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Acoustic Properties of Autoclaved Aerated Concrete (AAC) Based On Gypsum-Ceramic Waste (GCW)

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Abstract: Noise pollution and municipal solid waste (MSW) are two ongoing issues for inhabitants of urban due to the growth development. MSW such as gypsum and ceramic waste (GCW) needs to be managed properly to solve environment and acoustic issues. Autoclaved aerated concrete (AAC) is one of the lightweight concrete family and green building material which raw material can be partially replaced by using MSW. It was interesting to study the compressive strength and acoustic properties of AAC based on GCW. The objective of this work was to determine the performance of strength and the acoustic properties of AAC based on GCW. The AAC with different composition of GCW (5%, 10%, and 15%wt) has been prepared according to ASTM C1693-09. The compressive strength and acoustic properties of sample have been carried out according to ASTM D695 and ASTM E1050. The GCW succeeded in enhancing the compressive strength of AAC samples in the range of 23.43% to 44.32%. The maximum value of compressive strength was 7.22MPa for 15% wt of GCW. The sound absorption coefficient of sample was around 0.17 to 0.89 at high frequency (1000 – 2000Hz). The best sound absorption coefficient was showed by AAC with 10% wt of GCW i.e 0.89 at frequency 1200Hz. All AAC-GCW samples have class C and B at a high frequency in range 1000 – 1500Hz. Our results indicated the GCW can be used as an alternative natural source for partial fine aggregate replacement on AAC and improved the compressive strength and acoustic properties of AAC samples. Generally, AAC-GCW samples have higher sound absorbance coefficient compare to previous studies and suitable for wall application such as partition walls, party walls, and especially for sound insulation material.

Keywords: Strength, acoustic properties, autoclaved aerated concrete (AAC), gypsum-ceramic waste

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1. Introduction

Environmental and acoustical issues are two formidable challenges for Building Regulations or Planning Authorities. Both noise pollution and MSW increased with increasing the normal growth population and the growth development [1]. MSW was not only generated from the production stage (before construction), process stage (construction process), use stage (after construction) and end-of-life stage (de-construction or renovation) but also from the construction industry. Currently, the majority of MSW is dumped into local landfill in Malaysia. For instance, almost 94% of MSW such as gypsum waste has been delivered for disposal in landfills [2]. Meanwhile, almost 10%-30% of MSW such as ceramic waste has also been sent for disposal in landfills each year [3]. Both gypsum and ceramic waste in local landfills have an adverse effect on the ecological system such as leachate into the environment and waterways due to its chemical composition such as silica, alumina, and calcium oxide and a small amount of iron, magnesium, and alkali oxides. In addition, gypsum and ceramic waste in the landfill were also suspected to contribute to greenhouse gas (GHG) emissions. Specifically, gypsum waste has been recognized as hazardous waste with code SW 205 [4,5]. Waste material with code SW 2 mentions waste containing principally inorganic constituents which may contain metals and organic materials. Usually, the major chemical composition of gypsum is calcium sulphate, which exists in hydrous and non-hydrous i.e. compounds dehydrate ($CaSO_4 \cdot 2H_2O$), hemihydrate ($CaSO_4 \cdot 0.5H_2O$) and anhydrate ($CaSO_4$). According to chemical composition, ceramic waste in landfills is more hazardous than gypsum waste due to the major chemical composition of ceramic silica, alumina, and calcium oxide and the small amount of iron, magnesium, and alkali oxides [6].

Although gypsum waste has been recognized as hazardous waste but the gypsum material has also been approved to have a good building material due to its lightweight, excellent moldability, fire resistance, and sound absorption [7]. Gypsum materials have large uses in material building such as dry wallboards [8], clay brick [9] and fire clay brick [10]. According to Lushnikova and Dvorkin (2016) gypsum materials also have large uses in building materials such as autoclaved cement cellular concrete, non-autoclaved cement cellular concrete, claydite cement concrete, hollow lime-sand brick, hollow clay brick, ordinary clay brick, cellular gypsum blocks, gypsum concrete blocks (hollow) and gypsum concrete blocks (solid) [11]. The positive effect of gypsum addition on the hydration of the quaternary phase-gypsum system has been reported [12]. Meanwhile, the positive effect of gypsum addition on the mechanical properties of autoclaved aerated concrete (AAC) has also been reported [13]. Currently, gypsum products have been successfully used as sound and heat-insulating materials [14-16].

Meanwhile, the ceramic has also been recognized and approved to have a good building material due to its high surface area and permeability, low density and specific heat capacity, good moisture absorption, high thermal and acoustic insulation and high chemical resistance in addition to the fact that they are non-flammable and flame resistant, chemically inert and not-toxic unlike polymeric foams [17]. Ceramic waste's positive effect on concrete's mechanical properties has been reported [18-19]. Meanwhile, Hamad et al., (2021) studied the positive effect of ceramic waste powder on the mechanical properties of AAC [20]. In addition, the application of ceramic waste as inorganic insulation material in buildings has also been studied [21].

Today, acoustical issues also have the biggest problem for urban residential areas along busy streets. The noise pollution is coming from abnormal sounds. A sound is a form of energy that travels through solids, liquids or gasses in longitudinal waves by vibrating particles oscillating in a body. Actually, in a building, there are two types of audible sounds which are airborne sound and impact sound [22]. The speech, speakers, and musical instruments are examples of airborne sounds. Meanwhile, footsteps, falling objects, vibrating machines, closing doors, and slammed doors are examples of impact sounds. According to Lu et al. (2000), the sound became noise pollution when the sound level is above 60 dB and the frequency ranges from 2000 to 5000Hz [23]. For instance, the average noise levels for urban residential areas along a busy street ranged from 64.2 to 75.2dB over a 24-hour period in Klang Valley, Malaysia [24]. Due to environmental and acoustical issues, some researchers succeeded in producing good absorption materials based on MSW [25-28]. According to Bave et al. (1978), a good absorption material was not easily prepared due to porosity [29]. The porosity was suggested to play a key role in determining absorption coefficient values of materials but is difficult to control [30,31].

