated Charcoal as a Component of Mortar Material for Thermal Insulation of Buildings

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ABSTRACT

The main objective of this paper is to assess the feasibility of the application of activated charcoal (AC) that could be used as a component of mortar material for thermal insulation. To achieve the objective, several specimens were prepared by varying the content of AC in the mortar, and then the physical and mechanical properties of those specimens were tested. The result indicates a significant decrease in the compressive strength (13.33 MPa to 7.07 MPa at 28 days) with an increase in AC content [cement: AC - 1:2 (v/v) to 1:2.5 (v/v)] in the mortar. However, beyond a certain point [1:2.5 (v/v) to 1:4 (v/v)], the decrease in compressive strength is comparatively smaller (7.07 MPa to 4.71 MPa in 28 days). The thermal conductivity of cement-AC mortar is reduced by 54 - 71% compared to that of a mortar containing cement–sand. Overall, the study indicates that the incorporation of AC in the mortar has resulted in a significant reduction in thermal conductivity, with an acceptable range of compressive strength. The compressive strength of the mortar is within the permissible limit for a load-bearing structure having a cement to AC ratio up to 1:2.5. The composition having a cement to AC ratio within 1:4 could be used as mortar for non-load bearing structures

Keywords: **Activated charcoal, Building material, Compressive strength, Thermal conductivity, Mortar**

