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A Study into the Use of Recycle Iron and Steel Slag as an Alternative Aggregate in Concrete Production

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Abstract
The study researches into the use of recycle iron and steel slag as an alternative aggregate to granite in concrete production. X-ray diffract meter (XRD) and scanning electron microscopic (SEM) were implored to assess the mineral composition and morphology of the aggregate; mechanical properties of the aggregates that were assessed includes sieve analysis, water absorption, bulk specific gravity and Los Angeles abrasion value. In this study the workability of fresh concrete was assessed using slump and compacting factor tests and the strength of the concrete was assessed using the uniaxial compressive strength test to establish the suitability of recycle iron and steel slag aggregate as alternative aggregate in concrete production. Concrete of M20 grade was considered for a water cement ratio of 0.60 using 1:2:4 mix ratio, slag aggregate replacements were observed from 0 to 100% at interval of 10%. The results of experimental investigations carried out to evaluate the fresh and hardened concrete properties showed that the slump value at 100% granite was 17mm (true slump) while at 100% slag was 28mm (shear slump); while the compacting factor are 0.79 at 0% slag replacement and 0.87at100% slag replacement; which confirms that concrete casted with granite is more workable than concrete casted with slag aggregate. The compressive strength at 7,14, 21 and 28days for the control cubes of 0%, 50% and 100% slag content are; 23.11, 21.78, 24.44 and 27.79N/mm²; 13.78, 20.00, 20.67 and 29.89N/mm² ; and 19.56, 22.67, 24.00 and 23.33N/mm² respectively. The results showed that maximum strength is obtained at 50% slag replacement; though all the results met the requirement of 20N/mm² by standard BS 5328: part 1: 1997. The results of mineral composition and morphology showed that granite and slag aggregates contained (70.2, 11.56, 1.19, 1.12, 0.96, 0.75, 3.26, 3.41, 0.00, 0.08 and 0.05) % and (13.7, 1.68, 10.32, 24.08, 45.16, 7.31, 0.19, 0.04, 0.03, 0.81 and 5.89) % of minerals composition respectively. The water absorption, abrasion value and specific gravity of granite and slag aggregate are (0.12%, 20.0 and2.20) and (0.82%, 23.0, and3.54) respectively. The result showed that the slag aggregate is more porous and absorbed water than granite aggregate and great care must be taken when using slag aggregate in concrete production as reduced water-cement ratio as compared to granite aggregate is required for better performance ; adequate stalking is also required prior to usage. Based on overall observations it could be recommended that slag could be utilized as coarse aggregate in concrete production either as partial or full replacement of granite aggregate.
Keywords: granite, iron and steel slag, X-ray diffract meter (XRD), scanning electron microscopic (SEM), mineral composition and morphology.

1.0 Introduction

The use of normal natural aggregate (granite) varies from construction of civil engineering works such as roads, dams, culverts, rails and weirs to construction of residential and industrial buildings; as such, the stock of granite aggregates are being depleted on daily basis which create environmental degradation and ecological imbalance. Mohammed and Arun, (2012) asserted that aggregates (fine and coarse) make up of (70-75)% of concrete by volume, which makes aggregates the major constituent of concrete and the influence of aggregates on concrete properties cannot be over-emphasize as its improves both the volume stability and durability of the resulting concrete. In some parts of the Federal Republic of Nigeria (riverine and coastal) areas where this natural resource is scarce, where a single granite quarry cannot be sighted and needed granite aggregates for construction works have to be transported from other regions of the nation or locally available gravels which is usually ladened with silt and clay particles are used a comparative alternative substitute is needed which must be to a great extent locally sourced, readily available and of adequate strength (Joel, 2010) .

Gideon *et al*., (2016) attributed the better result in strengths obtained in concrete casted to the irregular, angular and rough texture of granite aggregate to the smooth, round and glassy of gravel aggregate. Light-weight aggregate (BSEN 15167-1:2006) such as palm kernel shell, periwinkle shell, pumice, vermiculite, expanded slate, shale, furnace clinker, broken bricks and blocks to mention but a few have been used to produced normal strength concrete and light-weight concrete; while heavy aggregates such as scrap iron, iron shot, lead shot, magnetite and ilmenite have been used to produce high strength concrete with varying degree of limitations among which are formation of oxides of iron which resulted to rust formation in the concrete that leads to reduction in strength and final disintegration of concrete, lead poison in concrete, voids in concrete and organic matter within the matrix of concrete structure.

