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QUARRY DUST FINE POWDER AS SUBSTITUTE FOR ORDINARY PORTLAND CEMENT IN CONCRETE MIX

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Abstract

Tremendous efforts have been done in the area of concrete technology to study the utilization of by-products and waste materials which can be used as a partial cement replacement in concrete production as well as identifying the benefits of these alternative materials as cement in concrete. Quarry dust as a by-product from crushing of coarse aggregates during quarrying activities has received considerable attention to enhance the properties of concrete. Thus, this paper reports the research conducted on the suitability of quarry dust fine powder (QDFP) as cementitious material in concrete. The performance in terms of its mechanical and durability index were evaluated on concrete composed of various w/b ratios (0.3, 0.4, 0.5 and 0.6) for replacement level of 3%, 5%, 10% and 15%, and with the inclusion of superplasticizer (Sp) to enhance the workability of concrete. The performance was measured at 7, 28, 60, 90 and 120 days of age. The results show that inclusion of QDFP did not enhance the compressive strength of concrete. Rebound number (RN) for QDFPSp concrete made of 0.3 and 0.4 w/b ratios achieved good quality, while for those made of 0.5 and 0.6 w/b ratios, it falls under category poor and fair respectively. In terms of durability index performance, the QDFP concrete in higher proportion (up to 15%) and with increasing w/b ratio from 0.3 to 0.6 increase the coefficient of permeability, while QDFP concrete can be considered as good concrete since the water absorption recorded below than 10% by mass.

Keywords: Cementitious material, Quarry dust fine powder, Compressive strength, Water absorption, Water permeability.

1. Introduction

In construction industry, resource constraints for building materials have burdened the industry. The increasing of market demand leads to increase of the

Nomenclatures

A	Surface area of specimen, mm^2
e	Depth of penetration of concrete, m
fc	Compressive strength, N/mm^2
h	Hydraulic head, m
K	Coefficient of permeability, m/s
P	Maximum indicated load, N
t	Time under pressure, seconds
v	Fraction of the volume of concrete occupied by pores
W	Water absorption after immersion, percentage
w_i	Weight of specimen after oven dry, g
w_t	Weight after immersion, at time t, g

Abbreviations

C-S-H	Calcium silicate hydrate
GGBS	Ground Granulated Blast Furnace Slag
LA	Los Angeles
LOI	Loss in Ignition
OPC	Ordinary Portland Cement
pfA	Fly Ash
QD	Quarry Dust
QDFP	Quarry Dust Fine Powder
QDFPSp	Superplasticizer Quarry Dust Fine Powder
RD	Rattan Dust
RH	Rice Husk
RN	Rebound Number
SD	Saw Dust
Sp	Superplasticizer
w/b	Water binder ratio
XRF	X-ray Fluorescence

cement prices. The forecast of cement demand continues to grow however; on the other hand the production of cement was tangentially related to the environmental issues, i.e., to global warming. The use of energy during the clinker burning process allows the environment to become warmer, thus, contribute to global warming [1, 2]. Besides, air pollutant emission during cement production and water pollution from washing-out water used at batching plant and discharge to stream or river can destroy the aquatic life. In responding to this matter, efforts were taken to look into the use of waste materials which may possible to be used as cementitious materials or replacement materials in concrete. Recycling waste materials into alternative materials in replacing cement will benefit the construction industry in two folds. First, overcoming the disposal issue of waste material and secondly, the use of waste materials will decrease the amount of carbon dioxide released during conversion due to thermal decomposition of limestone to clinker in cement production.

Quarry dust (QD) is one of the waste materials abundantly available and unused in a quarry industry. Previous finding showed that the substitution of QD as part of pozzolana gives good performance at fresh stated rheological properties and enhances compressive strength at hardened state [3]. However, there is still limited information on the behaviour of concrete properties with the inclusion of different replacement level of fine QDFP corresponding to different water binder (w/b) ratio. It is hypothesized that finer particle sizes of QD would further increase the pozzolanic reactivity between cement and the former during secondary hydration process. Therefore, this paper highlights the study on the suitability of Quarry Dust Fine Powder (QDFP) as cement replacement material in different w/b ratio by employing different percentages of replacement of OPC with QDFP.

2. Experimental Methods

2.1. Materials

The QD which was obtained from Negeri Roadstone Quarry, Negeri Sembilan, Malaysia was placed in Los Angeles (LA) Abrasion Machine to be grinded and later produced QDFP. Inside the LA machine, there are 16 nos. of balls bearing, in which about 5 kg of QD were placed and grinded for 5000 revolutions per minutes (rpm). After grinding, in ensuring the fineness of the powder, the crushed QD was passed through 90 µm sieve. Other materials used in the concrete mixture were crushed stone granite of 20 mm maximum size and mining sand passing 5 mm BS sieve. The fine and coarse aggregates that were used complied with the standard BS 812-103:1:1985 [4]. The fineness modulus for fine aggregate and the coarse aggregate were 4.61 and 2.43 respectively. The tap water free from contamination was used for the mixing and curing of concrete. The type of superplasticizer (Sp) used in this research is sulphonated naphthalene formaldehyde condensed polymer based admixture, commercially known as 'Rheobuild 1100', which is a water-soluble. It satisfies the requirements of ASTM C494 [5] Type A and Type F. In determining the oxide composition of QDFP, the elementary analysis using X-ray Fluorescence (XRF) was carried out, while in determining the fineness of cement and QDFP, a reference to BS EN 196-6: 1992 [6] using 90 µm sieve was made.

