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Research Paper

Evaluation of variations of coarse aggregate types on hardened properties of concrete

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ABSTRACT

Variation in coarse aggregate types, shapes, textures and means of production are known to have a profound effect on mechanical properties of concrete such as compressive and flexural strengths. Two coarse aggregates; uncrushed gravel (UG) and crushed granite (CG) were used as coarse aggregates. Coarse aggregates were partially replaced with crushed granite at the incremental rate of 20% by weight of total coarse aggregate from 0% to 100%. Mix proportion of 1:2:4 and the water-cement ratio of 0.65 were used. The concrete design targeted compressive strength of 20Mpa on the 28th day. Aggregate Crushing Value (ACV) test was conducted on various coarse aggregate combinations. Compressive strength and modulus of rupture were determined at various mix proportion of concrete containing different per-cent of coarse aggregates replacements at curing ages; 7th, 14th, and 28th days. Across curing ages, an increase in percent of crushed granite lead to an increase in compressive strength (CS) and modulus of rupture (MOR). Statistical analysis established strong positive relationship between percent of CG replacement and CS at 28th day (R^2 = 0.908 & $p < 0.01$), between percent of CG replacement and MOR at 28th day (R^2 = 0.832 & $p < 0.05$), and between CS at 28th day and MOR at 28th day for different mix proportions (R^2 = 0.878 & $p < 0.01$).

1 Introduction

Arguably aggregates are the most important constituents of conventional concrete and they occupied between 70-80% by volume of conventional concrete [1]. The strength and durability of coarse aggregates is a function of their physio-mechanical properties [2]. There is no doubt that aggregates have profound effects on mechanical, fresh and durability properties of concrete [3]. Variations in coarse aggregate types could lead to variation in mechanical properties of concrete, this is because the types of coarse aggregate greatly influenced strength development in high strength concrete [3]. Coarse aggregates are of utmost importance in the production of normal-strength concrete (NSC) because they provide robustness, durability and strength to concrete [1]. Mechanical properties of concrete as well as its functionality depend largely on the

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quality of constituent materials, their properties and mix proportion. Properties of constituent materials are of importance to strength in concretes. These properties defined the development of short and long-time strengths development in concretes. Mechanical properties such as compaction, grading of coarse aggregate, shapes, cement types, water-cement ratio etc. are of importance for structural concrete designers.

In a normal-strength concrete (NSC), the role of the sizes of coarse aggregates in strength development is insignificant compare to that of high-strength concrete but other features of the coarse aggregates such as textures and shapes might contribute significantly to strength development [1, 3, 4]. However, as the water-cement ratio increases from 0.4, the influence of shapes, sizes and textures of aggregates on workability and strength diminish [1, 5, 6]. High- performance concrete with larger maximum size aggregates developed greater propagation of micro-cracks compare to lower maximum size aggregate and vice-versa [7]. Small sizes of coarse aggregates significantly aid the development of compressive strength and caused a reduction in water permeability of the concrete, hence help in the development of better compressive strength and durability of concrete [8]. Concretes with larger coarse aggregates sizes make concrete appeared nonhomogeneous and they also have a lower surface area that tends to lead to the formation of lower bonding force or formation of gel which is responsible for the development of lower strengths [1, 2].

According to Shetty [1], coarse aggregate with rough texture/surface provides better strength through bonding of rough edges than the coarse aggregates with smooth surfaces. Rounded shape coarse aggregates are known practically to form weaker interlock at the interface of cement paste and coarse aggregate phase compare to that of angular and cubical shaped coarse aggregates. Textures and shapes depend largely on rock hardness, grain size, the porosity of the aggregate, crushing method and previous exposure. These properties not only affect the strength development, but it also affects workability, economy, pump-ability, paste demand [1]. For strength development, angular aggregates are more preferable to rounded aggregate for one of these reasons or both; angular aggregates provide a better interlocking effect in concrete and angular aggregate show better bond [1, 2]. Aggregates shapes, textures and sizes become more critical parameters for strength, durability, low water permeability in high-strength and high -performance concrete [1].