Peters (2015) identifies the sources of granite aggregates as those obtained by natural disintegration or by artificial crushing quarry rocks, boulders, cobbles or large-size igneous rocks; and aggregates dredged from pits, rivers, lakes or seabed, or resulted from weathering and erosion of rocks normally referred to as gravels and stones; the former are irregular, angular, rough, granular and crystalline in nature while the latter are smooth, round and glassy in nature. The study investigates the use of recycle iron and steel slag aggregate as viable and comparable alternative substitute to granite aggregate.

Recycle iron and steel slag aggregate, an industrial by-product generated during the production of iron and steel from scrap iron and steel which litters cities and towns in Nigeria. The slags which are manufactured under extensively quality of similar materials with chemical composition completely uniform with no reactive silica (Nippon Slag Association, 2015) was single out for study as comparative alternative to granite aggregate in concrete. Estimated total rolling capacity of mills in Nigeria stood at 3.48 million tonnes per year (Elijah, 2013) therefore, the industrial production of iron and steel in Nigeria stood at 1.91052 million tonnes per year using the capacity utilization of 54.9% released by the Central Bank of Nigeria (CBN, 2016). Iron and steel slag production in Nigeria was estimated at 0.29 tons per ton of steel produced (Uzondu, 2012) hence, the total estimated production of iron and steel slag in Nigeria was 0.55405 million tonnes per year.

Iron and steel slag are widespread in Nigeria because the industries producing these by-products are found in the north, south, west and east of Nigeria (Elijah, 2013). Hence, iron and steel slag as alternative substitute to granite aggregate in concrete production is readily and locally available. Previous studies on the utilization of iron and steel slag in concrete production recommends that these by-products can be used as alternative substitute to granite aggregate among such studies includes Olonade, Kadiri and Aderemi (2015), Palanisamy *et al*., (2015), Vasanthia (2014) and Hiraskar and Chetan (2013) to mention but a few.

The study facilitates the conversion of waste (recycled iron and steel slag) into useful slag aggregate (wealth) in concrete production which initially potent to be problematic and hazardous to the environment and also provides means of clearing municipal and cities of scrap iron and steel which have become health challenges to the environment.

2. Materials and Method

2.1 Materials

The materials used in the production of concrete for the study includes cement, granite aggregate, slag aggregate and sharp sand and water.

a.) Cement

Portland cement complying with NIS 444-1: 2003 was used as the binding agent. The cement was source from Lafarge Cement Company, Ewekoro, Ogun State.

b.) Aggregates

Two types of aggregate were used for the experiment viz: normal natural aggregate (granite) and slag aggregate. The granite aggregate conform to BS EN 13055-2:2004 and BS882 (1992); it was free of silt, clays, dirt and deleterious materials. The actual source for the granite aggregate was from Ratcon Limited quarry site along Lagos - Ibadan expressway for the coarse aggregate but the conventional fine aggregate was sourced from Ogun River. The slag aggregate was sourced from Major Engineering Company and Kew Metal Industries at Odogunyan area of Lagos State. The slag was crushed into pieces and sieved into particle sizes 5.00mm to 20mm.

c.) Water

Water used was source from Lagos State Water Corporation directly from the tap at the Concrete Workshop, Department of Building Technology, School of Environmental Studies, Yaba College of Technology, Yaba - Lagos. The specific gravity of water was 1, and the water was free of dirt and impurities; the water used conforms to BS3148 (1980).

