Penerbit Akademia Baru

Journal of Advanced Research in Engineering Knowledge

Journal homepage: www.akademiabaru.com/arek.html
ISSN: 2600-8440

Laboratory Study on Influence of Various Coarse Aggregate Gradation on Mechanical and Physical Properties of High-Performance Concrete (HPC)

Open Access

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ARTICLE INFO

Article history:
Received 5 June 2019
Received in revised form 4 July 2019
Accepted 12 July 2019
Available online 7 September 2019

Keywords:
High performance concrete, HPC, coarse aggregate gradation

ABSTRACT

This research examines the influence of coarse aggregate gradation toward High Strength Concrete (HPC) with targeted compressive strength 70MPa. Three gradations of coarse aggregate (4.75 – 9.50 mm, 9.50 – 12.50 mm and 12.50 – 19.00 mm) used in this studies and the laboratory work is done for compressive strength, splitting tensile strength, water absorption and ultrasonic pulse velocity test. The usage of superplasticizer is included in order to gain self-consolidated concrete for HPC. As a result, the highest strength of concrete obtained is 80.3 MPa at coarse aggregate gradation 12.50 mm to 19.00 mm which is the largest sizes used in this study.

1. Introduction

High-Performance Concrete (HPC) is a special designed concrete which provide a few benefits in building construction which are high strength, greater on durability properties and suitable for high-rise construction [1]. It possesses high strength, high modulus of elasticity, high workability, high dimensional stability, low permeability and also resistance to chemical attack [2-3]. According to ACI "High Performance Concrete is defined as concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using conventional materials and normal mixing, placing and curing practices.

Coarse aggregate fraction is known to strongly influence both fresh and hardened concrete's properties. Consequently, selection of both content and particle size distribution (PSD) for concrete mixture is an important issue regarding the predicted performance of concrete. About One third of the concrete volume is filled with coarse aggregate which 45% of them are coarse aggregates. Because of that, it is assumed that the aggregates properties greatly affect the durability and structural performance of concrete material [4,5]. M. Seddik [4] also revealed that compressive strength is strongly linked to the coarse aggregate parameters (content, proportion of fine to coarse aggregate and grain size distribution) of concrete mixture. However, the uses of high size of coarse

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aggregate will cause the strength of concrete decreasing and difficult to achieve the target of the minimum requirement, which is 80 MPa of compressive strength according to BS EN 197 – 1:2000 [6].

2. Methodology

The mixture proportion (Table 1) for this research involves classic element which are water, cement type 52.2, aggregates and high strength water reducer admixture [3]. The superplasticizer used in order to enhance the performance of HPC in increasing the workability of concrete thus improved its compressive strength. It was innovative polycarboxylic ether (PCE) that could be categorized as a very high workability, excellent in concrete quality and increased productivity of concrete. Usage of low water-content which is 0.26 that is used to achieved 80MPa minimum [6-7]

Table 1
Mixture Proportions

Content	HPC1	HPC2	HPC3
Cement (kg/m^3)	1000	1000	1000
Water (kg/m^3)	260	260	260
Superplasticizer (%)	1.80	1.80	1.80
Fine Aggregate (kg/m^3)	940	940	940
Coarse Aggregate (kg/m^3)	1410	1410	1410
Coarse Aggregate grading	Passing (19.0 mm – 12.5 mm)	Passing (12.5 mm – 9.5 mm)	Passing (9.5 mm – 4.75 mm)

While the accepted criteria for self-compacting concrete slump flow by Abrams cone is 650mm minimum and 700mm maximum [7]. The viscosity of SCC mixtures was evaluated through the slump flow test. The slump flow represents the mean diameter of the mass of concrete after release of a standard slump cone; the diameter is measured in two perpendicular directions [8]. According to ACI SP 301-314 [9], self-compacting property of highly-flowable concrete must achieve a slump flow ranging from 500 to 700 mm which is considered as the slump required for a concrete to be self-compacted.

For each mixture, the compressive strength was determined on three cylinders at 1, 7, and 28 days. The splitting tensile strength was determined on three cylinders also but only on 28 days. These two tests were carried out following the relevant ASTM standards. While water absorption percentage was determined according to British Standard 1881: Part 122: 1983. Lastly, the concrete quality is determined by using ultrasonic pulse velocity (UPV) which also followed the British standard BS 1881: Part 203: 1986.

3. Results

3.1 Physical Properties

3.1.1 Density

According to National Ready Mixed Concrete Association (2003), the density for normal concrete is in the range of 2240 to 2400 Kg/m3 while for lightweight concrete is in range of 1440 to 1840 Kg/m^3, but for HPC, the density should be higher to the normal weight concrete. Usually the density

of concrete is depend on the amount of the materials used in the mix concrete such as fine aggregate, coarse aggregate, admixture and cement. In this study, the cement used is Cement type 1 52.5 N; which is the highest grade of cement and its fineness. This cement usually used for the retaining wall and high rise building in construction to ensure that structure can afford the higher load before the structure occur failure. The density results for each coarse aggregate gradation showed in between of the value stated in the book of Design and Control of Concrete Mixture which is in the range of 2405 to 2462 Kg/m^3 [10].