Hardened properties of concrete such as compressive, splitting tensile and flexural strengths as well as electrical resistivity of concrete samples made with different coarse aggregate types such as Diabase, Dolomite, Dolomitic limestone, high absorption limestone, Micritic limestone, Granite, Granitic gneiss, siliceous gravel, marble, Meta-basalt, and quartz and sandstone were investigated [9]. Piasta et al. [10] compared the mechanical properties of concrete made with crushed aggregates with that of concrete gravel. Mechanical properties, as well as durability of self-compacting concretes with two different coarse aggregate types i.e. crushed granite and sea dredged gravel were studied and compared [11].

In principle, previous researchers on the subject matter did not base their assessment or evaluation of strength pattern on systemic variations of coarse aggregate types [9, 10, 12-14] but while they did base it on systemic variations, the economic benefits of variations of granite and gravel in concrete production was assessed or only the compressive strength was studied [15, 16].

Mechanical properties such as compressive, flexural strengths of hardened concrete can be influenced by variations in coarse aggregate types. Economically, aggregates are cheapest compare to other constituent materials of concrete, and they provide volume stability, better durability compares to cement paste. A 4% cost saving per volume of concrete is realizable when a gravel/granite combination of 60/40 percent with a mix proportion of 1:2:4 (cement: fine aggregate: coarse aggregate) and the water-cement ratio of 0.62 were used for compressive strength of 21.15N/mm^2 at 28-days curing age [15].

This research study involved systemic variations of coarse aggregates (uncrushed gravel and crushed granite) with uncrushed gravel as a base material for coarse aggregate. The main objectives of this research study were to evaluate the resistance of coarse aggregates (uncrushed gravel and/or crushed granite) to crushing, compressive and flexural strengths of concrete containing varying percent of crushed granite as well as correlating these parameters.

2 Materials and methodology

2.1 Materials

For this research work, materials used are coarse aggregates, CA (i.e. uncrushed gravel, crushed granite), ordinary Portland cement, fine aggregate (sharp sand).

Uncrushed gravel (UG) was locally sourced from naturally pit-run gravel at Oke Oja, Shao, Moro local government of Kwara state. Visual inspection showed that majority of the aggregates are smooth textured, flaky in shape and dark brown after sieving. UG is a product of sedimentation of hard rock through weathering and or erosion.

Table 1 – Physical and mechanical properties of cement (CEM I)

Specific gravity	Initial setting times	Final setting times	Compressive Strength at 28days
3.1	117 mins*	258 mins*	42 Mpa

*Joel & Mbapuun [17]

Table 2 – Chemical property/Oxides compositions of cement (CEM I)

CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	Pb_2O_5	TiO_2	MnO	Cl	LOI
61.76	20.62	5.35	3.07	1.93	1.52	1.03	0.20	0.13	0.12	0.04	0.13	3.47

Table 3 – Physical properties of aggregates

	Specific Gravity	Water absorption %	F.M	Maximum size (mm)	ACV
CG	3.15	0.34	4.5	20	13
UG	2.78	1.02	4.1	20	22
FA	2.52	1.5	2.4	4.75	-

The crushed granite (CG) used for this research was locally sourced from kam quarry at Ilorin west local government of Kwara state. Visual inspection showed that CG is greyish, rough-textured and angular (some are cubical and irregular) in shape. Both CG and UG were washed to remove clay lump and other deleterious materials. The aggregates were then sun-dried for two days before been sieved.

CEM I is a locally produced ordinary Portland cement. It has a strength grade of 42.5 and locally called Dangote 42.5R.

Fine aggregates (FA) or sharp sand used for this research was sourced from Busamu river in Moro local government area of Kwara State, sun-dried for days.

The concrete mix was prepared using batching by weight method. The mix proportion is as presented in Table 4

Table 4 – Concrete mix proportion (kg/m^3)

			CA (= CG + UG)		
Denote	CEM1	FA	CG	UG	W/C
M1	343	686	0(0%)	1372(100%)	0.65
M2	343	686	274.4(20%)	1097.6(80%)	0.65
M3	343	686	548.8(40%)	823.2(60%)	0.65
M4	343	686	823.2(60%)	548.8(40%)	0.65
M5	343	686	1097.6(80%)	274.4(20%)	0.65
M6	343	686	1372(100%)	0(0%)	0.65

2.2 Methods

The tests include aggregate crushing value (ACV), compressive strength and modulus of rupture carried out as stipulated in British standard codes of practice.

