Influence of Various Sand Gradation on Mechanical Properties and Concrete Quality of High Performance Concrete (HPC)

K Muhamad¹, N F Isa¹, N H Hashim¹, Z Tusimin², N Yahya¹, N A Naamandadin¹, R A Razak¹ and P Y Tham¹

¹Faculty of Engineering Technology, University Malaysia Perlis, 02100 Sg Cuchoh, Perlis, Malaysia
²Department Construction Engineering Technology (Advanced System), Kolej Kemahiran Tinggi MARA Sri Gading, 86400 Parit Raja, Batu pahat, Johor, Malaysia

Email: khairunnisa@unimap.edu.my

Abstract. High Performance Concrete (HPC) has a few characteristics: high strength, high early strength, high modulus of elasticity, high durability and long life in severe environments, low permeability and diffusion, resistance to chemical attack, toughness and impact resistance and so on. Almost 70 to 80% of the volume of the concrete is occupied by aggregate which have a great impact on characteristics and properties of a concrete. Not only course aggregate but fine aggregate also contributes a lot toward the performance of HPC. Thus, this research studied on the influence of various sand gradations on mechanical properties and concrete quality of HPC. The sand gradation utilized in the study are normal size sand, sand passing through sieve size 1180µm, sand passing through sieve size 600µm and sand passing through sieve size 300µm. The mechanical properties of HPC being studied are compressive strength and splitting tensile strength while the concrete quality of HPC is determined by using water absorption and Ultrasonic Pulse Velocity (UPV) test. The results show that the mechanical properties and concrete quality increased as the size of sand particles decreased. The optimum sand gradation is the sand passing through sieve size 300µm which achieved highest mechanical properties and concrete quality showing the highest result of compressive strength (123.9MPa), splitting tensile strength (8.91N/mm²), lowest percentage of water absorption (0.55%) and highest UPV value (7743N/mm²).

1. Introduction

High Performance Concrete (HPC) can be defined as the concrete that reach special performance and have their own specific requirements that cannot be achieved by using conventional materials and normal mixing [1]. HPC is the concrete that contained mechanical properties which exceeds the normal strength concrete [2][3][4]. HPC has a few characteristics: high strength, high early strength, high modulus of elasticity, high durability and long life in severe environments, low permeability and diffusion, resistance to chemical attack, toughness and impact resistance and so on. Normally, the HPC is used to build bridge, tunnel and also high rise building [5].

Nowadays, earthquakes had become a common issue that might happen on all over the earth. During an earthquake, high horizontal and vertical forces will be subjected to the beam-column joint region. The force had magnitudes that much higher than those within adjacent beams and columns. In this case, the conventional design of Ordinary Portland Cement is no longer meet many functional...
requirements [3]. Therefore HPC which contains high mechanical and durability properties is developed to fulfill the requirement of the market especially for the heavy construction works.

The High Performance Concrete have its own specific properties. HPC can achieved high strength which is 70 to 140 MPa at 28 to 91 days; high early compressive strength which is 20 to 28 MPa at 1 to 3 days; low absorption which is 2% to 5% and an excellent concrete quality with UPV value above 3705 m/s [1]. Different sand gradation will affect the strength of the concrete. The concrete with finer sand particles will gain the higher compressive, flexural and splitting tensile strength. This is because the sand with finer particles able to hold the internal moisture content of the concrete better than the sand with coarser particles [5]. So the aim of this research is to study the effect of sand gradation in terms of passing sieve sized 1180µm, passing 600µm, passing 300µm and the normal sand size (i.e. combination of all sizes of sand)

Besides, the aggregate used in concrete have a great impact on characteristics and properties of a concrete [4]. Yet, the study of the effect of fine aggregate which is the sand grading of self-compacting concrete is very limited [5]. Hamiruddin N A et. al, studied a different sand gradation on Self- Consolidate Ultra-High Performance Concrete (UHPC) which consist of normal sand size, sand sized 600 μm -1180µm, sand sized 300µm - 600µm and sand sized 63µm - 300µm. Study shows that the used of 600 - 1180µm sand gradation represented the excellent UHPC performance due to the present of void. The reduction in voids is influenced by high cement content, very low (w/c), (HRWR) and fine particles [6].