1. INTRODUCTION

Heat transmission from a building envelope constitutes a large part of the energy loss that eventually impacts the operational cost of a building. Traditionally, applications of regional insulating material in building construction were well adopted. However, with the exponential increase in construction in developing countries and extensive exploitation of energy, energy-saving design has become a serious concern. Buildings consume a lot of energy, water, and materials during their construction and operation. It is predicted that buildings will consume approximately one-third of the global energy and water by the next decade, which will cause more than 40 billion tons of carbon emissions annually [1]. It is also estimated that carbon emissions could be doubled by 2050 if suitable precautionary measures are not adopted [2]. Several researchers and commercial communities are exploring the possibility of the application of energy-saving construction materials. For example, the performance of various inorganic mineral-derived insulating materials such as stone wool, glass wool, glass foam, vermiculite, expanded clay, and organic plants or animal-derived materials such as wood fiber, cork, cellulose, straw bale, cotton, hemp, flax, sheep wool, reeds, miscanthus fiber, wheat straw, orange peel waste, date palm fiber, coconut fiber, sugarcane fiber, corn cob, etc. have been tested to be used as the building material for their energy-saving capabilities. Some recent studies have also explored the possibility of applications of innovative materials such as aerogels, vacuum insulation panels, nano insulation material, textile fibers, and recycled polyethylene terephthalate [3, 4]. The optimum level of thermal insulation in buildings not only helps to minimize the energy expenses but also contributes to the overall comfort. With the development of green technologies, there is a potential for saving almost 40-50% of energy through smart design [5]. Insulation in buildings is shouldering enormous importance and has the prospective to reduce up to 5-8% of energy consumption [5]. The introduction of building insulating material is important for achieving energy-efficient buildings. Numerous studies [6–10] have reported the possibility of applications of gypsum composites incorporating aerosol, ventilated channels. Cement mixed with sawdust and polystyrene material, stone wools (rolls/panels), glass wool, extruded polystyrene (XPS), and expanded polystyrene (EPS) are explored to be used in the roof as insulation materials. Ouhaibi et al. [6] reported that a gypsum aerosol composite could show high thermal performance and low density, which can be used as a thermal insulation material. Sakiyama et al. [7] showed that aerogel-based composite has low thermal conductivity, and it does not possess significant harmful effects over its lifetime. Borodulin and Nizovtsev [8] demonstrated that thermally insulated panels with ventilated channels are effective in eliminating water vapor from the insulation, which can provide a normal humidity regime in the building. Issa et al. [9] found that the application of cement, sawdust, and polystyrene in the composite can result in low thermal conductivity and good sound insulation and limit the risk of sawdust pollution in the environment. It is reported that the stone wool rolls exhibit low embodied energy, low rate of CO/CO2 emission during production, and better fire-resistant and soundproof capacity. Stone wool panels are also non-flammable material with good mechanical stability. Glass wool being resistant to microorganisms, is a non-flammable material with excellent sound insulation capacity; however, it has poor waterproofing quality. XPS and EPS have good thermal insulating and recycling properties. However, their main limitation is high embodied energy which can hurt the ozone layer. Sheep wool, on the other hand, is an eco-friendly material with excellent sound insulation properties; however, it is expensive and highly hygroscopic [10]. The application of solid waste-generated material in building construction aiming for the reuse and recycling of waste is a relatively new concept. Several researchers [11–15] have explored the possibility of the reuse of demolition waste as aggregate in building construction, which is expected to provide a more economical and environment-friendly solution [16–18]. The type of replaced material varies depending on the availability of materials and their uses [19, 20]. Activated charcoal (AC) is the material used extensively in the water purifications sector, and a huge amount of contaminant containing AC waste is produced after treating the water. In 2020, the global AC market reached around USD 4 billion, and by 2026, the market is predicted to grow 1.6 times larger. In a few studies, the possibility of applications of AC has been explored for specific purposes in building construction. For example, Chowdhury [21] found that AC-containing cement mortar has the potential ability to resist moisture ingress. Krou et al. [22] demonstrated that the presence of AC in hydrated cement paste reduces the reactivity of volatile organic compounds (VOCs) in cement mortar. VOCs are found in paint, paint thinners, wood materials, stored fuels, tobacco smoke, etc. The ACs being good adsorbents of VOCs can be used as an additive material in cement concrete to improve the quality of air. Few studies [23, 24] suggested that the application of powdered AC as a binder in concrete increased compressive strength. This is mainly attributed to the fact that the pores and air voids in the concrete reduce due to the presence of AC powered, which improves compressive strength. Zhang et al. [25] conducted experiments using four different types of AC i.e. coconut shell, fruit shell, wood, and coal in concrete. They showed zero bleeding in concrete when 10% and 15% ACs were used in it. Coconut shell-derived AC showed the highest reduced radon exhalation rate of concrete, followed by fruit shell, coal, and wood-based ACs, respectively. Zheng et al. [26] demonstrated that 4% (w/w) of AC content in cement mortar containing 20% (w/w) fly ash increases the compressive strength of the concrete significantly. In another study, Justo-Reinoso et al. [27] demonstrated that the compressive strength and tensile strength of concrete have increased when granular ACs are used as a partial replacement for fine aggregates. Porosity and critical pore diameter of the samples were reduced due to the addition of AC [< 1% (w/w)]. Lekkam et al. [28] showed that saturated AC powder results in a denser microstructure by filling the pores and improves the quality of hydration reaction products. Substitution of 4% cement by the ACs has resulted in a 4% reduction of CO2 emission to the atmosphere. Few studies have explored the possibility of applying ACs in the mortar or other building blocks and indicated potential performances. Given the porous structure and low thermal conductivity of ACs, it might also act as a good insulating material. To the best of the authors’ knowledge, not many studies have explored the thermal and mechanical characteristics of mortar when ACs are used as fine aggregate. Furthermore, the consumption of AC in building construction can also reduce the AC-based solid waste generated at the end of the lifecycle of the water purification system. Thus, this study aims to assess the feasibility of the application of activated charcoal (AC) that could be used as a component of mortar material for thermal insulation. To achieve the objective, mortar specimens are cast with varying content of AC, and the compressive strength, thermal conductivity, and thermal diffusivity are tested for those specimens. The samples are de-molded after 24 hours of casting and then cured for 7 days and 28 days before conducting compressive stress strength tests.

2. MATERIALS AND METHODS

2.1. MATERIAL AND SPECIMEN PREPARATION

The activated charcoal was obtained from Parth Multi Aqua Pvt. Ltd. Hanuman Nagar, Kankarbagh, Patna, India. It is a granular material. The cement used in this study is Portland Pozzolana Cement (PPC) fly ash based conforming to IS:1489 (Part 1) [29] which is obtained from UltraTech Cement Limited. For control mortar, sand of grading Zone II conforming to IS 383 [30] was used. In this study, a series of specimens were prepared by varying cement to AC ratios ranging from 1:2 (v/v) to 1:4 (v/v), as detailed in Table (1). To ensure the consistency and workability of the samples, the water content varied slightly. Control mortar containing cement-sand of ratio 1:2 (v/v) was also prepared for reference purposes. For the preparation of each mortar mix, first, the appropriate volume of AC, and cement was measured that is required for each condition, and mixed thoroughly in a pan for 3 minutes. Then, potable water was slowly added to the mixture and mixed uniformly for 4±1 minutes to make a homogeneous, workable, and consistent mortar mix. The material was filled in 50 mm × 50 mm × 50 mm cube mold uniformity. Finally, the upper surface of the mix was kept in the same level of mold by leveling it with a trowel presented in Figure (1). The samples were left for 24 hours at ambient temperature before demolding. One set of samples was cured for 7 days, and the rest were kept for 28 days for compressive strength testing.