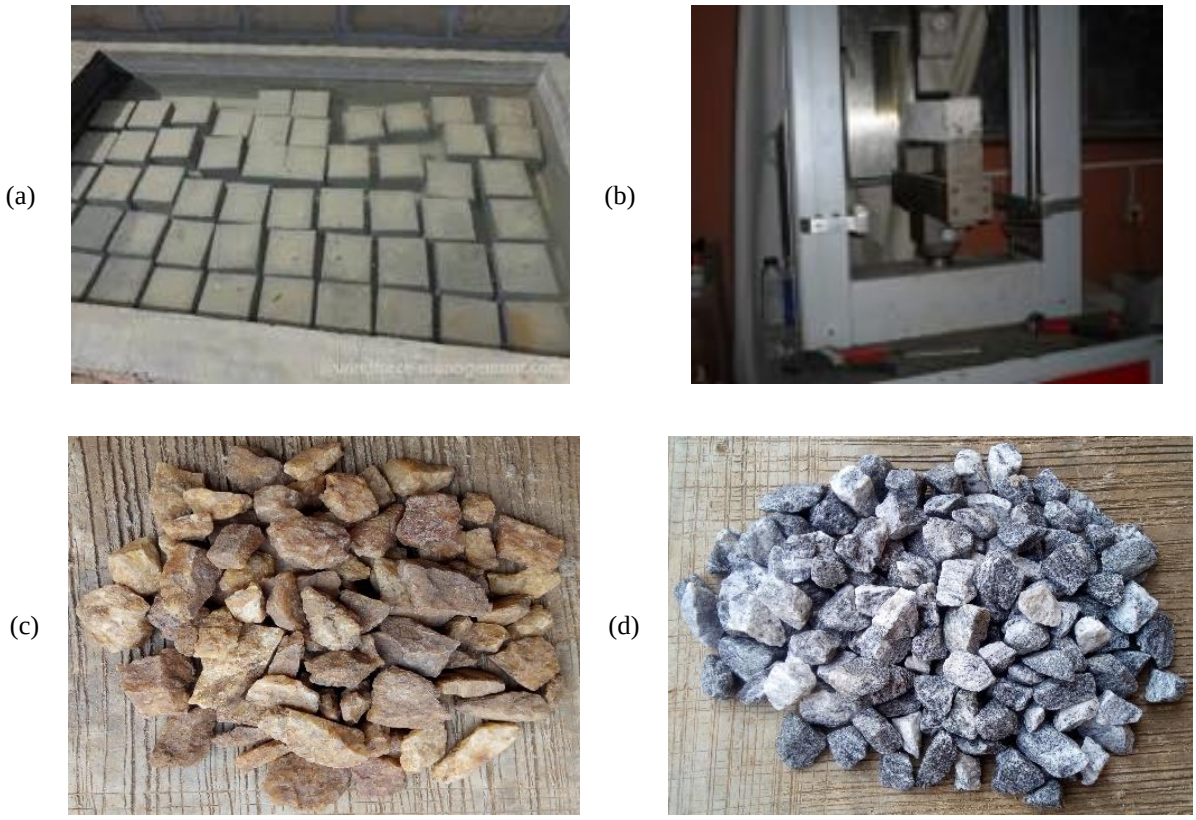


Fig. 1 – (a) Concrete cubes inside curing water (b) flexural test (c) uncrushed gravel (UG) (d) crushed granite (CG)

2.2.1 Aggregate crushing value (ACV)

This test evaluates the strength of the coarse aggregate and it is used in determining relatively the strength and resistance of a coarse aggregate to crushing compressive load. ACV is used to determine the suitability of coarse aggregate for concrete work and road construction. ACV test was carried out on coarse aggregate containing crushed granite (CG); 0%, 20%, 40%, 60%, 80% and 100% of the total weight of coarse aggregate. Crushed granite and uncrushed gravel were separately sieved, weighed, thoroughly mixed and added as mentioned above. The test was carried out in accordance with the procedure presented in BS 812-110 [18].

