THE FEASIBILITY STUDY OF USING ALTERNATIVE OR PARTIAL ALTERNATIVE OF ORDINARY PORTLAND CEMENT (OPC) IN AUTOCLAVED FIBER CEMENT BOARD MANUFACTURING AS A GREEN APPROACH

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ABSTRACT

Concerns over the impact of selecting aggregates and carbon emission released to environment have increased in recent years due to global warming issues. There are many studies of fly ash and slag by the cement or concrete manufacturers as partial replacement for aggregate in the concrete industry, but this might not be applicable for fiber cement manufacturers in Malaysia at this moment. However, we are keen to move forward to reduce the carbon footprint for our autoclaved cellulose fibre cement products by alternatively using less OPC cement in line with the global trend of green building material approach.

In this study, we have selected low LOI Class F (siliceous) fly ash and Ground Granulated Blast-Furnace Slag (GGBS) which is pozzolanic in nature to partially replace the OPC. GGBS blended cement obtained the closest performance comparing to OPC, and therefore it has a good opportunity to partially replace OPC. Further study on GGBS blended cement is required to find the optimum blending ratio and autoclave parameters setting in order to achieve the best product performance.

KEYWORDS:

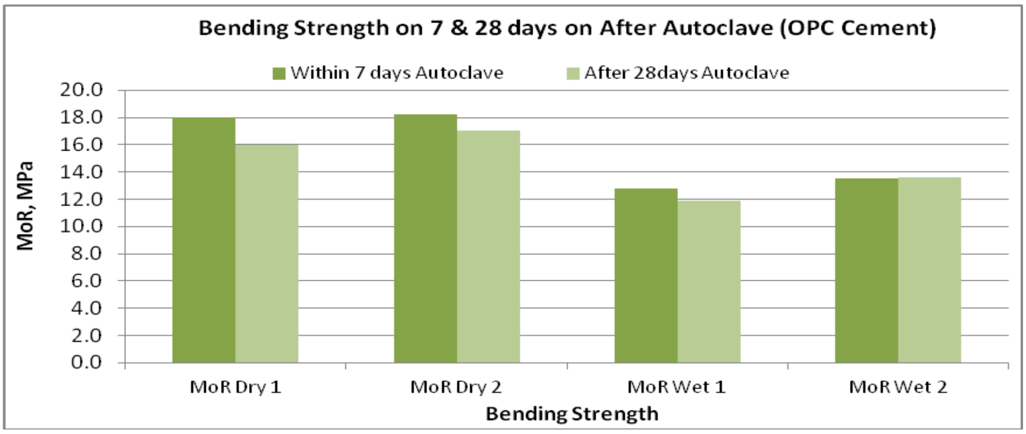
Fly ash; Ground Granulated Blast-Furnace Slag (GGBS); Autoclaved Cellulose Fibre Cement; Ordinary Portland Cement (OPC).

INTRODUCTION

The challenge to manufacture autoclaved fiber cement has kicked-off with the approach of using greener raw materials. The basic raw materials to produce autoclaved fiber cement are cellulose fiber (7-10%), fine silica (50-60%), OPC (30-40%) and additive (2-4%). Cellulose fiber is obtained from forest plantation resources while silica is obtained from leftover sand after tin and kaolin mining whereas Ordinary Portland Cement (OPC) is from the cement plant. OPC is the most common type of cement for general use around the world as a basic ingredient of concrete and mortar. It is a fine powder produced by grinding Portland cement clinker (more than 90%), a limited amount of calcium sulphate (which controls the set time) and up to 5% minor constituents as allowed by various cement standards. OPC chemical components are highly influenced by the lime source as different lime mining source will results in different chemical compositions. As we know OPC is not a green raw material, it is estimated that producing 1 ton of OPC, emits 1 ton of Carbon Dioxide into the environment.

In the process of manufacturing autoclaved fiber cement boards, cellulose fiber helps in the manufacturing process as a retention aid and also acts as reinforcement to the matrix. OPC and fine silica will react to form Calcium Silicate Hydrate (CSH) Tobermorite crystalline structure during the autoclave process at 180°C, 9-10 bars for 12-14hours. Thus, the purity of OPC is very important to the CSH crystalline structure formation which will promote the product strength and control the moisture movement. In general, after autoclave curing process, the board will be at full strength. OPC will be fully reacted during autoclaving process and no further reaction will take place even in longer storage period. This was shown in the Figure 1, the fibre cement sheet bending strength test results conducted by Hume Cemboard at 7^{th} and 28^{th} days after autoclaving. Finding a suitable substitute for OPC is very critical as it is this that determines the final strength of autoclaved fiber cement board. The most frequent approach taken by cement and concrete manufacturers is to replace OPC with pozzolanic materials such as fly ash and slag.

