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UTILISATION OF AUTOCLAVED AERATED CONCRETE WASTE AS PARTIAL CEMENT REPLACEMENT IN FIBRECEMENT BOARDS

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ABSTRACT

The production of cement and its emission of carbon dioxide has a significant impact to the environment thus legal limits have been set resulting in carbon tax. Fibre cement industry is a high consumer of cement, especially on the natural cured products. This paper discusses the use of autoclaved aerated concrete waste as a partial replacement of cement. Everite is a producer of autoclaved aerated concrete bricks and has generated enormous amount of waste during production of these blocks. Some of this material has been milled with silica sand as it contains high quartz content. Also, the autoclaved aerated concrete characteristics will be reviewed as well as its influence on the fibre cement properties.

Properties of the mix designs were also studies. The results showed that partial replacement of cement, up to 10%, reduced density and linear expansion of ceiling boards whereas the medium density boards resulted in slight reduction in density values and linear expansion. An increment of 53% and 8% was noted in fracture energy and modulus of rupture (MOR) for ceiling board mix, respectively. The gain was not only in product properties but cost saving benefit was also accomplished.

KEYWORDS:

Autoclaved Aerated Concrete waste (AAC); Mix design; ceiling board; medium density board.

1. INTRODUCTION

One of the most pressing concerns for the building industry is global warming, an increase in average temperature of the earth's atmosphere and oceans due to the build-up of greenhouse gases in the atmosphere. Many scientists believe the recent global warming is caused by greenhouse gas emissions from energy production, cement production, transportation industry and agriculture [1, 2]. In general, 1 ton of cement produced equals 1 ton of carbon dioxide released [1]. As a result researchers are investigating alternative materials that will reduce these gas emissions. These approaches include using waste products from other industries and non-standard cement components that do not undergo CO_2 emitting reactions during manufacturing [3, 5].

Cement replacement materials are materials that can be used for substituting cement in the production of other cementitious products. The replacement materials must possess pozzolanic properties to function [5]. A few materials have been explored in order to conserve the environment and reduce greenhouse effects in construction, such as the use pulverised fuel ash, ground granulated blast furnace slag, silica fume and limestone fines as industrial wastes. On the other hand, rice husk ash, palm oil fuel ash and sugarcane bagasse ash have been considered as agricultural wastes. Other work conducted explored replacement of cement by high volume fly ash and limestone [4]. As a combination lime and fly ash, up to 75% in concrete, increased the strength and gave about 40.78% cost beneficial to the original mix. It was observed that hydration of cementitious material performs in two types of hydration, primary hydration by cement content and secondary hydration by lime content.

This paper explores one of the industrial wastes of autoclaved aerated concrete (AAC) production, which are blocks and panels that are either cracked or do not meet the quality specification. Since these products are very fragile, some of this waste is generated on site as cracked or broken blocks. Additional benefit of using this waste include minimization of waste disposal. It is anticipated that this paper will create awareness of this type of waste and the impact of its partial cement replacement on the properties of fibre cement products. The discussions will only revolve around the autoclaved mix designs of ceiling boards and medium density boards.

2. MATERIALS

2.1 Cement

The cement used was rapid hardening cement (RHC) with its properties displayed in Table 1 and its crystal phase composition populated in Table 2.

Table 1: Properties of RHC

CaO (%)	Al_2O_3 (%)	SiO_2 (%)	Fe_2O_3 (%)	SO_3 (%)	MgO (%)	LOI (%)	Blaine (cm^2/g)	Initial Setting (min)	2 Day Strength (MPa)
66.4	5.0	20.8	2.7	2.5	2.5	3.4	3710	178	33.1

Table 2: Phase composition of RHC

Alite, C_3S (%)	Belite, C_2S (%)	C_3A, cubic (%)	C3A, ortho (%)	Gypsum (%)	Bassanite (%)	Quartz (%)	Free Lime (%)	Portlandite (%)	Periclase (%)	Calcite (%)
63.7	11.3	0.5	3.5	1.5	2.8	0.9	0.2	0.6	0.7	7.1

2.2 Sand

Sand, river sand, with lower clay content of less than 1% and milled to particle size of 90 µm less than 10%. The chemical composition of the sand is tabulated in Table 3 below.