AAC is one of the porous lightweight concrete family members and the major chemical compositions were silica, calcium sulfate and small amount of iron and aluminum [32]. In principle, the chemical composition of AAC such as silica, calcium sulfate, and a small amount of iron and aluminum has been got from Portland cement, quartz sand, and lime [33]. Furthermore, the AAC is not only lightweight concrete but also a green building material [34], eco-friendly environmentally [35], non-combustible building [36], does not emit smoke or toxic gases [37] and a good sound insulation material [38]. In addition, lightweight concrete has also been used as roof tiles due to its good vibration performance [39]. Although AAC has many advantages preparing AAC with suitable applications such as a good sound insulation material was not easy. This may be due to the properties of AAC was depending on many parameters such as chemical composition [40,41], pore size and pore size distribution [42], autoclave pressure and temperatures [43-46].

Due to the similarities in the major chemical composition and application of AAC with gypsum-ceramic material, and in addition to materials with environmental and acoustical issues, it was interesting to study the acoustic properties of AAC based on gypsum waster as well as ceramic waste as an alternative natural source for the partial fine aggregate replacement. Using GCW in AAC, this work will offer many advantages to solve several environmental problems such as reducing explore of large quantities of sand from the river or beach, reducing the landfill areas for GCW and reducing greenhouse gas (GHG) emissions. In addition, the work is also to support the program of the Malaysian government to reduce the municipal solid waste (MSW) that has been sent to landfills to 40% and minimize GHG emissions intensity by 45% by 2030. The objective of this work was to determine the performance of the compressive strength and acoustic properties of AAC based on GCW and the results were compared to previous research about lightweight concrete.

2. Materials and Methods

2.1 Materials

Four types of fresh AAC with different ratios of GCW have been prepared according to Table 1. The Portland cement used for preparing AAC samples was purchased from Pekan Pagoh, Johor. The lime and aluminum powder used for preparing AAC samples were purchased from industrial chemicals, in Malaysia which fulfills the requirement of AAC production according to American Society for Testing and Materials (ASTM) C1693-09. The sand as raw material for this AAC was obtained from Pekan Pagoh, Johor, Malaysia as natural sand. Whereas, the ceramic as partial replacement for sand was obtained from Prudent Deals Sdn Bhd 18 Lorong SS 1/11A, Petaling Jaya, 47301, Petaling Jaya, Selangor, Malaysia. The ceramic waste was sorted manually to remove other materials such as soil, stone, bitumen (asphalt), plasterboard, concrete, AAC, bricks, tiles, plastic, rubber, textile, glass, iron, aluminum, styrofoam, cable, nail, screw, anchors, wood, carpet, films, wallpaper remains paper, gypsum, etc. Then, ceramic waste was washed by using water to remove the dust, soil, or sand and dried using the hairdryer. After that, ceramic waste was ground manually by using Ball Mill Machine to get the ceramic waste powder (CWP). Then, the CWP has sieved manually to get a particle size of 1-5mm.

The gypsum waste was also obtained from Pekan Pagoh, Johor, Malaysia as natural sand. Whereas, the ceramic as partial replacement for sand was obtained from Prudent Deals Sdn Bhd 18 Lorong SS 1/11A, Petaling Jaya, 47301, Petaling Jaya, Selangor, Malaysia. The gypsum waste was sorted manually to remove other materials such as soil, stone, bitumen (asphalt), plasterboard, concrete, AAC, bricks, tiles, plastic, rubber, textile, glass, iron, aluminum, styrofoam, cable, nail, screw, anchors, wood, carpet, films, wallpaper remains paper, ceramic, etc. Then, gypsum waste was ground manually by using a Ball Mill Machine to get the gypsum waste powder (GWP). Our target particle size of GWP is also 0.5-1mm. To get the target size of the particle, the GWP has sieved manually. The water used for the experiment satisfies the technical requirements of the standard for AAC. Water from the laboratory of Kim Hoe Thye Industries, Johor, Malaysia was used to make AAC slurry (pre-preparation) and fresh AAC.

Table 1 - Fresh AAC with different ratios of GCW

No	Sample of Different ratio	Sand (%)	Gypsum Waste (%)	Ceramic Waste (%)	Lime (%)	Cement (%)	Aluminum Paste (%)	Water (%)
1.	Control Sample (CS)	70.00	0.00	0.00	3.87	17.10	0.65	8.39
2.	Sample A_60S_2G_3C	65.00	2.00	3.00	3.87	17.10	0.65	8.39
3.	Sample B_50S_2G_8C	60.00	2.00	8.00	3.87	17.10	0.65	8.39
4.	Sample C_40S_2G_13C	55.00	2.00	13.00	3.87	17.10	0.65	8.39

2.2 Methods

Raw material of each sample has been weighed according to the mixture proportion of Table 1. The error of powder material and water has been controlled in ±0.1 g, and aluminum (Al) powder was controlled in ±0.01 g. For instance, CS sample, the amounts of sand (70%), cement (17.10%), lime (3.87%) and water (8.39%) has been mixed together around 5 min and added some Al paste (0.65%) and stirring for 30 seconds to produce slurry. The mixed slurry has been poured into a 2/3 box mold and shaken slowly until the air bubbles rise to the top. The reaction takes around 30 minutes to expand the mixed slurry into the full mold. This step has been repeated for samples with codes A to C. Slurry has been cut at the cutting line and cured under hydrothermal conditions for 12 hours at 200℃ by using saturated steam at a pressure of 12 bar.

