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COMPARATIVE STUDY OF PROPERTIES OF CONCRETE MADE OF HYDRAULIC CEMENT (TIS 2594) AND ORDINARY PORTLAND CEMENT (TIS 15)

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ABSTRACT:

Cement is the most manufactured product in the world by mass and it is the 2nd most used substance after water. Cement industry alone is responsible for more than 5% of global CO2 emissions. Hydraulic cement for general construction (general use (GU) type) with lower clinker content than ordinary Portland cement (OPC) can help reduce the emissions, but with reduced clinker content performance and durability may become an issue with large scale adoption to significantly reduce the emissions. This research was focused to answer questions on performance of concrete made of hydraulic cement of GU type versus OPC. Three major cement manufacturers in Thailand with combined market share of more than 85% were chosen and their brands of cement had been studied in this research. The study covered fresh, hardened and durability properties of concrete. The results obtained displayed that hydraulic cement of GU type concrete had workability similar to OPC concrete and compressive strength similar to OPC concrete and in some brands even better. With respect to durability, both hydraulic cement of GU type concrete and OPC concrete had similar properties.

KEYWORDS: Hydraulic Cement, Ordinary Portland Cement, Durability

1. Introduction

Cement by mass is the most manufactured product in the world and the 2nd most consumed material next to water, with cement production responsible for more than 5% of Global anthropogenic CO2 emission [1]. For competitiveness of cement as a construction material, it is essential to improve the sustainability of cement used to make concrete. One of the most preferred ways world over is clinker substitution in cement during the manufacturing process leading to lower emissions.

Hydraulic cement can be defined as cement conforming to ASTM C1157 standard and in case of Thailand TIS 2594. Typically, this type of cement consists of normal clinker along with presence of additional renewable or green materials like limestone powder, fly-ash, and etc. in approximately 10% in Thailand [2]. It is proven that with the efficient use of cement, global warming can be reduced. This makes hydraulic cement a very good prospect as lower clinker content relates with lower CO2 emissions [3].

Since in Thailand, many concrete works in the past years required the use of OPC as the main cementitious constituent of concrete but now the appearance of hydraulic cement of GU type has come into the market as an alternative and green material to reduce CO2 emission four years ago. Therefore, it becomes important to study the performance of concrete made of GU and OPC with respect to fresh, hardened and durability properties.

Currently, there are 7 cement manufacturers in Thailand and for the study 3 of the major cement brands with a combined market share of 85% were chosen. The objective of this work was to compare the performance of concrete made of GU and OPC for each manufacturer separately. The fresh (slump), hardened (compressive strength) and durability properties including sorptivity, chloride ion penetrability and abrasion resistance of the concrete made with various cement brands were compared. All the mixes were produced as per ACI 211.1 and tests were conducted as per ASTM guidelines.

2. Experimental Program

2.1 Raw Materials

Ordinary Portland cement (TIS 15) and hydraulic cement of GU type (TIS 2594) from 3 different cement manufactures were selected. Local limestone aggregate with a specific gravity of 2.69 and bulk density of 1,550 kg/m^3 and local river sand with fineness modulus of 2.2, specific gravity of 2.42 and bulk density of 1,481kg/m3 were used for producing the concrete. The chemical composition of cement could not be determined due to COVID-19 lockdown during the time of this research work.

The specific gravity of the different cement brands used was determined as per ASTM C188 and is shown in the Table 1 below. It can be seen that all hydraulic cement brands have lower specific gravity than OPC cement.

Table 1 Specific gravity of various cement brands and types

Cement Manufacturer	Cement Type	Specific Gravity
Brand A	OPC	3.11
	GU	3.04
Brand B	OPC	3.12
	GU	3.02
Brand C	OPC	3.08
	GU	3.00

2.2 Mixture Proportions

The mix proportion was designed as per ACI 211.1 with a 28-day compressive strength requirement of 30 MPa, slump requirement of 50 ± 20 mm. The same mix proportion was used for all the cement brands. Table 2 below shows the mix proportion used.