Table 3: Composition of sand

SiO_2 (%)	Al_2O_3 (%)	TiO_2 (%)	Fe_2O_3 (%)	K_2O (%)	LOI (%)
94.72	2.21	0.19	0.75	1.06	0.21

2.3 Cellulose

Cellulose fibres comprise of three blended fibres –paper towel with shorter fibres as process fibre, two types of longer fibres for reinforcement where one is sourced locally and the other imported.

2.4 Pozzolanic additive

The clay material is used only in medium density boards. It is a mined material with pozzolanic properties and its composition can be seen in Table 4.

Table 4: Properties of additive

FeO (%)	Al_2O_3 (%)	SiO_2 (%)	TiO_2 (%)	Na (%)	MgO (%)	K (%)	Bulk Density (g/l)	Particle Sizing
0.28	24.1	67.5	0.89	0.38	0.43	5.38	640	99% passing 45µm 50% passing 9µm

2.5 Autoclaved aerated concrete (AAC) waste

This waste material is crushed to the particle size of cement. This is a very light weight, porous material with very good thermal and acoustic properties. Density range of the material used was 590 – 650 kg/m^3 and its phase composition is indicated in Table 5.

Table 5: Phase composition of AAC waste material

Quartz (%)	Tobermorite (%)	Calcite (%)	Xonotlite (%)	Anhydrite (%)
45.3	45.1	3.7	0.3	4.3

3. TEST METHODS

3.1 Quantitative XRD Analysis

The samples were prepared for XRD analysis using a back loading preparation method. Diffractograms were obtained using a Malvern Panalytical Aeris diffractometer with PIXcel detector and fixed slits with Fe filtered Co-Kα radiation. The phases were identified using X'Pert Highscore plus software and the relative phase amounts using the Rietveld method [6]. This technique was used to quantify the amount of tobermorite formed for the different mix designs.

3.2 Physical and mechanical properties

The boards were cut into 250 mm x 250 mm samples and dried in an air-ventilated oven at 105˚C. After drying, the samples were cooled in a desiccator before testing. The physical and mechanical properties were tested as per ASTM 1185-08 standard.

4. RESULTS AND DISCUSSION

4.1 Experimental Program

In this study, the fibre cement mixes were designed by partially replacing cement with AAC waste material in two products, ceiling boards and medium density boards. The reason for using the two formulations is one contains additive and the other does not. The partial replacement of cement alone may reduce the alkaline content due to the smaller formation of portlandite. This work is focused in the influence on physical and mechanical properties regarding the reduction of cement content in the fibre cement mix formulation. Autoclaved aerated concrete waste was employed with replacement and addition levels of 3%, 5% and 10% by mass of cement.

Table 6: Fibre cement material proportions

Mix design formulation	Cement (%)	AAC waste (%)	Sand (%)	Cellulose (%)
Standard Ceiling Board	35 - 40	0	55 - 60	7 - 8
3% AAC replacement CB	32 - 37	3	55 - 60	7 - 8
5% AAC replacement CB	30 - 35	5	55 - 60	7 - 8
10% AAC replacement CB	25 - 30	10	55 - 60	7 - 8
Standard Medium Density Board	39 - 40	0	48 - 50	7 - 8
3% AAC replacement MD	36 - 37	3	48 -50	7 - 8
5% AAC replacement MD	34 - 35	5	48 - 50	7 - 8
10% AAC replacement MD	29 - 30	10	48 - 50	7 - 8

Table 6 shows a summary of the fibre cement mix designs used. It is important to note that the cellulose was kept constant in all mix designs. Also, the medium density formulations had additional 4 – 5% additive per mix compared to ceiling board mix designs.

The cellulose was refined to 520 – 560 CSF for reinforcement purpose whereas the paper towel was only pulped resulting in a freeness of 360 – 390 CSF for filtration. Sand was drawn from the mills that reduced its particle size to less than 10% at 90 µm. Cellulose and sand slurry were then added to the mixer together with the dry powders, i.e. cement and AAC waste, for ceiling board formulation. On the other hand, medium density board formulations had an additional raw material, additive, mixed in as a slurry. All these mix designs were processed through the Hatschek pilot plant to form fibre cement sheets which were transferred to the autoclave for curing. The duration between production and autoclaving was 24 hours. The autoclave cycle consists of 2 hours ramp up, 8 hours at constant temperature and pressure of 180°C and 10 bar thereafter ramp down of 2 hours.