The compressive strength of all samples has been carried out by using a compressive strength test (ASTM D695) machine with brand Universal Testing Machine (UTM) Model No: VEW 2308, UTHM, Pagoh. The specimen's size of compressive strength was 100×100×100mm. The sound absorption coefficient (α) versus frequency has been carried out by using Impedance Tube Model No: AED1000 according to ASTM E1050 at low and high frequencies [47]. The specimen's dimension of sound absorption was 30mm and 100mm in radius with a thickness was 100mm for low and high frequencies respectively (Fig.1). The sound transmission coefficient (τ) has been calculated as reflected by sound absorption samples. Formula for was defined as:

$$\tau = 1 - \alpha \tag{1}$$

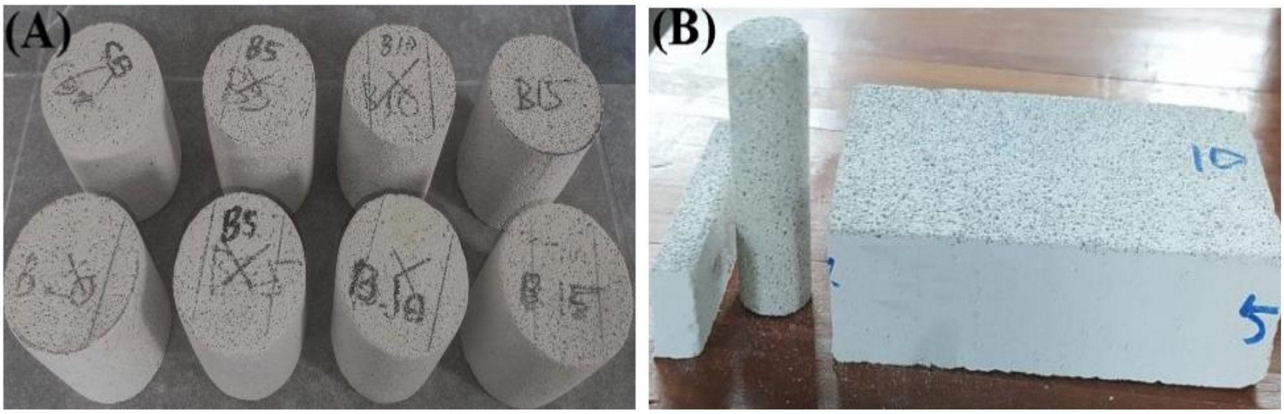

Fig. 1 - The specimen's dimension of sound absorption, (a) low frequency and (b) a high frequency

3. Results and Discussion

Fig. 2 showed the samples in sizes 100 x 100 x 100 mm with different ratios of GCW. All samples showed normal color behavior in grey. The physical surface of AAC-GCW samples had a free crack which can be seen by the naked eye. Few data could be collected from Fig. 1 during observation by the naked eye.

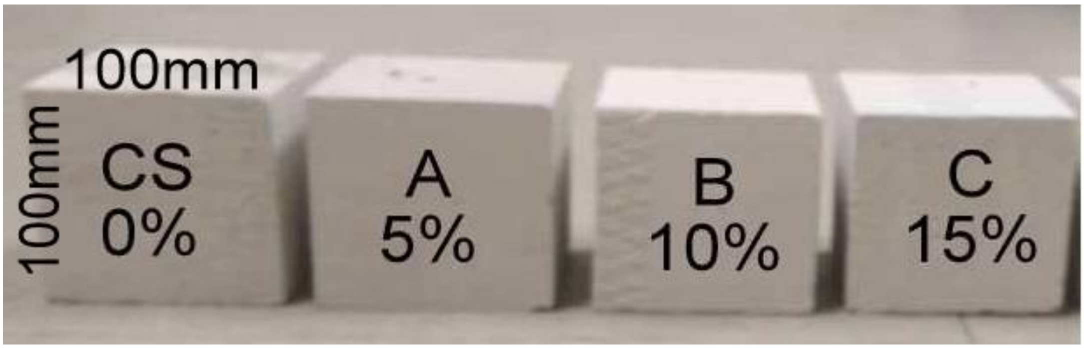

Fig. 2 - The fresh AAC based on GCW

3.1 Compressive Strength of AAC-GCW

Fig. 3 shows the compressive strength of fresh AAC based on GCW. The results showed the compressive strength increased with the increment of GCW. The GCW succeeded in enhancing the compressive strength of AAC samples in the range of 23.43% to 44.32%. The maximum value of compressive strength was 7.22MPa for 15% wt of GCW. The increase in the compressive strength of samples may be due to the pozzolanic effect of ceramic waste. According to Awoyera et al, (2018), ceramic material is pozzolanic material in which the chemical composition has a higher percentage of silica, alumina, and calcium oxide and a small amount of iron, magnesium, and alkali oxides [48]. The chemical composition such as silica, alumina, and calcium oxide are responsible for pozzolanic reactivity and cementitious property [49,50]. Meanwhile, according to Kunchariyakun et al., (2018), the pozzolanic effect of material always supported the formation of C-S-H, and tobermorite occurs as the major phase of AAC and enhanced the compressive strength of samples [51]. Furthermore, the calcium sulphate of gypsum waste also contributes to enhancing the strength of samples which calcium sulfate has played a key role in the formation of tobermorite plates. In addition, a proper ratio or contain of the gypsum waste could enhanced the strength of concrete [52].