3.1.2 Flowability

Since the HPC is gaining its high strength by low water cement ratio, the used of innovative polycarboxylic ether (PCE) is capable to increase the workability of the mixture. In this research, the amount of PCE used is maintained at 1.8% for all aggregate gradation. The result obtained are 940mm, 890mm and 910mm for coarse aggregate gradation between 4.75 mm - 9.50 mm, coarse aggregate gradation at 9.50 mm – 12.50 mm and coarse aggregate gradation 12.50 mm – 19.00 mm respectively. It is recommended that the usage of superplasticizer is reduced to achieve flow range of 500mm to 750mm. It is because, at more than 700 mm the concrete might segregate, and at less than 500 mm the concrete is considered to have insufficient flow to pass through highly congested reinforcement [9]

3.1.3 Water absorption

Figure 1 shows that the percentage of water absorption is increase as the coarse aggregate gradation increased. The maximum result is only 1.57% which is not meet to the requirement of ASTM C 642, which is must in range between 2% to 5%. The low water absorption of this mixtures may attributed by the low water cement ratio used which is 0.26. From Piasta and Zarzycki [11], which obtained the water absorption between 1.95 to 4.98 % were used a water cement ratio from 0.3 – 0.6, the results showed that the water absorption is decreasing when the water cement ratio is decreased. Besides of that Piasta and Zarzycki [11] also found that the water absorption not only affected by water cement ratio but also by the paste content.

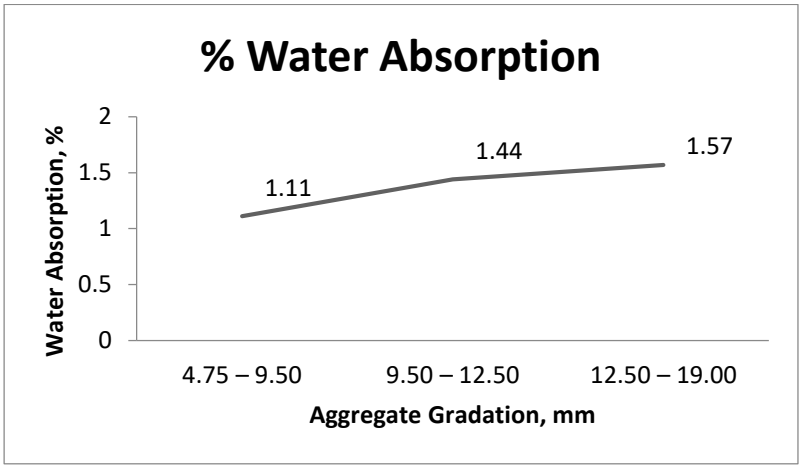

Fig. 1. *Water Absorption*

Based on Pulse velocity test (UPV), it shows that all the concrete specimens are in good and excellent condition as shown in Table 2. Based on Bora [12], the highest quality of concrete produced from this study is a mixture contained coarse aggregate gradation 9.50 mm – 12.50 mm. it can be said that when that the pores in the concrete sample is minimal thus reflecting to the result of water absorption dropped out to below 2%.

Table 2
Concrete Quality

Gradation of Coarse Aggregate	Type of Transmission	Path Length, L (mm)	Pulse Velocity by Cross Probing (km/s)	Concrete Quality
4.75 mm – 9.50 mm	Direct	150	4.41	Good
9.50 mm – 12.50 mm	Direct	150	4.82	Excellent
12.50 mm – 19.00 mm	Direct	150	4.21	Good

3.2 Mechanical Properties
3.2.1 Compressive Strength

Data presented in figure 2 shows that the compressive strength is increase when the aggregate gradation is increased. At 28 days the higher aggregate gradation achieved 80.3 Mpa while the other two grading achieved higher than 70Mpa. This finding is in line with [13] and within the HPC performance which should in range of 70Mpa – 140 Mpa as stated in the book of Design and Control of Concrete Mixtures. As we can see this result is associated with Krishna et.al [14] whom found that the compressive strength is directly proportional to the size of coarse aggregate. Besides that, according to Kosmatka, Kerkhoff, and Panarese, [10], the sample of High Performance Concrete must achieved 20 to 28 MPa at 1 to 3 days. So, it is found that all the samples used in this study achieved this target.