2. Methodology
The mixture constituents (Table 1) consist of 4 different fine aggregate gradations, (1) normal sand, (2) sand passing through sieve size 1180µm, (3) sand passing through sieve size 600µm, and (4) sand passing through sieve size 300µm. High strength cement class 52.5N is used as a binder and high range water reducer type of superplasticizer that being used in concrete mix is Masterglenium Ace 8589 to reach a minimum flow of 750mm. The amount of superplasticizer added increased as the size of sand decrease. This is because the sand with smaller size will have more fine particle and hence the total surface area of the particle will increase therefore higher amount of superplasticizer is needed to react with every single particle of the concrete to achieved the workability. [6]

| Content             | HPC1   | HPC2   | HPC3   | HPC4   |
|---------------------|--------|--------|--------|--------|
| Cement (kg/m³)      | 1000   | 1000   | 1000   | 1000   |
| Water (kg/m³)       | 200    | 200    | 200    | 200    |
| Sand (kg/m³)        | 669    | 669    | 669    | 669    |
| Superplasticizer (kg/m³) | 22.0  | 23.6   | 23.9   | 29.9   |
| Sand Gradation (µm) | Normal Sand | Passing | Passing | Passing |
|                     | 1180µm | 600µm  | 300µm  |        |

The flow test was conducted is according to ASTM C 1611 [8] to determine the workability of HPC. Based on Karihaloo [7]. In this study, the flowability demonstrated in the range of 860mm - 1180 mm (Figure 1) which means that the amount of superplasticizer can be reduce to below than 2%. In this study the uses of superplasticizer is to reduce the water cement ration usage in order to achieve high compressive strength of HPC [8].
3. Results and Discussions

3.1 Compressive Strength

As indicated in figure 2, the compressive strength results show that all the specimen achieve high strength concrete which is above 100Mpa at 28 days [9]. These results also comply with the book of Design and Control of Concrete Mixtures which should in range of 70Mpa – 140 Mpa. Besides that, this mixture also achieve a high early strength concrete as it achieved above 20 to 28 MPa at 1 to 3 days as stated by Kosmatka, Kerkhoff, and Panarese, [5].

In the study of different range of fine aggregate gradations, the result indicates that there is a slight different in compressive strength achievement due to the sample is taking as passing sieve sizes as stated above. It means that there are small particles of sand sized which will fill the void between larger particles size (Table 2). In this case it contributes a dense packing density between the particle sand inside the mixture proportion. A lesser air void contained in concrete mixed a higher compressive strength it will achieved [6]. These results also in line with Siong K L et. al [10] and Neville [11] which said that sand filler had contributed to the reduction of voids in mixture thus increase the strength of the concrete.

3.2 Splitting tensile strength

The splitting tensile strength of HPC increased as the size of sand particles decreased from 1180 to 300µm (Figure 3). The results showed the similar trend with the previous study done by Siong K L et al which the splitting tensile strength of concrete increase as the sand size decreased. They found that the increment might be happened as more internal moisture can be hold by the increment of finer particles. It’s occurred when more water is needed to wet the surface of every particles, hence, the free water held by the fillers could be used to hydrate the other cement particles which are not hydrated yet.
This late hydration can reduced the strength loss caused by the tropical weathering, and hence increase in splitting tensile strength [10].

| Sieve Size | Weight Retained (kg) | Cumulative Weight Retained (kg) | Cumulative % Retained | Cumulative Weight Passing (kg) | Cumulative % Passing |
|------------|----------------------|--------------------------------|-----------------------|-------------------------------|---------------------|
| 3.35 mm    | 0.0                  | 0.0                            | 0                     | 0.5                           | 100                 |
| 2.0 mm     | 0.01                 | 0.01                           | 2                     | 0.49                          | 98                  |
| 1.18 mm    | 0.01                 | 0.02                           | 4                     | 0.48                          | 96                  |
| 600µm      | 0.08                 | 0.1                            | 20                    | 0.4                           | 80                  |
| 300µm      | 0.31                 | 0.41                           | 82                    | 0.09                          | 18                  |
| 150µm      | 0.08                 | 0.49                           | 98                    | 0.01                          | 2                   |
| Pan        | 0.01                 | 0.5                            | 100                   | 0                             | 0                   |
| Total      | **0.50**             |                                |                       |                               |                     |

**Table 2. Sieve Analysis of Normal Sand.**

![The splitting tensile strength of High Performance Concrete with different sand gradation on 28th day](image)

**Figure 3. Split tensile strength.**

### 3.3 Water Absorption
The percent water absorption of HPC (Figure 4) was influenced by the size of sand particles used for concrete mix. As the size of sand particles decreased, the percent water absorption will be decreased; it means that less water were absorbed by the concrete sample. The HPC with normal size sand had the highest percent of water absorption while that of HPC with sand passing through sieve size 300µm achieved the lowest percent water absorption. This is because the HPC with finer sand particles will filled up more space between the cement and the sand therefore less voids will be formed inside a concrete sample. When the number of voids in a concrete decreased, the ability of the concrete to absorb water will decreased as the same time.