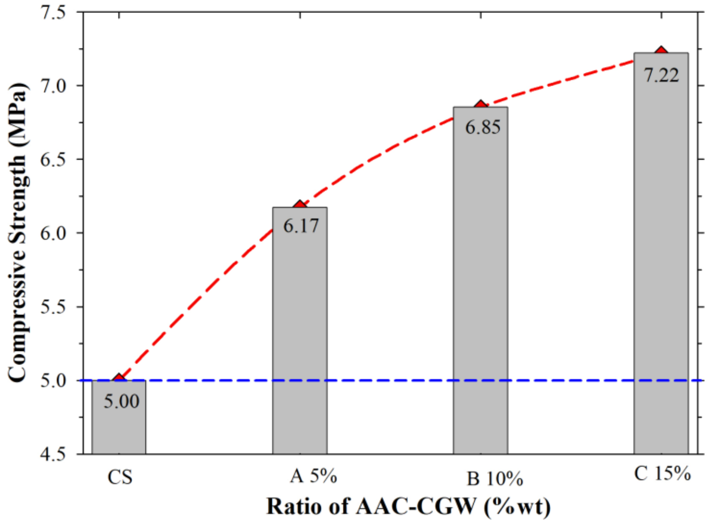

Fig. 3 - The compressive strength of fresh AAC based on GCW

3.2 Acoustic Properties of AAC-GCW

Fig. 4 shows the sound absorption coefficient of fresh AAC-GCW. The sound absorption coefficient was around 0.32 to 0.89 at 1200 – 1500Hz (Table 2). The sound absorption coefficient increased with increasing of the GCW ratio from 5 to 15% wt but in different frequency ranges. The sound absorption coefficient for CS was around of 0.33 to 0.78 at a frequency range of 1000 – 1800Hz. Whereas, the AAC with the ratio of 5% and 10% wt of GCW shows a good sound absorption coefficient value at a frequency range of 1000 to 1400Hz between 0.50 to 0.89. The highest sound absorption coefficient was shown for the AAC sample with the ratio of 10% wt of GCW at frequency 1200Hz is 0.89. Especially for AAC with the ratio of 15% wt of GCW, the sample shows a good sound absorption coefficient but at a high frequency in the range of 1200 to 2000Hz between of 0.38 to 0.87. The AAC sample with the ratio of 10% wt of GCW also shows a good sound absorption coefficient at low frequency.

Table 2 - The sound absorption coefficient of fresh AAC-GCW

No	Frequency (Hz)	Sound absorption coefficient			
		CS (0%)	A (5%)	B (10%)	C (15%)
1.	350	0.21	0.16	0.30	0.03
2.	450	0.06	0.03	0.09	0.10
3.	500	0.07	0.08	0.18	0.02
4.	600	0.08	0.10	0.24	0.04
5.	700	0.09	0.07	0.18	0.15
6.	800	0.12	0.15	0.18	0.18
7.	900	0.21	0.37	0.35	0.16
8.	1000	0.36	0.65	0.62	0.21
9.	1050	0.45	0.76	0.74	0.28
10.	1200	0.68	0.86	0.89	0.65
11.	1300	0.77	0.72	0.76	0.83
12.	1350	0.78	0.61	0.66	0.87
13.	1400	0.77	0.50	0.55	0.85
14.	1500	0.71	0.32	0.38	0.70
15.	1600	0.59	0.22	0.32	0.53
16.	1700	0.46	0.22	0.35	0.45
17.	1800	0.33	0.24	0.36	0.45
18.	1900	0.25	0.23	0.27	0.38
19.	1950	0.22	0.20	0.23	0.41
20.	2000	0.22	0.17	0.31	0.72

According to BS EN ISO 11654:1997, the sound absorption class of material refers to the sound absorption coefficient value at mid-band frequencies of 250Hz, 500Hz, 1000Hz, 2000Hz and 4000Hz. Except for AAC with ratio 10% wt of GCW, all samples are categorized as a class E absorber at low frequencies less than 900Hz. Meanwhile, at a high frequency (1000 – 1500Hz), the AAC with a ratio of 5% and 10% wt of GCW were categorized as a class C absorber. Especially for AAC with a ratio of 5% and 10% wt of GCW, the samples were categorized as class B absorbers at a frequency 1200Hz. Meanwhile, the AAC with the ratio of 15% wt of GCW was also categorized as a class B absorber but at frequency 1300 to 1400Hz. Material with class D class C absorber refers to a material that absorbs more than 30% of sound and a class C absorber is able to absorb more than 60% of sound while a class B absorber is able to absorb between 80% – 85 % of the sound [53].

The AAC-GCW has shown a good sound absorption coefficient may be due to the effect of the gypsum and ceramic waste. Both gypsum and ceramic waste are porous structure materials [54,55]. The porous structure of gypsum and ceramics is thought to play an active role in the formation of AAC micropores. According to Bave 1980, the macro-pores are formed during the aluminum-driven expansion of the slurry, whereas microspores (or gel-pores) resulted from the packing of tobermorite plates [56]. In addition, the pore size, pore size distribution, and connected pores and closed pores are also suspected to play a key role in strength and sound absorption coefficient. Maybe in these results, the micro-pores are more than macro-pores so that the samples have high compressive strength and been being good absorbers. And in other facts, maybe the closed pore is also more than connected pore. According to Leitch (1980), the acoustic property is affected by the closed porous structure of materials [57]. Nevertheless, further studies are needed to evaluate precisely the physical properties of AAC-GCW samples such as major phase, pore size, pore size distribution, connected pores and opened pores to get the correlation with acoustic properties of samples.