Table 2 Mixture proportions for Concrete

Constituent	Amount
Cement	365 kg/m^3
Coarse Aggregate 4.75-19 mm	1,060 kg/m^3
Sand 0-4.75 mm	725 kg/m^3
Free Water	197 L/m^3
w/c ratio	0.54

2.3 Specimen Fabrication, Curing and Testing Methods

Thirteen 100 by 200 mm cylindrical and two cubical 150 by 150 mm concrete specimens were casted for each of the cement brand and type as per ASTM C192. After concrete was mixed for each cement type and brand, the slump of the mixture was measured as per ASTM C143. The average of three slumps was taken and was restricted to only measuring initial slump. Slump loss with time was not considered for the study.

Specimens were demolded after 24 hours and were stored in curing tank for 3, 7 and 28 days, respectively. Compressive strength was measured after 3, 7 and 28 days of curing as per ASTM C39. Durability tests were performed after 28 days of curing as per ASTM C1585 for rate of water absorption or sorptivity, chloride ion penetrability as per ASTM C1202 and abrasion resistance as per ASTM C944.

3. Results and Discussions

3.1 Slump Test

The slump achieved by hydraulic cement was lower by 13-30% as compared to OPC cement for the same w/c ratio, but it fell within the target slump range set in the objective. All the brands of cement showed the same trend from the slump test that hydraulic cement requires more water than OPC to achieve the same slump. The lower slump can be easily resolved using superplasticizers when slump requirement is high with low w/c ratio. The slump of all the mixes is tabulated in Table 3.

Table 3 Slump of Concrete Mix

Cement Manufacturer	Cement Type	Slump (mm)
Brand A	OPC	60
	GU	42
Brand B	OPC	55
	GU	45
Brand C	OPC	37
	GU	32

3.2 Compressive Strength

Results show all mixes achieved more than the target strength of 30 MPa at 28 Days. The 28-days compressive strength achieved by Brand A and C hydraulic cement was higher than OPC cement except brand B. 3-day early strength gain in hydraulic cement was higher by 1.23 % to 15%. The compressive test results are shown in Table 4 and the graph for strength gain with age is shown in Figure 1.

Table 4 Compressive Strength

Cement Manufacturer	Cement Type	3-day Strength (MPa)	7-day Strength (MPa)	28-day Strength (MPa)
Brand A	OPC	24.06	31.20	33.67
	GU	26.64	35.83	37.78
Brand B	OPC	25.54	33.13	37.07
	GU	29.37	31.32	35.53
Brand C	OPC	28.35	32.65	37.66
	GU	28.70	32.33	38.24

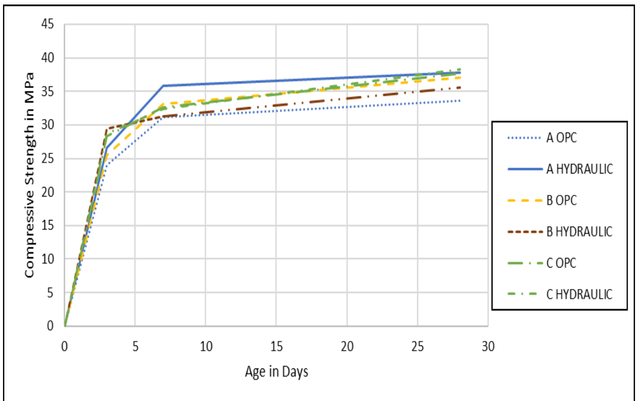

Figure 1 Compressive strength development with age

3.3 Rate of Water Absorption/Sorptivity

The rate of water absorption or sorptivity was determined as per ASTM C1585. The test determines the rate of absorption of water by hydraulic cement concrete by measuring the increase in mass of a specimen resulting from absorption of water as a function of time when only one surface is exposed to water. This test is intended to determine the susceptibility of concrete surface to penetration of water. Figures 2 and 3 show how the rate of water absorption is determined. In this work, the initial rate of water absorption could not be determined but the secondary rate of water absorption was determined and is shown in Table 5 and Figure 4. It is seen that concrete made of hydraulic cement of GU type has a higher rate of water absorption as compared to that made of OPC.