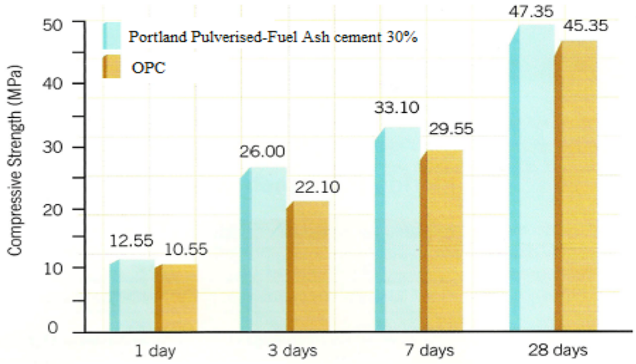
Figure 1- Bending strength (MoR Dry &MoR wet) of fibre cement sheet within 7 days and 28 days after autoclaving process



Fly ash is widely used in cement plants to blend with OPC. It has significant pozzolanic properties and when mixed with OPC, reacts with lime produced by the hydration of OPC to form stable Calcium Silicate and Calcium Aluminate Hydrates. Fly ash is generated in burning coal combustion furnace at above 1000°C and the fine particles that rise together in the outlet gases are known as fly ash. Heavy ash will drop at the bottom furnace known as bottom ash. The components of fly ash vary depending on source and makeup of the coal being burned in the furnace but in general all fly ash includes large amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO).Fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. There are two classes of fly ash defined by ASTM C618 those are Class F fly ash and Class C fly ash but not all fly ash meet their requirements. Generally, Class F fly ash contains less than 20% lime (CaO) and Class C fly ash contains more than 20% lime (CaO). Fly ash in Malaysia is from coal burning power plants (Khairul, 2007).Using fly ash as a partial replacement for Portland cement in Malaysia is generally limited to Class F fly ashes and only certain size will be selected. It can replace up to 45% by mass of Portland cement, and can add to the concrete's final strength and increase its chemical resistance and durability. In Figure 2, the compressive strength of concrete using 30% fly ash replacement for OPC increases with a longer air curing period. When we replace one single ton of OPC with fly ash, we are not only eliminating waste from our planet but we are also reducing the emission of 850kg of CO_2 into our atmosphere. It is a green approach to study fly ash blended cement as OPC substitution.

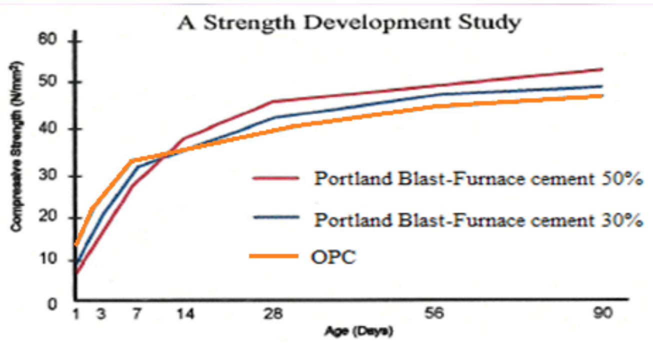
Slag is a partially glassy by-product from steel manufacturing process. It can usually be considered as mixture of metal oxides and Silicon Dioxide. Blast Furnace Slag is principally Calcium Silicate and can hydrate to produce Calcium Silicate Hydrate at as low rate.In the ore smelting process, slag is channelled out of the furnace and water is poured over it. This rapid cooling, often from a temperature of around 1430°C, is the start of the granulating process. This process causes several chemical reactions to take place within the material, and gives the slag its cementitious properties. Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. GGBS is often used in concrete with Portland cement as part of blended cement. GGBS reacts with water to produce cementitious properties. Concrete containing GGBS develops strength over a longer period, leading to reduced permeability and better durability (Warid, 2007). In Figure 3, higher amount of GGBS obtained higher compressive strength with a longer air cure period. GGBS can be considered as green material as it is a by-product and assist in conserving the environment. Every ton of GGBS used to replace clinker saves almost 900kg of CO_2 being released into the atmosphere. Figure 4 shows the actual CO_2 emissions for GGBS and OPC production.

Figure 2 - Compressive strength studied by Lafarge cement using OPC &PPFA (30%) cement on air cure concrete



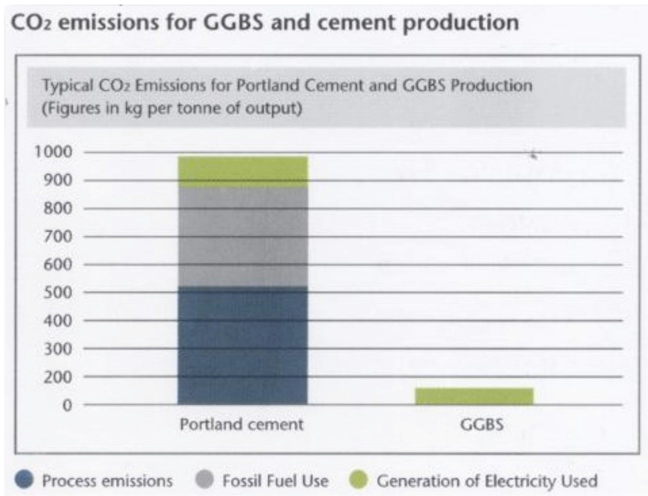
Source from Lafarge Cement, Malaysia

Figure 3 - Compressive strength studied by YTL cement using OPC, PBFC 30% & 50% on air cure concrete