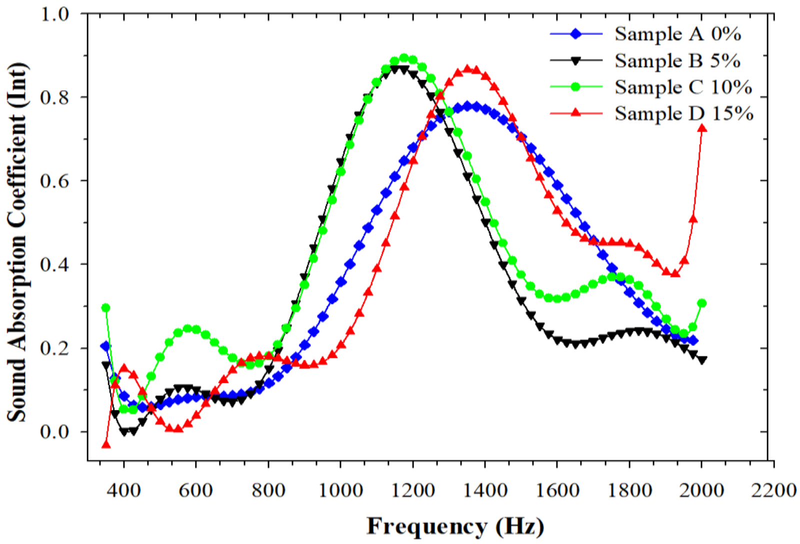

Fig. 4 - The sound absorption of fresh AAC-GCW

The result also showed that the samples have the best value of sound absorption coefficient and did not decrease with increasing compressive strength. These results contrast with the results of Holmes et al. (2014) which the sound absorption coefficient of concrete panels based on crumb rubber (CR) increased with decreasing the compressive strength [58]. The maximum coefficient of sound absorption of Holmes's sample was 0.20. In 2020, the sound absorption coefficient of concrete based on coal bottom ash (CBA) for wall concrete application has been reported by Hanna et al., (2020) [59]. However, the maximum sound absorbers of samples were categorized as class D absorbers i.e around 0.30 at frequency 500–2000Hz. According to Łaskawiec et al., (2016), all of our samples can be categorized as grade-6 AAC [60]. Meanwhile, the maximum sound absorption coefficient of grade-6 AAC is very low at 0.20 [61]. For instance, the sound absorption coefficient of AAC made by the Hebel enterprise was also very low at 0.25 [62].

In 2006, Laukaitis and Fiks have been investigated three types of AAC i.e AAC gas cement concrete, AAC gas cement concrete with a combined binder and AAC foam cement concrete with densities around 250-500 kg/m^3 [63]. The maximum sound absorption coefficient was 0.36 and 0.21 for samples with densities of 250 kg/m^3 and 500 kg/m^3 respectively. Usually, the AAC with low densities will have a high sound absorption coefficient but not for our results. Although our samples have a compressive strength of around 5.00 to 7.22MPa, the sound absorption coefficient was categorized as a class C and B absorber at a high frequency (1000 – 1500Hz). Recently, Manaf et al. (2021) studied the sound absorption coefficient of LWC based on High-Density Polyethylene (HDPE) plastic waste [64]. But the maximum coefficient of sound absorption was only 0.47. Another researcher such as Kang et al. (2021), also reported the sound absorption coefficient of LWC based on eggshell waste and the maximum sound absorption coefficient was 0.39 [65]. Table 3 showed the comparison in our results with previous studies.

Table 3 - The sound absorption coefficient (SAC) from previous studies

No	Sample	Densities/Compressive strength	The maximum of the sound absorption coefficient	References
1.	AAC-CGW	Compressive strength 6.17 and 6.85MPa	0.89	Our results
2.	Concrete-CR	Density 500kg/m^3	0.20	Holmes et al.,[56]
3.	Concrete-CBA	Compressive strength 30MPa	0.30	Hanna et al., [57]
4.	AAC-grade-6	Compressive strength 55MPa	0.20	Mathey & Rossiter [59]
5.	AAC-Hebel	Density 500kg/m^3	0.25	CSR Hebel [60]
6.	AAC-gas cement	Density 500kg/m^3	0.35	
	AAC- gas cement with-binder	Density 500kg/m^3	0.36	Laukaitis & Fiks [61]
	AAC- foam cement concrete	Density 500kg/m^3	0.24	
7.	LWC-HDPE	Compressive strength 97.28 kN	0.47	Manaf et al. [62]
8.	LWC-eggshell	Compressive strength 5.04MPa	0.39	Kang et al. [63]

Generally, the sound absorption coefficient of material has an inverse correlation with sound transmission coefficient. Figure 5 shows the sound transmission coefficient of AAC-GCW. The results show that the sound transmission coefficient of AAC-GCW is very low at the frequency range of 1000–1500Hz. Although the compressive strength of AAC-GCW increased with the increasing ratio of GCW, it did not affect the sound transmission coefficient. The sound transmission coefficient also decreased with increasing the GCW ratio. This work showed that the ratio of GCW has a significant influence on acoustic properties of AAC.