4.2 Ceiling board mix designs

The physical properties of the materials with replacement of 3%, 5% and 10% were bench marked against the standard, see Figure 1. The results indicate a reduction in density of 1.57%, 4.65% and 6.2% for cement replacement of 3%, 5% and 10% respectively. The reduction in density was due to the light weight properties of the AAC waste material. The fracture energy of the ceiling boards with 3%, 5% and 10% cement replacement were significantly enhanced by 53.75%, 60% and 62.5% respectively. The increment was as a result of the crystal structure of the AAC waste. The last physical property evaluated was the water absorption and the results are graphically illustrated in Figure 2. The increment percentages of the ceiling boards with cement replacement were all below 9%, i.e. 0.2%, 8.12% and 5.69% increase compared to standard for 3%, 5% and 10% cement replacement. As the density values were reduced and water absorption increased.

The most beneficial effect of using this waste material was the reduction in linear expansion, i.e. the dry-wet movement. This will result in boards that are moving less when installed hence no cracking can be expected when boards are plastered. The linear expansion reduction trends for 3%, 5% and 10% were 26.83%, 31.71% and 39.02% respectively. According to Figure 2 substitution of cement with AAC waste decreased the modulus of rupture. The MOR, with grain, showed a reduction of 21.23%, 38.11% and 38.52% for 3%, 5% and 10% cement replacement respectively. On the other side, MOR across grain for 3%, 5% and 10% resulted in a reduction of 27.73%, 32.38% and 29.24% respectively. Although the strength values were reduced, the product quality remained within specification.

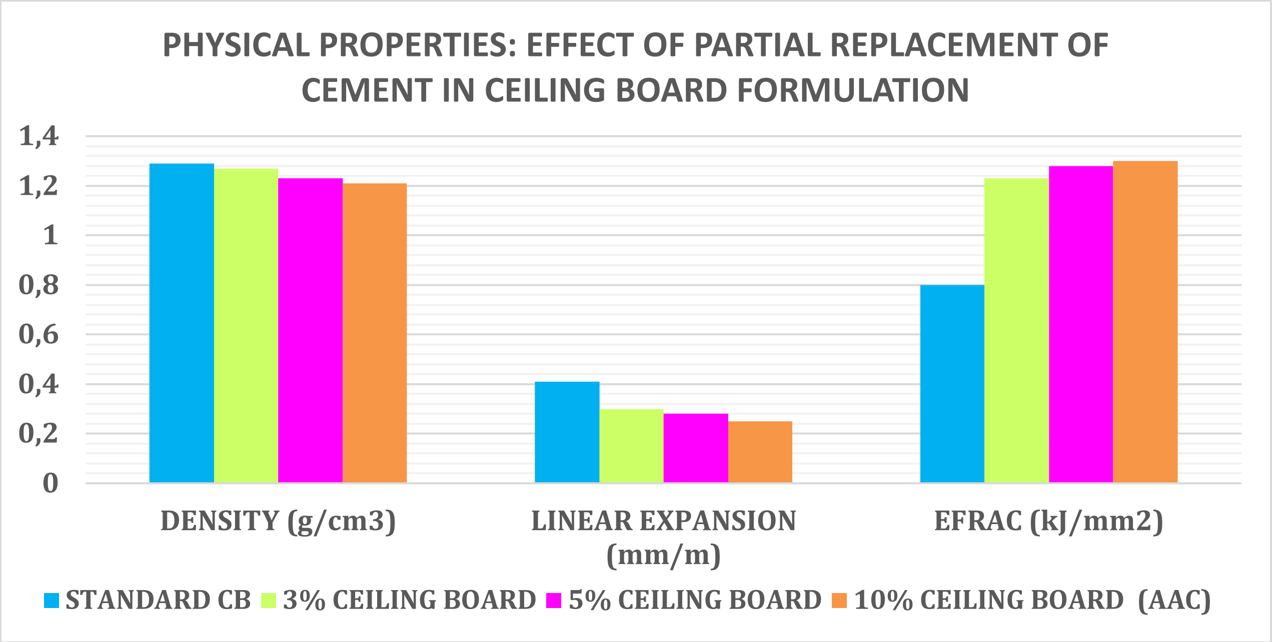

Figure 1: Physical properties of ceiling boards with partial substitution of cement

