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Equal Volumes of Sand and Gravel Concrete Mix Ratios in Cameroon and Its Effect on Concrete Compressive Strength

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Abstract

In recent years, the rationalization of concrete mix ratios which batches equal volumes of sand and gravel in building projects has been gaining grounds in the Cameroon construction industry. The main objective of this study is therefore to investigate if the concrete produced with rationalized mix ratio can be adopted as conventional mix ratio in terms of minimum required compression strength of concrete for buildings. Specifically this work compared the conventional mix ratio of 350 kg of cement: 400 liters of sand: 800 liters of gravel for a cubic meter and the rationalized batch of 350 kg of cement: 600 liters of sand: 600 liters of 5/15 gravel, 15/25 gravel and a combination of 5/15 + 15/25 gravel. Average compressive tests' results for both the conventional and the rationalized mix ratios were found to meet the minimum compressive strength of 65% at 7 days, 90% at 14 days and 99% at 28 days for gravel size combination 5/15 + 15/25. Single size gravel of 5/15 and 15/25 did not meet the minimum required compressive strength of 20 N/mm^2 for the rationalized mix ratio at 28 days curing based on the minimum compressive strength required, this study arrives at the conclusion that the equal volumes of sand and gravel mix ratio of 350 kg/m^3 of cement: 600 liters of sand: 600 liters of gravel mix ratio can be adopted as a conventional concrete mix ratio for gravel size 5/15 + 15/25.

Keywords

Conventional Concrete, Rationalized Concrete, Mix Ratio, Compressive Strength, Equal Volumes of Sand and Gravel

1. Introduction

The quest to simplify concrete production using locally available materials, construction equipments, labor force and practices is on the increase on a daily bases and has led to the need for a variety of methods of producing concrete. This encourages the researchers in the construction industry to attempt to enhance the current concrete technology practices and develop new ones. The construction industry has therefore witnessed a lot of modifications in the production of concrete around the world for some time now.

Japanese researchers invented self-compacting concrete in 1980 which is a kind of concrete that preserves its homogeneity and flows under its particular weight in its state of plastic during filling any form even surrounding the congested reinforcement of the framework, attaining compaction without vibrating mechanically [1]. Other researchers investigated a high-strength concrete using coarse aggregates and crushed lime stone of 10, 15 and 20 mm sizes [2]. It was also shown that with the application of coarse recycled concrete aggregate, as the component materials in the concrete mixtures, it is possible to produce structural concrete that can be satisfactory and even of high quality, which primarily depends on the characteristics of crushed demolished concrete [3].

In another research which investigated the mechanical properties of concrete containing recycled concrete aggregate (RCA) and ceramic waste as coarse aggregate replacement it was found that the concrete containing 35% RCA and 35% ceramic waste showed the best properties compared with the normal or conventional concrete [4]. Other researchers recounted that, there are various ways by which concrete has been modified for various purposes without compromising its strength, such as coarse aggregate combination and partial replacement of either fine or coarse aggregate. They further advised that concrete production can be modified provided the minimum required strength is reached and serves the intended purpose [5].

Some investigated the mixture of glass powder and silica fume in concrete as a partial cement replacement, to study its effect upon concrete strength. The mix proportion of 1:2:4 was selected for all the concrete samples with water to binder ratio of 0.55. For comparison, a control sample of concrete was prepared without mixture of glass powder and silica fume to compare it with the various samples containing different percentages of mixture of glass powder and silica fume as a partial replacement of cement in concrete. Results showed that the usage of mixture of glass powder and silica fume in concrete as a partial replacement of cement increases the concrete strength [6].

The safety, strength and structural integrity of concrete structures depend largely on the quality of concrete used for their construction and one of the most important quality parameters is the compressive strength of the concrete [7]. Concrete grade/strength class C20/25 is the minimum concrete grade/strength class recommended for the construction of reinforced concrete load-bearing members (beams, slabs and columns) of building under mild exposure condition [8]. Class 20/25 concrete is a concrete with a minimum cylinder crushing strength of 20 MPa or a minimum cube crushing strength of 25 MPa.

In making concrete, it is important to use the correct concrete mixing ratios.

