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Evaluation of physical properties of autoclaved aerated concrete (AAC) based glass-gypsum waste into concrete

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Abstract

The world produces billions of tonnes of municipal solid waste (MSW) yearly, with part of it not being disposed of properly. To approach sustainable development and reduce waste in landfill, using waste in material production is proposed. According to the World Green Building Council, construction projects have expanded and demand for green buildings is likely to increase in the next three years. Autoclaved aerated concrete (AAC) is considered as an environmentally friendly product compared to standard concrete and bricks. This paper aims to investigate the influence of glass waste (GW) and gypsum wastes as additional materials on the physical properties and compressive strength of AAC is to determine the optimum proportion of GW addition to produce AAC based glass-gypsum waste (AAC-GGW) and to compare the properties of AAC-GGW with reference sample. The materials used were ordinary Portland cement (OPC), quartz sand, lime, aluminium paste, GW and gypsum waste. The ratios of all materials were kept constant except GW with increment of 0%, 5%, 10%, 15%, 20%, 25%, and 30%. The density, water absorption, porosity, and average compressive strength of the samples were measured and compared. It was found that increasing GW increased the samples' density and decreased the samples' water absorption and porosity. It was also found that addition of GW from 5 to 25% achieved better average compressive strength than reference sample with no addition of GW. Maximum compressive strength was achieved at 20% GW addition.

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1.0 Introduction

Every year, the planet produces 2.01 billion tonnes of municipal solid waste, with at least 33% of it not being handled in an environmentally sound manner. Looking ahead, global waste is estimated to reach 3.40 billion tonnes by 2050, more than double the rate of population growth during that period according to (The World Bank Group, 2021). Global glass recycling volumes are currently projected to be 27 million tonnes, accounting for just 21% of total output. Container glass has the highest recycling rates, at 32% on average, while flat glass has a recycling rate of only 1% (Tiseo, 2020).

According to the World Green Building Council, construction projects have expanded considerably in recent years around the world and demand for green buildings is likely to increase in the next three years. Green buildings are becoming increasingly widespread as a result of an increase in the number of efforts made by various organisations. Furthermore, in the coming years, the growing adoption of green construction concepts, as well as the widely available raw materials, are projected to fuel demand for green concrete

(Market Research Future, 2021). Autoclaved aerated concrete (AAC) is considered an environmentally friendly material because it is energy efficient, cost-efficient and recyclable (Kamal, 2020). The advantages also include thermal and sound insulation, excellent fire resistance, high resource and energy efficiency, outstanding structural performance, low density, low shrinkage, high compressive strength, low cost product, high termite resistance, high thermal mass stores and releases energy over time, easy handling and installation due to light weight, easy to cut for chases and holes for electrical and plumbing lines, and its economical shipping and handling compared to the commercial concrete block (Arslan et al., 2021; Demir et al., 2020; Kamal, 2020; Mingliang et al., 2020; Stepien, 2021).

Previously, Stepien (2021) studied the usage of glass sand in the construction of autoclaved bricks to identify the suitability of glass sand utilisation in autoclaved materials and to establish their qualities and durability. In this study, the silicate brick was produced at a temperature of 203 °C, whereby the tobermorite was the main phase producing the microstructure, as opposed to the C-S-H phase, which dominates in concretes and has a greater specific surface. Computer tools were used to investigate the nature of pores, their number, appearance, and organisation in a material such as scanning electron microscope (SEM), X-ray diffraction (XRD), computed tomography, and porosimetry. In comparison to a traditional sample, the porosimeter test for bricks modified by glass sand addition revealed a high accumulation of pores in the size range of 0.1 to 50 µm. This indicates that the 'new' substance is more compact and tougher. The glass sand-modified material's structure is uniform and compact, and the sand grains are well integrated with the binder, indicating that the material would last for a long time. The findings suggest that the more glass sand used, the better the resistance and density. According to the computed tomography (micro-CT analysis), the number of voids in the material changed by glass sand is around 20% of the product's weight. The product's density with glass sand was found to be 2.2 kg/dm^3 while maintaining the strength at 10–15 MPa.