Source from YTL Cement, Malaysia

Figure 4 - The CO_2 emissions for GGBS and Portland cement production



Source: YTL Cement, Malaysia

Table 1 - Chemical composition on OPC, GGBS and Fly Ash

Chemical Composition	Cement		
	OPC, YTL	GGBS	Fly Ash
SiO_2	20	32.9	46.6
Al_2O_3	5	14.1	27.5
Fe_2O_3	3	0.5	7.0
CaO	64	43	6.2
MgO	2	4.8	1.9
SO_3	3	0.3	0.6
K_2O	0.5	0.27	1.4
Na_2O	0.05	0.16	1.1
Cl	-	0.01	0.03

Source: YTL cement and Lafarge cement, Malaysia.

Table 2 - Physical properties on GGBS, Fly ash, OPC, PBFC & PPFAC.

Physical Properties	Pozzolanic Materials		Cement		
	GGBS	Fly Ash	OPC, YTL	PBFC	PPFAC
Blaine (m2/kg)	450	240	350	-	410
Soundness, mm	1	-	1	1	0.5
Setting time, Initial (minutes)	305	-	185	220	165
Compressive strength Mortar Prisms (1:3:0.5) 28 days, Mpa	60.6	-	60.8	59.5	-
Compressive strength Concrete (1:6:0.6) 28 days, Mpa	-	-	-	-	31

Source: YTL cement and Lafarge cement, Malaysia.
Remark: PBFC meets MS522: Part 1:2007 requirement.
PPFAC meets MS1227:2003 requirement.
OPC meets MS EN 15167-1:2010 requirement.

There are many studies being conducted on fly ash and slag in concrete manufacturing to replace the OPC, mainly through the normal air curing process. The general finding for air curing is that blended OPC with fly ash or slag gives lower early strength but manages to achieve comparable or better final strength in 28 days depending on the amount of pozzolanic materials added to the OPC. However, there is a lack of study on OPC substitution in autoclaved fiber cement products. As mentioned earlier, the autoclaved board with OPC will obtain full strength after autoclave process and a longer storage period will not contribute much in late strength. However, it is possible this may happen if we use different types of cement or cement substitution compared with pure OPC. The main objective of this study is to find OPC substitution for autoclave fiber cement board. Besides looking forward to produce environment friendly board by using less OPC, we are also keen to get lower board density with comparable or better performance by substitute OPC with other cement or pozzolanic materials. A comparison of chemical composition and physical properties of OPC, Fly ash and GGBS is listed in Table 1 & 2.

RAW MATERIALS

A) Cement

A controlled lot of sample is prepared for each and every laboratory press sheet preparation. Table 3 shows type of cement used in this study. Fly ash and Portland Pulverised-Fuel Ash cement (PPFAC) are obtained from Lafarge cement (supplier A). Slag (GGBS) and Portland Blast-Furnace cement (PBFC) are obtained from YTL cement (supplier B). PPFAC and PBFC are the current commercial cement products made by local Malaysian cement manufacturers and easily available. These have been selected for this study because they can be used directly without any additional processes.

Table 3 - Types of cement evaluated

Type of Cement	Abbreviation
Controlled Lot, Ordinary Portland Cement	OPC
Portland Pulverised-Fuel Ash Cement with 15% Fly Ash, ready mix by manufacturer	PPFAC 15
Portland Pulverised-Fuel Ash Cement with 30% Fly Ash, ready mix by manufacturer	PPFAC 30
Portland Blast-Furnace Cement with 20% GGBS, ready mix by manufacturer	PBFC 20
Portland Blast-Furnace Cement with 30% GGBS, ready mix by manufacturer	PBFC 30
OPC with 5% GGBS, blended in house	GGBS 5
OPC with 10% GGBS, blended in house	GGBS 10
OPC with 5% Fly Ash, blended in house	Fly Ash 5
OPC with 10% Fly Ash, blended in house	Fly Ash 10

b) Silica

Silica is collected from ball mill production with minimum of 22% retention at 325 mesh (45 micron).

Table 4 - Silica properties in fiber cement board.

Properties	Specification for Fiber cement pulp
Clay content, %	< 2
SiO_2 content, %	> 90
Retention at 45micron mesh, %	>22

c) Cellulose Pulp

A single lot of softwood unbleached Kraft pulp was collected for this research. Table 5shows the cellulose pulp specification used in this study. The cellulose pulp specification must meet the minimum requirement as it contributes to the final board results.