2.2. Mix proportion

The mix design adopted to prepare concrete specimens for this research was based on the British method, i.e., the Department of the Environment [7]. In this present study, five (5) series of concrete specimens were prepared based on replacement level of 0%, 3%, 5%, 10% and 15% of QDFP to the OPC by weight. These mixes are designated as OPC, 3QDFPSp, 5QDFPSp, 10QDFPSp and 15QDFPSp representing concrete made of OPC plain, 3%, 5%, 10% and 15% of QDFP to the OPC respectively. Each series is composed of different w/b ratio of 0.3, 0.4, 0.5 and 0.6, with cement content of 684 kg/m3, 513 kg/m3, 410 kg/m3 and 342 kg/m3 respectively. The mixes of 100% OPC without adding Sp were used as control reference. The amount of Sp and the percentage of Sp were kept constant to ensure its consistency when OPC was replaced with QDFP. The increased in the amount of QDFP content was expected to result in dry mix concrete, therefore Sp was used to enhance the fluidity of the mixes. The Sp dosage in subsequent mixtures was tailored to achieve slump in the range of 100 mm to 150 mm. The concrete specimens size of 150 mm in diameter (Ø)×150 mm in height and 100 mm ×100 mm × 100 mm were prepared for this study. All the requirements for making the specimen are in accordance with BS EN 12390-1:2000 [8]. The specimens were tested for 7, 28, 60, 90 and 120 days of water curing. Table 1 shows the details of the series of the mix proportion prepared.

Table 1. Mix Proportion of OPC and QDFPSp Concrete.

Designation	Cement (kg/m^3)	QDFP (kg/m^3)	Water (kg/m^3)	w/b ratio	Sp (%)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)	
							10 mm	20 mm
OPC	684	-	205		-	457	355	710
3QDFPSp	664	21	205		1.61	457	355	710
5QDFPSp	650	35	205	0.3	1.61	457	355	710
10QDFPSp	616	68	205		1.61	457	355	710
15QDFPSp	581	103	205		1.61	457	355	710
OPC	513	-	205		-	542	384	767
3QDFPSp	498	14	205		1.61	542	384	767
5QDFPSp	487	26	205	0.4	1.61	542	384	767
10QDFPSp	462	51	205		1.61	542	384	767
15QDFPSp	436	77	205		1.61	542	384	767
OPC	410	-	205		-	611	395	790
3QDFPSp	398	12	205		1.61	611	395	790
5QDFPSp	390	20	205	0.5	1.61	611	395	790
10QDFPSp	369	41	205		1.61	611	395	790
15QDFPSp	349	62	205		1.61	611	395	790
OPC	342	-	205		-	671	398	795
3QDFPSp	332	10	205		1.61	671	398	795
5QDFPSp	325	17	205	0.6	1.61	671	398	795
10QDFPSp	308	34	205		1.61	671	398	795
15QDFPSp	291	51	205		1.61	671	398	795

2.3. Test methods

Several tests were performed to determine the chemical composition, fineness of QDFP and workability of fresh QDFP concrete, and hardened QDFP concrete. The tests were outlined in the following sub-sections.

2.3.1. Slump test

In order to determine the workability of the fresh concrete, slump test was conducted in accordance with BS EN 12350-2:2000 [9]. The slump test is conducted to ensure that the designated concrete mixes satisfy the requirement of the workability, i.e., slump of 40 mm to 50 mm and 100 mm to 150 mm for mixes without and with Sp respectively.

2.3.2. Compressive strength

In determining the strength of the hardened concrete, the compressive strength test as a destructive test was conducted based on procedures prescribed in BS EN 12390-4:2000 [10]. The Compression Auto Test machine with the capacity of 1000 kN with the rate of load at 3.00 kN/m was employed. The compressive strength of 100 mm cube specimens was evaluated at 7, 28, 60, 90 and 120 days of water curing.

The compressive strength of the specimens was computed using the formula given by BS EN 12390-3:2000 [11] as expressed below:-

$$fc = P/A \tag{1}$$

where, fc is compressive strength, (N/mm^2), P is maximum indicated load, (N), and A is surface area of specimen, (mm^2)

2.3.3. Schmidt rebound hammer

BS EN 12504-2: 2001 [12] was used to assess the OPC and QDFP concrete specimens using non-destructive test, i.e., Schmidt Rebound Hammer. It works principally on surface hardness of concrete consisting of a spring loaded hammer which a fixed amount of energy applied against the test surface by pushing the hammer. The plunger was allowed to strike perpendicularly (90º) to the 100 mm cube surfaces. Anand [13] classified the quality of concrete based on the rebound number reading of concrete specimens, with an average of rebound number (RN) greater than 40 has having very good hard layer, 30-40 as good hard layer and 20-30 as fair concrete, while, RN less than 20 shows poor concrete and RN reading zero (0) as delaminated concrete.