2.2 Preliminary Investigation

Initial tests were conducted on the aggregates (granite and slag), X-ray diffract meter (XRD) and scanning electron microscopic (SEM) were implored to assess the mineral composition and morphology of the aggregates. The prepared samples (aggregates) were exposed to X-ray with the 2θ angle varying between 10º and 80º with Cu Kα radiation. The applied voltage and current was maintained at 40KV and 30mA respectively. The SEM analysis was carried out at × 100 magnification to examine the morphological. Mechanical properties of the aggregates that were assessed include Sieve analysis, Water absorption, Bulk Specific gravity, and Los Angeles Abrasion value.

a.) Sieve Analysis

In coarse analysis, a set of 100mm, 63mm, 20mm, 12mm and 5.00mm sieves are used. Dry sieving was performed by arranging the various sieves one over the other in the order of their aperture, the largest aperture sieve being kept at the top and the smallest aperture sieve at the bottom. A receiver was kept at the bottom, and a cover was kept at the top of the whole assembly. The sample (aggregate) was put on the top sieve, and the whole assembly was fitted on a sieve shaking machine. The sieves were shaking for at least 10 minutes. The portion of the sample retained on each sieve was weighed. The Percentage of sample retained on each sieve was calculated on the basis of total weight of sample, and from these results, percentage passing through each sieve was calculated. The particle analysis was done for both granite aggregate and coarse slag aggregate.

b.) Water Absorption and Bulk Specific Gravity Test

Determination of water absorption at atmospheric pressure was conducted in accordance with BS EN 13755:2002. A representative sample of the aggregate (granite aggregate and slag aggregate (2-3) kg was immersed in distill water in a wire-mesh container for 24 hours after which its buoyant weight (w_1) was determined. The aggregate was surface dry and its saturated weight (w_2) was determined. The aggregate was then oven dry at a temperature of 100 - 110^{0}c before it dry weight (w_3) was determined. The percentage of water absorption was thus determined; as expressed in equation 2.1

$$\%\,\mathrm{W.A} = \frac{(W_2 - W_3)}{W_1} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

and the bulk specific gravity of aggregate determined as expressed in equation 2.2

$$\mathrm{B.S.G} = \frac{\text{Dry weight of Aggregates } (W_3)}{\text{Volume of Aggregates}}$$

$$\mathrm{B.S.G} = \frac{\mathrm{W_3}}{\mathrm{N} \div \mathrm{Q}}$$

$$\mathrm{B.S.G} = \frac{\mathrm{W_3}}{(\mathrm{W_2} - \mathrm{W_1})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

Where:
W_1= Buoyancy weight
W_2 = Saturated weight
W_3= Dry weight
N = Vol. of displaced water
Q = Specific gravity of water
B.S.G = Bulk Specific Gravity

c.) Aggregate Abrasion Value Test

The abrasive value of coarse aggregate may be determined by either Deval Machine or by Los Angeles Machine. In this study Los Angeles Machine was adopted. The test was standardized as ASTM – C 131:2006.

The abrasive machine consists of steel drum of 700mm internal diameter and 500mm in length. The steel drum is mounted on horizontal axis enabling it to be rotated; the abrasive charge consists of steel sphere of approximately 48mm in diameter and weighing 390 – 445gm. The abrasive charge that was used is of grade A consisting of 12 number of sphere, having weight of charge of 5000 ± 25g. The test sample consisted of clean aggregate dried in an oven at 105- 110ºC to substantially constant weight.

The test sample and the abrasive charge are placed in the Los Angeles abrasion testing machine and the machine was rotated at a speed of 20 to 33 rev / min. The machine was rotated for 500 revolutions; it is so driven and so counter-balanced as to maintain a substantially uniform peripheral speed. At the completion of the test, the material was discharged from the machine and a preliminary separation of the sample made on a sieve coarser than 1.700mm. These materials are washed, dried in an oven at 105 - 110ºC to a substantially constant weight, and accurately weighed to the nearest gram. The difference between the original and the final weights of the test sample expressed as a percentage of the original weight of the test sample gives the percentage of wear.