2.2.2 Compressive strength test

Compressive test is the most commonly carried out on hardened concrete since it has desirable characteristic properties of concrete related to its compressive properties and structural engineer designed concrete structures based on this key design parameter. A 150mm cube mould was used for this purpose. This test was carried out for different mix proportions. The freshly prepared concrete samples were stored and water cured for 28 days and tested for compressive strength at 7th, 14th, 28th days as per BS 1881-116 [19].

2.2.3 Modulus of rupture or flexural strength test

Modulus of rupture (MOR) or Flexural strength measures the ability of materials to resist bending loads. A beam mould of 100 × 100 × 500 mm^3 was used for this purpose. MOR of concrete containing different percent of CG was determined after the concrete samples were stored and water cured for 28 days and the flexural strength test conducted at 7th, 14th, 28th days. The test procedure is as laid out in BS 1881-118 [20].

The current research study considered only the normal strength concrete (NSC) and it involved only two types of coarse aggregates; crushed granite sourced from the local quarry and uncrushed gravel sourced from naturally run pit.

3 Results and discussions

This section will be divided into two. The first will deal with aggregate crushing value (ACV) and hardened properties of concrete containing crushed granite in different variations while the second section will deal with correlations between hardened properties and percent of crushed granite replacement on one hand and correlations between hardened properties on the other hand.

3.1 Hardened properties of concrete

Under this section, results from ACV will be discussed along with compressive strength and modulus of rupture results.

3.1.1 Aggregate crushing value (ACV)

Table 5 shows that as the percentage of crushed granite replacement increases, the ACV decreases. The higher percent of crushed granite replacement translates to lower ACV while the higher percent of uncrushed gravel translates to higher ACV and vice versa. Lower ACV indicates better compressive strengths for the coarse aggregate and vice versa.

Table 5 – Percent of crushed granite replacement versus Aggregate Crushing Value (ACV)

% of Crushed Granite Replacement	0%	20%	40%	60%	80%	100%
Aggregate Crushing Value (ACV)	22	20	18	17	15	13

By formation, gravel is majorly sourced from loose sediments of fluvial, lacustrine etc. [3]. Granite is formed from hard rock such as igneous rock while gravel is formed from unconsolidated sediments. Granite has higher crushing compressive strength compare to gravel as such gravel aggregates are inherently weak compare to granite [1, 10, 14]. Aggregates with ACV value of 10% are considered very strong while ACV of 10 – 20% are considered strong and ACV of 20 – 30% are just good enough for road concrete work [21, 22].

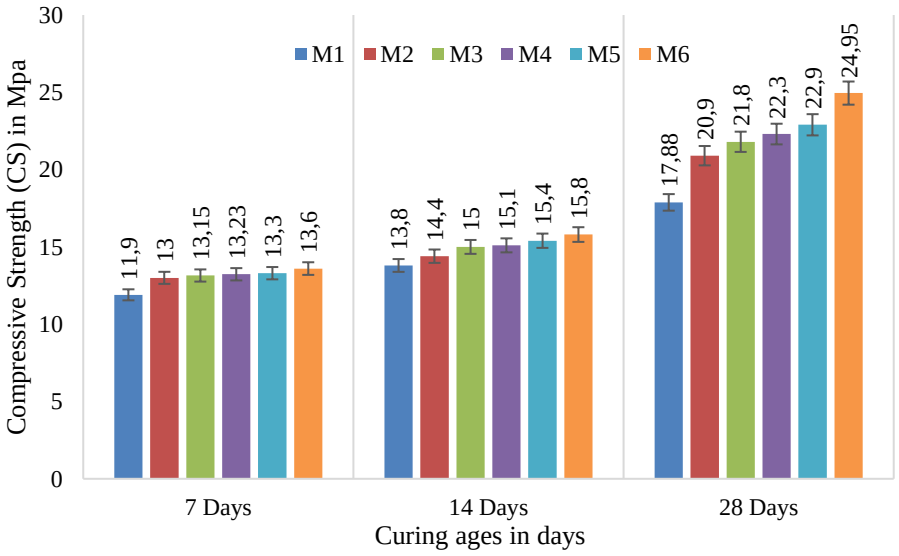


Fig. 2 – Compressive strength (CS) in MPa for different mix proportions and curing ages

3.1.2 Compressive strength (CS)

As shown in Figure 2, it is observed that across all curing ages, concrete with a higher percent of crushed granite replacement have higher compressive strength and concrete with a higher percent of uncrushed gravel replacement have lower compressive strength and compressive strength also increases with curing ages for all mix proportions. Only concrete samples denoted with M2 – M6 meet our targeted characteristics strength of 20 Mpa at 28 days curing age.