2.3.4. Water permeability

The water permeability test conducted was based on BS EN 12390-8:2000 [14]. For this test, the cylindrical specimens of 150 mm in diameter by 150 mm height were cast and subjected to the pressure of 0.5 N/mm^2 for 3 days (see Fig. 1). Immediately after the pressure was released, the specimen was removed and sectioned into halved. In determining the average depth of penetration of water, the dark spotted imprint on the broken faces of the specimen was taken. The average depth of penetration was then converted into the coefficient of permeability, K (m/s) which is equivalent to that of Darcy's law using the expression developed by Valenta [15] as cited in the Concrete Society Technical Report No. 31 [16] as shown below:

$$K = \frac{e^2 v}{2ht} \tag{2}$$

where K is coefficient of permeability, (m/s), e is the depth of penetration of concrete, (m), h is the hydraulic head, (m), t is the time under pressure, (s), and v is the fraction of the volume of concrete occupied by pores.

The hydraulic head applied is 5 bars which equivalent to 51.075 m of hydraulic head and the porosity of concrete (v) were assumed to be 1.02, taking as 2% for normal concrete.

2.3.5. Water Absorption

The amount of absorption is the measurement of the volume of pore space in concrete. Water in concrete is a primary agent which gives effects to the durability of concrete. In determining the durability properties of the concrete specimens, the water absorption test was conducted in accordance with BS 1881-122:1983 [17].

The cylindrical specimens of 50 mm in diameter by 100 mm height were oven dried to constant mass at 105±5ºC for 72±2 hours and then stored in the air-tight containers. The specimens were cured for 7, 28, 60, 90 and 120 days before testing. Before immersion in water for 30 minutes, 60 minutes, 120 minutes and 240 minutes, the specimens were weighed as initial weight. Figure 2 shows the specimens immersed in water. The water absorption of the specimens is expressed as increase in mass as percentage of dry mass is calculated as follows:

$$W = \frac{w_t - w_i}{w_i} \times 100\% \quad (3)$$

where W is water absorption after immersion, (%), w_i is weight of specimen after oven dry, (g), and w_t is the weight after immersion, at time t, (g).

Fig. 1. The set-up for the water permeability test.

Fig. 2. Specimens immersed in water in water absorption test.

3. Results and Discussion

The chemical composition and fineness of QDFP are compared with that of OPC to classify the pozzolanic reactivity level of the former. The workability, compressive strength, rebound hardness, permeability and absorption change due to the inclusion of QDFP in concrete mixes corresponding to different w/b ratio are discussed in the following sections.

3.1. Properties of QDFP

Table 2 shows the oxide composition of OPC and QDFP used in the study. The fineness of QDFP and OPC obtained based on percentage retained on 90 µm sieve are about 7.9% and 1.4% respectively. This shows that the OPC was much finer compared to QDFP. With higher fineness, it will increase the reactivity of OPC particles, thus enhances the strength. ASTM C 618: 2003 [18] states that for material to be classified under category for mineral admixture Class F and N pozzolanic, the total of SiO2, Al2O3 and Fe2O3 should be 70% minimum. Thus, for QDFP, the total compositions of these three chemical compounds were found to be 87.05%. Table 2 shows the chemical composition test for OPC and QDFP using X-ray Fluorescence test.

The loss on ignition (LOI) was conducted to show the amount of carbon in the sample and hydration of free lime and free magnesia due to the atmosphere exposure. The maximum LOI of cement at 1000oC permitted by BS EN 197-1:2000 [19] and ASTM C150-2005 [20] is 5% and 3% respectively, while for pozzolanic material, the maximum was 6%. In this present study the LOI for OPC and QDFP obtained was 1.33% and 1.32% respectively. Thus, QDFP satisfies the requirement of ASTM C 618: 2003 [18].

Table 2. Chemical Composition (%) of OPC and QDFP.

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MgO	CaO	Na_2O	K_2O	P_2O_5	MnO	SO_3	LOI
OPC	15.05	2.56	4.00	0.12	1.27	72.17	0.08	0.41	0.06	0.06	2.90	1.32
QDFP	69.96	12.81	4.28	0.22	0.44	1.84	0.51	8.12	0.20	0.10	0.20	1.32

3.2. Workability

The results of the slump of all the mixes are as shown in Fig. 3. For each w/b ratio, the amount of water, the percentage of Sp, cementitious and the aggregates were kept constant as the replacement level of QDFP increases to ensure its consistency. The slump recorded for mixes made of 0.3, 0.4, 0.5 and 0.6 w/b ratio are ranging from 38 mm to 127 mm, 40 mm to 141 mm, 45 mm to 150 mm and 51 mm to 168 mm respectively. It can be clearly seen that without the addition of Sp, the slump values for each w/b ratio are ranging from 38 mm to 51 mm, however, with addition of Sp in the QDFP concrete resulted in higher slump, and with higher w/b ratio the slump increases. It is also interesting to note that with higher replacement level of OPC with QDFP, the workability in terms of slump was improving.