2.3 Specimen Preparation

Two (2) sets of concrete cubes were casted viz: control and treatment experiment; the control experiment was casted without granite replacement with coarse slag while treatment experiment has granite replacement with coarse slag. Sieve analysis was carried out on the aggregates and from the sieve analysis particle sizes 5.00mm to 20mm was used for the concrete mixes. The designing and proportioning of the freshly mixed concrete conforms to BS 8110 Part 1:1990 with minimum cement content of 300kg/m^3 for concrete grade 20N/mm^2; and the batching was by weight. The mix ratios adopted was 1:2:4 with granite replacement for coarse slag of (10, 20, 30, 40, 50, 60, 70, 80, 90 and 100) percent. After the cast, all the test specimens were finished with a steel trowel and immediately covered with plastic sheet to minimize the moisture loss. The cubes were de-moulded after 24 hours and put into the water tank for curing maintaining temperature of ($27^0C \pm 2^0C$) as per BS EN 206-1, 2000: Concrete-Part 1 (2) requirement. Workability of the concrete mix grades was viewed from two perspectives viz: slump and compacting factor tests. The concrete cubes were subjected to compressive strength test after curing for (7, 14,21and 28) days.

2.4 Testing of Specimen

Testing of concrete specimen was carried out fewer than two major headings viz: tests on fresh concrete and tests on hardened concrete. Tests on fresh concrete includes slump and compacting factor tests; while uniaxial compressive strength test was used as test for hardened concrete.

2.4.1 Tests on Fresh Concrete

a.) Slump Test

This test is for consistence, which is allied to workability of the concrete. To conduct this test a truncated cone of steel 30cm high, 20cm diameter at the base, 10cm diameter on the top and provided with handles was used. Concrete of mix proportions of 1:2:4 was fed into the cone in layers of 7.5cm at a time, each layer being rammed 25 times with a metallic tamping rod 16mm diameter and 60cm long. Once the slump cone was filled, tamped and struck off level, it was lifted off the concrete. The inverted cone was placed alongside on the base plate, a straight edge laid across and the slump measured with a rule from the straight edge down to the top of the concrete to the nearest 5mm. The extent by which the concrete drops was called the slump. Slump vary from nil for a stiff concrete that has very low workability to, say 100mm or more for a very easily worked soft mix. Figure 2.1(a) showed the slump test apparatus and Figure 2.1(b) showed different types of slump.

b.) Compacting Factor Test

This test measures workability of concrete more truly than slump test, as it is designed to give a figure as a measure of workability for any kind of concrete mix made with aggregate not over 38mm maximum size. The apparatus is as shown in Figure 2.2; it consists of two hoppers, one below the other, with hinged flap bottoms, and a cylinder below. The cylinder was weighed empty, set in position and covered. Concrete as mixed earlier for slump test was poured into the top hopper gently to fill approximately, but no consolidation was given. It was allowed to fall into the second hopper by release of the top flap. When settled in the second hopper, the cylinder was uncovered and the second flap opened. The cylinder fills and some concrete spills over, consolidation was only by gravity. The excess concrete was cut off by trowels working inward and the full cylinder was removed and weighed. The net weight (W_1) was obtained by subtracting the weight of empty cylinder from the weight of cylinder with concrete consolidated by gravity.

The cylinder was emptied, and refilled in layers approximately 50mm deep and heavily rammed and completely filled. The objective was to remove all air voids before reweighing, the second net weight (W_2) was obtained and the compacting factor was calculated as shown in equation 2.3.

$$Compacting\ factor\ (CF) = \frac{1st\ net\ weight\ (\mathrm{W1})}{2nd\ net\ weight\ (\mathrm{W2})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

2.4.2 Tests on Hardened Concrete

The research adopted Unstressed Residual Strength Test Method, URSTM to access the compressive strength of the concrete cubes. Uniaxial Compressive Test (UCT) was performed on the concrete cubes.

a.) Uniaxial Compressive Strength Test

The compressive strength of the specimens was determined by destructive test method and was conducted at Lagos State Material Testing Laboratory, Ojodu Berger, Lagos State. The test was conducted in accordance with (BS 1881: Part 116, 1983). The compressive test machine was electronically operated, the digital machine test cube specimens in accordance to (BS 1881: Part 115, 1983). The compressive test machine as shown in figure 2.3 was named Tecnotest Modena – Italy, Model: 2007, Serial No F050 - TC, with capacity ranges from 500 - 2000KN. Before the 150mm cube specimen was tested, it was wiped clean of grit and placed centrally in the compressive testing machine and load to destruction, the highest load reached is recorded. The compressive strength was measured to the nearest 0.5N/mm^2. The report state: identification mark, nominal size, date of test, age of specimen, compressive strength, curing conditions and any unusual appearance of fracture (Emesiobi, 2000).