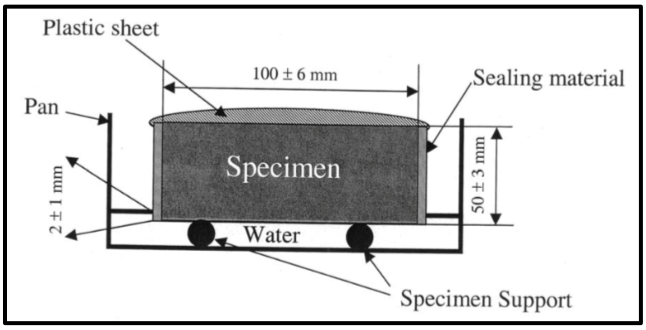

Figure 2 Schematic for determination of rate of water absorption (ASTM C1585)

Figure 3 Actual sealed sample used for sorptivity test

Past work by Souza et.al. [4] showed that addition of limestone powder to the clinker could lead to increment in water absorption. Hence, the increased rate of water absorption of hydraulic cement samples may possibly be due to addition of limestone powder or other renewable materials.

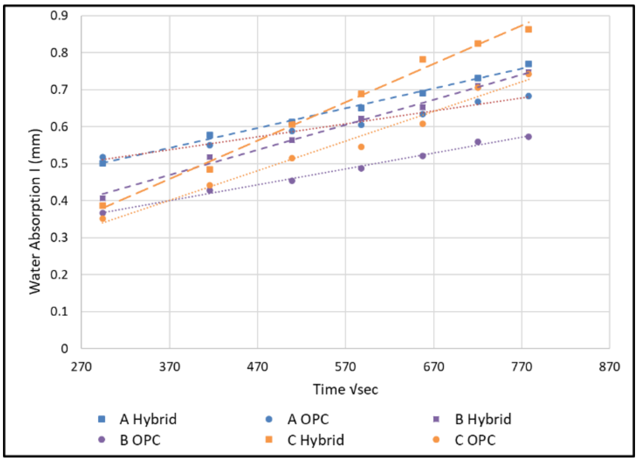

Figure 4 Water Absorption vs Time for OPC and Hydraulic Cement Specimens

Table 5 Secondary Rate of Water Absorption

Cement Manufacturer	Cement Type	Secondary Rate of Water Absorption (mm/√sec)
Brand A	OPC	3.49 x 10^{-4}
	GU	5.37 x 10^{-4}
Brand B	OPC	4.28 x 10^{-4}
	GU	6.79 x 10^{-4}
Brand C	OPC	8.01 x 10^{-4}
	GU	10.39 x 10^{-4}

3.4 Chloride Ion Penetrability

The chloride ion penetrability of the concrete specimens was determined as per ASTM C1202. The total charge passing through the samples is tabulated below in Table 6. The total charged passed shows the susceptibility of concrete to chloride ion penetrability. The total charge passed through hydraulic cement specimens was 19-22% lower than OPC specimens. All the specimens had moderate chloride ion penetrability as per ASTM C1202 shown in Table 7.

Past research works showed that presence of fly ash or limestone powder could lower chloride ion penetration [5-7]. Thus, the lower chloride ion penetrability of hydraulic cement brands can be attributed to presence of either limestone powder or fly-ash as a clinker replacement.

Table 6 Total Charged Passed in Coulombs for Chloride Ion Penetrability Test

Cement Manufacturer	Cement Type	Charge Passed (coulombs)
Brand A	OPC	3411
	GU	2760
Brand B	OPC	2905
	GU	2315
Brand C	OPC	2684
	GU	2085

Table 7 Limits for chloride ion penetrability (ASTM C1202)

Chloride Ion Penetrability	Charge Passed (coulomb)
High	>4000
Moderate	2000-4000
Low	1000-2000
Very Low	100-1000
Negligible	<100

3.5 Abrasion Resistance

The Abrasion resistance of concrete was determined as per ASTM C944. The specimens used were fabricated with a size of 150 x 150 x 150 mm ±3 mm. The surface was smoothly finished. The specimens were cured for 28 days. The surface of the specimens was subjected to 2 minutes of abrasion on three sides under normal load and the mass loss was noted down. The trend observed was that specimens made of OPC performed slightly better than those made of hydraulic cement. The mass loss by hydraulic cement specimens was 5-30% higher than OPC specimens. The results are shown in Table 8 and Figure 5.