A previous study replaced one of the primary components of AAC, sand as natural raw material, with two forms of inorganic waste, i.e., glass cullet and waste brick. The sand substitution rate ranged from 12.5 to 100% by weight. The findings show that both glass and brick waste can be included into AAC structure without causing significant apparent density changes with maximum 10% increase in correlation with substitution amount. The compressive strength and thermal conductivity of AACs increased as their apparent density rises. The partial replacement of sand with waste glass powder results in an increase in compressive strength and thermal conductivity that was proportional to the increase in density. It is also found that the presence of glass and brick wastes affects the microstructure of AAC, and the morphology of the principal hydrate generated in AAC, tobermorite (needle-like and plate-like crystals), is connected to the amount and reactivity of silicon oxide (SiO_2) in the initial mixture (Ismael et al., 2020).

Černý et al. (2020) investigated the use of fly and bottom ash, slag, and waste glass as among the secondary raw materials in the manufacturing of AAC. AAC composite specimens with secondary raw material admixtures were cured in a laboratory autoclave under hydrothermal circumstances for 7 and 12 hours of isothermal durability at 190 °C. All the samples including secondary raw materials exhibited higher strength after a shorter autoclaving time. The main explanation for this is thought to be lengthier autoclaving, which created stress inside the samples and microcracks. The tobermorites, on the other hand, crystallised better for all samples after a longer autoclaving time. The specimen with a 10% waste glass admixture had the highest strength of the secondary raw materials examined under laboratory settings, it can be achieved 33% higher compressive strength than the reference sample. The maximum determined glass admixture content was 30%, after which mechanical characteristics began to deteriorate. Waste incinerator slag was another additive that had a favourable effect on specimen mechanical properties. The addition of secondary raw materials does not reduce strength, but it does improve mixture rheology and aids in the synthesis of tobermorite, as shown by the findings of this study.

Another research focused on mixing an AAC powder with various ratios of window GW powder (Abdulhussein et al., 2020). In comparison to the standard samples, the density increased with increasing glass addition of 10, 20, and 30%. The porosity of a composite material was lowered by adding glass, which resulted in a reduction in absorption when compared to the standard sample. With the addition of 30% by weight of glass, the bulk density increased to around 1562 kg/m^3, whereas porosity and water absorption decreased to about 39.8% and 23.4%, respectively. In addition, with the same percentage increase in glass addition, compression strength and Vickers' hardness improved as well. The compressive strength can be improved at 26.27 N/mm^2 and hardness up to 13.88 were improved when the proportion of waste glass with the concentration 30% by weight was compared to the no-additive sample. Thermal conductivity increased for less porosity with increasing ratio of glass at 0.5311 Watt/m·°C at the 30% of waste glass, although thermal shock performed successfully with additives of 10, 20, and 30 wt.% at temperature 250 °C for 1 hour but failed at 350 °C for the same duration. The influence of gypsum and limestone as mineral additive on AAC properties was studied (Cai et al., 2021). The materials used were ordinary Portland cement (OPC) CEM I 42.5N, burned lime, quartz sand, gypsum, and limestone. The same water/solid coefficient and the same amount of aluminium powder were used to prepare all of the samples, while the difference in percentage of gypsum: limestone for each sample were 0:0, 4:0, 2:2, and 0:4. Samples were conditioned at 25 °C for 4 hours and autoclaved at 190 °C for 8 hours after casting process. It was found that the sample with 4:0 percent ratio of gypsum: limestone addition achieved the lowest dry density at 485 kg/m^3, highest compressive strength up to 2.9 N/mm^2, lowest drying shrinkage at 0.24 mm/m and highest thermal conductivity coefficient of 0.140 W/m·K. This research aims to investigate the addition of GW and gypsum waste as additional materials into AAC to produce AAC-GGW with the optimum proportion by testing the density, water absorption, porosity and compressive strength of the samples and comparing the results with the reference sample.