The inappropriate mix ratios or incorrect proportioning of concrete ingredients, leads to production of concrete that do not meet the designed target strengths. Research affirms that concrete mix for normal concrete is conventionally batched in ratios depending on the targeted design strength. Concrete mix ratios are the proportions of concrete components namely cement, sand, aggregates and water decided based on the type of construction and mix designs [9].

Some researchers undertook a prediction of fresh and hardened properties of normal concrete via choice of aggregate sizes, concrete mix-ratios and Cement and arrived at a series of conclusions. First they concluded that the different mix ratios 1:2:4, 1:2:3 and 1:3:6 should be adopted for different purposes. Secondly they found that, the 1:2:4 mix ratio is a very suitable mix ratio for normal concrete while the 1:2:3 mix ratio (very high in cement content and therefore more expensive) should be used for constructions where extra compressive strength may be required as it has a higher strength than the 1:2:4 mix ratio. Thirdly, the 1:3:6 mix ratio has the lowest compressive strength of the three and is not suitable for the casting of major structural elements such as beams and columns. It could be used for blinding purposes and for structural elements of less importance. Fourth they found that the concrete produced with the mixed-size aggregate had the highest compressive strength. This may be due to the fact that all pore spaces between the aggregates were completely filled with the smaller aggregates and cement. This confirms the preference for mixed aggregate sizes to single aggregates in practice [10].

From the literature above, it can be observed that different mix ratios have been adopted for different purposes. But little information is available on rationalized concrete mix ratio despite the fact that its usage is on the increase on most building sites in Cameroon. The compressive strength of concrete produced with the rationalized mix ratio is still not investigated and documented. The main objective of this study is therefore to investigate if the concrete produced with equal volumes of sand and gravel mix ratio can be adopted as conventional mix ratio in terms of minimum required compression strength of concrete for buildings. The specific objective of this work was to compare the conventional mix ratio of 350 kg of cement: 400 liters of sand: 800 liters of gravel for a cubic meter and the rationalized batch of 350 kg of cement: 600 liters of sand: 600 liters of 5/15 gravel, 15/25 gravel and a combination of 5/15 + 15/25 gravel.

2. Materials and Method

2.1. Materials

The materials used for making concrete are cement, fine/coarse aggregate and water.

Cement: cement grade CPJ 35 from the CEM II family of cements produced by the Dangote cement factory in Cameroon. This cement was bought from a building material store at mile 2 Bamenda and was confirmed to be aged five days from the date of manufacture. The cement was taken directly from the truck that brought in the cement from the factory located in Douala. This was to guarantee that the cement was of good quality. From the field tests conducted on the cement, the color of the cement was uniform and of grey color with a light greenish shade. The cement was free from any hard lumps. The cement felt smooth when rubbed in between fingers. When a hand was inserted in the bag of cement, it felt cool and not warm. When a small quantity of cement was thrown in a bucket of water, the particles floated for some time before sinking. When a thick paste of cement with water was made on a piece of glass plate and kept under water for 24 hours, it set and not cracks. These field tests confirmed that the cement used was of good quality.

Fine aggregate: the fine aggregate used was river sand from Wum road. This sand was of 0/5 diameter range and was free from clay materials and organic matter. The particle size distribution or grading of the sand was determined by sieve analysis.

Coarse aggregates: the course aggregates used in the study was gravel from crushed stones that are commonly used for concrete production in Cameroon; the gravel was crushed in the Dreamland rock quarry enterprise located at Mankon-Bamenda. The gravel sizes selected was 5/15mm and 15/25mm and it was free from clay materials and organic matter.

Mixing water: The concrete was produced with water of drinkable quality obtained from a spring at upstation, Bamenda, located opposite the fire fighting unit.

2.2. Methods

Concrete cylinders were cast with two mix ratios of 50 kg of cement: 400 liters of sand: 800 liters of gravel for the conventional mix ratios and 350 kg of cement: 600 liters of sand: 600 liters of gravel for the rationalized mix ratio. The concrete cylinders were made and cured in accordance with NF EN 12390-4 [11]. The water-cement ratio was employed for the research was 0.50. For each mix ratio, the aggregates and the cement were thoroughly mixed then water of specified volume and added into the concrete mixer and mixing was continued for 2 minutes to ensure consistency. The concrete mix was then poured into each cylinder mould of 15cm diameter by 30cm height. The concrete cylinder moulds were filled in three layers with each layer manually compacted with 25 blows of a tamping rod so as to allow for proper compaction to prevent void on the concrete in accordance with EN 12390-4 [11].