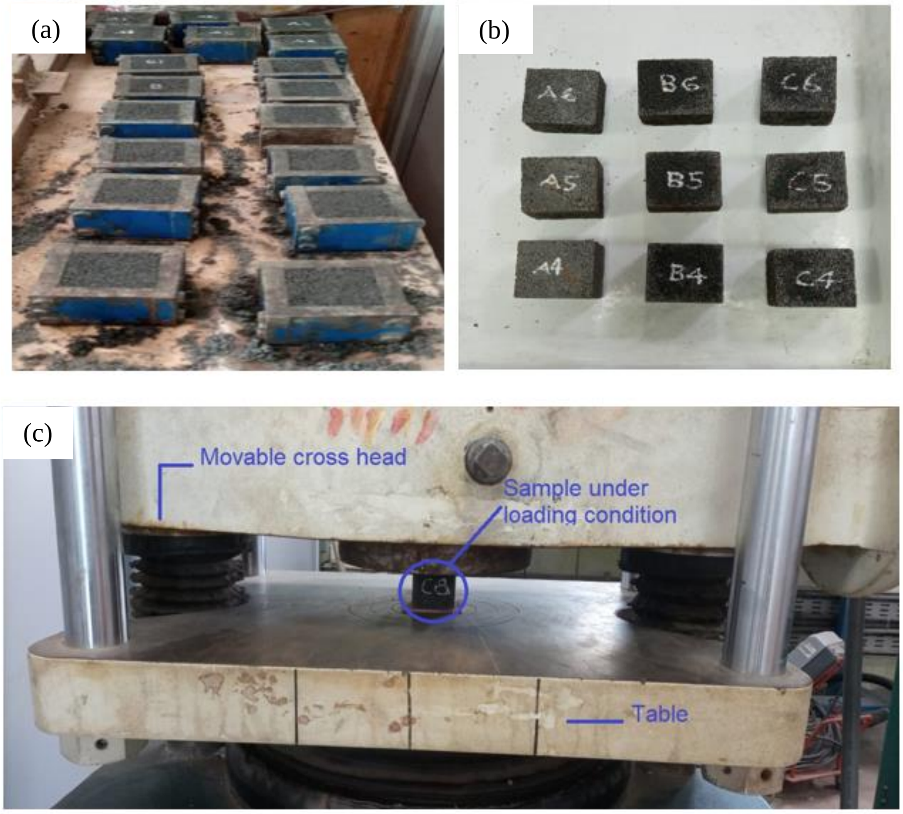

Figure 1. The specimens (a) after preparation of mold, (b) de-molded after 24 hours, and (c) during testing of compressive strength under UTM

2.3. CHARACTERIZATION OF AC-CEMENT MORTAR SPECIMENS

The standard sieves were used for the determination of the particle size of AC. The sieves have openings ranging from 75 µm to 4.75 mm. The particle size distribution of AC was obtained following the standard method as given in IS 2386 (Part 1) [31].

2.4. SEM IMAGE ANALYSIS

The surface morphology of ACs and all the mortar samples were imaged through Field Emission Scanning electron microscopy (FE-SEM, SEM-500 ZEISS, Gemini, Germany). A thin layer of mortar slice (10 mm x 10 mm) was cut from the cement-AC composite sample at the end of 28 days. The samples were then dried in an oven at 60oC for 24 h coated with gold spray before imaging.

2.5. FTIR ANALYSIS

The chemical bonding at the surface of the mortar is identified with Fourier Transforms Infrared analysis (FTIR, NICOLET iS50, Thermo Fisher Scientific, India). The samples were prepared by grinding a small piece of mortar such that the size becomes less than 90 µm. Then, 1 mg of mortar was taken and mixed with 300 mg of potassium bromide (KBr) powder to form a pellet for FTIR measurement. The samples were subjected to infrared radiation, and transmission spectra were recorded with wavelengths ranging from 400 to 2000 cm-1.