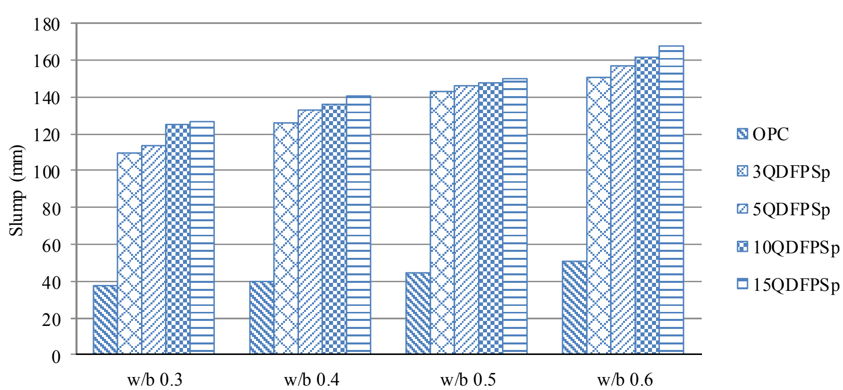


Fig. 3. Slump Values of OPC and QDFPSp Concrete of Various w/b.

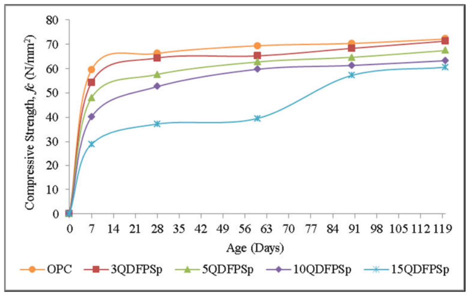
3.3. Compressive strength

Figures 4 show the results of compressive strength versus ages of curing with respect to the w/b ratio taken at 7, 28, 60, 90 and 120 days of water curing. From Fig. 4(a), it appears that the compressive strength for all the QDFPSp concrete made of w/b 0.3 are lower than those of the plain control OPC concrete. However, the compressive strength of the 3QDFPSp of w/b 0.30 achieved similar strength towards to 28 days of age as compared to that of control concrete of same w/b. The compressive strength for all QDFPSp concrete ranges from 54 N/mm^2 to 71 N/mm^2 taken at age of 7 days to 120 days. It also shows that the compressive strength of the QDFPSp concrete reduces as the percentage of QDFP replacement increases from 3% to 15% as compared with control OPC concrete, simultaneously due to the reduction in the cement content. It is also interesting to see that the difference of strength between OPC and the QDFP concrete were higher at the earlier age, however as the period of curing prolong, the relative difference were smaller. This clearly shows that the development of strength of QDFP as pozzolanic material at the earlier age was slow.

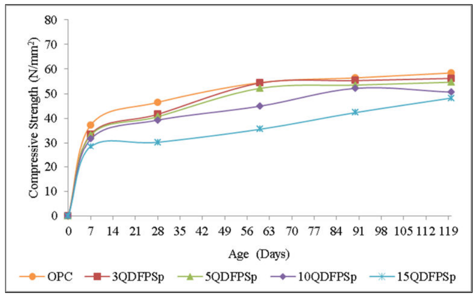
From Figs. 4(b) and (c), the highest compressive strength for concrete made of 0.4 and 0.5 w/b ratios with 3% replacement of QDFP are 33 N/mm^2 to 56 N/mm^2 and 33 N/mm^2 to 50 N/mm^2 respectively taken at age of 7 days to 120 days. Similar trend is observed for all those made of all levels of QDFP replacement. Therefore, with increase of w/b ratio, the compressive strength of all mixes decreases at all replacement levels. This is definitely true as strength decreases with increase in water content [21, 22].

Figure 4(d) shows the compressive strength of five (5) series of concrete made of 0.60 w/b ratio with respect to age of curing. The highest compressive strength for 0.60 w/b ratio of QDFPSp concrete is recorded for specimens made of lowest level of replacement which is 3% replacement of QDFP, in which the value recorded were 31 N/mm^2, 36 N/mm^2, 37 N/mm^2, 49 N/mm^2 and 50 N/mm^2 at ages of 7, 28, 60, 90 and 120 days respectively.