2.0 Methodology

2.1 Material

The main materials used to produce AAC-GGW were GW, gypsum waste, ordinary Portland cement (OPC), quartz sand, lime, aluminium paste, and water. The wastes used in this study is a type of clear soda lime glass obtained from a landfill site for GW while the gypsum waste is a type of tile waste obtained from a demolishing site. The obtained GW and gypsum waste were each crushed into cullet size and then ground to fine particles using ball mill. They were then sieved into desired particle size range. The size range for GW and gypsum waste particles were 0.5 to 1 mm. The materials used to produce AAC-GGW samples is summarized in Table 1. Samples with no addition of GW and gypsum waste were prepared as reference.

2.2 Methods

GW were set to be added with different percentages to a mixture of 20% gypsum waste, 25% OPC, 20% quartz sand, 15% lime, and 5% aluminium paste. Both GW and gypsum waste were set to be added into AAC production as additional materials. Milled GW and gypsum waste, cement, quartz sand, lime, aluminium paste and water were mixed with different proportions to produce AAC-GGW samples with various ratios The methods used to produce AAC-GGW were referred to Raj et al. (2020).

Each material had their own storage which enabled them to be batched in the appropriate proportions by setting the storage to feed a certain ratio to the mixing drum. The control mechanism released all ingredients into the mixing drum and mixed with water to produce slurry. Since any delay or stoppage in the mixing and dosing phase causes residual matter to harden and choke the plant, the process of dosing and mixing were performed simultaneously.

Before pouring in the slurry, the inner surface of the mould was greased or oiled to prevent the uncooked slurry like a green cake from sticking to it. When the slurry was poured along with the small amount of aluminium paste, the reaction between aluminium, calcium hydroxide, and water occurred, resulting in the rapid release of hydrogen gas.

Because of the release of hydrogen gas, this high-speed reaction caused the green cake to expand, making it light and porous. The voids created because of air release were around 2 to 5 mm in diameter (macropores), giving it insulating properties. The cake was required to settle and was pre-cured after the process is completed. The pre-curing and raising process took about 1 to 4 hours.

The foaming and hardening processes took place in the pre-curing chamber at a controlled temperature. Since the pre-curing took place at a specific temperature, it was also known as heating-room-pre-curing. Although it was not a complicated process in general, any form of vibration was avoided in the entire process.

The pre-cured block was then cut into smaller sizes using cutting machine that consists of a large wire mesh that could pass through the cake when cutting it (Construction Technology Today (n.d.); MEPCO (2021)). The mould was simply unhooked or opened

Table 1: Different ratios of materials for various proportions of AAC-GGW in wt.%

Sample	GW	Gypsum waste	OPC	Quartz sand	Lime	Aluminum paste
A	0	20	25	20	15	5
B	5	20	25	20	15	5
C	10	20	25	20	15	5
D	15	20	25	20	15	5
E	20	20	25	20	15	5
F	25	20	25	20	15	5
G	30	20	25	20	15	5

once the block has sufficient cutting strength. During this time, the AAC-GGW block was cut into sizes required for various testing. After the mould was separated from the cake, it was cleaned, oiled, and closed to original form before it will be reused for the next batch of slurry.

The cut blocks were fed into the autoclave, where they were cured under high pressure of 1.25 MPa and a high temperature of about 90 °C for 12 hours. After that, the blocks were taken out of the autoclave and continued with the next batch. Under this humid and hot environment, the AAC-GGW blocks went through the final stages of hydrothermal synthesis reaction to turn the green cake into the final solid AAC-GGW block with the desired properties and necessary strength.