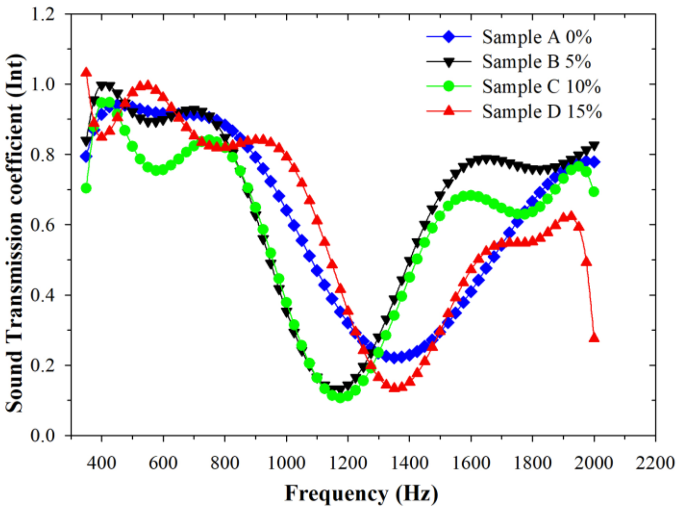

Fig. 5 - The sound transmission coefficient of fresh AAC-GCW

4. Conclusion

AAC based on GCW as an alternative natural source for partial fine aggregate replacement has been successfully prepared according to C1693-09. The GCW succeeded in enhancing the compressive strength of AAC samples in the range of 23.43% to 44.32%. The maximum value of compressive strength was 7.22MPa for 15% wt of GCW. The sound absorption of all samples has been carried out at a range of 350Hz to 2000Hz according to ASTM E1050. The results found that AAC-GCW performed well in terms of sound absorbance but in different frequency ranges. The sound absorption coefficient of sample was around 0.17 to 0.89 at high frequency (1000 – 2000Hz). The best sound absorption coefficient was shown by AAC with 10% wt of GCW at 0.89 with the frequency of 1200Hz. All AAC-GCW samples have class C and B at a high frequency in range 1000 – 1500Hz. Our results indicated that GCW can be used as an alternative natural source for partial fine aggregate replacement on AAC and improved the compressive strength and acoustic properties of AAC samples. Generally, AAC-GCW samples have higher sound absorbance coefficients compared to previous studies and are suitable for wall applications such as partition walls, party walls, and especially for sound insulation material.

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References

[1] Mian, M. M., Zeng, Z., Nasry, A. N. B., & Al-Hamadani, A. N. B. (2017). Municipal solid waste management in China: a comparative analysis. Journal of Mater Cycles Waste Manag, 19, 1127–1135.

[2] Pariatamby, A. (2017). Country Chapter State of the 3Rs in Asia and the Pacific, United Nations Centre for Regional Development (UNCRD), Ministry of the Environment, Government of Japan.

[3] Senthamarai, R. M., Manoharan, P. D., & Gobinath, D. (2010). Concrete made from ceramic industry waste: Durability properties. Construction and Building Materials, 25(5), 2413–2419.

[4] Aja, O. C., Al-Kayiem, H. H., Zewge, M. G., & Joo, M. S. (2016). Overview of Hazardous Waste Management Status in Malaysia. Management of Hazardous Wastes, Chapter 5, Intech Open Science.doi.org/10.5772/63682.

[5] Halimah, H. (2014). Environmental Quality Report, Department of Environment Malaysia, Ministry of Natural Resources and Environment Malaysia, Putrajaya, Malaysia.

[6] Gautam, L. Jain, J. K. Kalla, P., & Choudhary, S. (2021). A review on the utilization of ceramic waste in sustainable construction products. Materials Today: Proceedings, 43, 1884–1891.

[7] Iucolano, F., Campanile, A., Caputo, D., & Liguori, B. (2021). Sustainable Management of Autoclaved Aerated Concrete Wastes in Gypsum Composites. Sustainability, 13(7), 3961.

[8] Lesie, T. (2020). Dry and Ready in Half the Time: Gypsum Wallboard's Uneasy History. History of Building Systems and Materials. doi.10.13140/RG.2.2.30855.83365.

[9] Lopez, C. M., Araiza, J. L. R., Ramirez, A. M., Pinon, J. P., Landaverda, M. A. H., Bueno, J. D. J. P., & Angle. M. D. J. (2011). Effect of fly ash and hemihydrate gypsum on the properties of unfired compressed clay bricks. International Journal of the Physical Sciences, 6(17), 5766-5773.

[10] Hamid, N. J. A., Kadir, A. A., Hashar, N. N. H., Pietrusiewicz, P., Nabiałek, M., Wnuk, I., Gucwa. M., Palutkiewicz, P., Hashim, A. A., Sarani, N. A., Nio, A. A., Noor, N. M. & Jez, B. (2021). Influence of Gypsum Waste Utilization on Properties and Leach ability of Fired Clay Brick. Materials, 14, 2800. doi.org/10.3390/ma14112800.

[11] Lushnikova, L., & Dvorkin, L. (2016). Sustainability of Gypsum Products as a Construction Material. Sustainability of Construction Materials, 25, 643–681.

[12] Shen, P., Lu, L., He, Y., Wang, F., & Hu, S. (2017). Hydration of quaternary phase-gypsum system. Journal of Construction and Building Materials, 152, pp. 145-153. doi.org/10.1016/j.conbuildmat.2017.06.179.

[13] Małaszkiewicz, D., & Chojnowski, J. (2017). Influence of addition of calcium sulfate dihydrate on drying of autoclaved aerated concrete. Open Eng, 7, pp. 273 – 278. doi.org/10.1515/eng-2017-0032.

[14] Hansen, S., & Sadeghian, P. (2020). Recycled gypsum powder from waste dry walls combined with fly ash for partial cement replacement in concrete. Journal of Cleaner Production, 274, 12278.

[15] Raghavendra, T., & Udayashankar, B. C. (2015). Engineering properties of controlled low strength materials using fly ash and waste gypsum wall boards. Construction and Building Materials, 101, 548–557.

[16] Guerra, B. C., Bakchan, A., Leite, F., & Faust, K. M. (2019). BIM-based automated construction waste estimation algorithms: The case of concrete and drywall waste streams. Waste Management, 87, 825–832. doi.org/10.1016/j.wasman.2019.03.010.

[17] Rincon, A., Marangoni, M., Cetin, S., & Bernardo, E. (2016). Recycling of inorganic waste in monolithic and cellular glass-based materials for structural and functional applications. Journal of Chemical Technology & Biotechnology, 91, 1946–1961.