The rough texture and angular shape of granite lead to the formation of stronger bond and better interlocking strength between coarse aggregate phase and cement-mortar paste. However, the marginal difference in strengths is due to high w/c ratio of 0.65 [1]. The direct cause of mechanical deformation or failure in the concrete is not due to the resistance of coarse aggregates to crushing (i.e. ACV of the coarse aggregate) but the texture and the shape of coarse aggregates because the strengths of coarse aggregates and cement-mortar paste are well above the strength of normal strength concrete (NSC) [1-3].

3.1.3 Modulus of rupture (MOR)

Figure 3 shows the modulus of rupture, as percent of CG increases, so does the flexural strength increase.

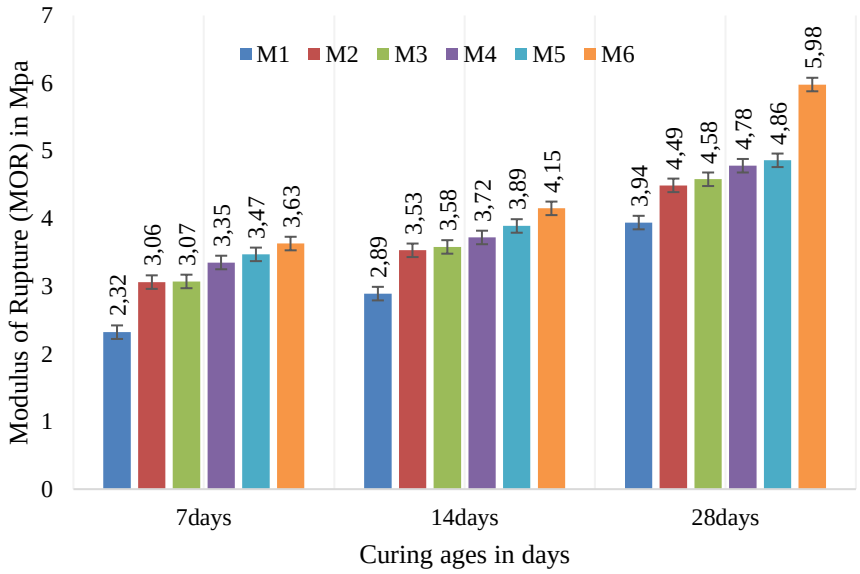


Fig. 3 – Modulus of rupture (MOR) in MPa for different mix proportions and curing ages

It can be seen from Figure 3 that for each curing age, concrete mixes with more crushed granite possess higher strength in comparison to concrete with lower crushed granite. For early curing day, the marginal differences are very small compare to other curing ages due to high w/c (=0.65) and lower strength contribution from shape and texture of the crushed granite. The cause of an increase in flexural strength is because of the rough texture and angular shape of granite aggregates, which increase leads to increase in flexural strength. The mechanical deformation and failure of a normal-strength concrete such as this concrete are purely by removing or "debonding" the bonding strength and unlocking the interlocks between the coarse aggregate and cement-mortar paste caused by shape and texture of granite [3]; this implies that the concrete resistance to flexural or bending failure has not been influenced by the ACV of the coarse aggregates but rather with the textures and shapes of the coarse aggregates. So, a high percentage of granite leads to low ACV and consequentially leads to high flexural strength (and not lower ACV). The lower strength difference is as a result of high w/c ratio of 0.65 [1].

3.2 Correlation between hardened properties of concrete & percent of crushed granite

This section deals with modest prediction and correlation between CS and percent of CG replacement, between MOR at 28th day and percent of CG replacement, and between CS at 28th day and MOR at 28th day for different mix proportions.

