

Determination of Optimum Characteristics of Binary Aggregate Mixtures

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Abstract
To obtain an efficient and economic concrete mix, determination of the optimum proportions of binary aggregate mixtures of coarse and fine aggregates is necessary. This study was aimed at obtaining the appropriate percentages of binary aggregate mixtures that will yield optimum binary aggregate properties of maximum bulk density, minimum specific binary aggregate volume and minimum void ratio. Two coarse aggregate types (Granite Chippings & Gravel) and three fine aggregate types (River Dredged Sand, Granite Dust & Dolomite Dust) were selected to give six binary aggregate mixtures - Granite Chippings + River Dredged Sand, Granite Chippings + Granite Dust, Granite Chippings + Dolomite Dust, Gravel + River Dredged Sand, Gravel + Granite Dust, and Gravel + Dolomite Dust. Individual aggregate types were characterized and the binary aggregates mixtures were tested for both loosed and rodded aggregate conditions. From the study, the optimum coarse aggregate volume fraction that will give the maximum binary aggregate bulk density was determined for each binary aggregate mixture. Results of the study revealed that at the optimum coarse aggregate volume fraction, specific binary aggregate volume and void ratio were minimum for all the binary aggregate mixtures. Further analysis of the results showed that binary aggregate mixtures of Gravel produced a better mixture than binary aggregate mixtures of Crushed Granite and consequently likely better concrete mix. It is concluded that to obtain a concrete mix that is both economical and efficient in terms of strength, workability, durability and shrinkage, concrete mixes should be designed at the optimum binary coarse aggregate volume fraction obtained in this study.
Keywords: binary aggregate mixture, bulk density, specific binary aggregate volume, void ratio, coarse aggregate volume fraction

1. Introduction

Concrete is regarded as a two-phase material comprising of paste phase and aggregate phase. Paste phase consists of all cementitious and powder materials, water, all kinds of mineral and chemical admixtures and air voids, while the aggregate phase, considered to be much more in volume, consists of coarse and fine aggregates (Tangtermsirikul & Tatong, 2001). Coarse aggregate is usually greater than 4.75 mm (retained on a No. 4 sieve), while fine aggregate is less than 4.75 mm (passing the No. 4 sieve) (Mehta, 1993).
It is well established that aggregate plays an important role in concrete. Mehta (1993) reported that aggregate accounts for 60 to 80 percent of the volume and 70 to 85 percent of the weight of concrete and that although aggregate is considered an inert filler, it is a necessary component that defines the concrete’s thermal and elastic properties and dimensional stability.

Aggregate is such important matter in concrete that maximum properties and workability of concrete are directly changed with the properties of aggregates. The overall or mechanical properties of concrete depends on certain properties of aggregates like source of aggregates, normal or light or heavy weight aggregate, size of aggregate, shape of aggregate, crushing type of aggregates, angularity index, surface texture, modulus of elasticity, bulk density, specific gravity, absorption and moisture content, bulking of aggregates, cleanliness, soundness of aggregates, thermal properties and grading of aggregates (Muhit et al., 2013).
Coarse aggregate content is known to strongly influence both fresh and hardened concrete’s properties and selection of content of aggregate for concrete mixture is an important issue regarding the predicted performance of concrete (Mohammed et al., 2012). According to Thomas and Jennings (2008), if the packing of the aggregate particles is too dense, then the cement paste cannot coat the particles uniformly and the workability will be poor. But to keep the cost of the concrete down, the mix design should call for as much aggregate (i.e., as little cement) as possible. However, it is possible to be too efficient with the aggregate grading. Therefore, a determination of the optimum content of coarse aggregate is necessary in order to obtain an efficient mix as per specific design requirements.
According to Mohammed et al. (2012), estimation of the void ratio of concretes can provide tools to improve the performance of fresh and hardened concrete by reducing the content of free water and cement and maximizing the amount of solids (Mohammed et al, 2012). Also, minimum void will require minimum paste and this will mean less cement and less quantity of water, which will further mean increase in economy, higher strength, lower shrinkage and greater durability (Shetty, 2005)
From experiments conducted by Tasdemir and Karihaloo (2001), it was discovered that compressive strength