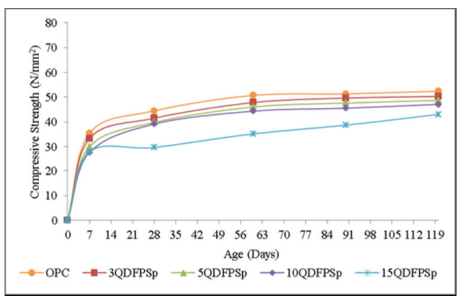
It is noticed that the compressive strength of plain OPC concrete is found to be higher than those of QDFP concrete for all w/b ratios. For OPC control concrete, the strength of mixes made of 0.3, 0.4, 0.5 and 0.6 w/b ratio were 66 N/mm^2, 46 N/mm^2, 45 N/mm^2 and 44 N/mm^2 respectively. For QDFP concrete, the strength reduces as the percentage replacement of QDFP increases (3%, 5%, 10% and 15%). The reduction level in percentage varies from 3% to 46% corresponding to that of plain control concrete and the reduction is more pronounced as the w/b ratio is higher. The 28 days strength recorded for 0.3, 0.4, 0.5 and 0.6 w/b ratio for 3% replacement were 64 N/mm^2, 42 N/mm^2, 42 N/mm^2, and 36 N/mm^2 respectively, while for 5% were 58 N/mm^2, 41 N/mm^2, 40 N/mm^2, and 34 N/mm^2 respectively. Further increased the percentage of replacement to 10%, the compressive strength taken at 28 days for 0.3, 0.4, 0.5 and 0.6 were 53 N/mm^2, 39 N/mm^2, 39 N/mm^2, and 34 N/mm^2 respectively. For 15% replacement, the strength reduces further to 37 N/mm^2, 30 N/mm^2, 30 N/mm^2, and 24 N/mm^2 for 0.3, 0.4, 0.5 and 0.6 respectively. Thus, indicating the influence of w/b ratio in the mixes in which higher w/b ratio resulted in reduction of strength. Study by Ikpong [23] also stated that the compressive strength of concrete decreases as the w/b ratio increases.



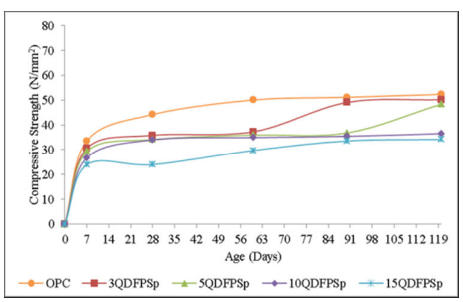
(a) 0.3 w/b



(b) 0.4 w/b



(c) 0.5 w/b



(d) 0.6 w/b

Fig. 4. Compressive Strength of Five (5) Series of QDFPSp Concrete Made of 0.3, 0.4, 0.5 and 0.60 w/b with respect to Age.

3.4. Rebound Number (RN)

Figure 5 shows the RN of OPC, 3QDFPSp, 5QDFPSp, 10QDFPSp and 15QDFPSp concrete taken at 28 days made of 0.3, 0.4, 0.5 and 0.6 w/b ratios. It is noticed that the RN of the control OPC concrete attained higher than the QDFP concrete at 28 days for all w/b ratios. This is might be due to the high fineness of OPC as compared to QDFP thus increase the reactivity of OPC particles. Study by Habeeb [24] stated that the increasing of fineness would increase the reactivity thus enhances the strength of the concrete. For 0.3, 0.4, 0.5 and 0.6 w/b ratios, the RN of OPC control concrete recorded 36, 35, 30 and 24 respectively. QDFP concrete shows an increase in RN with lower w/b ratio. The RN of QDFP concrete ranges from 30 to 34, 31 to 33, 25 to 29 and 17 to 22 for 0.3, 0.4, 0.5 and 0.6 respectively. The relative reduction in percentage as compared to that of plain concrete varies from 3.3% to 29%. The reduction is becoming more noticeable as the replacement level of QDFP and w/b ratio was higher. Figure 5 also highlights that replacing cement with QDFP by 3%, 5%, 10% and 15% for 0.3 and 0.4 w/b ratios achieved a good quality of concrete at age of 28 days as the amount of RN attained ranges from 31 to 34. However, for 0.5 and 0.6 w/b ratio, the concrete can be categorized as poor and fair concrete as the RN ranges between 17 and 29 are recorded [13]. It also can be seen that the RN taken from OPC and QDFP concrete decrease with increase in QDFP replacement level for a given w/b ratio.

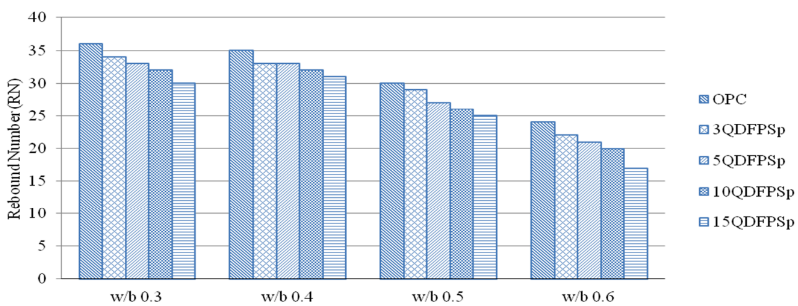


Fig. 5. Rebound Number of OPC and QDFPSp Concrete Made of 0.3, 0.4, 0.5 and 0.6 w/b Ratios Taken at 28 Days.