3.2.1 Correlation between CS and CG

CS of concrete containing varying percent of CG at the 28th day and varying percent of CG were modelled and correlated using Pearson's correlation method.

$$Y' = \alpha X' \pm \beta \tag{1}$$

where: Y', is the 28th -Day compressive strength (CS) in Mpa; α is the gradient of the predictive model in (Mpa/%); X' is

the percent of crushed granite replacement (CG) and β is the intercept at Y' in Mpa.

$$CS = 0.0598CG + 18.799 \quad (2)$$

Table 7 and Figure 4 show a strong positive relationship between 28th-day CS and percent of CG replacement for various mix proportions. With the significant figure of $p < 0.01$ and $R^2 = 0.908$, there is a strong link between CG and CS at 28th day. Shetty [1] had also established experimentally a good relationship between CS and coarse aggregate based on two properties of coarse aggregates; sources (uncrushed and crushed) and shape (angular, irregular and flaky). In a similar research study carried out by Orie and Orojo [23], the results of compressive strength versus coarse aggregate predicted that linear correlation was formed between compressive strength and coarse aggregate.

Table 6 - Percent of CG replacement with corresponding 28th -day (CS) in Mpa

% of Crushed Granite Replacement	0%	20%	40%	60%	80%	100%
28th-Day Compressive Strength (CS)	17.88	20.90	21.80	22.30	22.90	24.95

Table 7 - Model Summary for Correlation between CS and CG

R	**R^2**	**Adjusted R Square**	**Std. Error of the Estimate**	**Sig. fig.***
0.953	0.908	0.885	0.79652	0.003

*Correlation is significant at the 0.01 level (2-tailed)

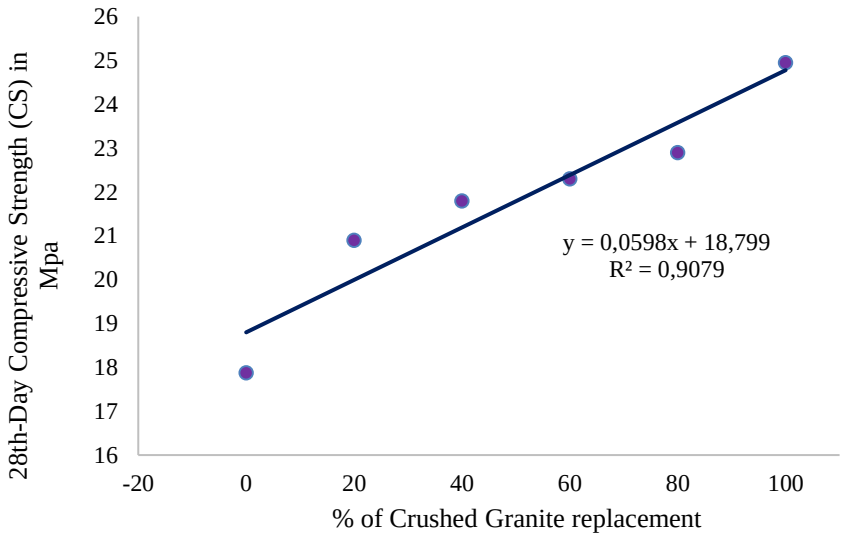


Fig. 4 – Correlation between 28th-Day CS and CG

3.2.2 Correlation between MOR and CG

MOR or flexural strength of concrete containing varying percent of crushed granite at 28th day and varying percent of crushed granite were modelled and correlated using Pearson's correlation method.

$$Y' = \alpha X' \pm \beta \quad (3)$$

where: Y' is the 28th -Day Modulus of rupture (MOR) in Mpa; α is the gradient of the predictive model in (Mpa/%); X' is the percent of crushed granite replacement (CG) and β is the intercept at Y' in Mpa.

$$MOR = 0.0164CG + 3.9495 \quad (4)$$

Table 9 and figure 5 indicated that there existed a strong linear relationship between MOR at 28th day and percent of CG replacement, meaning an increase in CG will directly leads to increase MOR at the 28th day. $R^2 = 0.832$ and significant figure of $p < 0.01$, these point to a positive linear relationship between MOR at 28th day and CG. This is similar to result obtained by Orie and Orojo [23]. They also suggested that there existed a relationship between MOR and coarse aggregate. In a similar research study, Manjunath & Prakash [24] established linear relationship for MOR of different coarse aggregate types but with moderate modification, Umeonyiagu [25] labelled the correlation between MOR and coarse aggregate as a linearly polynomial relationship. Results from Orie and Orojo [23] suggested that the best correlation between MOR and coarse aggregate to be quadratic polynomial.