2.2.1 *Determination of physical properties and compressive strength*

For testing physical properties, the density, water absorption and porosity of the samples were tested in accordance with ASTM C642 before compression test. Three cylinders with the radius of 15 cm and height of 30 cm for each proportion were prepared for density, water absorption and porosity test. The mass of the samples was determined and recorded before they were dried in an oven at 100 °C for 24 hours. After that, the samples were cooled in dry air. Then, the mass of the samples was determined and recorded again to be compared with the original mass. The drying and weighing processes were repeated until the new mass closely agrees with the original mass and were recorded as A. Next, the samples were immersed in water at 21 °C for 48 hours. The samples were then surface-dried using a towel and placed in a container and boiled in tap water for 5 hours. After that, the samples were further cooled for more than 14 hours until their temperature reached 25 °C and then surface-dried with a towel. The samples' mass was determined and recorded as B. Finally, the samples were suspended by wires and their apparent mass in water was determined and recorded as C. The samples' density, water absorption and porosity were calculated using Eq. 1, 2, and 3, respectively:

$$\text{Apparent density, g/cm}^3 = [A/(A-D)] \times \rho \tag{1}$$

$$\text{Water absorption after immersion and boiling, \%} = [(B-A)/A] \times 100 \tag{2}$$

$$\text{Volume of permeable pores, \%} = (B-A)/(B-D) \times 100 \tag{3}$$

where:

A = mass of oven-dried sample in air, g

B = mass of surface-dried sample in air after immersion and boiling, g

C = apparent mass of sample in water after immersion and boiling, g

ρ = density of water = 1 g/cm^3

Three cubes with the dimension of 100 mm × 100 mm × 100 mm for each proportion were prepared for the compressive strength test according to EN BS 12390-3:2002. The compressive testing machine used was universal testing machine (UTM) (model no. VEW-2308) at Material Science Laboratory, UTHM. The samples were placed between compression plates and the load was applied at the rate of 0.5 MPa/s until the samples failed. The maximum load applied before the samples failed were recorded.

3.0 Results and discussion

The influence of GW and gypsum waste addition in AAC were studied by their physical properties of density, water absorption and porosity, and their compressive strength.

3.1 *Density, water absorption, and porosity*

The effects of different proportions of GW on the samples' density is as shown in Fig. 1, and water absorption and porosity are illustrated in Fig. 2. From the graph (Fig. 1), the density of the samples increased along with the increase of GW percentage. GW and gypsum wastes were added to AAC as additional materials. Therefore, the increase of GW also increased the mass at constant volume and hence increased the density of the samples.

The graph (Fig. 2) shows a decreasing pattern for water absorption when the GW percentage increases.