decreases with an increase in the aggregate volume fraction up to a value of 0.5, and remains practically constant at higher values. Therefore, determination of the minimum specific aggregate volume is necessary in concrete production if the maximum possible compressive strength is to be achieved.
As reported by Darwin (1995), there is strong evidence that aggregate type is a factor that influences the properties of concrete. Ezeldin and Aitcin (1991) compared concretes with the same mix proportions containing four different coarse aggregate types. They concluded that, in high-strength concretes, higher strength coarse aggregates typically yield higher compressive strengths, while in normal-strength concrete, coarse aggregate strength has little effect on compressive strength.
Optimization of the composition of the aggregate material in concrete is beneficial with respect to economy (low cement content), strength and durability (Mohammed et al, 2012). To predict the behaviour of concrete and optimize the composition of its constituents requires an understanding of the effects of aggregate type, aggregate size, and aggregate content (Kajul and Darwin, 1997).
In this study, two types of coarse aggregate and three types of fine aggregate were studied for the purpose of obtaining the best binary combination of the different types of coarse and fine aggregates under study. The study is aimed at improving the understanding of the role of aggregates composition and packing in concrete and involves determination of the appropriate percentages and proportions in the mixing of different available fine aggregates and coarse aggregates (binary aggregate mixtures) that will give the maximum bulk density, minimum specific aggregate volume and the minimum void ratio.

2. Materials and Methods

In carrying out this study, different coarse and fine aggregate types were selected and relevant properties of the aggregates were determined. This was done for the purpose of characterization of the materials used. Tests were conducted and the results analysed to determine the optimum coarse aggregate content, the minimum specific aggregate volume and the minimum void ratio of all possible combinations of binary aggregate mixtures of the coarse and fine aggregates.

2.1 Materials

The materials used for the study include two coarse aggregate types and three fine aggregate types. The coarse aggregates types were Crushed Granite (Granite Chippings) and Gravel while the fine aggregates included River Dredged Sand, Granite Dust and Dolomite Dust. These materials were selected for the study because they are the most commonly used type of aggregates in concrete production (Edward, 2008).

2.2 Test on Aggregates

Tests were carried out to characterize the aggregates. Tests conducted were particle size distribution, specific gravity, bulk density, void ratio and moisture content tests. The tests were carried out in accordance with BS EN 12620:2013. Whereas Particle Size Distribution of aggregates affect relative aggregate proportions, the bulk density of aggregate influences its void ratio and the higher the bulk density, the lower the void ratio that needs to be filled by the fine aggregate and cement (Edward, 2008; Shetty, 2005). The specific gravity of aggregate is also important when dealing with both lightweight and heavyweight aggregates and the determination of the moisture content in coarse and fine aggregates is important as aggregate will absorb additional moisture based on its natural moisture content.

Characterization of aggregates ensures that aggregates conform to minimum specification criteria and also permits equitable comparison amongst different aggregates (Alexander & Mindess, 2005). Thus, characterization of the aggregates will allow for proper selection of aggregate and application of results obtained from this study.

2.3 Test on Binary Aggregate Mixtures

An investigation into the binary aggregate behaviour was carried out. The relationship between binary aggregate bulk density and the coarse aggregate volume fraction was analysed. Also, relationship between binary aggregate specific volume and coarse aggregate volume fraction at maximum bulk density; and the void ratio of the binary aggregate and coarse aggregate volume fraction at maximum density were studied. This was for the purpose of obtaining the coarse aggregate fraction that will give the desired binary aggregate mixture property.
Tests were conducted on loosed and rodded cases of binary aggregate mixtures of the fine and coarse aggregates under study. The binary aggregate mixtures tested were: i) Crushed Granite + River Dredged Sand ii) Crushed Granite + Granite Dust iii) Crushed Granite + Dolomite Dust iv) Gravel + River Dredged Sand v) Gravel + Granite Dust vi) Gravel + Dolomite Dust.

3. Results and Discussions

3.1 Characteristics of Aggregates

3.1.1 Particle Size Distribution of Aggregates

Figure 1 shows the Particle Size Distribution curves for the aggregates. From the curves, it is observed that the coarse aggregates have finess modulus of 2.9 for crushed granite and 5.0 for gravel and that gravel has a cumulative percentage passing sieve 600μm of 40%. Finess modulus & percentage passing 600μm sieve for River Dredged Sand, Granite Dust and Dolomite Dust were respectively 4.53 & 67%, 6.69 & 35%, and 6.45 & 27.35%. Whereas gravel and all three fine aggregates samples were well graded, Particle Size Distribution curve for Crushed Granite indicated a more or less single sized grade.