Table 8 – Percent of CG replacement with corresponding 28th day MOR in Mpa

% of Crushed Granite Replacement	0%	20%	40%	60%	80%	100%
28th-Day Modulus of Rupture (MOR)	3.94	4.49	4.58	4.78	4.86	5.98

Table 9 – Model Summary for Correlation between MOR and CG

R	**R^2**	**Adjusted R Square**	**Std. Error of the Estimate**	**Sig. fig.***
0.912	0.832	0.790	0.30948	0.011

*Correlation is significant at the 0.05 level (2-tailed)

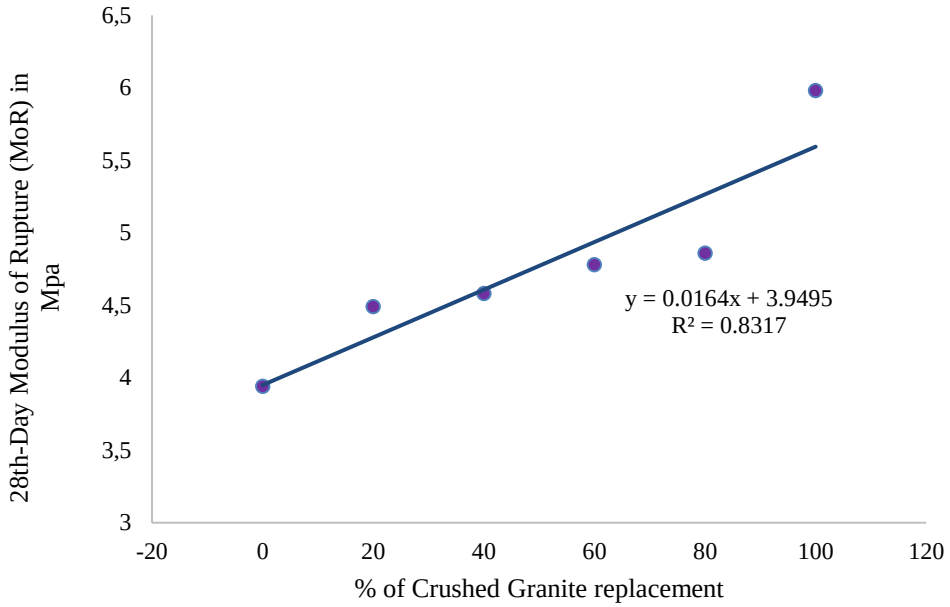


Fig. 5 – Correlation between 28th-Day MOR and CG

3.2.3 Correlation between MOR and CS

MOR of concrete containing varying percent of crushed granite at the 28th day and CS of concrete containing varying percent of crushed granite at 28th day were modelled and correlated using Pearson's correlation method.

$$Y' = \alpha X' \pm \beta \tag{5}$$

where: Y' is the 28th -Day Modulus of rupture (MOR) in Mpa; α is the gradient of the predictive model in (Mpa/%); X' is 28th -Day compressive strength (CS) in Mpa and β is the intercept at Y' in Mpa

$$MOR = 0.2693CG - 1.0958 \tag{6}$$

Table 11 and figure 6 shown that they might be a linear positive relationship between MOR and CS. Ahmed et al., [26] and Kępniak and Woyciechowski [27] had predicted that they existed a relationship between MOR and CS while some suggested logarithmic, exponential relationship others suggested linear relationship. $R^2 = 0.8782$ and significant figure of $p < 0.01$, indicating that positive linear relationship between MOR at 28th day and CS at 28th day for different mix proportions.