[18] El-Dieb, A. S., & Kanaan, D. M. (2018). Ceramic waste powder an alternative cements replacement characterization and evaluation. Sustainable Materials and Technologies, 17, e00063.

[19] Medina, C., Rojas, S. D. M. I., & Frías, M. (2012). Reuse of sanitary ceramic wastes as coarse aggregate in eco-efficient concretes. Cement and Concrete Composite, 34(1), 48–54.
[20] Hamad, A. J., Sldozian, R. J. A. & Mikhaleva, Z. A. (2020). Effect of ceramic waste powder as partial fine aggregate replacement on properties of fiber-reinforced aerated concrete. Engineering Reports, 2, e12134.
[21] Wi, S., Yang, S., Berardi, U., & Kim, S. (2019). Assessment of recycled ceramic-based inorganic insulation for improving energy efficiency and flame retardancy of buildings. Environment International, 130, 104900.
[22] Bies, D. A., Hansen, C. H., & Howard, C. Q. (2009). Engineering Noise Control, Theory and Practice (5th ed.). Spon Press, New York.
[23] Lu, T. J., Chen, F., & He, D. (2000). Sound absorption of cellular metals with semiopen cells. The Journal of the Acoustical Society of America, 108(4), 1679–1709.
[24] Halim, H., Abdullah, R., Nor, M. J. M., Aziz, H. A., & Rahman, N. A. (2017). Assessment of road traffic noise indices in urban residential areas of Klang Valley Malaysia. AIP Conference Proceedings 1892, 040002.
[25] Fodzi, M. H. M., Marsi, N., & Shariff, H. H. (2020). Analysis of Epoxy Composite with Diapers Waste as Fillers: Relationship of Density, Porosity and Sound Absorption Coefficient. International Journal of Advanced Research in Engineering and Technology (IJARET), 11(4), 137–146.
[26] Zhu, M., Ji, R., Z. Li, Z., Wang, H., Liu, L., & Zhang, Z. (2016). Preparation of glass ceramic foams for thermal insulation applications from coal fly ash and waste glass. Construction and Building Materials,112, 398–405.
[27] Rus, A. Z. M., Normunira, N. M. H., & Rahmi, R. A. (2014). Influence of Multilayer Textile Biopolymer Foam doped with Titanium Dioxide for Sound Absorption Materials. Key Engineering Materials Vols. 594–595.
[28] Hassan, N. N. M., Rus, A. Z. M., & Ghazali, M. I. (2013). Acoustic Performance of Green Polymer Foam from Renewable Resources After UV Exposure. International Conference on Mechanical Engineering Research (ICMER2013), 1–3 July 2013.
[29] Bave, N. J., Bright, F. N., Leitch, W., Rottan, G., Svanholm., & Trambovetsky, V. P. (1978). Autoclaved aerated concrete. Comitte Euro-International du beton CEB, The construction Press, New York, 90p.
[30] Hoff, G. C. (1972). Porosity-strength considerations for cellular concrete. Cement and Concrete Research, 2(1), 91–100.
[31] Petrov, I., & Schlegel, E. (1994). Application of automatic image analysis for the investigation of autoclaved aerated concrete structure. Cement and Concrete Research, 24(5), 830–840.
[32] Kurama, H., Topu, I. B., & Karakurt, C. (2009). Properties of the Autoclaved Aerated Concrete Produced from Coal Bottom Ash. Journal of Materials Processing Technology, 209, 767–773.
[33] Mostafa, N. Y. (2005). Influence of air-cooled slag on physicochemical properties of autoclaved aerated concrete. Cement and Concrete Research, 35, 1349–1357.
[34] Narayanan, N. & Ramamurthy, K. (2000). Structure and Properties of Aerated Concrete: A Review. Cement and Concrete Composites, 22(5), 321–329.
[35] Jerman, M., Keppert. M., Výborný, J. & Černý, R. (2013). Hygric, Thermal and Durability Properties of Autoclaved Aerated Concrete. Construction and Building Materials, 41, 352–359.
[36] Bonakdar, A., Babbitt, F., & Mobasher, B. (2013). Physical and mechanical characterization of Fiber-Reinforced Aerated Concrete (FRAC). Cement and Concrete Composites, 38, 82–91.
[37] Stanescu, A. A., Lalu, O., Luca, O., & Gaman, F. (2021). Permormance of autoclaved aerated concrete (AAC) exposed to standard fire. IOP Conference Series: Earth and Environmental Science, 664, 012028.
[38] Rositsa, P. S., & Sinan, O. T. (2018). Autoclaved Aerated Concrete and itApplication as Sound Insulation Material. X Jubilee International Scientific Conference, Vaena, Bulgaria. Sept 20–22,
[39] Marsi, N., Rus, A. Z. M., & Sulong, N. (2017). Vibration Performance of Lightweight Concrete Coated Biopolymer Based on Used Cooking Oil. ARPN Journal of Engineering and Applied Sciences, 12(14), 4236–4242.
[40] Karakurt, C., Kurama, H., & Topçu, I. B. (2010). Utilization of Natural Zeolite in Aerated Concrete Production. Cement & Concrete Composites, 32, 1–8.
[41] Baspinar, M. S., Demir, I., Kahraman, E., & Gorhan, G. (2014). Utilization Potential of Fly Ash together with Silica Fume in Autoclaved Aerated Concrete Production. KSCE Journal of Civil Engineering, 18 (1), 47–52. doi.10.1007/s12205-014-0392-7.
[42] Kreft, O., Hausmann, J., Hubálková, J., Aneziris, C. G., Straube, B., & Schoch, T. (2011). Pore size distribution effects on the thermal conductivity of light weight autoclaved aerated concrete. 5th International Conference on Autoclaved Aerated Concrete "Securing a sustainable future" to be held at Bydgoszcz to celebrate 60 years of AAC experience in Poland, Bydgoszcz, 14-17, September.
[43] Yazal, A., Kavas, T., & Soyal, A. D. (2018). Effects of Different Autoclaving Pressure on Mechanical Properties of AAC. ce papers, 2,591–594. doi.10.1002/cepa/829.