The top surface of each cylinder mould was smoothened and leveled with a hand trowel. The concrete cylinders were demoulded after twenty four hours and cured for 7 days, 14 days and 28 days respectively. For each mix ratio per gravel size range considered, twelve concrete cylinder samples were subjected to compressive strength test in accordance with EN 12390-4 [11]. Sieve analysis was carried out on the sand and gravel samples to determine their particles seize distribution for each of the aggregate used. Percentages of aggregates passing and retained were analyzed and grading curved plotted for interpretations. Other tests were carried out in order to determine the specific gravity, apparent density, sand equivalent and finesse modulus of sand and gravel used. The investigations studied mixed ratios for gravel 5/15, gravel 15/25 and also a combination of gravel 5/15 and 15/25 as used in construction sites in Cameroon.

3. Result and Discussion

Physical characteristics of cement: the physical characteristics of cement studied as presented in Table 1 are specific gravity, specific surface area, consistency and apparent (bulk density).

The specific gravity shows that it is within the range of 3.1 to 3.16. This shows that the cement was properly ground into fine powder during its production and that the pores of cement are not filled with moisture which can affect the mix and bonding. The specific surface area of cement is greater than 2250 cm^2/g, it can be deduced that the cement has a good fineness which offers a greater surface area for hydration and hence faster the development of strength. The consistency obtained is within the range of 25% to 35%. This shows that for every 1000 g of cement, 290 g of water will be the minimum required to make the cement paste. Apparent (bulk) density is within the range of 0.9 to 1.2 t/m^3.

Properties of sand and gravel

Table 2 shows the result of sieve analysis for sand and gravel that was carry out on the following sieve size: 25 mm, 20 mm, 15 mm, 12 mm, 10 mm, 5.00 mm, 2.5 mm, 1.25 mm, 0.63 mm, 0.315 mm, 0.16 mm, 0.08 mm and the bottom bowl as per AFNOR [12] to determine the distribution of sand and gravel by sieving them per sieve. The results of sieve analysis of percentage passing for each aggregate type are presented here below in Table 2.

The table above shows that the sand is continuous graded and the grading is within zone II envelope of the British standard showing that the Wum road sand is well graded for the concrete work. Aggregates have to be graded so the whole mass of concrete acts as a relatively solid, homogeneous, dense combination with the smallest particles acting as inert filler for the voids that exist between the larger particles [13]. The Specific gravity for Wum road sand obtained is within the range of 2.65 to 2.67 and that for the various gravel sizes are also within the range of 2.5 to 3. Therefore the pores in the Wum road sand and also

Table 1. Physical characteristics of the CPJ 35 cement.

S/N	Test Parameter	Result
1	Apparent density	3.1
2	Constituents	Clinker (65%), gypsum (5%), pozzolans (30%)
3	Grain size	80 µm
4	Specific area	3100
5	Apparent (bulk) density	1.17

in the various gravel sizes are within the acceptable range. The apparent density of both the sand and the gravel are minimum 1.6 and 1.5 respectively. Therefore the volume that the graded aggregate will occupy in concrete, including the solid aggregate particles and the voids between them will produce good concrete at constant moisture content for each mix ratio. The Sand Equivalent (SE) is within the range of above 80% as specified in the French norms AFNOR [14], therefore it is very clean sand. The fineness modulus (FM) obtained is within the FM range of 2.2 to 2.8 therefore, the Wum road sand is suitable for construction works. **Table 2** also shows the result of sieve analysis for gravel 5/15, gravel 15/25 and gravel 5/15 + 15/25 that was carried out on as per AFNOR [12]. All the percentages passing shown in table for the various gravel sizes considered for this study are continuous. This proofs that their distributions are good for production of dense concrete.

Quantities of Materials used for the experiments

The quantity of cement for every test was 50 kg meanwhile the quantity of

Table 2. Grading vaues for Wum road sand and various gravel sizes.