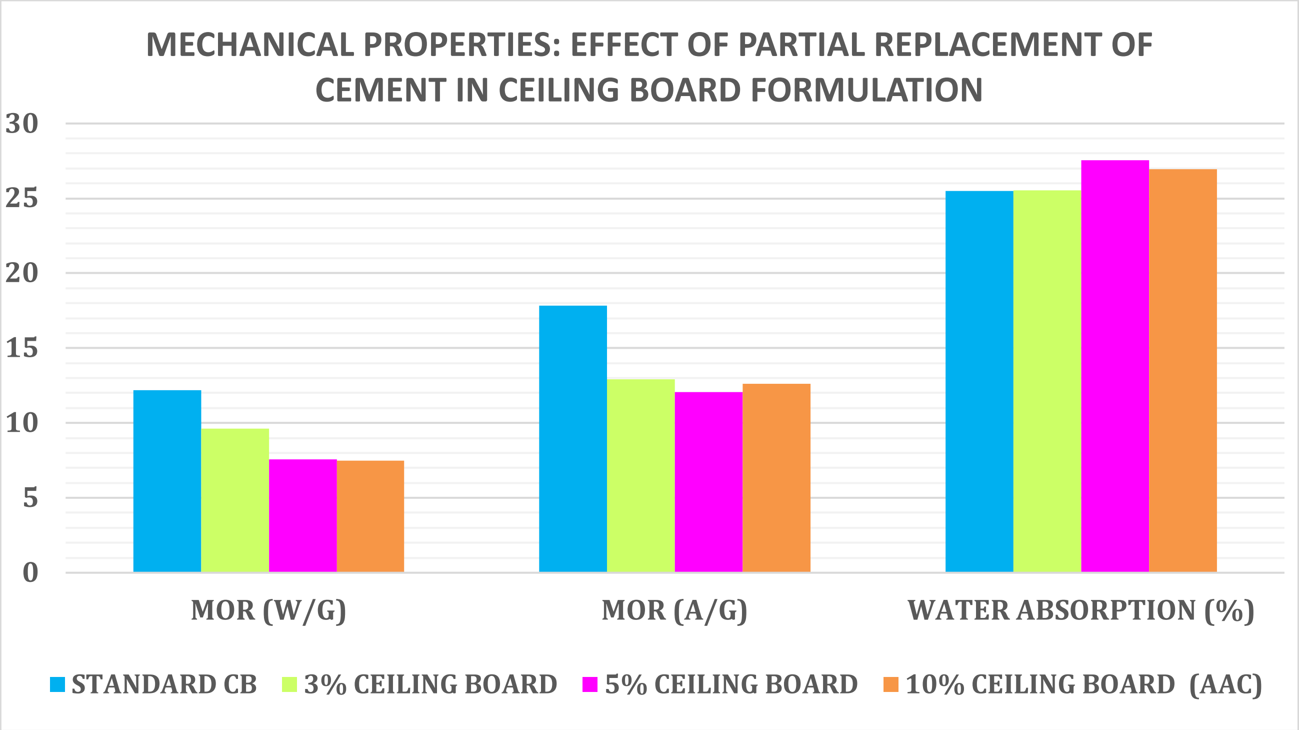

Figure 2: Comparison of mechanical properties of cement replacement ceiling boards

The samples were also sent out for XRD quantification to determine the contribution of AAC waste to crystal phase formation. The results are tabulated below, see Table 7. In case of AAC waste being used as a partial replacement of cement, the increase in tobermorite formation is due to high quantity of tobermorite in AAC waste although the effect of the decrease of cement amount generating portlandite during hydration happened. The calcite content is a result of the additional calcium carbonate milled into the cement as an extender.