Table 5 - Cellulose fiber properties in fiber cement board.

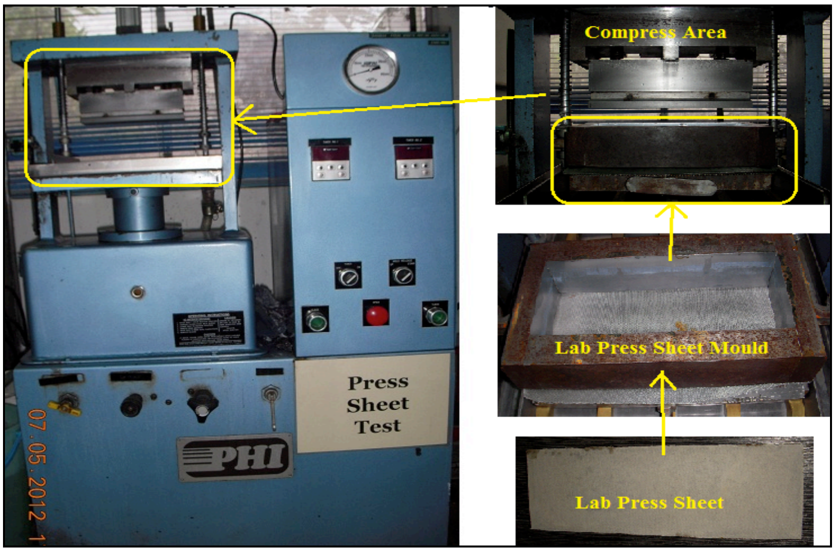
Properties	Specification for Fiber cement pulp
Fiber Length, mm	> 2.5
Fiber Coarseness, mg/100m	> 20
Kappa Number	25 – 28
Zero Span Tensile Strength, km	> 15

RESEARCH METHODOLOGY

a) Laboratory press sheet preparation:

Cement and silica materials are measured in the dry state, according to the recipe. Pulp will be prepared at 2% consistency using British Pulpability Apparatus equipment (BPEA) and amount required is measured according to recipe. Materials are mixed together in a plastic container and stirred for 5 minutes .Slurry is transferred to a rectangular mould with 50mesh sieve on the bottom. Slurry needs to be evenly distributed in the mould using scraper. Another top sieve of 50mesh is placed on top of slurry and followed with a 2 minutes pressing process at 20000 lbs. A vacuum tube is placed on top to suck the excessive water produced during the pressing. Then the green sheet will be de-moulded and put on a flat board in the laboratory environment for 8 hours before autoclaving at 180°C, 9bar for 14 hours.Figure 5 is an illustration of how the laboratory pressed sheet is made.

Figure 5 - Laboratory press sheet equipment



b) Board Testing

After autoclaving process, sheets were tested for bending strength, density and moisture movement.

i) Bending strength

After the autoclave process, the sheet is subjected to Modulus of Rupture (MoR) dry and wet test. For MoR dry, the board is dried in the oven at 100^{o}C for 24 hours whereas for MoR wet, the board is immersed in water for 24 hours before subjected to bending test (Figure 6 left).

i) Density

The density measurement is using Archimedes method that excludes the voids which are inherent in the material. Firstly, we need to immerse sheet samples in water for 24hours. Secondly, we need to weigh the wet sheet mass and suspended weight sheet mass in water. Then oven dry for 24hours to get the dry sheet sample weight.

ii) Moisture movement

Moisture movement test in fiber cement is defined as the changes in length of a specimen exposed to 2 different prescribed temperatures and relative humidity till steady weight condition is achieved. We are using in-house moisture movement test method. A piece of dented stud is glued at the centre on the top and bottom of the sheet. After the glue is fully cured, the sample is pre-conditioned in the oven at 100^{o}C for 3 days before its total length is measured (Figure 6 right). Then, the sample needs to be saturated in water for 3 days and the total length is measured again. The length changes from dry to saturated condition are then calculated in percentage.

Figure 6 - Bending strength and moisture movement equipment

RESULTS & DISCUSSION

The laboratory press sheets were evaluated on board physical test such as density, bending strength and moisture movement. The percentage results were calculated based on changes of new types of cement compared with the controlled lots using OPC only.

Board Density:

Figure 7 and 8 show the density results on different types of cement used. Overall the differences of density results did not exceed 5% compared to the controlled lots, OPC.

In Figure 7, the positive percentage indicates higher density or heavier sheet compared to the controlled lots and vice versa. Samples using GGBS 5, PPFAC 15 and PPFAC 30 obtained similar results with controlled lots. Samples using GGBS 10, PBFC 20, PBFC 30 (within 7 days after autoclave only), Fly ash 5 and Fly ash 10 obtained slightly lower density compared with controlled lots. Significant increased for PBFC 30 sample, tested in 28days after autoclave process. This could be an outlier results and further investigation is required. In general, the obtained density result is within the normal range of autoclave fiber cement sheet produced from OPC.