Sieve designation size (mm)	Sand Percentage passing (mm)	Gravel 5/15 Percentage passing (mm)	Gravel 15/25 Percentage passing (mm)	Gravel 5/15 + 15/25 Percentage passing (mm)
25			100	100
20			56	80
15		100	0.00	56
12		64.3		28
10		35.7		5
5	100	0.00		0.00
3.15	88.95			
2.5	76.01			
1.25	61.38			
0.63	45.85			
0.315	23.73			
0.16	9.78			
0.08	5.4			
Bowl	0			
Physical Properties				
Grading	Zone II			
Specific gravity	2.65	2.77	2.75	
Apparent density	1.60	1.51	1.58	
Sand equivalent	81.8	/	/	
Fineness modulus (FM)	2.70	/	/	

water was 25 liters for every test. The batching of aggregates for the conventional mix ratio consisted of 60 liters of sand plus 120 liters of gravel in all the single size gravel cases meanwhile in the case of combination of two gravel sizes, 60 liters of gravel from the 5/15 size and also 60 liters from the 15/25 size were used. For the rationalized mix ratio, the batching 90 liters of sand and 90 liters of gravel in all single size gravel meanwhile in the case of combinations of the two gravel sizes, 45 liters of gravel from the 5/15 size and also 45 liters from the 15/25 size were used. The average slump test for the all conventional mix was 6.4 cm and for the rationalized mix it was averagely 5.1 cm. This shows that the rationalized mix ratio is less workable and requires more water as compared to the conventional mix ratio at the same water cement ratio. However, as the amount of water in a concrete mix increases, the strength decreases.

Compressive tests results of concrete

Case of 5/15 gravel

From the result in Figure 1 for gravel size 5/15, the average compressive strength of concrete for seven days of curing for concrete made of 350 kg of cement: 400 liters of sand: 800 liters of gravel mix ratio is 13.5 N/mm^2 and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel mix ratio is 12.78 N/mm^2, we can deduce that, the concrete strengths in both mix ratios met

Table 3. Quantities of Materials used for experiment for conventional mix ratio and the rational mix for each gravel size.

S/N	Material Type	5/15 gravel		15/25 gravel		5/15 + 15/25 gravel	
		Conventional	Rational	Conventional	Rational	Conventional	Rational
1	Cement (CPJ) 42.5	50 kg	50 kg	50 kg	50 kg	50 kg	50 kg
2	Sand 0/5	60 liters	90 liters	60 liters	90 liters	60 liters	90 liters
3	Gravel 5/15	120 liters	90 liters	-	-	60 liters	45 liters
4	Gravel 15/25	-	-	120 liters	90 liters	60 liters	45 liters
5	Water (w/c = 0.5)	25 liters	25 liters	25 liters	25 liters	25 liters	25 liters
6	Slump test	6.1 cm	4.8 cm	6.6 cm	5.4 cm	6.5 cm	5 cm

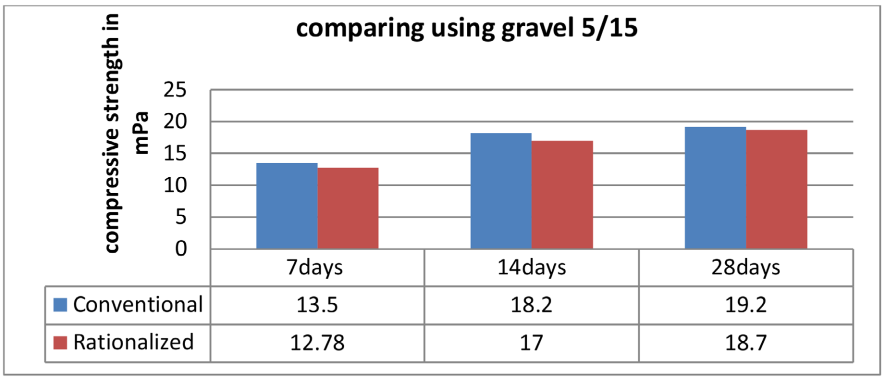
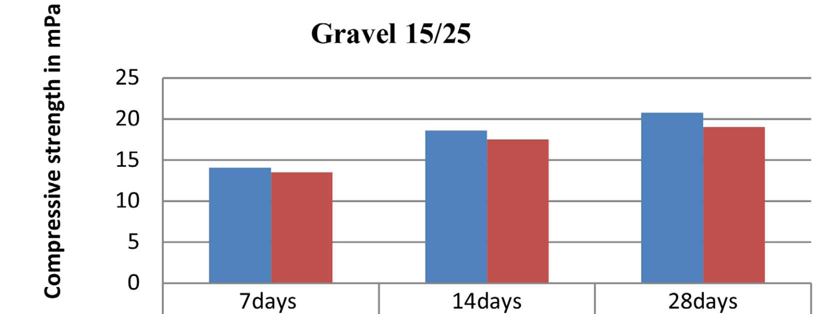