- **Relationship between compressive strength and rebound number of QDFP concrete**

Table 3 shows estimated surface strength for OPC and QDFP concrete taken at 28 days. From the data recorded, it appears that the estimated surface strength for OPC concretes taken at 28 days for 0.3, 0.4, 0.5 and 0.6 w/b ratios were 43%, 23%, 42% and 64% highercorresponding to actual compressive strength respectively. The inclusion of QDFP in the mix reduces the estimated surface strength, and with higher w/b ratio, the estimation is farther deviated from the actual, i.e., far below the actual compressive strength. It is highlighted that in the present study, the specimens were undergoing water curing, thus the outer surface of the specimens were exposed to water, and since RN were obtained only within the 30 mm of the surface zone as stipulated in BS EN 12504-2:2001 [12], thus the softening of the outer surface leads to the reduction of the hardness that reflected of its low number or rebound. This effect is found to be more pronounced to the lower strength of concrete.

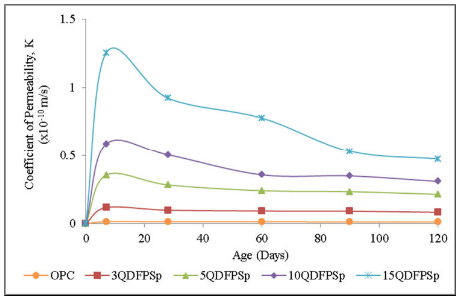
Table 3. The Estimated Surface Strength of OPC and QDFPSp Concretes Based on Rebound Number.

Mixture Designation	w/b ratio	Estimated surface strength (N/mm^2)	Actual cube compressive Strength (N/mm^2)	% differences between actual and estimated
OPC	0.3	38	66	43
3QDFPSp		34	64	47
5QDFPSp		32	58	45
10QDFPSp		30	53	44
15QDFPSp		26	37	30
OPC	0.4	36	46	23
3QDFPSp		32	42	24
5QDFPSp		32	41	22
10QDFPSp		30	39	24
15QDFPSp		28	30	7
OPC	0.5	26	45	42
3QDFPSp		24	42	43
5QDFPSp		21	40	48
10QDFPSp		20	39	50
15QDFPSp		18	30	40
OPC	0.6	16	44	64
3QDFPSp		14	36	61
5QDFPSp		12	34	65
10QDFPSp		11	34	68
15QDFPSp		8	24	66

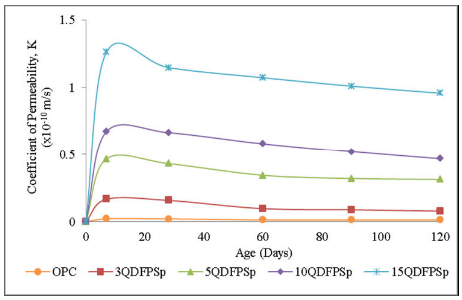
3.5. Water permeability

Figures 6 show the coefficient of permeability versus age of curing for OPC and QDFPSp concretes of different w/b ratio (0.3, 0.4, 0.5 and 0.6). It can be seen that the coefficient of permeability for OPC control concrete is lower compared to the QDFPSp concrete. The coarser of QDFP particles (retained on 90 μm - 7.9%) compared to OPC (retained on 90 μm - 1.4%) might contribute to this phenomenon. The fineness of cement which is expressed in specific surface area governs the pozzolanic reactivity. Higher specific surface attributed to very fine cement would accelerate the hydration and pozzolanic reaction leads to densification of cement gel matrix. The coefficient of permeability for w/b ratio of 0.3, 0.4, 0.5 and 0.6 taken at 7, 28, 60, 90 and 120 days for OPC control concrete ranges from 0.0128×10^{-10} m/s to 0.0141×10^{-10} m/s, 0.0124×10^{-10} m/s to 0.0215×10^{-10} m/s, 0.0128×10^{-10} m/s to 0.0221×10^{-10} m/s and 0.0272×10^{-10} m/s to 0.0425×10^{-10} m/s respectively.