Generally Fly ash and GGBS are not able to reduce the sheet density which we desired to achieve, <1.30 g/cm^3.

Figure 7 - Sheet Density with different blended cement compared with OPC controlled lots (in % difference)

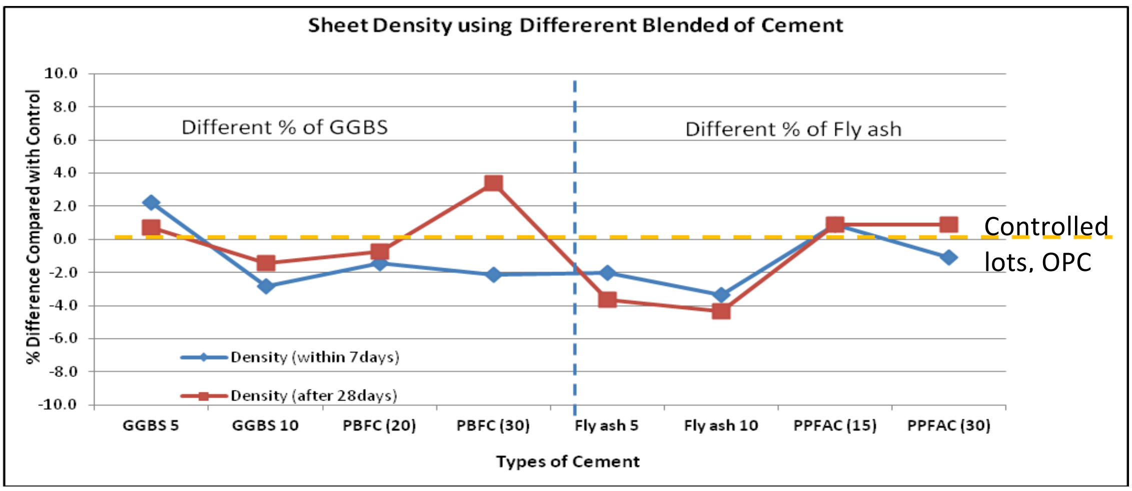
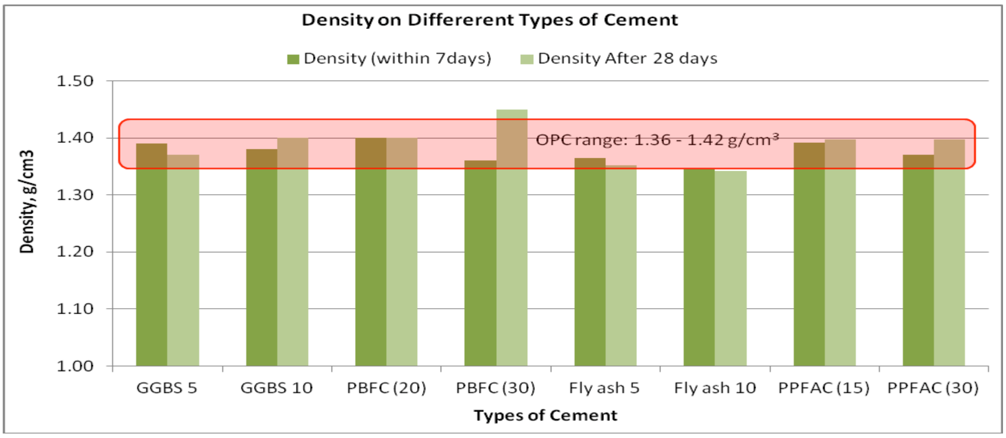


Figure 8 - Sheet Density with different types of cement in g/cm^3.



Bending Strength / Modulus of Rupture (MoR):

Bending strength or Modulus of Rupture (MoR) is measured by the maximum load applied at the centre of the board with 2 support bars at left and right edges. It is a destructive test and the board must fail or break in between 10-30 seconds. If the test specimen breaks faster or slower than the recommended speed, it will affect the final results.

Referring to Figure 9 and Figure 11, the positive percentage indicates higher strength compared to the controlled lot and vice versa. The controlled lot results were not tabulated in the figure as different press sheets produced in different periods will give a slightly different result. For MoR dry as shown in Figure 9, GGBS 5 (5% GGBS) obtained comparable results with the controlled lot. However, the strength reduced for GGBS 10 samples but subsequently the strength started to increase for PBFC 20 and PBFC 30 samples. This is applied for samples tested within 7 days and 28days after autoclave process. Noticed that there was a huge strength improvement (49% increase in MoR Dry for PBFC 30 samples tested 28 days after autoclave process) comparing with the controlled lot. Refer to Figure 10 & 12, there was not much MoR changes between measurements done on 7 days and 28 days after autoclave although there was some increase in MoR dry found in samples with higher GGBS content. Generally, GGBS blended cement samples provide comparable and better MoR dry performance comparing with OPC samples, this was also found for MoR wet as showed in Figure 11 & 12.

