Durability Performance of Utilising Quarry Dust as Sustainable Material in Self-Compacting Concrete

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Abstract. Self-compacting concrete (SCC) a latest innovation in concrete technology is being regarded as one of the most promising developments in the construction industry due to numerous advantages over conventional vibrated concrete. SCC is an innovative construction material that can be placed into forms without mechanical vibration which able to flow and consolidate under its own weight and can be filled in formwork completely even in the congested reinforcement [2]. Other advantage by eliminating vibration and compaction in concrete is the noise reduction can increase the worker productivity, labour requirement for SCC placement can be reduced and also improves the working environment and safety [3]. The rheological properties of concrete can be changed by adding high-range water reducers (superplasticizers) or viscosity-modifying agents (VMA) as the chemical admixtures in SCC [2]. SCC has been used construction for placement

1. Introduction

Self-compacting concrete (SCC) was first developed by Professor Okamura in 1988 to produce durable concrete structures which do not require any vibration and compaction in concrete [1]. SCC can be able to flow and also consolidate under its own weight and can be filled in formwork completely even in the congested reinforcement [2]. Other advantage by eliminating vibration and compaction in concrete is the noise reduction can increase the worker productivity, labour requirement for SCC placement can be reduced and also improves the working environment and safety [3]. The rheological properties of concrete can be changed by adding high-range water reducers (superplasticizers) or viscosity-modifying agents (VMA) as the chemical admixtures in SCC [2]. SCC has been used construction for placement...
in congested reinforcement concrete structures where difficult to cast especially in high rise building [4,5].

Nowadays, the use of aggregate in concrete production lead to a question about the sources of natural aggregate as the concrete consumption become increased [6]. Due to the depletion of natural sand, the utilization of Quarry Dust (QD) can be used to replace sand in SCC which also can reduce the greenhouse gases amount into the atmosphere and one of the way to promote green building practice [7]. QD is one of the waste materials abundantly available and unused which obtained from crushing of coarse aggregate during quarrying activities that has been received considerable attention in order to enhance the concrete properties [8]. Moreover, it was reported that 322 quarries throughout the country which manufactures limestone and granite [9]. Therefore, the replacement of fine aggregates with QD in concrete, it is hoped that the economic problem and environmental impact can be reduced. Furthermore, segregation in concrete also can be eliminated by adding a large amount of powdered material [10].

Different percentages of QD as fine aggregates replacement with 0%, 10%, 20%, 30%, 40%, 50%, 70%, and 100% had been studied to determine the workability of SCC. The slump flow was observed to be consistent at 30% replacement of fine aggregate by QD [11]. Water absorption of SCC incorporating with different percentages of QD which were 0%, 10%, 20%, 30%, and 40% had been studied as partial replacement for sand and all the SCC mix containing QD were combined with a constant 10% of fly ash as partial replacement for cement [12].

Since workability and durability performance of concrete are among the problems and issues that had been raised up nowadays, the workability and durability performance of conventional vibrated concrete and QD in SCC in term of water absorption and water permeability were determined in present study.

2. Experimental Programme

2.1. Material Preparation

The material used in this study were water, Ordinary Portland Cement, sand, quarry dust, gravel, and superplasticizer. The quarry dust was obtained from Negeri Roadstone Sdn Bhd, Malaysia. The additional high-range superplasticizers (Mighty 21HA) chemical base Aqueous Solution of Modified Polycarboxylates manufactured from KAO Industrial Co., Ltd had been used as the chemical admixtures. The maximum passing size used for Sand and QD were 5 mm sieve while the maximum passing size used for coarse aggregates from crush granite gravel was 10 mm sieve.

2.2. Gradation of Fine Aggregates

Sieve analysis for sand and QD were conducted in accordance to BS 812-103.1:1985 [13] in order to ensure the grading for particles size used in this study complied with the overall limits according to BS 882:1992 [14]. Based on the sieve analysis, the gradation for sand and QD were fall between lower and upper limit of fine aggregates and the particle size distribution curve.

2.3. Mix Design Proportion

The conventional vibrated concrete with water cement ratio of 0.48 and concrete grade 35 N/mm² were designed using DOE method [15]. Different mixtures consist of conventional vibrated concrete designated as OPC mix and different percentages of QD which are 0%, 10%, 20%, 30%, 40% and 50% had been used to replace the fine aggregates content in SCC designated as SPOPC, SPQD10, SPQD20, SPQD30, SPQD40 and SPQD50. The proportion of QD as partial fine aggregate replacement in SCC was designed based on volume replacement. The additional high-range superplasticizers (Mighty 21HA) chemical base Aqueous Solution of Modified Polycarboxylates which is 1.5% of cement weight was used as the chemical admixture that can change the rheological properties of concrete. The concrete mix design proportion used for this study is shown in Table 1.
Table 1: Concrete mix design proportion.