Figure 1. Comparative bar chart for gravel 5/15 showing the comparison between concrete made of mix ratio 350 kg of cement: 400 liters of sand: 800 liters of gravel and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel.

the minimum required standard for seven days of curing which is 60% - 65% of the 20 N/mm^2 cylinder strength considered in this study. The average compressive strength of concrete for 14 days of curing for concrete made of 350 kg of cement: 400 liters of sand: 800 liters of gravel mix ratio is 18.2 N/mm^2 and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel mix ratio is 17 N/mm^2, we can deduce that, the concrete strengths in both mix ratios met the minimum required standard for 14 days of curing which is 90% of 20 N/mm^2 cylinder strength. Still on **Figure 1**, the results of the average compressive strength of concrete for 28 days of curing for concrete made of 350 kg of cement: 400 liters of sand: 800 liters of gravel mix ratio is 19.2 N/mm^2 and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel mix ratio is 18.7 N/mm^2, we can deduce that, the concrete strengths in both mix ratios did not meet the minimum required standard for 28 days of curing which should be 99% of 20 N/mm^2 cylinder strength.

Case of 15/25 gravel

From the result in **Figure 2** for gravel 15/25, the average compressive strength of concrete for seven days of curing for concrete made of 350 kg of cement: 400 liters of sand: 800 liters of gravel mix ratio is 14.1 N/mm^2 and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel mix ratio is 13.5 N/mm^2, we can deduce that, the concrete strengths in both mix ratios met the minimum required standard for seven days of curing which is 60% - 65% of 20 N/mm^2 cylinder strength. The average compressive strength of concrete for 14 days of curing for concrete made of 350 kg of cement: 400 liters of sand: 800 liters of gravel mix ratio is 18.6 N/mm^2 and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel mix ratio is 17.5 N/mm^2, we can deduce that, the concrete strengths in both mix ratios met the minimum required standard for 14 days of curing which is 90% of 20 N/mm^2 cylinder strength. Again, from the result in **Figure 2** of the average compressive strength of concrete for 28 days of curing for concrete made of 350 kg of cement: 400 liters of sand: 800 liters of gravel mix ratio is 20.8 N/mm^2 and concrete made of 350 kg of cement:



	7days	14days	28days
Conventional	14.1	18.6	20.8
Rationalized	13.5	17.5	19

Figure 2. Comparative bar chart for gravel 15/25 showing the comparison between concrete made of mix ratio 350 kg of cement: 400 liters of sand: 800 liters of gravel and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel.

600 liters of sand: 600 liters of gravel mix ratio is 19 N/mm^2, we can deduce that, the concrete strength in the conventional mix ratio met the minimum required standard for 28 days of curing which should be 99% of 20 N/mm^2 cylinder strength but the rationalized mix ratio did not.

Case of mix with 5/15 + 15/25 gravel

From the result on Figure 3 for the combination of gravel 5/15 + 15/25, the average compressive strength of concrete for seven days of curing for concrete made of 350 kg of cement: 400 liters of sand: 800 liters of gravel mix ratio is 14.6 N/mm^2 and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel mix ratio is 13.8 N/mm^2, we can deduce that, the concrete strengths in both mix ratios met the minimum required standard for seven days of curing which is 60% - 65% of 20 N/mm^2 cylinder strength. The average compressive strength of concrete for 14 days of curing for concrete made of 350 kg of cement: 400 liters of sand: 800 liters of gravel mix ratio is 19 N/mm^2 and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel mix ratio is 18 N/mm^2, we can deduce that, the concrete strengths in both mix ratios met the minimum required standard for seven days of curing which is 90% of 20 N/mm^2 cylinder strength. Still on Figure 3, from the result of the average compressive strength of concrete for 28 days of curing for concrete made of 350 kg of cement: 400 liters of sand: 800 liters of gravel mix ratio is 21.9 N/mm^2 and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel mix ratio is 20 N/mm^2, we can deduce that, the concrete strengths in both mix ratios met the minimum required standard for 28 days of curing which is 20 N/mm^2 for structural concrete.