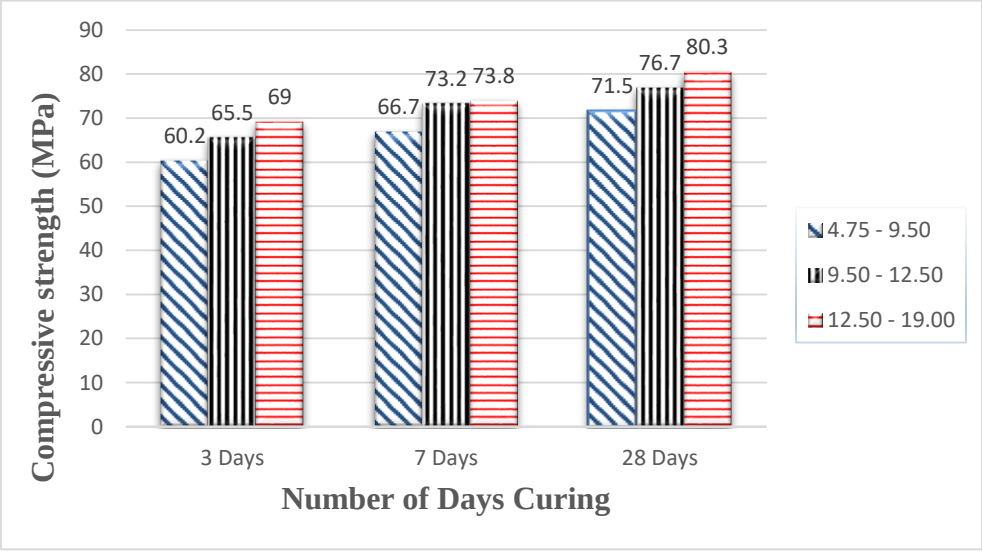

Fig. 2. Compressive Strength

3.2.2 Splitting tensile strength

As shown in table 2, splitting tensile strength on the 28th day achieved in range of 3.15 to 5.17 MPa which is in line with Zain, Mahmud, Ilham, and Faizal, [15] which obtained in their research between 3.5 to 6.5 MPa.

Table 3
Split Tensile Strength

Gradation of coarse aggregate	28 Days
	Splitting Tensile strength, F_{spt} (MPa)
4.75 mm – 9.50 mm	3.15
9.50 mm – 12.50 mm	4.13
12.50 mm – 19.00 mm	5.17

Figure 3 shows the relationship between of splitting tensile strength against compressive strength on 28th day of curing. It shows that the split tensile strength is increased when the compressive strength increase. However the function obtained quite different with ACI 363 [9] which is *fst = 0.59 (fc)*$^{0.5}$. This happened due to the larger range of data obtained for Splitting tensile strength in this study. This result may attributed by the high flow obtained which is up to 900mm. The flow that exit maximum 750mm may contribute to segregation thus provide inhomogeneous mixture due to high density matrix settled down and vice versa. Consequently, it lowered the bonding strength between cement paste and aggregate in concrete samples.

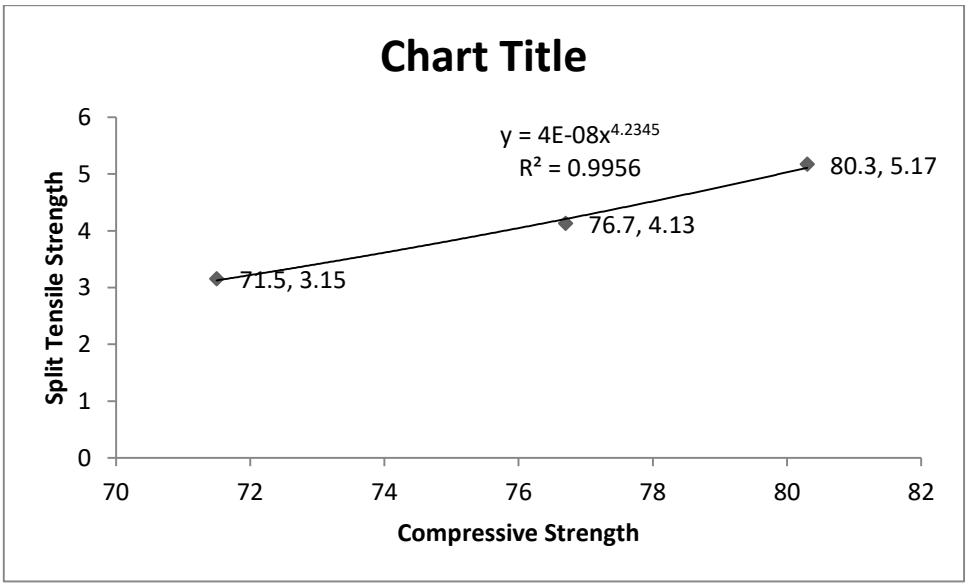

Fig. 3. Relationship between Split Tensile Strength and Compressive Strength

4. Conclusions

As conclusion, aggregate gradation has a significant effect on HPC performance. The optimum range of the coarse aggregate gradation is 12.50 – 19. 00 mm produced high strength of concrete which is 80.3 MPa.

Acknowledgement

This research was done at Faculty Engineering Technology, University Malaysia Perlis.

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