| Concrete Mix          | Mixture Designation | Cement (kg/m³) | Water (kg/m³) | Sand (kg/m³) | Quarry Dust (kg/m³) | Coarse Aggregates (kg/m³) | Sp (kg/m³) |
|-----------------------|---------------------|----------------|---------------|--------------|---------------------|--------------------------|------------|
| 0% Control Mix        | OPC                 | 445            | 215           | 1010         | -                   | 730                      | -          |
| 1.5% SP               | SP                  | 445            | 215           | 1010         | -                   | 730                      | 6.675      |
| 10% QD + 1.5% SP      | SPQD10              | 445            | 215           | 909          | 114                 | 730                      | 6.675      |
| 20% QD + 1.5% SP      | SPQD20              | 445            | 215           | 808          | 228                 | 730                      | 6.675      |
| 30% QD + 1.5% SP      | SPQD30              | 445            | 215           | 707          | 342                 | 730                      | 6.675      |
| 40% QD + 1.5% SP      | SPQD40              | 445            | 215           | 606          | 456                 | 730                      | 6.675      |
| 50% QD + 1.5% SP      | SPQD50              | 445            | 215           | 505          | 570                 | 730                      | 6.675      |

*Percentage of replacement by volume. Sp = Superplasticizer

2.4. Specimens Preparation

In order to produce a uniform color and consistence of concrete, the constituent materials need to be thoroughly mix together. Method for mixing was conducted in accordance to BS 1881: Part125:1986 [16]. Two different sizes of cylindrical specimens measuring of 50 mm ø x 100 mm were casted for water absorption test while 150 mm ø x 150 mm were casted for water permeability test. All concrete specimens for conventional concrete and SCC mixes were demoulded after 24 hours of casting and were placed in water tank for curing. The water cured concrete specimens were taken out and water absorption test and water permeability test were conducted at the age of 7, 28 and 60 days of curing. The method and procedure used for curing is in accordance to BS 1881:Part 111:1983 [17].

2.5. Test Methods

2.5.1. Slump Test. The slump test was conducted to determine the workability of conventional concrete which was designated as OPC in accordance to BS EN 12350 –2:2000 [18]. The value of slump was designed according to DOE method which slump height used was in range of 30 – 60 mm. The difference in level between the height of the mould and that of the highest point of the concrete was recorded and this difference in height is the slump of the concrete.

2.5.2. Slump Flow Test. Slump flow test was conducted to determine the workability of SCC in accordance to BS EN 12350-8:2010 [19]. The average diameter of the concrete circle is a measure for the filling ability of the concrete. Measurement of slump flow indicates the flowability of SCC and determine the consistency and cohesiveness of the concrete. \( T_{500\text{mm}} \) is the time measured from lifting the cone to the concrete reaching a diameter of 500 mm. The measured \( T_{500\text{mm}} \) indicates the deformation rate or viscosity of the concrete. The fresh property test for slump flow and \( T_{500\text{mm}} \) should fall under the limits and acceptance criteria for SCC specified by EFNARC [20] as shown in Table 2.

Table 2. Acceptance criteria for self-compacting concrete for slump flow and \( T_{500\text{mm}} \) [20].

| Test methods | Units | Minimum | Maximum | Property   |
|--------------|-------|---------|---------|-----------|
| Slump flow   | mm    | 650     | 800     | Filling ability |
| \( T_{500\text{mm}} \) | sec   | 2       | 5       | Filling ability |

2.5.3. Water Absorption Test. Water absorption test was conducted to determine the water absorption in concrete in accordance to BS 1881 Part 122: 2011 [21]. All cylindrical specimens were cured for 7 days, 28 days and 60 days before conducting the test and were dried in an oven to constant mass at 105 ± 5°C for 72 ± 2 hours before testing. The concrete specimens were removed from the oven and were cooled for 24 ± 0.5 hours in the desiccators. All concrete specimens were immersed in the water tank and the depth of 25 ± 5 mm of water should be over the top of the specimens. The concrete specimens before
immersion and after immersion were weighed for 0.5 hour until 4 hours. Water absorption was calculated as a percentage of the mass of the dry specimen as expressed in Equation 1 [22].

\[
\text{Water Absorption} \ (\%) = \frac{W_s - W_d}{W_d} \times 100
\]

Equation 1

Where, \(W_d\) = Concrete specimens weight before immersed in water.
\(W_s\) = Concrete specimens weight after immersed in water.