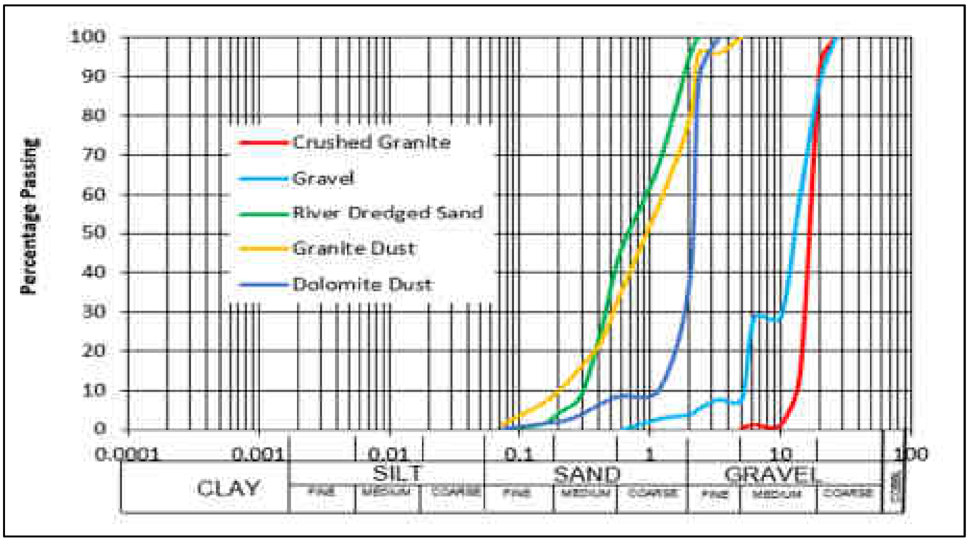

Figure 1: Particle size distribution curves of aggregates

3.1.2 Moisture Content of Aggregates

Results of moisture content of the aggregates are presented in Table 1. The highest value of moisture content was recorded for granite dust with a moisture content of 41%. While the lowest value of moisture content was recorded for dolomite dust with a moisture content of 30%.

Table1: Moisture Content of Aggregates

Aggregate	**Coarse Aggregate**		**Fine Aggregate**		
	Crushed Granite	Gravel	River Dredged Sand	Granite Dust	Dolomite Dust
Moisture Content (%)	31.00	40.00	37.00	41.00	30.00

3.1.3 Specific Gravity of Aggregates

Results of specific gravity for aggregates tested is presented in Table 2. Dolomite dust gave the highest specific gravity of 2.83 which can be attributed to its crystalline nature. River Dredged Sand had the lowest value with a specific gravity of 2.59.

Table 2: Specific Gravity of Aggregates

Aggregate	**Coarse Aggregate**		**Fine Aggregate**		
	Crushed Granite	Gravel	River Dredged Sand	Granite Dust	Dolomite Dust
Specific Gravity	2.69	2.61	2.59	2.65	2.83

3.1.4 Bulk Density and Void Ratio of Aggregates

Bulk density and void ratio were determined for loosed and rodded cases of all aggregates and the results are presented in Table 3. Bulk density results for the coarse aggregates indicate that for loosed case, gravel had a higher bulk density value than granite chippings. But for the rodded case, gravel had a lower bulk density value. For the fine aggregates, the bulk density of River Dredged Sand and Dolomite Dust were the same for both loosed and rodded conditions. This can be attributed to the similarity in the grading of both aggregates. It was also observed that aggregates with better grading gave higher values of bulk densities for both loosed and rodded test conditions.

Results of void ratio of the aggregates showed that aggregates with higher bulk density tend to have lower void ratios. This is in line with the findings of Edward (2008) and Shetty (2005). Also, Void ratio for loosed aggregates were higher than respective void ratio values for rodded aggregates.