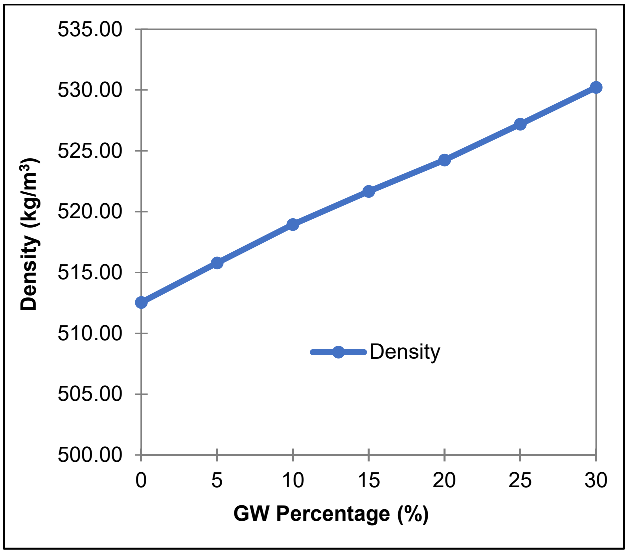

Fig. 1: AAC with different GW percentage against density

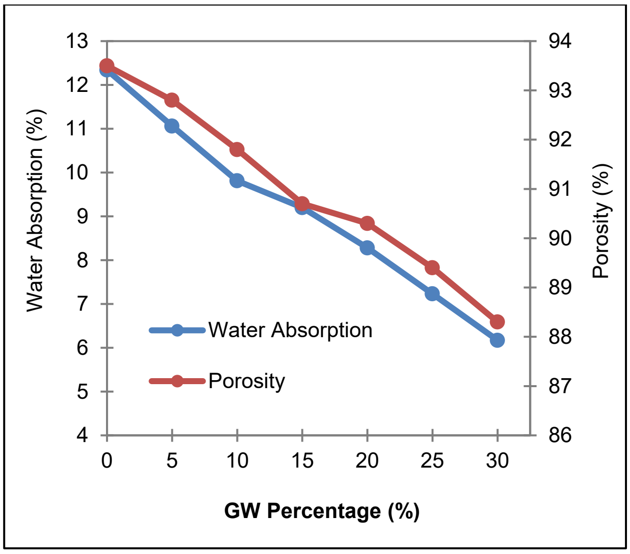

Fig. 2: AAC with different GW percentage against water absorption and porosity

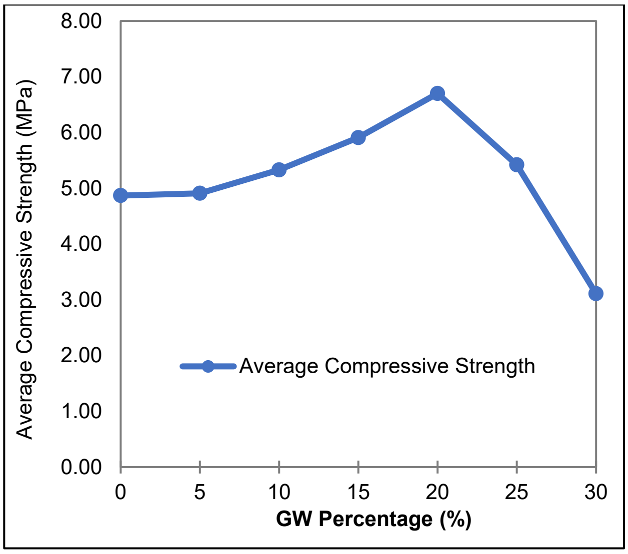

Fig. 3: AAC with different GW percentage against average compressive strength

The reference sample (0% GW) have more voids present in composite that leads to higher water absorption (Chen et al., 2021). The volume of pores with diameter lower than 0.1 mm plays a minor role in the water absorption of cement-based materials (Juan-Valdés et al., 2021). Hence, the sample with 30% GW have higher water resistance compared to other samples due to less presence of voids. The presence of voids increases the water absorption rate and decreases the strength of AAC (Chen et al., 2021).

The porosity of all samples indicated a decreasing trend as the ratio of GW increases. The fine GW and gypsum waste particles were much finer than the sand particles and thus filled into the high porosity region for packing density improvement and pore structure refinement (Balasubramanian et al., 2021).

3.2 *Compressive strength*

The influence of different percentages of GW on average compressive strength of the samples is shown in Fig. 3. Based on the graph, the more the GW percentage added until up to 20%, the higher the compressive strength of the samples. The ratio of 20% GW endured the highest maximum force value of 6.70 MPa. The addition of GW percentage for more than 20% decreased the compressive strength of the samples. It can be seen that, the addition of GW from 5% up to 25% in AAC-GGW achieved better compressive strength than standard AAC with no addition of GW. It was well known that the compressive strength decreases with the reduction in density and increase in porosity (Chen et al., 2021). Therefore, the compressive strength increased in relation with the density but only up to 20% GW percentage.

From the results, the addition of GW and gypsum waste into AAC as additional materials yielded better results than reference sample. The inclusion of GW and gypsum waste in AAC provides a sustainable approach to reduce wastes in landfill and may help to reduce landfill areas which can be used for other purposes. Future research should focus on flexural strength, Young modulus, thermal conductivity, fire resistance and sound insulation properties of AAC-GGW to further establish it as a green building material.

4.0 Conclusions

This research aimed to investigate the effect of GW and gypsum waste addition in production of AAC to produce AAC-GGW. The density, water absorption, porosity and compressive strength of the samples were studied and compared. It was found that the fine ground GW and gypsum waste can be used as additional materials in AAC. The increase of GW percentage increases the density of the samples because more mass was added into the samples but decreased the water absorption and porosity of the samples due to the micro filling of the pores by the GW and gypsum waste particles. The addition of GW from 5% to 25% in AAC-GGW yielded better average compressive strength compared to reference sample with no addition of GW. Maximum average compressive strength was achieved at 20% of GW addition.

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