2.6. COMPRESSIVE STRENGTH TESTS

The compressive strength of 50 mm x 50 mm x 50 mm mortar cubes prepared with cement to AC ratios of 1:2 (v/v), 1:2.5 (v/v), 1:3 (v/v), 1:4 (v/v) and control mortar of ratio 1:2 (v/v) was assessed after 7 and 28 days of casting. Test specimens were kept for curing by covering them with a gunny bag and curing daily at room temperature. Samples were tested in Universal Testing Machine (UTM, Tinius Olsen India Pvt. Ltd. Noida, India) following the method given in ASTM C 109 [32], where a uniaxial compressive load of 1 mm/minute was applied, and the ultimate loads were recorded. The method of testing was displacement control. The photograph of the sample specimen during molding, after demolding, and during testing with UTM are presented in Figure (1). In this study, all these molds were cast in triplicates, and the average strength values were reported.

2.7 THERMAL CHARACTERISTICS

Any material's thermal diffusivity indicates the heat transfer rate with the surrounding. Where thermal conductivity refers to the transfer of heat through a homogeneous material due to a unit temperature gradient [33]. In this study, the thermal diffusivity and conductivity of the samples having varying content of AC and control mortar were measured following the method reported elsewhere [34]. For sample preparation, a core of dimension 15 mm x 15 mm x 15 mm was cut from the broken sample generated after 28 days of compressive strength testing. The samples were then tested with the LFA 447 Nanoflash system (NETZSCH-Gerätebau GmbH, Germany) from the Department of Mechanical Engineering, IIT Kanpur, India. Four samples were tested for thermal properties, and the average value with standard deviation is reported.

3. RESULTS AND DISCUSSION

3.1. CHARACTERISTICS OF AC

The grain size distribution, SEM image analysis, and the thermal conductivity of ACs collected from the market are assessed. The sieve analysis of the AC indicates the average grain size (d50) of AC is 0.7 mm. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) of the AC are 2.11 and 0.67, respectively, which indicates that the AC used in this study is poorly graded with a uniform size of grains. The SEM image in Figure (2a) indicates that the AC has a rough surface with surface irregularities, and the presence of crystal structure at the surface in the size range of 1-2 µm is observed. The SSA of AC is measured using a BET analyzer (Autosorb 1C, Quantachrome Instruments, USA), and it is found to be 155.172 m2 g−1. The thermal conductivity of AC is as low as 0.27±0.03 W/m·K.

3.2. PHYSICOCHEMICAL CHARACTERISTICS OF AC-CEMENT MORTAR CUBES

3.2.1. SEM Image Analysis

The SEM image of AC and four different mortar specimens having cement to AC ratio of 1:2 (v/v), 1:2.5 (v/v), 1:3 (v/v) and to 1:4 (v/v) was analyzed. The image presented in Figure (2) indicates that the surface morphology of mortar with the cement to AC ratio of 1:2 (v/v) becomes more uniform and crystalline compared to the surface of AC. The surface roughness has also been reduced in the mortar than that of AC. With an increase in AC content in the cement-AC mortar from 1:2 (v/v) to 1:4 (v/v), the surface morphology becomes comparatively non-uniform with the appearance of an irregular crystalline structure. These morphological changes in the mortar with an increase in AC content may indicate an increase in the porous nature of the mortar.