Table 7: Phase formation in ceiling board mixes

Mix design	Tobermorite (%)	Calcite (%)
Standard	8.3	8.5
3% replacement	8.4	7.3
5% replacement	9.7	3.5
10% replacement	11.4	3.5

4.3 Medium density board mix designs

The results in Figure 3 indicate density reduction of 3.08%, 5.38% and 7.69% for 3%, 5% and 10% cement replacement respectively. The reduction of density with increment of AAC waste in the formulation is due to AAC waste being a light weight material. At higher percentages of replacement linear expansion decreases steeply, noted at 26.92%, 30.77% and 46.15% for 3%, 5% and 10% respectively. Significant increase in fracture energy was noted in 3% cement replacement but the value dropped for 5% replacement whereas a slight increment of 6.09% was noted for 10% cement replacement. The water absorption increases were also below 9% as observed in ceiling boards – 3.58%, 6.23% and 7.74% for 3%, 5% and 10% cement replacement, respectively.

The reduction in MOR, with grain, was less than noted in ceiling board mix designs. The 3%, 5% and 10% cement replacement resulted in a reduction of 17.34%, 23.12% and 24.06% respectively. But, the MOR across grain was similar to the ceiling board mix designs at 27.46%, 27.51% and 32.59% for cement replacement of 3%, 5% and 10% respectively.

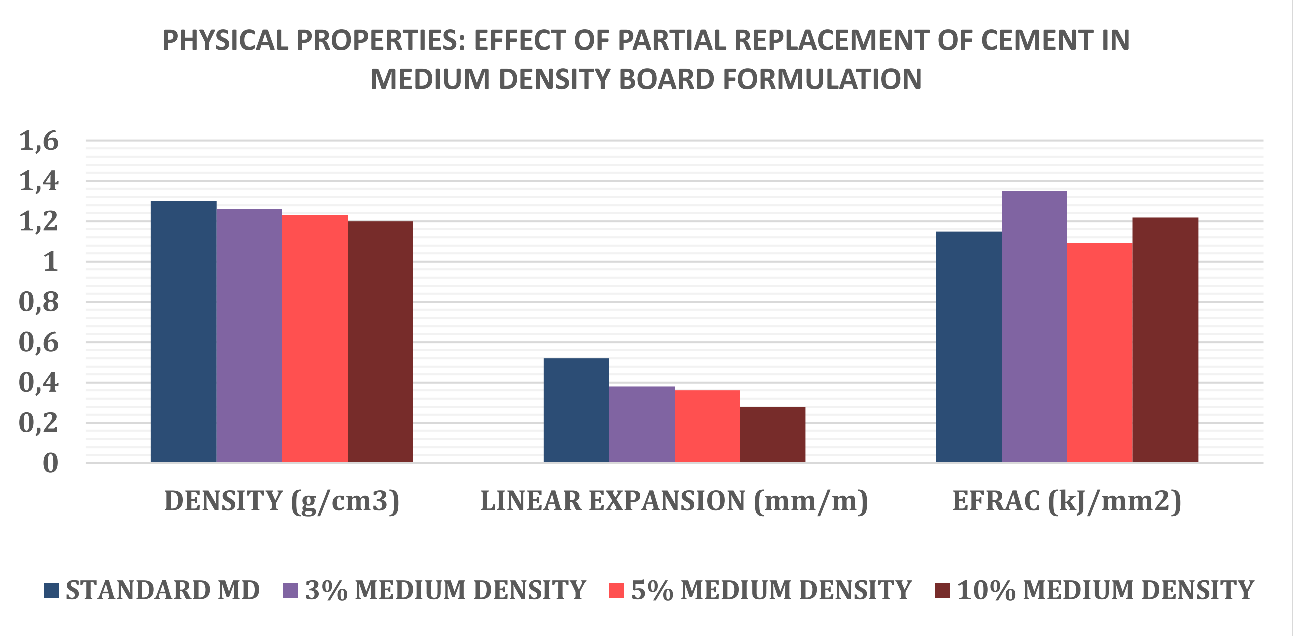

Figure 3: Comparison between cement replacement mix designs and standard formulation