The previous research by Gameiro [12] that study about the durability properties of structural concrete incorporating fine aggregates from the waste marble industry stated that the concrete that contained finer marble aggregates achieved lower water absorption by immersion. This is because the marble aggregates are smaller in size. The finer aggregates had increased the compactness of the particles inside the concrete and therefore reduce its ability to absorb water.
Figure 4. Water Absorption Capacity of HPC with Different Sand Gradation at 28th Day.

3.4 Ultrasonic Pulse Velocity (UPV)

The results of UPV (Table 3) show the concrete quality of the HPC was in good and excellent quality. The concrete with excellent concrete quality means that there are less voids being formed in the concrete. As compare to the results of UPV, the HPC-300 achieved the highest transition time because HPC-300 is the finest compared to others sand gradation. The sand particles can fill up more spaces between the cement and sand. Besides, the finer aggregates exhibit higher bonding strength between cement matrix and sand particles. As stated by G Kadir [13], the surface roughness of the aggregate grains has a significant effect on adhesion of the cement matrix – aggregate interface. The increase in compressive strength of aggregates with high surface roughness is caused by the stronger interfacial transition zone (ITZ). This situation is thought to be causing the increase in UPV values (Figure 5).

Table 3. Ultrasonic Pulse Velocity of High Performance Concrete with different sand gradation on 28th day.

| Sand Gradation   | Ultrasonic Pulse Velocity (m/s) | Concrete Quality |
|------------------|---------------------------------|------------------|
|                  | Reading 1 | Reading 2 | Average |                  |
| HPC-NS Normal Sand | 5100      | 5150      | 5125    | Excellent       |
| HPC-1180 Passing 1180µm | 4545      | 4600      | 4573    | Excellent       |
| HPC-600 Passing 600µm | 4445      | 4440      | 4443    | Good            |
| HPC-300 Passing 300µm | 7810      | 7675      | 7743    | Excellent       |

Figure 5. Relationship between compressive strength vs Ultrasonic Pulse Velocity.
4. Conclusion
In this study where the effects of fine aggregate gradation on mechanical and concrete quality were investigated, the following results were obtained:

- As the size of sand particles decreased, both the mechanical properties and concrete quality of HPC increased.
- The optimum sand gradation of HPC to perform better mechanical properties and concrete quality is the sand passing through sieve size 300µm (HPC-300). The HPC-300 had achieved 93.40MPa early strength on the 3rd day, 101.20MPa compressive strength on the 7th day and 123.90MPa compressive strength on the 28th day which is higher than the other sand gradation. The splitting tensile strength of HPC-300 also achieved the highest value which equal to 8.91N/mm² on 28th day. The percentage of water absorption for HPC-300 is 0.55% which is the lowest among the other sand gradation. Furthermore, the HPC-300 also showed the best concrete quality with highest UPV value which is 7743m/s.

Acknowledgement
The author would like to acknowledge the Faculty of Engineering Technology, University Malaysia Perlis (UniMAP) for providing equipment and laboratory in this project.

References
[1] Jalal M, Esmaeel M, Mohammad S, Ali R P, Mater and Des 34 389-400 (2012).
[2] Jayesh S G and Awari U R, Int J Res Eng Technol, 5, 1965 (2018).
[3] Kannan S U, Int. J. Eng. Res and Dev, 13, 42-49 (2017).
[4] Muhammad K et al, J. Adv. Res Eng, 8 23-28 (2019).
[5] Kosmatka S H, Kerkhoff B & Panares W C (2002) Design and Control of Concrete Mixtures: High Performance Concrete 14th ed(Skokie: Portland Cement Association) 5420 299-313.
[6] Hamiruddin N A, Solid State Phenomena 280 pp 476-480 (2018).
[7] Deeb R Ghanbari A, and Karihaloo B L, Cement Concrete Comp, 34, 185-190 (2012).
[8] Al Tayeb M M and Hamouda H, Civil and Environmental Research, 7 35-43 (2015).
[9] Mahure N V, Vijh G K, Sharma P, Sivakumar N and Murari R, International Journal Of Earth Sciences and Engineering, 4, 871-874 (2011).
[10] Siong K L et. al ,Construction and Building Materials 38 348-355 (2013).
[11] Neville A Properties of Concrete 4th ed 2009 Pearson Prentice Hall (Harlow, England).
[12] Gameiro F J G 2013 Durability properties of structural concrete incorporating fine aggregates from the waste marble industry Master's Dissertation at Civil Engineering (Instituto Superior Técnico, Lisbon).
[13] Gucluer G, Journal of Building Engineering 27, 100949 (2019).