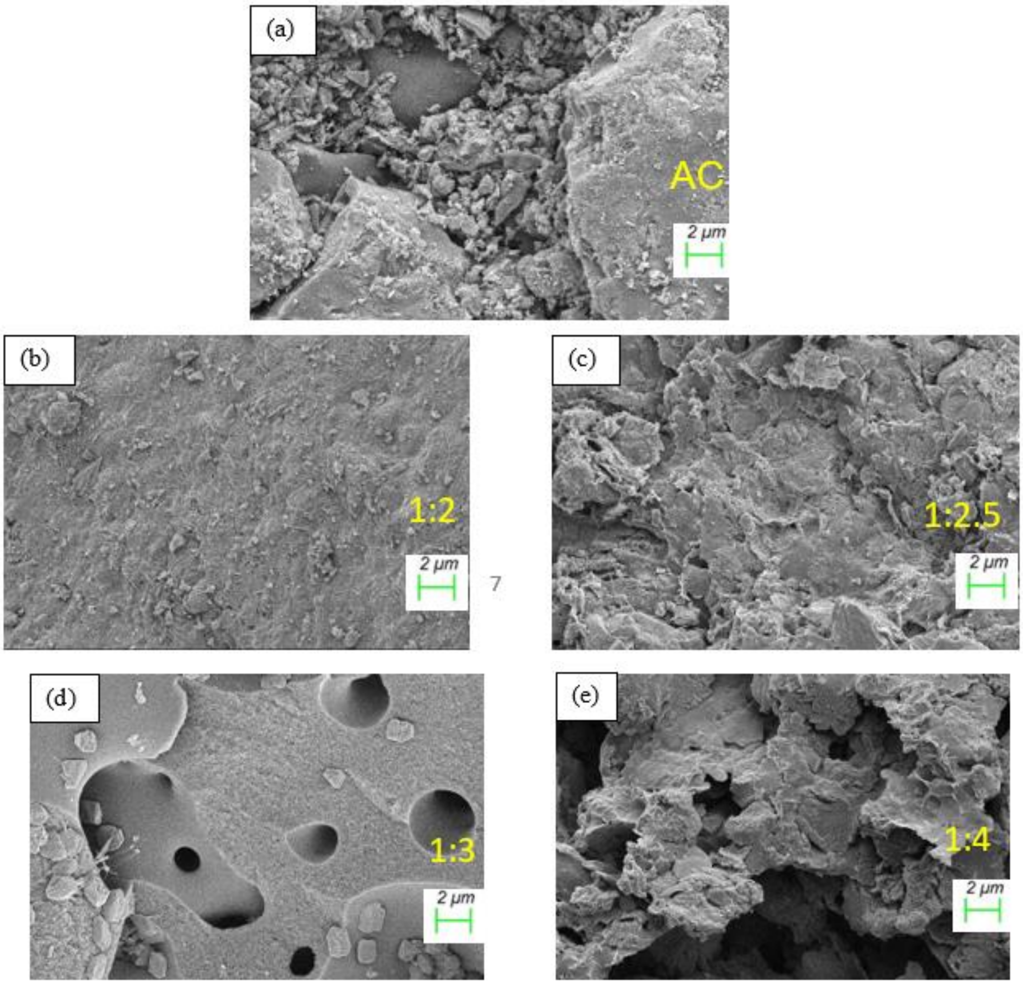

Figure 2. SEM of (a) AC, and different mortar having cement to AC ratio of (b) 1:2 (v/v), (c) 1:2.5 (v/v), (d) 1:3 (v/v), and (e) 1:4 (v/v). The image was taken at operating voltage of 5 kV and the magnification of 5000X

The porous structure in the mortar with the increase in AC content is likely to result in less thermal conductivity in those mortars and less compressive strength, as discussed later. Frías et al. [35] reported that with an increase in AC content, the strength of the specimen decreases due to the presence of spherical pores. The cavities of granular AC produce these air voids. The results are in agreement with the observations reported in Lekkam et al. [28]. The authors suggested the formation of a large number of air voids in the mortars due to the presence of AC powder that contains micropores of varying diameters.

3.2.2. Bulk Density

After demolding the cubes for 24 hours, the weight of the sample was measured. The dimensions of each side of the mold were measured with a scale to calculate volume. The bulk density of each set of samples is calculated as the mass of mold per unit volume. Finally, the average of six samples of each set is reported in Table (1).

3.2.3. FTIR Analysis

FTIR analysis of AC and mortar having a cement to AC ratio of 1:2.5 (v/v) was conducted to identify the chemical interactions due to cement-AC interaction and the functional groups present at the surface of AC and mortar. The peak appearing at 875 cm-1 for the mortar corresponds to the Si-O band. It is probably indicating that the mortar contains silica, which is likely to be a component in cement. The infrared spectrum is shown in Figure (3) reveals that there is a slight relative shift in the peaks in the mortar due to AC-cement interactions. The main vibrations of AC are 1085, 796, 695, and 475 cm-1. The absorption band at 1085 cm-1 corresponds to the stretching vibration of the C-O bond. The absorption band at 796 and 695 cm-1 correspond to the C-H out-of-plane vibration of aromatic ring structures. A broad infrared absorption at 1421 cm-1 is caused by asymmetric stretching in 1:2.5 (v/v) mortar. One more broad peak at 1091 cm-1 and a slightly narrow peak at 465 cm-1corresponds to Si-O vibration. The band at 797 cm-1 corresponds to Si-OH vibration mode. When AC is combined with hydrated cement, the existence of an absorption band at 711 cm-1 verifies the creation of the calcite phase of $CaCO_3$ particles. The position of these bands is in agreement with the findings of a number of previous literature [36–41].