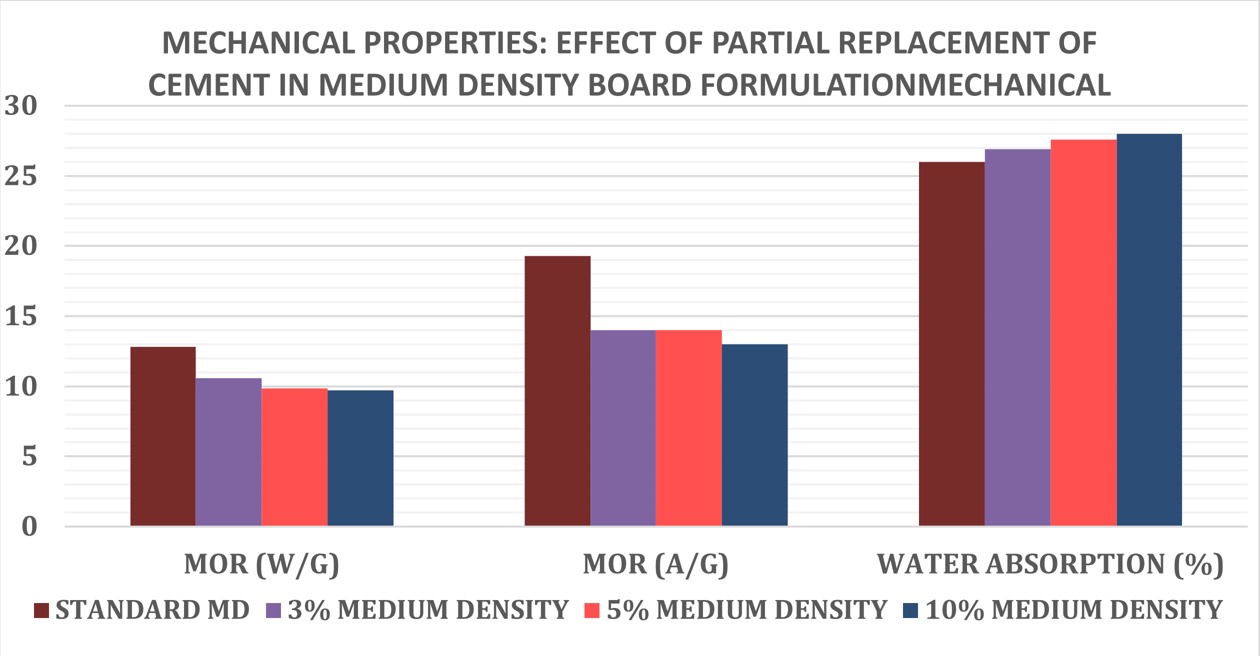

Figure 4: Mechanical properties of partial cement replacement in medium density boards

The quantitative XRD results for medium density mix designs can be seen in table 8. There is an increase in tobermorite, due to the high amount in AAC waste, as more cement was replaced with AAC waste. The high amounts of katoite values can be contributed to the introduction of alumina based additive in medium density mix design.

Table 8: Phase formation in medium density board mixes

Mix design	Tobermorite (%)	Calcite (%)	Katoite (%)
Standard	12.6	5.3	2.1
3% replacement	11.8	8.1	1.3
5% replacement	12.9	5.5	2.7
10% replacement	13.4	8.1	1.4

5. CONCLUSIONS

This paper explored the utilisation of AAC waste as partial replacement of cement to reduce carbon emissions in the fibre cement industry. The following conclusions can be deduced from the results:

- Replacement of cement partially with AAC waste was optimised at 10% for ceiling board mix. Significant improvement in linear expansion and fracture energy was noted. Lighter products resulted from the light weight waste material but there was no brittleness observed.
- The same trends were seen in the medium density mix designs with optimisation level at 5%. The fracture energy values were significantly lower compared to the ceiling board mix designs at all levels tested.
- The MOR, both with and across grain, values dropped but the quality specification was within the acceptable range.

- The high amount of tobermorite observed as the increment in cement replacement occurred can be attributed to the high tobermorite content in AAC waste.
- By replacing the cement content at 5% and 10% for medium density and ceiling board mix designs, significant cost benefit will be achieved as cement is one of the expensive raw materials.

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