Figure 9 showed that Fly ash 5 (5% fly ash content) and Fly ash 10 obtained comparable strength with controlled lots but further increase in fly ash content such as PPFAC 15 and PPFAC30,theMoR dry decreased; a similar trend was found in Figure 11MoR wet, where increasing the fly ash content reduced the product strength. There was not much change in the MoR for measurements done at 7 days and 28 days except MoR wet for Fly ash 5 and Fly ash 10 where we found about 2 MPa increase in MoR value at 28 days. Generally, blended OPC cement with fly ash has lower strength comparing with GGBS blended cement and OPC.

Figure 9 - MoR dry for sheets with different blended cement compared with OPC controlled lots (in % difference)

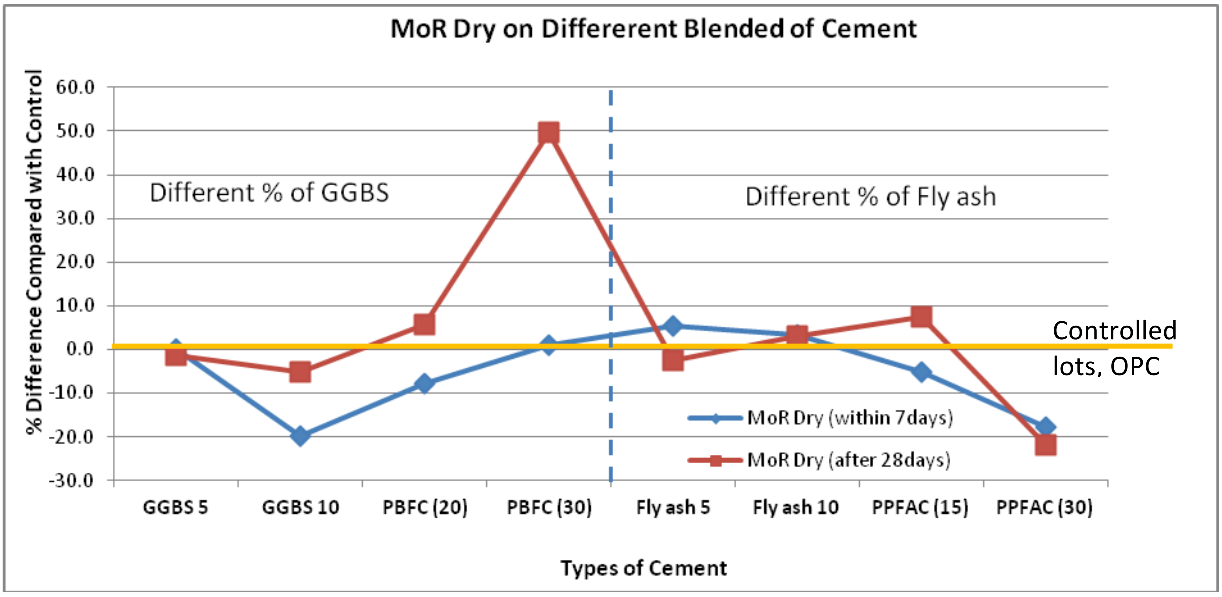


Figure 10 - MoR dry for sheet with different types of cement in MPa

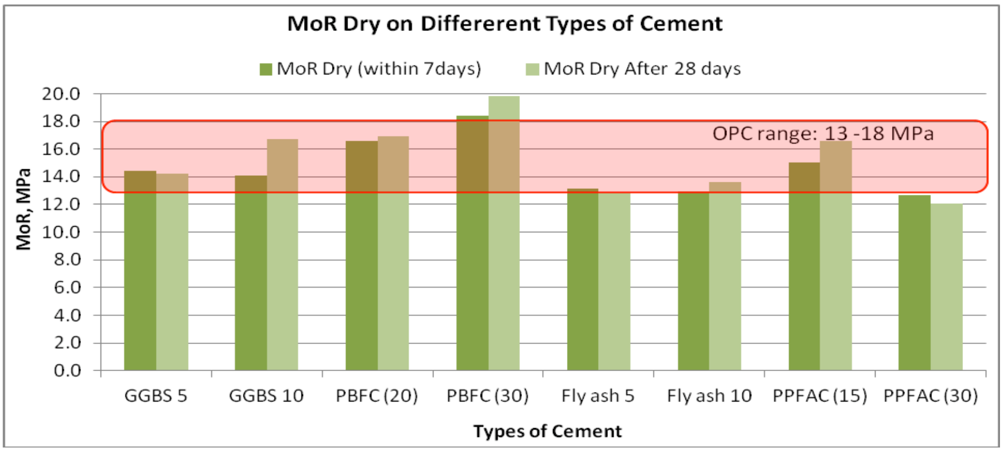


Figure 11 - MoR wet of sheets with different blended cement compared with OPC controlled lots (in % difference)