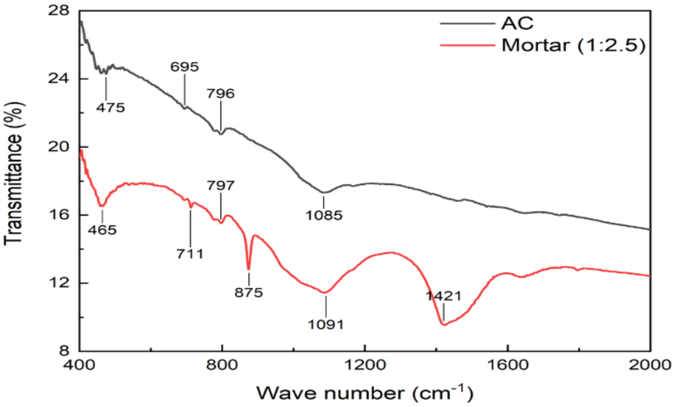

Figure 3. FT-IR Spectral of AC and mortar having cement to AC ratio of 1:2.5

3.3. COMPRESSIVE STRENGTH OF AC-CEMENT MORTAR CUBES

Compressive strength of mortars having varying content of AC [cement: AC - 1:2 (v/v) to 1:4 (v/v)] and control mortar [cement: sand – 1:2 (v/v)] was tested after 7 days and 28 days of casting. Three molds were tested for each condition, and average values of compressive strength with standard deviation are presented in Figure (4) and Table (1). The compressive strengths at 7 days are 10.55±0.98 MPa, 4.04±0.52 MPa, 3.44±0.18 MPa, 2.75±0.26 MPa and at 28 days are 13.33±1.22 MPa, 7.07±0.56 MPa, 5.05±0.19 MPa, 4.71±0.75 MPa for the mortars having cement to AC ratios of 1:2 (v/v), 1:2.5 (v/v), 1:3 (v/v), and 1:4 (v/v), respectively. The compressive strength of the control mortar at 7 days is 22.83±1.80 MPa and at 28 days is 33.57±2.36 MPa. The result indicates that the compressive strength of mortar having a cement to AC ratio of 1:2 (v/v) is reasonably high. However, there is a drastic decrease in compressive strength with an increase in AC content from 1:2 (v/v) to 1:2.5 (v/v), as shown in Figure (4). The reduction in compressive strength is relatively low with a further increase in AC content. This observation matches well with the SEM image, which suggests the porous nature of the structure is more evident with an increase in AC content. The less porous and denser crystalline structure of mortar having cement: AC of 1:2 (v/v) possesses better compressive strength. The water-cement ratio is another factor that can influence the compressive strength of mortar. In this study, the water-cement ratios varied slightly (between 0.9 to 1.4) to maintain the workability and consistency of the mortar mix [42]. It is important to note that the compressive strength has reduced significantly with an increase in AC content from 1:2 (v/v) to 1:2.5 (v/v), although there was a negligible increase in water-cement ratio from 0.9 to 1. This observation indicates that the content of AC has a predominant role in altering the compressive strength rather than the water-cement ratio, especially in the working conditions. Na et al. [43] found that adding activated carbon up to 1.5 % (w/w) had higher compressive strength over the curing period than the control mortar without AC. The filling of micropores with AC powder is responsible for the increase in compressive strength, especially up to an AC content of 1.5%. When AC content is increased above 1.5%, hydration of cement is hindered due to the lack of water in the cement. The application of a large amount of AC resulted in a decrease in strength because the intrinsic compressive strength of AC granules is weaker than that of sand. Wang et al. [44] reported that the compressive strength of mortar has increased when 0.5-2% (w/w) of AC is used in the powder form. This is because pores and air voids in the concrete get reduced due to the presence of powdered AC, which improves compressive strength. This is in agreement with the results of Lekkam et al. [28], where the addition of 0.5% and 1% of saturated AC powder resulted in an increase in the compressive strength of mortar. However, the addition of more than 4% of AC resulted in a decrease in the compressive strength of the mortar. The compressive stress-strain curves for four mortars with varying content of ACs are presented in Figure (5). The stress-strain curves of the specimens at the ages of 7 days and 28 days exhibit a linear relationship initially. However, as the stress level reaches the maximum, the curves become non-linear. The expansion of the existing cracks in the specimens is linked with the descending branch following the peak stress. With an increase in AC content, initial slope and peak stress decreased for both 7 days and 28 days test. This is likely to be attributed to the fact that AC has a lower modulus of elasticity and poorer bonding strength compared to that cement and sand. The specimens undergo more significant plastic deformation with a lower rate of decline in post-peak strength with the increased proportion of AC Aocharoen and Choticka i [45].