Table 3: Bulk Density and Void Ratio of Aggregates

Aggregate	Bulk Density		Void ratio	
	Loosed	Rodded	Loosed	Rodded
Granite Chippings	1.34	1.72	0.50	0.36
Gravel	1.38	1.55	0.47	0.41
River Dredged Sand	1.38	1.52	0.47	0.41
Granite Dust	1.31	1.52	0.51	0.41
Dolomite Dust	1.38	1.52	0.51	0.41

3.2 Optimization of Binary Aggregate Mixture

3.2.1 Optimum Coarse Aggregate Fraction of Binary Aggregate Mixture

The variation of bulk density with coarse aggregate volume fraction was studied for all combinations of coarse and fine aggregates under study. Figures 2a and 2b show the graph of bulk density against coarse aggregate volume fraction for loosed and rodded cases. The graphs were concave downwards with a local maxima. The coarse aggregate fraction corresponding to the local maxima of the curves represents the optimum coarse aggregate volume fraction as it occurs at the maximum bulk density recorded.

From the results, the binary mixture of Gravel + Granite Dust gave the highest bulk density of 2.40g/cm^3 at a coarse aggregate fraction of 0.55 when rodded. For the loosed case, the binary mixture of Gravel + River Dredged Sand gave the highest bulk density with a value of 2.30g/cm^3 at a coarse aggregate fraction of 0.51. The maximum bulk densities for the rodded aggregates were higher than respective values for loosed aggregates except for the binary mixture of Gravel + River Dredged Sand.

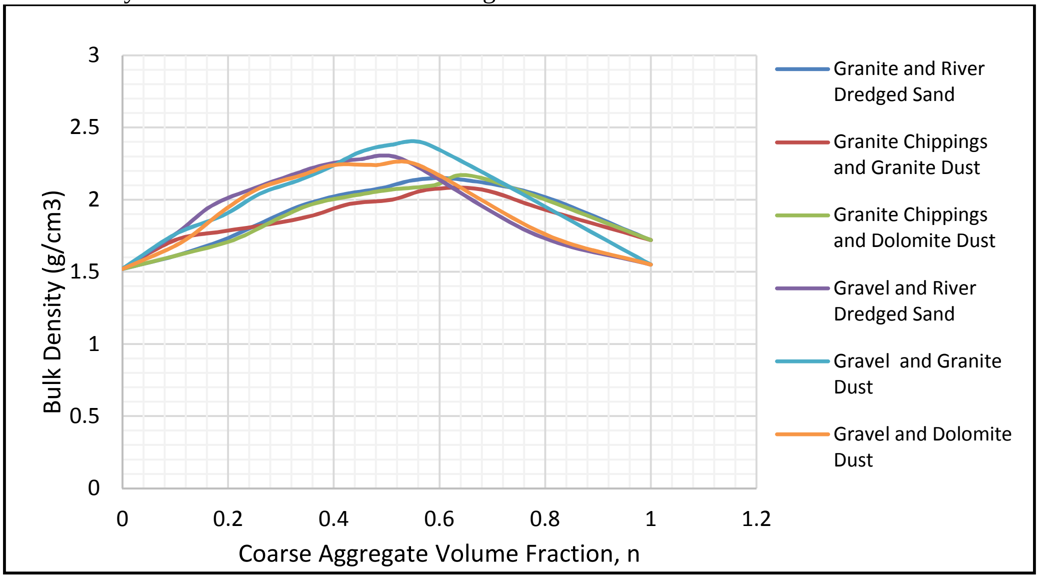

Figure 2a: Graph of Bulk Density against Coarse Aggregate Volume Fraction for Rodded Binary Aggregate Mixtures