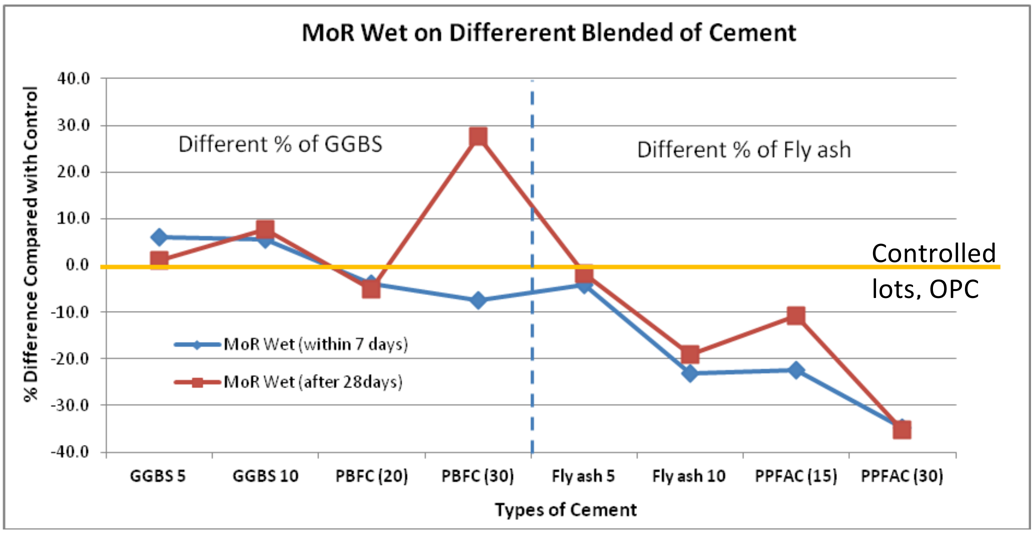
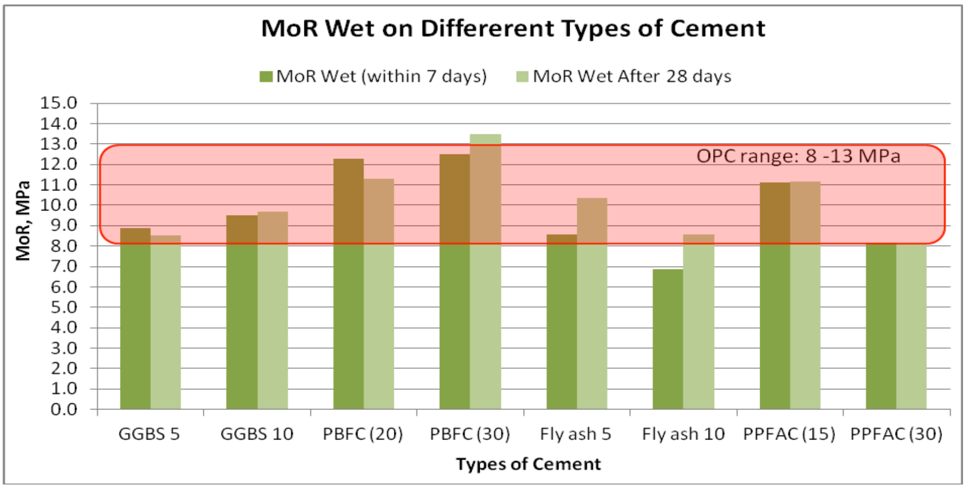


Figure 12 - MoR wet of sheets with different types of cement in MPa



Moisture Movement

Referring to Figure 13, the positive percentage indicates higher movement compared to the controlled lots and negative percentage indicates lower movement and better results. In Figure 13, the Fly Ash 5 and Fly Ash 10 give lower moisture movement from Dry to Saturated condition at 7 days and 28 days after the autoclave process compared with the controlled lots. Further increases in fly ash amount as shown in PPFAC 15 and PPFAC 30 increased the moisture movement results producing poorer results comparing with OPC as is clearly shown in Figure 13 on PPFAC 30 sample. In general, all GGBS samples obtained comparable moisture movement results at7days and 28days after autoclave process compared with the controlled lots. The higher amount of GGBS added in the fiber cement sheet did not effect its moisture movement. Thus, the GGBS in blended cement has no influence on sheet moisture movement. In Figure 14, sheets made from blended cement with GGBS and fly ash achieved the moisture movement values in the range obtained by using purely OPC while fly ash blended cement seemed to have lower moisture movement compared with GGBS blended cement.