Table 1. Mix design details of cement and AC composite mortar

Cement- AC ratio (v/v)	Water- cement ratio (v/v)	Bulk density (g/cm^3)	Avg. 7 days comp. str. (MPa)	Avg. 28 days comp. str. (MPa)
1:2	0.9	1.42	10.55±0.98	13.33±1.22
1:2.5	1.0	1.34	4.04±0.52	7.07±0.56
1:3	1.3	1.14	3.44±0.18	5.05±0.19
1:4	1.4	1.11	2.75±0.26	4.71±0.75

Overall, the result suggests that all four compositions can be used as a component of mortar material for non-load bearing walls, given the 28 days of compressive strength those are greater than the permissible limits of 2.4 MPa as given in ASTM C270 [46]. The compositions having the cement to AC ratio of 1:2 (v/v) and 1:25 (v/v) could also be used as a component of mortar material for the load-bearing wall as the 28 days' compressive strength of those compositions exceeds the permissible limits of 5.2 MPa that are recommended for load-bearing walls as given in ASTM C270 [46].

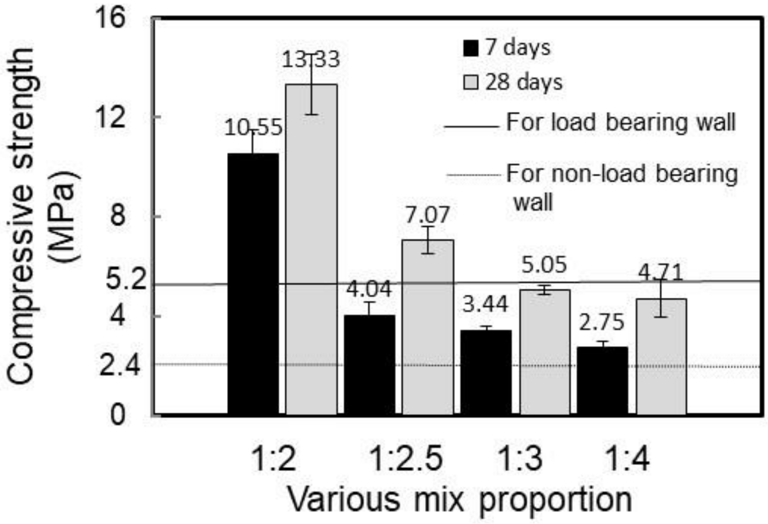

Figure 4. Result of compressive strength both at 7 and 28 days

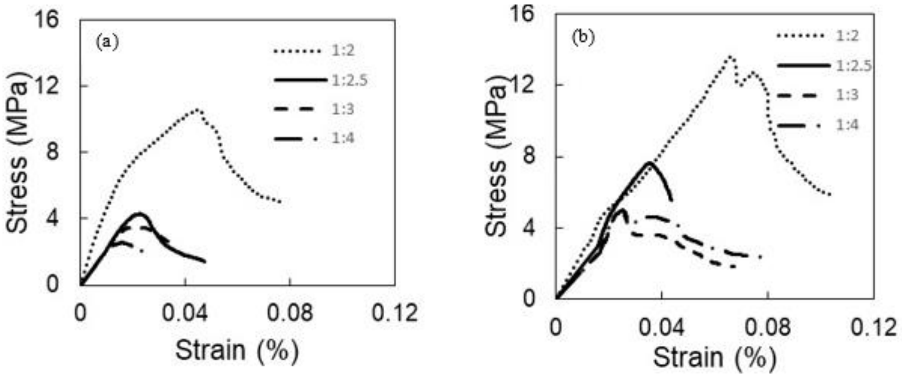

Figure 5. Stress-strain curves of different samples tested after (a) 7 days and (b) 28 days

