Mechanical, Durability And Rheology Properties Of Ultra High Performance Concrete (UHPC) With Low Cement Content

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Abstract. This current study attempts to investigate the mechanical, durability as well as rheology properties of Ultra-High Performance Concrete (UHPC) with low cement content and using coarse aggregate. The cement content used in UHPC mix in current study was 800 kg/m³. The slump flow, compressive strength, splitting tensile strength, modulus of elasticity, water absorption and water penetration tests were conducted to determine the workability, mechanical and durability properties of explored UHPC mixture. The test results show that the above properties were exceptional and comparable with other UHPC mixtures.

1. Introduction
Production of Ultra-High Performance Concrete (UHPC) consumes high volume of cement. Past research shows that the cement content in UHPC can be up to 1200 kg/m³. In UHPC mixtures there is no coarse aggregate used like normal concrete and it replaced with ultrafine constituents like cement. Besides act as binder, cement in UHPC also functions as filler since only 30 to 60% of cement content in UHPC mixtures hydrated due to low water cement content in UHPC production [1]. The use of great volume of expensive cement increases the cost of UHPC. In long term, the huge consumption of cement shall harm our environment since the manufacturing of cement contributes about 8% of CO2 emission worldwide in year 2014 [2]. Therefore the use of less cement in UHPC may greatly benefit the overall cost of UHPC and sustainable for the environment. [3] has modified the UHPC mix designed by [4] to meet the condition of Malaysia. However, [3] disclosed only compressive strength of the UHPC mix. The major difference between other type of concrete and UHPC is not only the compressive strength but rather in other properties such as workability sufficient to achieve self-compacting cementitious material and very low permeability for better protective function at
serviceability [5,6]. Therefore this study attempts to investigate the workability as well as permeability properties of UHPC mixture with low cement content proposed by [3]. The compressive strength also tested to compare with original mix. Other mechanical properties such as splitting tensile strength and modulus of elasticity were examined and the results were discussed.

2. Materials and methods
The UHPC mix used in this study is shown in Table 1 below. This mix was adopted from [3] with slight modification in term of superplasticizer in which current study adopted different type of superplasticizer with similar quantity to obtain UHPC with sufficient workability for self-compacting cementitious material. Other material used are basic material such as Ordinary Portland Cement (OPC), sand with passing sieve of 4.75 mm as fine aggregate, granite with maximum size of 10 mm as coarse aggregate and water. Water to cement ratio adopted in this current study was 0.2

| No. | Material                        | Quantity (kg/m³) |
|-----|--------------------------------|------------------|
| 1   | Cement (Ordinary Portland Cement) | 800              |
| 2   | Fine aggregates (sand)          | 400              |
| 3   | Coarse aggregate (granite)      | 800              |
| 4   | Superplasticizer (Glenium Ace 389) | 16               |
| 5   | Water                           | 160              |

The mixing process started with pouring water followed by superplasticizer into the cement in mixing bowl while the mixing blade was whirling and then let the blade rotates for about 5 minutes or until paste is formed. Then fine aggregate was gradually added into the mixture and left for about 5 minute or until the fine aggregate well mixed with the paste. Finally, the coarse aggregate was slowly added and let them mix together for about 5 minutes or until all coarse aggregate were coated with paste. Then, the UHPC paste was vibrated using vibrating table to reduce the air void. Immediately after that the inverted slump flow test as accordance to BS EN 12350-8 [7] was conducted. The inverted slump test was adopted in this study because the UHPC mix was designed to be self-compacting cementitious paste and make it suitable to be used for cast in-situ application such as repair works [8]. Then the UHPC paste was poured into the mold and left it for 24 hours before cured it in water. After 28 days the three UHPC and three Normal Concrete (NC) cylinder and cube specimens underwent compressive strength test in accordance to BS EN 12390-3 [9]. Besides that three UHPC and three NC cylinder specimens were tested for splitting tensile strength in accordance to BS EN 12390-6 [10]. Three 100 mm cylinder specimens of UHPC were also tested for Modulus Elasticity following ASTM 469 [11]. In this method the strain-measuring equipment were attached at the specimens as shown in Figure 1(a). The compression load was applied until the longitudinal strain reached 0.00005 and 40% of its ultimate load. The stress at longitudinal strain of 0.00005 (S1) and the stress at 40% of ultimate load (S2) as well as its corresponding strain, ε₁ and ε₂ were recorded. The modulus of elasticity is the ratio of stress different (S2-S1) to the strain different (ε₂ - ε₁). In term of durability properties, there were three UHPC and NC cylinders with 100 mm diameter underwent water absorption test in accordance to BS 1881-122(1983) [12] and three UHPC and NC cylinders with the dimension of 40mm of high and 55mm of diameter were placed in the permeability cell first and 2.5 bars of pressure head water was applied on the top of the specimens for 3 hours to allow the water penetrate through the specimens. After that, the specimens were compressed by using the compression machine to split the specimens into half. Then, the depth of the water penetration was measured and recorded. The Figure 1(b) shows the test set up for water permeability test. The permeability coefficient was calculated by using equations proposed by [13], where strength and the cube compressive strength obtained from current study was 27% lower than the cube compressive strength obtained by [3].
3. Results and Discussion
Table 2 reports the results of splitting tensile strength test. It was found that the average splitting tensile strength obtained from current study was 24.3 MPa which is about 21% and 34% of averaged cube and cylinder compressive strength, respectively. This indicates that the splitting tensile strength of UHPC is much higher than normal concrete which is in common practice is estimated as 10% of its respective cylinder compressive strength. Meanwhile, modulus elasticity was 49.32 GPa which is 3.5 times higher than normal concrete and it is comparable with previous studies [17].

| Specimens  | Splitting Tensile Strength (MPa) |
|------------|----------------------------------|
| Specimen 1 | 25.5                             |
| Specimen 2 | 24.0                             |
| Specimen 3 | 23.5                             |
| Average    | 24.3                             |

The water absorption for UHPC tested in current study was 2.9% which is 9% lower than normal concrete (3.2%). The results of water permeability test shows that Water Permeability Coefficient (WPC) for UHPC was 2.52 x 10^-10 m/s which was 33% lower than normal concrete with recorded WPC of 3.81 x 10^-10 m/s. The results of water absorption test and water permeability test verifies that the UHPC mixed used in current study have much better durability properties compared to normal concrete even though the less cement content used and coarse aggregate was introduced in the mix.

4. Conclusion
The objective of this current study was to investigate the rheology, mechanical and durability properties of UHPC mixture with coarse aggregate and low cement content. Based on the test results, the following conclusions can be made:

- The recorded slump flow diameter was 800 mm which is within EFNARC (2002) standard specification.
- The cube compressive strength of 117.37 MPa is comparable with previous study for UHPC but the much lower cylinder compressive strength obtained in this study must be further check.
- The averaged splitting tensile strength was 24 MPa which is 34% of its averaged cylinder compressive strength.
- The averaged modulus of elasticity was 49.32 GPa which is comparable with previous study.
- The water absorption and water permeability properties of UHPC mix used in current study is much lower than normal concrete indicate that this UHPC mixture has better durability properties even though the low cement content adopted, and coarse aggregate were incorporated into the mix.

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