Figure 13 - Moisture movement (Dry to Sat.)of sheets with different blended cement compared with OPC controlled lots (in % difference)

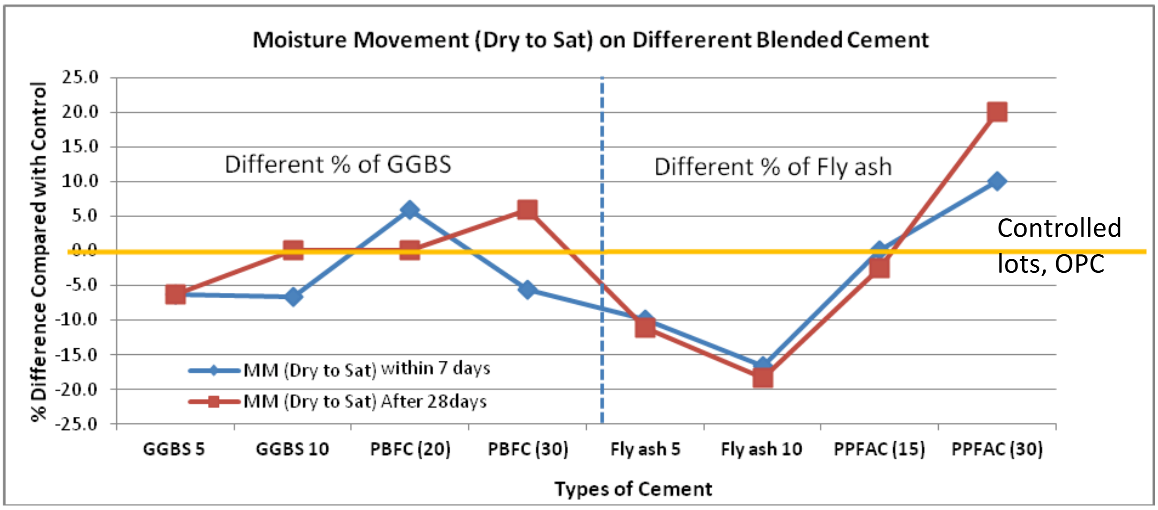
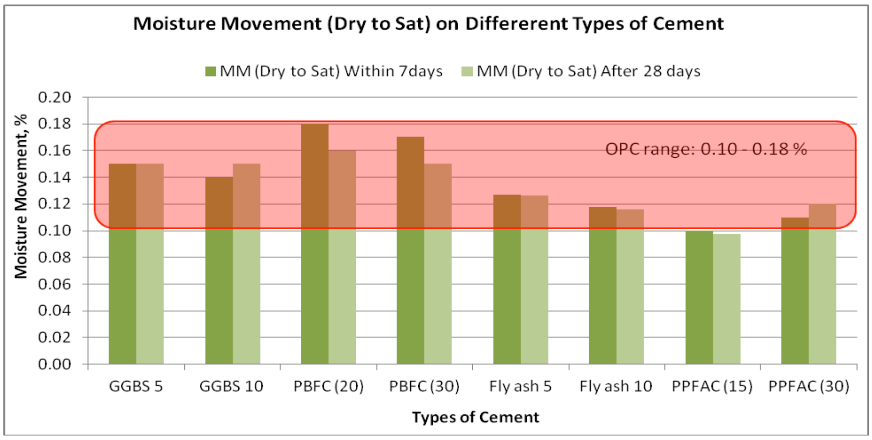


Figure 14 - Moisture movement (Dry to Sat) of sheets with different types of cement in %



CONCLUSION

Based on the above findings, there was no significant change in density for samples using GGBS and fly ash blended cement. The overall differences of density results did not exceed 5% compared to the controlled lots i.e. OPC sheets. The GGBS and fly ash did not help in reducing in sheet apparent density. As for bending strength, GGBS blended cement sheets seemed to have better and comparable performance than OPC especially when the GGBS content increased. However, this was not found in fly ash blended cement sheets. Fly ash blended cement products have slightly inferior strength performance comparing with OPC products. In term of moisture movement, fly ash blended cement sheets have generally lower or better moisture movement results comparing with OPC sheets. Where as, GGBS blended cement sheets showed comparable results as OPC sheets.

To conclude, the GGBS blended cement has the closest performance to OPC and therefore can be used to partially replace OPC. We will further pursue the studies on GGBS blended cement to find the optimum blending ratio and its process parameters such as autoclave parameters setting in order to achieve the best product performance. Meanwhile, we will also study the CSH structure formation in detail to gain better understanding on the chemical reactions occurring between the blended cement with silica during the autoclaving process. Last but not least, the durability of fibre cement products with GGBS blended cement will also be evaluated before any implementation into our production. Thus we hope to be able to reduce the carbon footprint of our fibre cement products by introducing this blended cement in near future.

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