[44] Shabbar, R., Nedwell, P. & Wu, Z. (2016). Influence of temperature and curing method on strength of autoclaved aerated concrete. Proceeding of the MACE PGR Conference, ISSN 2397-7833 (ONLINE).
[45] Yahaya, F. M., Muthusamy, K. & Hussin, M. W. (2015). Effect of Curing Regime on Compressive Strength of Aerated Concrete Containing Palm Oil Fuel Ash as Partial Sand Replacement. Concrete Research Letters, 2015. 6(2): p. 54–59.
[46] Ungsongkhun, T., Greepala, V. & Nimityongskul, P. (2008). The effects of the curing technique on the compressive strength of Autoclaved Aerated mortar. Excellence in Concrete Construction through Innovation, 1st Edition, CRC Press, pages 6, eBook ISBN 9780429207198.
[47] Sukontasukkul, P. (2009). Use of crumb rubber to improve thermal and sound properties of pre-cast concrete panel. Construction and Building Materials, 23, 1084–1092.
[48] Awoyera, P. O., Ndambuki, J. M., Akinmusuru. J. O., & Omole, D. O. (2018). Characterization of ceramic waste aggregate concrete. Housing and Building National Research Center (HBRC) Journal, 14, pp. 282–287.
[49] Rashid, K., Razzaq, A., Ahmad, M., Rashid, T., & Tariq, S. (2017). Experimental and analytical selection of sustainable recycled concrete with ceramic waste aggregate. Construction and Building Materials, 154, pp. 829–840.
[50] Hussin, M. W., Muthusamy, K., & Zakaria, F. (2010). Effect of mixing constituent toward engineering properties of Palm Oil Fuel Ash (POFA) cement-based aerated concrete. Journal of Materials in Civil Engineering, 22(4), 287–295.
[51] Kunchariyakun, K., Asavapisit, S., & Sinyoung, S. (2018). Influence of partial sand replacement by black rice husk ash and bagasse ash on properties of autoclaved aerated concrete under different temperatures and times. Construction and Building Materials, 173, pp. 220 - 227.
[52] Hansen, S., & Sadeghian, P. (2020). Recycled gypsum powder from waste drywalls combined with fly ash for partial cement replacement in concrete, Journal of Cleaner Production, 274, 122785.
[53] Mohammed, S. A., Koting, S., Katman, H. Y. B., Babalghaith, A. M., Patah, M. F. A., Ibrahim, M. R., & Karim, M. R. (2021). A Review of the Utilization of Coal Bottom Ash (CBA) in the Construction Industry, Sustainability, 13, 8031.
[54] Khamidulina, D. D., Nekrasova, S. A., & Voronin, K. M. (2017). Foam glass production from waste glass by compression. IOP Conference Series: Materials Science and Engineering, 262(1).
[55] Hansen, S., & Sadeghian, P. (2020). Recycled gypsum powder from waste dry walls combined with fly ash for partial cement replacement in concrete. Journal of Cleaner Production, 274, 12278.
[56] Bave, G. (1980). Aerated light weight concrete current technology. Proceedings of the Second International Symposium on Lightweight Concretes, London.
[57] Leitch, F. N. (1980). The properties of aerated concrete in service. Proceedings of the Second International Conference on Lightweight Concretes, London.
[58] Holmes, N., Browne, A., & Montague, C. (2014). Acoustic properties of concrete panels with crumb rubber as a fine aggregate replacement. Construction and Building Materials, 73, 195–204.
[59] Hanna, H. I. R. R., Shahidan, S., Ali, N., Bunnori, N. M., Zuki, S. S. M., & Ibrahim, M. H. W. (2020). Acoustic and non-acoustic performance of coal bottom ash concrete as sound absorber for wall concrete. Case Studies in Construction Materials, 13, e00399.
[60] Łaskawiec, K., Gębarowski. P., & Misiewicz, L. (2018). Performance of Autoclaved Aerated Concrete from the Designer, Developer, and User Perspective. ce papers, 2, 535–540.
[61] Mathey, R. G., & Rossiter, Jr. W. J. (1988). A Review of Autoclaved Aerated Concrete Products, U. S. Department of Commerce, National Bureau of Standards, NBSIR 87-3670.
[62] CSR Hebel Company. (1992). Technical handbook. 5 ed., Updated May 102p.
[63] Laukaitis, A., & Fiks, B. (2006). Acoustical properties of aerated autoclaved concrete. Applied Acoustics, 67(3), 284–296.
[64] Manaf, I. A., Marsi, N., Genesan, V., Yusrianto, E., Shariff, H. H., Adnan, S. H., Awang, M., Ali, R., & Jamir, M. R. M. (2021). Compressive strength, sound absorption coefficient (SAC) and water absorption analysis of HDPE plastic waste reinforced polystyrene and Portland cement for lightweight concrete (LWC). Journal of Physics: Conference Series, 2051, 012043.
[65] Kang, L. S., Poh, F. K., Wei, L. F., Yong, T. H., Ling, L. Y., Hock, L. J., & Jin, K. Y. (2021). Acoustic Properties of Lightweight Foamed Concrete with Eggshell Waste as Partial Cement Replacement Material. Sains Malaysiana, 50(2), 537–547.