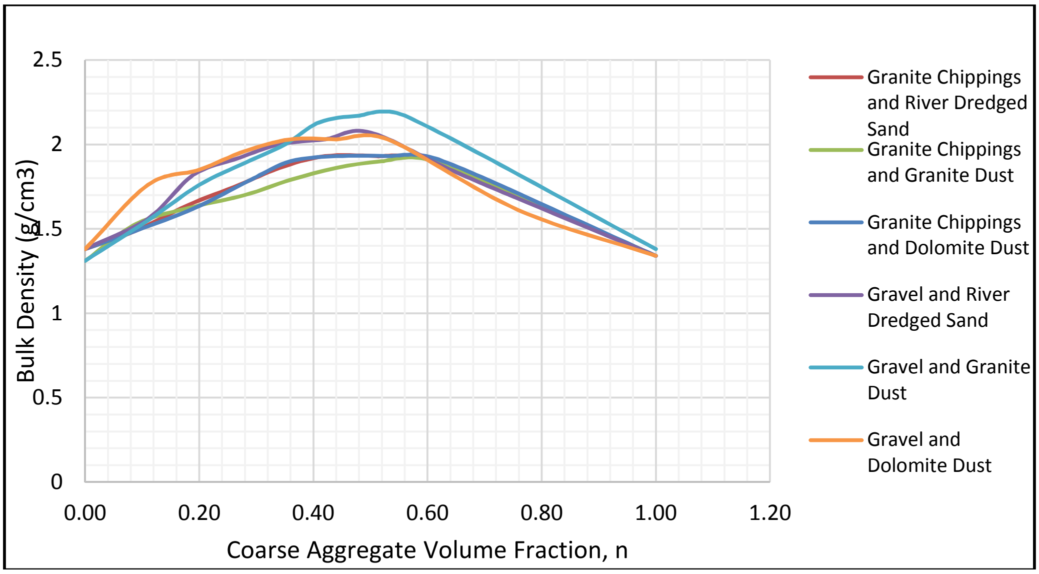

Figure 2b: Graph of Bulk Density against Coarse Aggregate Volume Fraction for Loosed Binary Aggregate Mixtures

3.2.2 Specific Binary Aggregate Volume

Haven obtained the optimum coarse aggregate fraction for the different binary aggregate mixtures, the specific aggregate volume was determined and plotted against the coarse aggregate fraction. The results are presented in Figures 3a and 3b. It was observed that the graphs were 'U'- shaped (concave upwards) each having a local minimum which represents the minimum specific aggregate volume.

It was also observed that the specific aggregate volume fraction values obtained were minimum at the optimum coarse aggregate fraction obtained earlier. Therefore, binary aggregate mixtures have maximum density at minimum specific aggregate volume. The minimum specific aggregate volume was highest for the binary mixture of Granite Chippings + Granite Dust for the loosed case with a specific aggregate volume of 0.53. For the rodded aggregate case, minimum specific aggregate volume was highest for the binary mixture of Granite Chippings + River Dredged Sand with a specific aggregate volume of 0.49.

The binary aggregate mixture of Gravel + River Dredged Sand gave the lowest value of minimum specific binary aggregate volume with a value of 0.46, while the binary mixture of Gravel + Granite Dust gave the lowest value of minimum specific binary aggregate volume with a value of 0.42. Minimum specific aggregate volume for the loose aggregates were higher than respective values for the rodded aggregate.