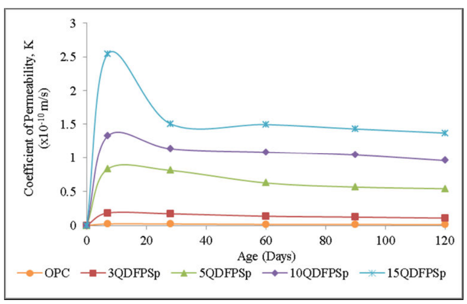
It also shows that the coefficient of permeability of concrete containing QDFP increased as the percentage of QDFP replacement level increased from 3% to 15% and it decreases with age from 7 days to 120 days of water curing. The coefficient of permeability ranges from 0.0824×10^{-10} m/s to 1.2557×10^{-10} m/s for 0.3 w/b ratio, 0.0783×10^{-10} m/s to 1.2628×10^{-10} m/s for 0.4 w/b ratio, 0.1080×10^{-10} m/s to 2.5439×10^{-10} m/s for 0.5 w/b ratio and 0.6530×10^{-10} m/s to 6.8240×10^{-10} m/s for 0.6. Despite of its pozzolanic characteristic, the inclusion of QDFP is found unable to create additional secondary hydrated C-S-H gel that would to fill up pores. From Figs. 6, it also shows that as the w/b ratio increases from 0.3 to 0.6, the coefficient of water permeability increases. This might be due to the large amount of water in the mixes resulted in excess of pores as the cement hydrated. The pores increase the tendency of concrete to absorb the water when the former is immersed in water, thus increase the permeability of the resulted concrete. This is in line with the statement by Neville [21] in which he stated that the coefficient of permeability increases as the w/b ratio increases. Study by Hwang and Wu [25] showed that the higher the w/b ratio, the higher will be the water permeability in the concrete.



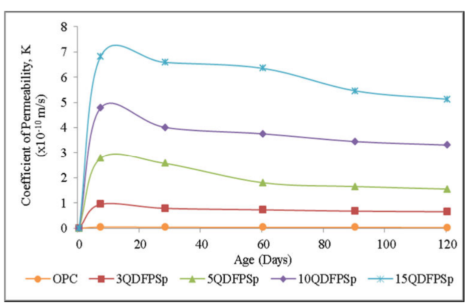
(a) 0.3 w/b



(b) 0.4 w/b



(c) 0.5 w/b



(d) 0.6 w/b

Fig. 6. Coefficient of Permeability of Five (5) Series of QDFPSp Concrete Made of 0.3, 0.4, 0.5 and 0.60 w/b with respect to Age.

3.6. Water absorption

Table 4 shows the water absorption (in percentage) for OPC, 3QDFPSp, 5QDFPSp, 10QDFPSp and 15QDFPSp concrete composed of 0.3, 0.4, 0.5 and 0.6 w/b ratio, taken at 28 days of water curing. From the table, OPC control concrete attained water absorption ranges from 0.59% to 1.93%, 0.67% to 3.43%, 1.18% to 5.27% and 0.90% to 7.77% when immersed for 30, 60, 120 and 240 minutes respectively, while for QDFPSp concrete, the water absorption ranges from 0.60% to 3.42%, 0.94% to 5.47%, 1.26% to 7.32% and 1.44% to 8.95% respectively. It shows that the water absorption increases as the immersion period prolongs. It is noted that the water absorption for OPC control concrete is lower as compared to QDFPSp concrete at all w/b ratios and the percentage replacement levels from 3% to 15%. This may be attributed to the fact that when the amount of water in the mix increases, the production of pores also increases as the amount of hydrated product is not enough to fill the higher volume of space created by the water. Thus, the presence of the capillary pores and air voids increase the tendency of concrete to have higher absorption characteristic [26]. However, the QDFPSp concrete still can be considered as a good quality concrete as the percentage of water absorption is below than 10% by mass [21]. From the table, it can also be seen that for the 30 minutes immersion, the percentage of water absorption for concrete specimens regardless of the w/b and QDFP content gave values below than 3%. With reference to the Technical Report No 31 of the Concrete Society [16], these concrete can be considered as having an 'average absorption properties'.

Table 4. Water Absorption for OPC and QDFPSp Concrete Taken at 28 Days Curing.

Mixture Designation	w/b ratio	Water Absorption (%) Immersion Period (minutes)			
		30	60	120	240
OPC	0.3	0.59	1.05	1.43	1.93
3QDFPSp		0.60	1.11	1.80	2.87
5QDFPSp		0.60	1.23	2.01	3.06
10QDFPSp		0.61	1.16	2.16	3.18
15QDFPSp		0.65	1.35	2.18	3.42
OPC	0.4	0.67	1.86	2.74	3.43
3QDFPSp		0.94	2.60	4.49	4.56
5QDFPSp		1.04	3.31	3.98	4.63
10QDFPSp		1.06	2.09	4.89	5.29
15QDFPSp		1.22	3.35	5.12	5.47
OPC	0.5	1.18	2.07	3.16	5.27
3QDFPSp		1.26	2.39	4.17	5.60
5QDFPSp		1.57	3.48	4.00	6.17
10QDFPSp		2.08	2.75	4.15	6.47
15QDFPSp		2.16	3.18	4.40	7.32
OPC	0.6	0.90	2.33	5.28	7.77
3QDFPSp		1.44	4.11	5.68	7.95
5QDFPSp		1.85	4.20	5.48	8.45
10QDFPSp		1.69	3.70	7.59	8.37
15QDFPSp		1.29	5.50	6.57	8.95

4. Conclusions

From the results and discussion, the following conclusions can be drawn:

- Higher replacement level of QDFP to the cement content in the concrete mixes results in lower compressive strength as compared to that of control specimens, the reduction recorded is 3%, 12%, 20% and 40% for 3%, 5%, 10% and 15% of QDFP concrete with w/b of 0.3 respectively. Similar trend of reduction level are depicted for QDFP concrete made of 0.4, 0.5 and 0.6 ratios.
- Replacing cement with QDFP by 3%, 5%, 10% and 15% for 0.3 and 0.4 w/b ratios can be considered as good quality concrete based on the rebound number (RN). However, for 0.5 and 0.6 w/b ratios the superplasticized QDFP concrete fall under poor and fair category based on the same parameter. The estimated compressive strength of QDFP obtained from the RN chart for 0.3, 0.4, 0.5 and 0.6 was lower compared to the actual compressive strength. The reduction level corresponding to the control specimen varies from 5.6% to 16.7% for all replacement levels of QDFP made of 0.3 w/b. The reduction level is found to be more pronounced varies from 3.3% to 29% when w/b ratio rises to 0.6.
- Replacement of QDFP in higher proportion and increasing the w/b ratio from 0.3 to 0.6 increases the coefficient of permeability and water absorption of the resulted concrete specimens. However, the QDFP concrete still can be considered as low water permeability and good quality concrete.
- Up to 15% replacement level of QDFP to cement and with low w/b of concrete, a good quality concrete still can be achieved.

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References

1. Chin, M.O.Y. (1997). *Energy consumption and carbon dioxide* (CO_2) *emissions in the cement industry - A case study*. Faculty of Civil Engineering, Universiti Teknologi Malaysia, 3-4.
2. Dash, A.K. (2010). *Effect of pozzolanas on fiber reinforced concrete*. M.Sc. Thesis. Department of Civil Engineering, National Institute of Technology Rourkela, 6.
3. Felekoglu, B.; and Baradan, B. (2003). Utilisation of limestone powder in self-levelling binder. Recycling and reuse of waste material. *International Conference, Recycling and reuse of waste materials*, 475-484.
4. BS 812-103.1:1985. Testing aggregates. Methods for determination of particle size distribution. Sieve tests. London.
5. ASTM C 494:2004. Specification for chemical admixtures for concrete.
6. BS EN 196-6:1992. Method of testing cement. Determination of fineness.

7. Department of Environment (1998). *Design of normal concrete mixes*. Building Research Establishment, U.K.
8. BS EN 12390-1:2000. Testing hardened concrete: Shape, dimensions and other requirements for specimen and mould.
9. BS EN 12350-2:2000. Testing fresh concrete: Slump test.
10. BS EN 12390-4:2000. Testing hardened concrete. Compressive strength. Specification for testing machines.
11. BS EN 12390-3:2000. Testing hardened concrete. Compressive strength of test specimens.
12. BS EN 12504-2:2001 Testing concrete. Non-destructive testing. Determination of rebound number.
13. Arya, A.S.; and Agarwal, A. (2007). *Disaster risk management programme*. National Disaster Management Division, Ministry of Home Affairs, North Block, New Delhi.
14. BS EN 12390-8:2000. Testing hardened concrete. Depth of penetration of water under pressure.
15. Oldrich, V. (1969). Kinetics of water penetration into concrete as an important factor of its deterioration and of reinforcement corrosion. *RILEM International Symposium on the Durability of Concrete*, Prague, 93-177.
16. Concrete Society, London (1988). Technical Report No. 31: Permeability testing of site concrete – A review of methods and experience. ISBN 0-94661-21.5, London, 43.
17. BS 1881-122: 1983. Testing concrete. Method of determination of water absorption.
18. ASTM C 618:2003. Specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.
19. BS EN 197-1: 2000. Cement. Composition, specifications and conformity, criteria for low heat common cements.
20. ASTM C 150: 2005. Standard specification for Portland cement.
21. Neville, A.M. (2002). *Properties of concrete* (4th ed. and final ed.). Pearson Education Limited, England, 488-493.
22. Raman, S.N.; Zain, M.F.M.; Mahmud H.B., and Tan, K.S. (2005). *Influence of quarry dust and fly ash on the concrete compressive strength development*. Department of Civil Engineering, Universiti Malaya, Kuala Lumpur, 5.
23. Ikpong, A.A.; and Okpala, D.C. (1992). Strength characteristics of medium workability ordinary portland cement-rice husk ash concrete. *Building and Environment*, 27(1), 105-111.
24. Habeeb, G.A.; and Fayyadh, M.M. (2009). The effect of RHA average particles size on mechanical properties and drying shrinkage. *Australian Journal Basic and Applied Science*, 3(3), 1616-1622.
25. Hwang, C.L.; and Wu, D.S. (1989). Properties of cement paste containing rice husk ash, ACI SP-114 (35). *Proceedings of 3rd International Conference Trondheim, Norway*, 733-765.
26. Sutan, M.N.; Hamdan, S.; and Jin, E.C.C. (2002). The influence of porosity to the accuracy of ultrasonic pulse velocity method. *Faculty of Engineering, Universiti Malaysia Sarawak*, 7(11), 1.