Table 10 – 28th -day CS with the corresponding 28th -day MOR

28th-Day Compressive Strength (CS)	17.88	20.90	21.80	22.30	22.90	24.95
28th-Day Modulus of Rupture (MOR)	3.94	4.49	4.58	4.78	4.86	5.98

Table 11 – Model Summary for Correlation between MOR and CS

R	R^2	Adjusted R Square	Std. Error of the Estimate	Sig. fig.*
	0.878	0.848	0.26325	0.006

*Correlation is significant at the 0.01 level (2-tailed)

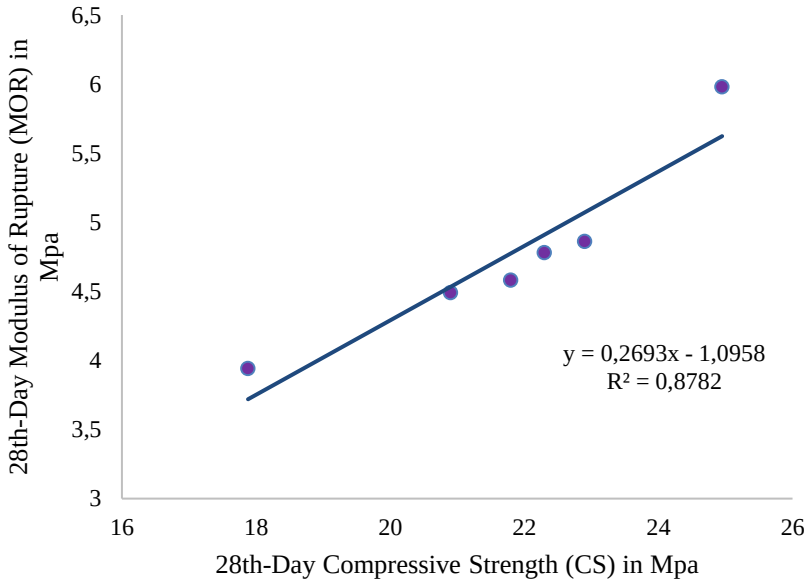


Fig. 6 - Correlation between 28th-day MOR and 28th-day CS

4 Conclusion

ACV reduces as percentage of crushed granite increases in the combination. It has already been established experimentally that lower ACV indicates better performance [18], therefore coarse aggregates with lower aggregates have better crushing resistance in comparison with the coarse aggregates with a higher value. From this research study, it is therefore obvious that crushed granite has better ACV than uncrushed gravel. Works of literature have also shown that ACV figures between 10 – 20% and 20 – 30% can be used for concrete work and therefore both crushed granite and uncrushed gravel are qualified to be used in concrete work but crushed granite is more suitable for concrete work than uncrushed gravel based on their ACV.

It can also be concluded that CS of concrete containing crushed granite is higher than that of concrete containing uncrushed gravel. As percentage of crushed granite in the concrete increases, so thus CS in the concrete increases. Mix proportion M2 (80% of uncrushed gravel & 20% crushed granite coarse aggregate combination in concrete mix) had gained in compressive strength of 9.2% on 7th-day, 4.3% on 14th-day and 17% on 28th-day higher than any other mix proportions containing varying percent of crushed granite replacement in terms of gained in CS. This indicates that small addition of crushed granite has a significant influence on compressive strength development.

Increase in the percent of crushed granite also leads to an increase in MOR of the concrete across all ages. A curious look at 20% replacement of uncrushed gravel with crushed granite across all curing ages indicates that 31.9% gained in MOR at 7^{th}-day, 22.2% at 14^{th}-day and 14% at 28^{th}-day higher than any other mix proportions containing varying percent of crushed granite replacement except for 100% replacement of uncrushed gravel at 28^{th} day with a gained in MOR of 23.0%. This was made possible because MOR is more sensitive to shapes, textures, sizes and other characteristics of coarse aggregates than CS [28]. This is also an indication that small replacement of crushed granite with uncrushed gravel have a profound effect on MOR of concrete.

It can also be concluded that with $R^2 = 0.908$, the correlation between 28^{th}-day CS of concrete containing varying percent of crushed granite and percent of crushed granite replacement is a near-perfect linear relationship. A good degree of a linear relationship ($R^2 = 0.832$) was also established between 28^{th}-day MOR for varying percent of crushed granite and percent of crushed granite replacements. An $R^2 = 0.878$ correlation indicates a good linear relationship between 28^{th}-day MOR containing varying percent of crushed granite and 28^{th}-day CS containing varying percent of crushed granite.

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