3.4. THERMAL CHARACTERISTICS OF AC-CEMENT MORTAR

Thermal conductivity and thermal diffusivity of AC and four different mortars are measured following the procedure discussed above. The results are summarized in Table (2) and in Figure (6). Thermal conductivity of mortars with cement-AC ratios of 1:2 (v/v), 1:2.5 (v/v), 1:3 (v/v) and 1:4 (v/v) are 0.76±0.02 W/m.K, 0.71±0.02 W/m.K, 0.57±0.02 W/m.K and 0.48±0.02 W/m.K respectively. The thermal conductivity of AC is as low as 0.27±0.03 W/m.K, where the value of conductivity is 1.67±0.05 W/m.K obtained for the control mortar when only sand is used as the fine aggregate. The results clearly indicate a reduction in thermal conductivity with the increase in AC content in the mortars presented in Table (2) and Figure (6). The incorporation of AC in cement has resulted in a reduction of 54% and 71% in thermal conductivity for mortar having cement to AC ratios of 1:2 (v/v) and 1:4 (v/v), respectively. The mortars with cement-AC ratios of 1:2 (v/v), 1:2.5 (v/v), 1:3 (v/v) and 1:4 (v/v) have the thermal diffusivities of 0.54±0.017 mm^2/s, 0.45±0.01 mm^2/s, 0.44±0.01 mm^2/s and 0.45±0.02 mm^2/s respectively. On the other hand, the measured thermal diffusivity of AC is 0.72±0.10 mm^2/s, whereas the measured value of the same for the control mortar is 0.94±0.01 mm^2/s. The result indicates that the rate of transfer of heat has reduced in cement-AC mortars compared to both the AC and the control mortar. The value of diffusivity decreases slightly as the AC content increases from 1:2 (v/v) to 1:2.5 (v/v), and then it becomes stable with a further increase in AC content. This observation indicates that the rate of change of heat energy is less in the mortar having a cement to AC ratio of more than 1:2 (v/v). The presence of more air voids might have resulted in less diffusivity in those mortars having higher AC content. Overall, the results indicate that the mortar's thermal diffusivity and thermal conductivity decrease with a reduction in the density. AC-cement mortars having lower densities show lower thermal diffusivity and thermal conductivity. Those are likely to be better insulation materials both in steady and transient thermal conditions. This is because the air inside the pores has a lower thermal conductivity than other mortars, which prevents heat from being transferred between the two surfaces of the construction material. This observation is also in accordance with the SEM image and compressive strength test results, which show that an increase in AC content in mortar has made the mortar more porous. That eventually resulted in more air voids, better insulation, and a reduction in compressive strength of mortar having low cement to AC ratio.

Table 2. Result of thermal conductivity and thermal diffusivity

Binder-AC ratio (V/V)	Thermal conductivity (W/(m·K))	Thermal diffusivity ($mm^2 s^{-1}$)
1:2	**0.76±0.02**	**0.54±0.017**
1:2.5	**0.71±0.02**	**0.45±0.01**
1:3	**0.57±0.02**	**0.44±0.01**
1:4	**0.48±0.02**	**0.45±0.02**
AC	**0.27±0.03**	**0.72±0.10**

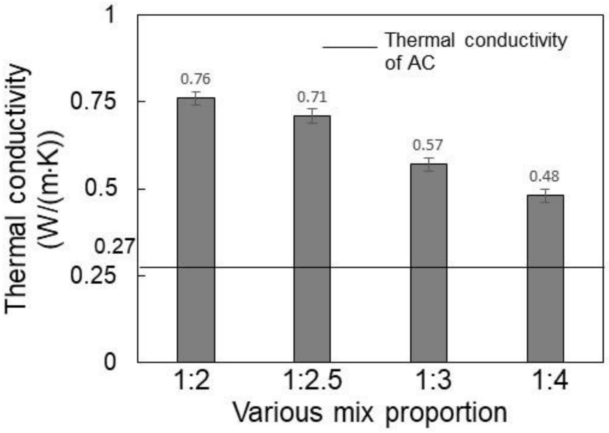

Figure 6. Thermal conductivity of mortars having various cement-AC ratios

4. CONCLUSION

Heat transmission from a building envelope results in extensive loss of energy. On the other hand, a large amount of AC is generated as waste from the water purification industry, which is likely to have less thermal conductivity. The main focus of this study is to assess the feasibility of the application of AC that could be used as a component of mortar material for thermal insulation. A series of specimens are prepared with varying content of AC, and their physical, mechanical, and thermal properties are assessed. This study shows a significant reduction in thermal conductivity with the increase in AC content in the mortars, where the thermal diffusivity decreases slightly. The compressive strength of mortar having a cement to AC ratio of 1:2 (v/v) is reasonably high. However, there is a drastic decrease in compressive strength with an increase in AC content from 1:2 (v/v) to 1:2.5 (v/v), and then the reduction of compressive strength is relatively low with a further increase in AC content. The presence of AC in mortar resulted in more air voids, better insulation, and reduced compressive strength. Overall the study suggests that the AC could be used as a component of mortar material for the thermal insulation of buildings. Furthermore, the cement to AC ratio up to 1:2.5 (v/v) can be used as a component of mortar material for load-bearing structures. In contrast, it could still be used as mortar material for non-lead bearing structures with the cement to AC ratio up to 1:4 (v/v).

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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