4. Conclusions

From the study, it is observed that average compressive tests result for both the conventional and the rationalized mix ratios met the minimum compressive strength at 7 days and 14 days in one case meanwhile in some cases, both did not meet the minimum required standard for 28 days of curing which is minimum

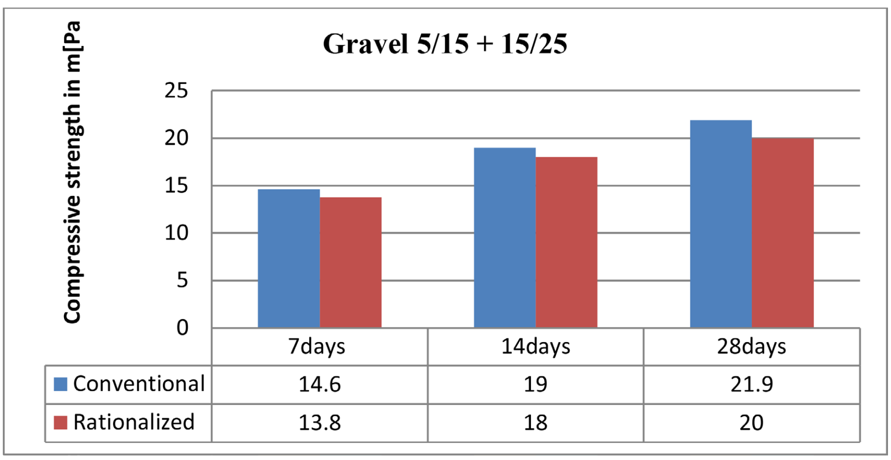


Figure 3. Comparative bar chart for gravel 5/15 + 15/25 showing the comparison between concrete made of mix ratio 350 kg of cement: 400 liters of sand: 800 liters of gravel and concrete made of 350 kg of cement: 600 liters of sand: 600 liters of gravel.

20 N/mm^2 for structural concrete for building projects. Using the 5/15 gravel size alone, resulted in strengths below 99% of the 20 N/mm^2 cylinder strength for both the conventional and the rationalized mix ratios hence leading to the conclusion that 5/15 gravel results in lower strength concrete and should not be used for rationalized concrete mix ratio except it has to be combined with larger size gravel.

When gravel size 15/25 was used alone, the cylinder strength was 20.8 N/mm^2 for the conventional mix ratio which is a good result for compressive strength. The strength of the rationalized mix ratio did not meet the minimum required standard for 28 days of curing which should be 99% of 20 N/mm^2 cylinder strength. This result also leads to the conclusion that 15/25 gravel results in lower strength concrete and should not be used for rationalized concrete mix ratio except if it has to be combined with other size aggregates.

When a combination of gravel sizes 5/15 + 15/25 was used, the result of the average compressive strength of concrete for 28 days of curing for both the conventional mix and the equal volumes of sand and gravel mix ratio met the minimum required standard for 28 days of curing. Based on this, this study arrives at the conclusion that the equal volumes of sand and gravel mix ratio of 350 kg/m^3 of cement: 600 liters of sand: 600 liters of gravel mix ratio can be adopted as a conventional mix design using a combination of 5/15 + 15/25 gravel. Therefore, in determining the compressive strength of concrete it is important to consider the mix ratio of concrete.

However, from the slump test result, the rationalized mix ratio is less workable and requires more water as compared to the conventional mix ratio at the same water cement ratio. The high fine aggregates in the rationalized mix ratio caused an increase in surface area of particles within the mixture, thereby increasing the demand for the amount of water required to coat the surfaces which will result in segregation and bleeding in the fresh state and also increased drying shrinkage and cracking in the hardened state. Further study is required in the area of mixing water in the equal volumes of sand and gravel mix ratio.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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