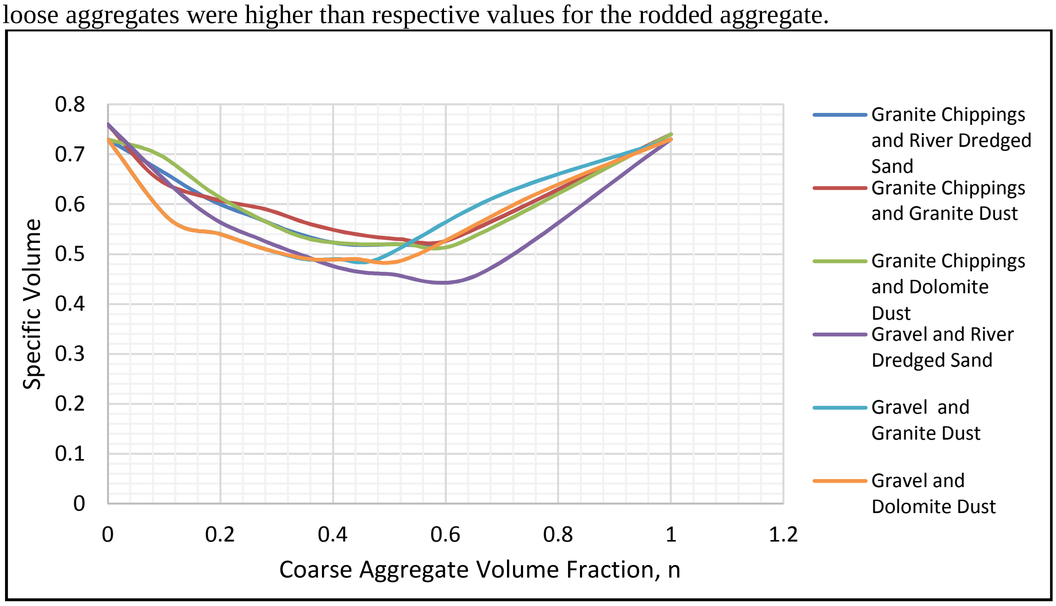

Figure 3a: Graph of Specific Binary Aggregate Volume against Coarse Aggregate Volume Fraction for Loosed Binary Aggregate Mixtures

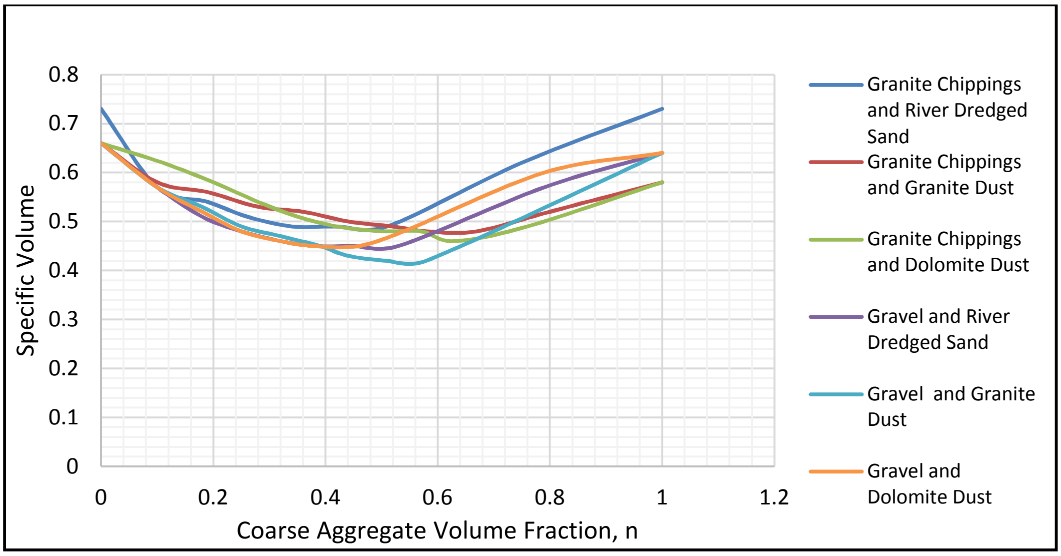

Figure 3b: Graph of Specific Binary Aggregate Volume against Coarse Aggregate Volume Fraction for Rodded Binary Aggregate Mixtures

3.2.3 Minimum Binary Aggregate Void Ratio

As for the specific aggregate volume, a graph of void ratio of binary aggregate mixture was plotted against coarse aggregate volume fraction for all binary aggregate mixtures (Figures 4a and 4b). The graphs were also 'U'-shaped (i.e. concave upwards) with local maxima corresponding to the minimum void ratios of the binary aggregate mixtures. From the graph, it was observed that void ratio is minimum at optimum coarse aggregate volume fraction.

For the loosed aggregates, minimum void ratio was highest for the binary mixture of Granite Dust + Dolomite Dust with a value of 0.38 and lowest for the binary mixture of Gravel + Granite Dust with a value of 0.20. The curves for Gravel + River Dredged Sand and Gravel + Granite Dust overlapped, indicating that both binary mixtures have the same void ratio for a particular coarse aggregate volume fraction. For the rodded case, the minimum void ratio was highest with a value of 0.28 for the Crushed Granite + Granite Dust binary aggregate mixture and lowest with a value as low as 0.10 which was recorded for the Gravel + Granite Dust binary aggregate mixture.