Table 8 Mass loss due to Abrasion

Cement Manufacturer	Cement Type	Mass Loss (g)
Brand A	OPC	4.75
	GU	5.00
Brand B	OPC	7.25
	GU	8.25
Brand C	OPC	5.17

Cement Manufacturer	Cement Type	Mass Loss (g)
	GU	6.75

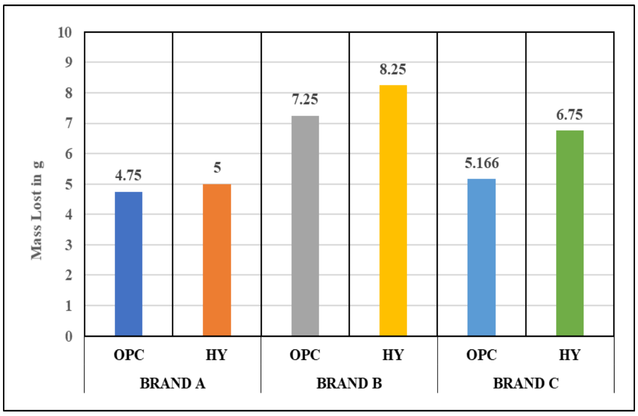

Figure 5 Mass Loss due to Abrasion

4. Discussion

The results have shown that hydraulic cement can have a positive effect on compressive strength, both early age strength and 28-day strength, but the slump achieved by hydraulic cement with the same w/c ratio has lower slump. Thus, the water requirement of hydraulic cement could be a little higher than OPC to achieve the same workability.

When durability was considered, hydraulic cement and OPC cement performed similarly if not better. For sorptivity test, it was observed that OPC had lower sorptivity than hydraulic cement for all the brands of cement. This is the same trend as in [8] for w/b of 0.42, 0.46 and 0.61 with cement replacement with limestone of 15 to 30%. The increased sorptivity in hydraulic cement concrete could possibly be due to the lower amount of clinker in the cement paste [8-9] but the trend reversed when chloride ion penetration resistance was measured. It was observed that hydraulic cement had lower chloride ion penetrability than OPC. This decreased chloride ion penetrability was possible due to the filler effect of the limestone powder when mixed with cement paste [9]. The similar trend for chloride ion penetration of concrete was also observed for concrete under normal curing conditions at 28 days with cement replacement with limestone of 8% was used but the opposite was observed when the replacements were higher at 16 and 24% [10].

The similar trend for both sorptivity (higher) and chloride ion penetrability (lower) was also reported by Ramezanianpour et.al. [9] whose work showed that for 0.55-w/b concrete with cement replaced with 15% limestone powder possessed higher sorptivity and lower chloride ion penetrability at 28 and 90 days, but the opposite performances of chloride ion penetrability were observed at cement replacement with limestone of 5, 10, and 20%. However, this decrease in rapid chloride ion permeability for concrete with limstone of 15% replacement was only marginal at 2-4% and the performances were still classified to be in the same classification for chloride ion penetrability according to ASTM C1202.

Abrasion resistance of OPC cement concrete was slightly superior than hydraulic cement concrete. Dhir et.al [11] reported that addition of limestone powder as cement replacement up to 15% does not have any significant effect on the abrasion resistance of concrete when compared with OPC cement.

4. Discussion

The following general conclusions were drawn from the study by comparing various fresh, hardened and durability properties of concrete produced with 3 different brands of hydraulic cement of GU type and OPC.

1. Water requirement of hydraulic cement was slightly higher to obtain slump similar to OPC.

2. Early age strength of hydraulic cement was higher than OPC while 28 days compressive strength was higher or similar to OPC concrete.

3. Durability properties like sorptivity, chloride ion penetrability and abrasion resistance of concrete made with hydraulic cement were similar to OPC.

4. From the results it can be safely stated that OPC can be replaced with hydraulic cement without any adverse effects in terms of fresh, mechanical or durability related properties for concrete of medium strength.

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