3. Results and Discussion

3.1 Results of X-Ray Diffract Meter (XRD) and Scanning Electron Microscopic (SEM)

The results of X-ray diffract meter (XRD) and scanning electron microscopic (SEM) is as presented in Table 2.1 and 2.2. From the results it showed that slag aggregate has higher percentages of non-hydrated lime which includes calcium oxide (CaO) and magnesium oxides (MgO) ; which are (45.16 & 7.31)% compared to granite aggregate which have (0.96 & 0.75) %. These oxides later hydrate when come in contact with moisture which causes volume expansion that influences both the mechanical and physical properties of the resulting concrete produced with the slag aggregate. In order to overcome the problem of expansion the intended slag to be used should be stockpiles for months before usage.

3.2 Results of Particle Size Distribution (Sieve Analysis)

The results of sieve analysis (Table 2.4) for slag aggregate showed that particle sizes from 5mm to 20mm were retained on sieve sizes; while higher sieve sizes (100, 60 & 40) mm recorded nil. The percentage retained on each sieve size showed that the aggregates sizes spread across the sieve sizes (5, 10, 14 & 20) mm in the order of (12.62, 18.12, 46.33 & 10.32) %. Table 2.3 presented the results of sieve analysis on granite aggregate, the percentage retained on each sieve size showed that sieve sizes (5, 10, 14 & 20) has particle sizes retained (19.14, 20.99, 38.89 & 13.58)% and higher sieve sizes (100, 60 &40) mm has nil. Hence, the particle sizes falls under gravel size of US standard sieve sizes and particle sizes of (100, 60 & 40) mm were not included in the sub-sample used for casting the concrete.

3.3 Results of Water Absorption and Abrasion Value Test

From Table 2.1 and 2.2 the abrasive value of slag aggregate (23) % was higher than that of granite aggregate (20) %; and the specific gravity of slag aggregate (3.54) % is also higher than that of granite aggregate of (2.2) % which account for it high resistance to abrasion and impact forces, high strength and durability. The water absorption of granite aggregate (0.12) % was lower than that of slag aggregate of (0.82) % these was as a results of high porosity of the slag aggregate hence, slag aggregate thus absorb water when exposed to moisture and the problem can be overcome by stockpile the slag aggregate for a period of time before usage to attain better result in concrete works.

3.4 Results of Fresh Concrete Test

a.) Slump Test Result

Table 2.5 showed the result of the slump test carried out on concrete casted with slag replacement. From the results the slump values at (0, 50 and 100) % slag replacement was (17, 20 and 28) mm. The result showed that workability of the concrete mix decreases as the percentage of slag replacement increases.

b.) Compacting Factor Test Result

The result of compacting factor test conducted on the freshly mixed concrete is as presented in Table 2.6. The result showed that at (0 and100) % slag replacement the compacting factor value are (0.79 and 0.87) respectively. This result further confirms that workability of concrete mix decreases as slag replacement increases; the result also depicts the consistency of the concrete mix.

3.5 Hardened Concrete Test Results

a.) Uniaxial Compressive Strength Test Result

Table 2.7 showed the result of uniaxial compressive strength test conducted on concrete cubes. The control cubes compressive strengths at 0% slag replacement were (23.11, 21.78, 24.44 and 27.79) N/mm^2; while the treatment cubes at 50% slag replacement were (13.78, 20.00, 20.67 and29.89) N/mm^2 and at 100% slag replacement were (19.56, 22.67, 24.00 and 23.33) N/mm^2 at (7, 14, 21 and 28) days respectively. The result showed that compressive strength of control cubes is higher than the treatment cubes compressive strengths at 28 days though, the compressive strengths of the treatment cubes increase progressively as the percentage of slag replacement increases at 28 days and the maximum compressive strength attained by treatment cubes was 29.89 N/mm^2 at 50% slag replacement. The result further showed that all the cubes (control and treatment) cubes satisfied the strength requirement prescribed in BS 8110 Part 1:1990 for grade 20 concrete.