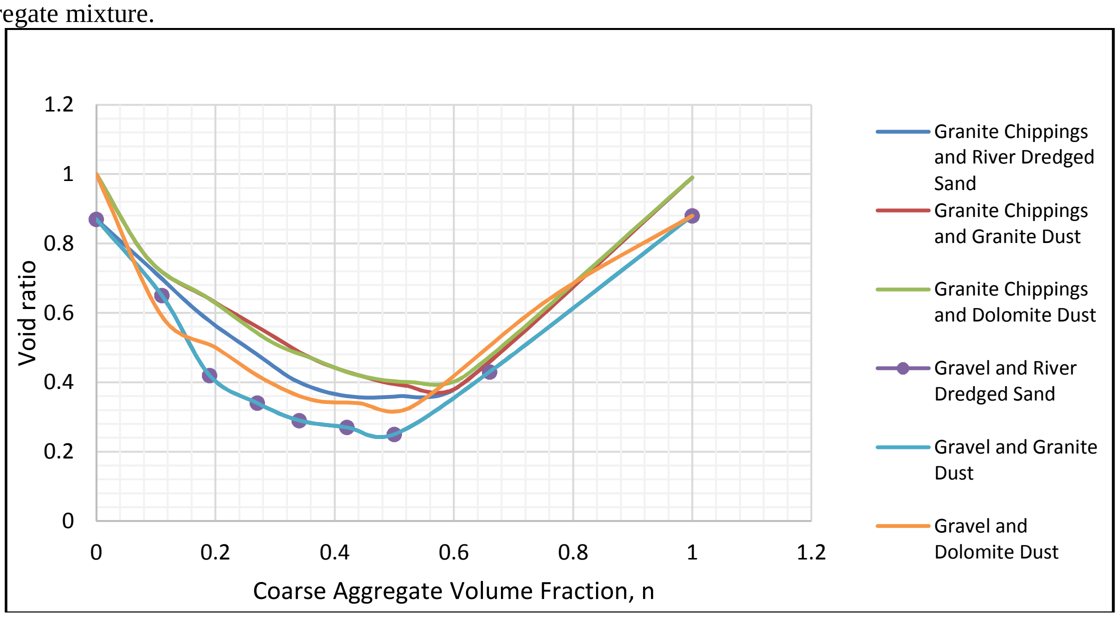

Figure 4a: Graph of Void Ratio against Coarse Aggregate Volume Fraction for Loosed Binary Aggregate Mixtures

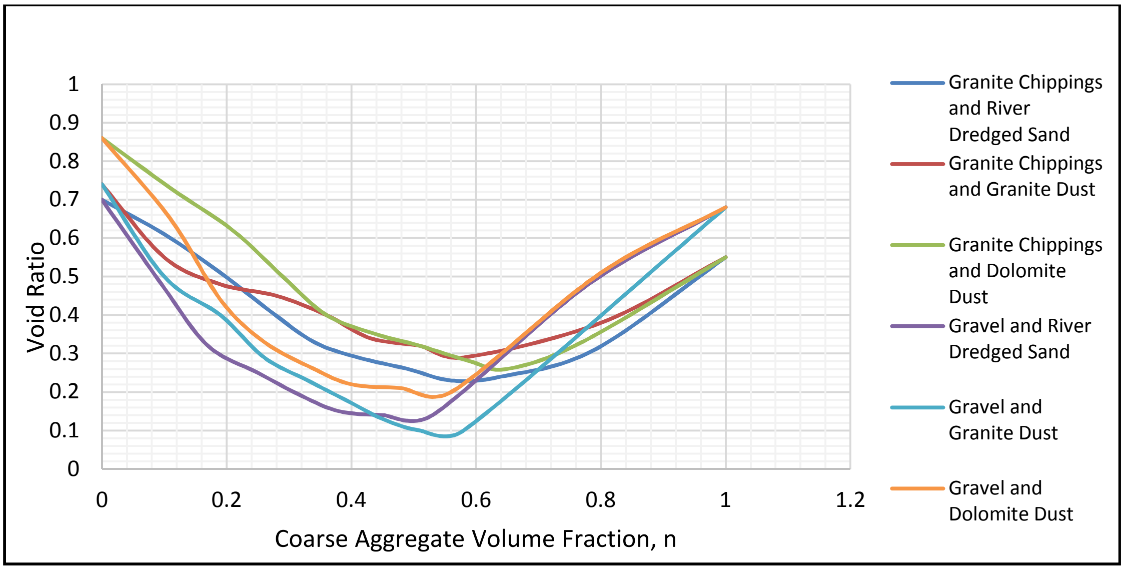

Figure 4b: Graph of Void Ratio against Coarse Aggregate Volume Fraction for Rodded Binary Aggregate Mixtures