2.5.4 Water Permeability Test. Water permeability test was conducted to determine the resistance of concrete against penetration of water in accordance to BS EN 12390 Part 8: 2000 [23]. The pressure of 0.5 N/mm\(^2\) was exerted on the concrete for a period of 72 hours. A pressure chamber was sealed and attached to the concrete surface in order to prevent water leakage and contains no air voids during the test. The pressure chamber was filled with water and a specified water pressure was applied to the surface. Depth of penetration was measured after about 5 to 10 minutes and the depth of penetration obtained from this test was then converted into the coefficient of permeability, \(K\) (m/sec). The porosity of concrete (\(v\)) was assumed to be 1.02, taking as 2 % for normal concrete and the hydraulic head applied in conducting this test was 5 bars which equivalent to 51.075 m [24,25]. The water permeability was calculated by using Darcy’s law and the calculation formula is expressed in Equation 2.

\[
\text{Coefficient of permeability, } K = \frac{e^2v}{2ht}
\]

Equation 2

Where,
\(K\) = Coefficient of permeability, (m/s)
\(t\) = time under pressure, (seconds)
\(e\) = Penetration of concrete depth, (m)
\(h\) = hydraulic head, (m)
\(v\) = Fraction of the volume of concrete occupied by pores

3. Data and Analysis

3.1 Workability Test Result

The slump height of 35 mm was obtained for OPC mix which was in the range of 30 - 60 mm according to DOE design method. The result for slump flow diameter and slump flow time \(T_{500mm}\) for all SCC mixes designated as SPOPC, SPQD10, SPQD20, SPQD30, SPQD40 and SPQD50 were recorded and presented in the Figure 1 and Figure 2.

Based on Figure 1, it shows the slump flow diameter result for SPOPC was 682 mm and the slump flow diameter increased with the increasing of QD in SCC mix. The slump flow diameter for SPQD10, SPQD20, SPQD30, SPQD40 and SPQD50 were 651mm, 659mm, 662mm, 697mm and 716mm. The highest peak of the slump flow diameter is 716mm which is represented at SCC mix contained 50% of QD, meanwhile the lowest is at mix contained 10% of QD with slump flow of 651mm. \(T_{500mm}\) slump flow values were the time taken when the slump flow for SCC mixes reached at 500 mm diameter. Based on Figure 2, it shows the \(T_{500mm}\) slump flow values for SPOPC was 4.2sec and \(T_{500mm}\) decreased with the decreasing of QD in SCC mix. The \(T_{500mm}\) slump flow for SPQD10, SPQD20, SPQD30, SPQD40 and SPQD50 were 4.9sec, 4.7sec, 4.3sec, 3.7sec and 3sec. The highest and slowest duration of \(T_{500mm}\) slump flow value is 4.9sec is at SCC mix contained 10% of QD meanwhile the lowest and fastest duration of \(T_{500mm}\) slump flow value is 3sec which is represented at SCC mix contained 50% of QD. All values for slump flow diameter and \(T_{500mm}\) that had been measured were within the range of recommended values of EFNARC which all mixes were classified as SCC.

This indicates that as the higher the replacement of QD in SCC, the higher the slump flow diameter of the SCC mix and the lower the time taken for the SCC mix to reach the slump flow until 500 mm diameter. The slump flow diameter increased with the increasing of QD in SCC due to the properties of the quarry dust itself as QD is less water absorbent material than sand. Workability of SCC was improved by replacing sand with QD. Thus, it makes the mix become more flowable [12].
3.2. Water Absorption Test Result
The water absorption test result for OPC, SPOPC, SPQD10, SPQD20, SPQD30, SPQD40 and SPQD50 taken at 7, 28 and 60 days water curing were analysed in this study. Absorption capacity is the maximum amount of water that can be absorbed and the percentage of water absorption calculated by using the Equation 1. Figure 3 and Figure 4 show the water absorption results for OPC and SCC containing different content of QD at initial 0.5 hour and 4 hours water immersion. It can be seen that the result for water absorption increased with the increasing immersion duration. The longer immersion duration of concrete in water, the more water can flow and absorb into capillary suction and the increasing of water absorption due to immersion time was stopped until it reached the water absorption limit [26].

Water absorption of concrete at initial 0.5 hour water immersion below than 3% can be classified as low absorption of concrete while water absorption of concrete from 3 to 5% can be classified as average absorption of concrete. The water absorption of concrete more than 5% can be classified as high absorption concrete [25]. According to result presented in Figure 3, concrete mixes for OPC, SPQD10, SPQD20, SPQD30, SPQD40 and SPQD50 curing at 7, 28 and 60 days were classified as low absorption of concrete as water absorption result for all conventional concrete and QDSCC mixes at initial 0.5 hour water immersion were below than 3%. Other than that, only SPOPC mix at initial 0.5 hour water immersion for 7 days water curing was classified as low absorption of concrete while at SPOPC mixes for 28 and 60 days water curing were classified as average absorption of concrete which the results were in range 3% - 5%. There was no mix classified as high absorption concrete since all the results for water absorption conducted in this research study were below than 5%.