4.0 Conclusion

From the analysis of the results of various tests conducted, the following conclusions are drawn:

i. Slag aggregate can serve as replacement for granite aggregate in concrete production.
ii. The compressive strength of control cubes is higher than the treatment cubes compressive strengths at 28 days
iii. Maximum compressive strength is obtained by treatment cubes are at 50% slag replacement though, all the results met the requirement of 20N/mm² by standard BS 5328: part 1: 1997 (9) for mix ratio of 1:2:4.
iv. Compressive strength of concrete increases as the slag aggregate content increases and as the days of curing increase.

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Competing Interests

The authors have declared that no competing interest exists.

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Table 2.1: Result of X-Ray Diffract Meter (XRD) And Scanning Electron Microscopic (SEM) on Granite Aggregate.

S/N	PARAMETER	LEVELS DETECTED
1.	SAMPLE DESCRIPTION	GRANITE STONE (GRAY SOLID)
2.	SiO_2 (%)	70.20
3.	Al_2O_3 (%)	11.56
4.	Fe_2O_3 (%)	1.19
5.	FeO (%)	1.12
6.	CaO (%)	0.96
7.	MgO (%)	0.75
8.	Na_2O (%)	3.28
9.	K_2O (%)	3.41
10.	S (%)	0.00
11.	P_2O_5 (%)	0.08
12.	MnO (%)	0.05
13.	Moisture (%)	-
14.	L. O. I (%)	-

NB: L. O. I. = Loss on Ignition

S/N	**PARAMETER**	**GRANITE STONE**
1.	Water Absorption (%)	0.12
2.	Los Angeles Abrasion	20.0
3.	Specific gravity	2.2

Source: Institute of Public Analysis of Nigeria (2016)

Table 2.2: Result of X-Ray Diffract Meter (XRD) And Scanning Electron Microscopic (SEM) on Slag Aggregate.

S/N	**PARAMETER**	**LEVELS DETECTED**
1.	SAMPLE DESCRIPTION	SLAG (DARK BROWNSOLID)
2.	SiO_2 (%)	13.70
3.	Al_2O_3 (%)	1.68
4.	Fe_2O_3 (%)	10.32
5.	FeO (%)	24.08
6.	CaO (%)	45.16
7.	MgO (%)	7.31
8.	Na_2O (%)	0.19
9.	K_2O (%)	0.04
10.	S (%)	0.03
11.	P_2O_5 (%)	0.81
12	MnO (%)	5.89
13.	Moisture (%)	-
14.	L. O. I (%)	-

NB: L. O. I. = Loss on Ignition

S/N	**PARAMETER**	**SLAG**
1.	Water Absorption (%)	0.82
2.	Los Angeles Abrasion	23.0
3.	Specific gravity	3.54

Source: Institute of Public Analysis of Nigeria (2016)

Table 2.3: Particle Size Distribution for Granite

Sieve sizes	**Weight Retained (Kg)**	**% Retained**	**Cumulative % Retained**	**Cumulative % Passing**
20mm	46.36	13.58	13.58	86.42
14mm	132.76	38.89	52.47	47.53
10mm	71.65	20.99	73.46	26.54
5mm	65.33	19.14	92.60	7.40
Total	341.39			

Table 2.4: Particle Size Distribution for Slag

Sieve sizes	Weight Retained (Kg)	% Retained	Cumulative % Retained	Cumulative % Passing
20mm	35.23	10.32	10.32	89.68
14mm	158.16	46.33	56.65	43.35
10mm	61.86	18.12	74.77	25.23
5mm	43.06	12.62	87.39	12.61
Total	341.37			