Table 4 presents a summary of optimum coarse aggregate fraction that will yield maximum bulk density, minimum void ratio and minimum specific aggregate volume for the binary aggregate mixtures. Table 4 also show at a glance which binary aggregate performs better in terms of having the highest maximum bulk density, the lowest minimum specific binary aggregate volume and the lowest minimum void ratio. From the results, it was observed that binary mixtures of gravel are better than respective binary mixtures of granite chippings in this regard.

Table 4: Optimum Coarse Aggregate Fraction for Maximum Bulk Density, Minimum Specific Binary Aggregate Volume and Minimum Void Ratio

Binary Aggregate Mixture	**Optimum Coarse Aggregate Volume Fraction (n)**		**Optimum Coarse Aggregate Weight Fraction (N)**		**Maximum Bulk Density (g/cm^3)**		**Minimum Specific Binary Aggregate Volume, (cm^3/g)**		**Minimum Void Ratio (μ)**	
	Loose d	Rodde d	Loose d	Rodde d	Loose d	Rodde d	Loose d	Rodde d	Loose d	Rodde d
Crushed Granite + River Dredged Sand	0.46	0.56	0.46	0.69	1.95	2.16	0.51	0.46	0.35	0.23
Crushed Granite + Granite Dust	0.57	0.66	0.64	0.72	1.93	2.09	0.56	0.50	0.37	0.28
Crushed Granite + Dolomite Dust	0.55	0.65	0.46	0.64	1.96	2.16	0.61	0.55	0.38	0.26
Gravel + River Dredged Sand	0.55	0.56	0.50	0.56	2.09	2.30	0.48	0.41#	0.20¤	0.09¤
Gravel + Granite Dust	0.55	0.56	0.50	0.56	2.19	2.40*	0.44#	0.41#	0.20¤	0.09¤
Gravel + Dolomite Dust	0.53	0.56	0.44	0.50	2.40*	2.31	0.48	0.43	0.33	0.20

*Highest maximum bulk density; #Lowest minimum specific binary aggregate volume; ¤Lowest minimum void ratio

4. Conclusion

Properties of binary aggregate mixtures for optimum combination of its constituent was studied and the fraction of coarse aggregate required was determined.

From the study, the coarse aggregate fraction of binary aggregate mixtures that will give the maximum bulk density was determined. This represents the optimum percentage or fraction of coarse aggregate in the binary aggregate mixture.

From the graph of specific binary aggregate volume against coarse aggregate volume fraction and graph of void ratio against coarse aggregate volume fraction, it can be concluded that void ratio and specific binary aggregate volume of binary aggregate mixtures are minimum at the optimum coarse aggregate fraction. This further validates values of coarse aggregate fraction that yields maximum bulk density as the optimum coarse aggregate fraction in binary aggregate mixtures. Therefore, concrete manufactured at this optimum value will possess less free water and cement and maximize the amount of solids. The concrete will also require minimum paste and this will mean less cement and less quantity of water, which will further mean increase in economy, higher strength, lower shrinkage and greater durability.

The study also revealed that the better the grading of aggregates, the higher their bulk densities. Hence, well graded aggregates should be used as much as possible in binary aggregate mixtures for the manufacture of concrete so as utilize fully the optimum characteristics of the binary aggregate mixtures.

From the study, binary aggregate mixtures of gravel were found to have higher maximum bulk densities, lower minimum specific binary aggregate volume and lower minimum void ratio compared to binary aggregate mixtures of Crushed Granite (Granite chippings), and hence will produce concrete with better relative characteristics.

This study is limited to the study of properties binary aggregate properties of different binary aggregate mixtures and based on previous studies of how these properties affect concrete, optimum binary aggregate properties for best possible concrete were determined. However, further research on the properties of concrete manufactured at the optimum binary aggregate properties determined from this study is necessary to explain in detail the variation in the properties performance of concrete among different binary aggregate mixtures.

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