According to result illustrated in Figure 3 and Figure 4, water absorption for SPOPC at initial 0.5 hour water immersion for 7, 28 and 60 days of water curing were the highest which were 2.68%, 4.23% and 3.78% respectively. Water absorption for SPOPC at 4 hours water immersion for 28 days of water curing was the highest which was 6.63% while water absorption for SPQD30 immersed in water at 4 hours for 7 and 60 days water curing were the highest which were 6.40% and 5.85% respectively. The lowest water absorption for QD in SCC mix at initial 0.5 hour water immersion for 7 days water curing was 1.01% for SPQD10 while 0.41% and 0.39% for 28 and 60 days respectively for SPQD50.

The lowest water absorption for QD in SCC mix at 4 hours water immersion for 7, 28 and 60 days water curing were 3.64%, 2.63% and 2.60% respectively designated as SPQD50. The highest water absorption for QD in SCC mix at initial 0.5 hour water immersion for 7 days water curing was 2.41%
designated as SPQD40 while 2.59% and 2.22% for 28 and 60 days respectively designated as SPQD20. The highest water absorption for QD in SCC mix at 4 hours water immersion for 7, 28 and 60 days water curing were 6.40%, 6.50% and 5.85% respectively designated as SPQD30. SPQD50 was the lowest water absorption while SPQD30 was the highest water absorption for SCC mix containing QD at 4 hours water immersion for 7, 28 and 60 days water curing. According to this study, 50% of QD as fine aggregates replacement in SCC is the optimum dosage that can be used in order to achieve the lowest water absorption for SCC mix containing QD, thus, increasing the durability performance of SCC. Moreover, the water absorption for SCC containing QD is more lower than conventional concrete [12].

3.3. Water Permeability Test Result
The water permeability test result for OPC, OPCSP, SPQD10, SPQD20, SPQD30, SPQD40 and SPQD50 taken at 7, 28 and 60 days water curing were analysed in this study. Based on the water permeability result shown in Figure 5, water permeability decreased with the increase of QD in SCC up to 40% of sand replacement and started increased at 50% of sand replacement. Water permeability result for OPC and SCC mixes decreased with the increasing duration of water curing excepted for SPOPC which the water permeability increased at 60 days water curing. Water permeability result for all specimens taken at 7, 28 and 60 days decreased with the increased of QD percentages in SCC from 0% until 40% which were designated as SPOPC, SPQD10, SPQD20, SPQD30 and SPQD40. However, the water permeability started to increase from SPQD40 to SPQD50. SPQD40 was the lowest coefficient of water permeability for all OPC and QD in SCC specimens taken at 7, 28 and 60 days water curing which were 2.41x10⁻¹¹m/sec, 2.04 x10⁻¹¹m/sec and 1.70 x10⁻¹¹m/sec respectively while SPOPC was the highest coefficient of water permeability which were 13 x10⁻¹¹m/sec, 10.02 x10⁻¹¹m/sec and 10.42 x10⁻¹¹m/sec respectively. According to this study, 40% of QD as fine aggregates replacement in SCC is the optimum dosage that can be used in order to achieve the lowest water permeability for SCC mix containing QD, thus, increasing the durability performance of SCC.
4. Conclusion
From the investigation carried out, the following conclusions are outlined:
1. The highest peak of the slump flow diameter is exhibited by SPQD50 meanwhile the lowest slump flow was recorded by SPQD10. The highest and slowest duration of T$_{500mm}$ slump flow recorded by SPQD10 meanwhile the lowest and fastest duration of T$_{500mm}$ slump flow was recorded by SPQD50. The slump flow diameter of SCC mix increased while T$_{500mm}$ decreased with the increasing of QD content in SCC mix.
2. SPQD50 is the optimum dosage that can be used in order to achieve the lowest water absorption for QD in SCC mix. Thus, by replacing sand with QD, the durability performance of SCC in term of water absorption can be improved.
3. SPQD40 is the optimum dosage that can be used in order to achieve lowest water permeability for QD in SCC mix. Thus, by replacing sand with QD, the durability performance of SCC in term of water permeability can be improved.

Acknowledgement
The authors would like to thank Institute of Research Management & Innovation (IRMI), UiTM for the Research Entity Initiative (REI) [600-IRMI/DANA 5/3/REI (001/2018)] Grant provided, Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM) and Department of Civil Engineering and Construction, Infrastructure University Kuala Lumpur (IUKL) for the guidance and also support in making this research a success.

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