Table 2.5: Slump Test Result for Different Slag Replacement

S/N	(%) GRANITE	(%) SLAG	SLUMP VALUE (MM)	WORKABILITY CATEGORY
1.	100	0	17	TRUE SLUMP
2.	90	10	19	TRUE SLUMP
3.	80	20	20	TRUE SLUMP
4.	70	30	21	TRUE SLUMP
5.	60	40	22	TRUE SLUMP
6.	50	50	20	TRUE SLUMP
7.	40	60	24	TRUE SLUMP
8.	30	70	24	TRUE SLUMP
9.	20	80	25	TRUE SLUMP
10.	10	90	26	SHEAR SLUMP
11.	0	100	28	SHEAR SLUMP

Table 2.6: Compacting Factor Test Result

S/N	GRANITE (%)	SLAG (%)	PARTIAL WEIGHT	COMPACTED WEIGHT	COMPACTING FACTOR	REMARK
1.	100	0	8.06	10.2	0.79	Workable
2.	0	100	10.9	12.5	0.97	Workable

Table 2.7: Average Compressive Strength Test Result

Average Compressive Strength Test Result (N/mm^2)						
S/N	GRANITE (%)	SLAG (%)	7 DAYS	14 DAYS	21 DAYS	28 DAYS
1.	100	0	23.11	21.78	24.44	27.79
2.	90	10	17.78	17.78	18.45	17.78
3.	80	20	14.45	14.45	16.89	17.78
4.	70	30	15.56	17.78	21.11	20.00
5.	60	40	15.56	19.56	23.33	22.67
6.	50	50	13.78	20.00	20.67	29.89
7.	40	60	18.45	17.78	22.22	23.11
8.	30	70	18.71	21.78	22.22	22.57
9.	20	80	19.34	21.78	22.89	22.22
10.	10	90	19.39	21.80	24.00	22.59
11.	0	100	19.56	22.67	24.00	23.33

Figure 2.1(a): Slump Apparatus

Source: Emesiobi (2000)

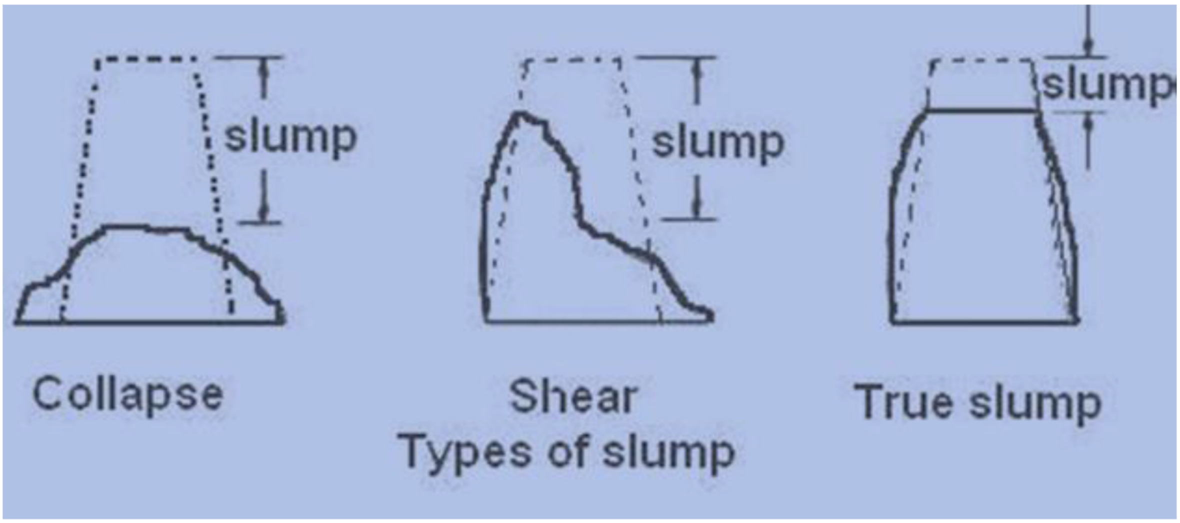

Figure 2.1(b): Different Types of Slump

Source: Emesiobi (2000)

Figure 2.2: Compacting factor Apparatus

Source: Emesiobi (2000)