Effects of Different Sizes of Coarse Aggregates On Splitting Tensile Strength of Concrete

[1]Mmeka P. T., [2]Ezeagu C. A., [3]Ososona C. O.
[1]Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli.
[2]Department of Civil Engineering, Nnamdi Azikiwe University, Awka.
[3]Department of Civil Engineering, University of Ibadan, Ibadan.
Email: pt.mmeka@coou.edu.ng[1], ac.ezeagu@unizik.edu.ng[2]

ABSTRACT
The aim of the study was to determine the effect of different sizes of coarse aggregates on the splitting tensile strength of concrete. Preliminary investigations using ACI mix design method for test such as splitting tensile strength of the different aggregates sizes were conducted. The aggregates (fine and coarse) used for the concrete were collected from gneiss rock deposits from L-Adisa, along Ojoo-Moniya Road, Ibadan. The aggregates were sun-dried and sieved to different sizes with the set of sieves: BS sieve 19mm, BS sieve 13.2mm, BS sieve 9.5mm, BS sieve 4.75mm, and were classified based on aggregates passing the aforementioned sieves in the Department of Civil Engineering. Splitting strength test were conducted after duly checking ages of curing to ascertain its relatedness to structural failures. The result was an increase in splitting tensile strength of concrete at 7days (with 5.71Mpa for concrete of coarse aggregate size of 19mm), rising to splitting tensile strength of 6.94Mpa after 28days. There was increase in splitting tensile strength of concrete made from different sizes of coarse aggregates based on progressive increase in curing age. Similarly, there was corresponding decrease in the splitting tensile strength of concrete as coarse aggregate sizes decreased. So, from these results it was deduced that, generally, the bigger the mean size of aggregates (MSA), the greater the splitting tensile strength of concrete, so long the coarse aggregates are properly graded and the maximum size of aggregates used doesn't exceed 1/5th of the least dimension of the concrete work.

Keywords: Aggregates sizes, concrete, curing, splitting tensile strength, mean size of aggregate.

1.0 INTRODUCTION

The role of coarse aggregate in concrete is central to its strength. While the topic has been under study for many years, an understanding of the effects of coarse aggregate has become increasingly more important with the introduction of high-strength concretes (since coarse aggregate plays a progressively more important role in concrete behavior, as strength increases). In normal-strength concrete, failure in compression almost exclusively involves de-bonding of the cement paste from the aggregate particles at what, for the purpose of this report, will be called the matrix-aggregate interface. In contrast, in high-strength concrete, the aggregate particles as well as the interface undergo failure, clearly contributing to overall strength. As the strength of the cement-paste constituent of concrete increases, there is greater compatibility of stiffness and strength between the normally stiffer and stronger coarse aggregate and the surrounding mortar. Thus, micro-cracks tend to propagate through the aggregate particles (since, not only is the matrix-aggregate bond stronger than in concretes of lower strength, but the stresses due to a mismatch in elastic properties are decreased).

This report describes work that is aimed at improving the understanding of the role of aggregates in concrete. The variables considered are aggregate sizes (19mm, 13.2mm, 9.5mm, 6.7mm). Splitting tensile test carried out at different ages are used to better understand the effects different aggregate sizes have in concrete.

This involves:

i. Preparing the appropriate materials for concrete-casting (i.e. sand, coarse aggregate, cement and water;
ii. Determine appropriate intervals for experimental work;
iii. Cast concrete cubes and cylinders (based on the pre-determined schedule and different coarse aggregate sizes);
iv. Determine the splitting tensile strength.

It must be noted that coarse aggregate is a necessity for concrete, as food, shelter and clothing are necessary for human needs. Therefore, the importance of different coarse aggregate sizes to concrete cannot be overemphasized, especially when it deals with catering for the structural integrity of concrete works in Nigeria. Concrete is a mixture of cementious material, aggregate and water. Although aggregate is considered inert filler, it is a necessary component that defines the concrete's thermal and elastic properties and dimensional stability (www.engr.psu.edu, 2017). The splitting tensile strength of an aggregate is an important factor in its selection. Other physical and mineralogical properties of the aggregate must be known before mixing concrete to obtain a desired mixture. These properties include shape and texture, size gradation, moisture content, specific gravity, reactivity, soundness and bulk unit weight. These properties along with the water/cementitious material ratio determine the strength, workability, and durability of concrete (www.engr.psu.edu, 2017).

The shape and texture of aggregate affects the properties of fresh concrete more than hardened concrete. Although aggregates are most commonly known to be inert fillers in concrete, the different properties of aggregate have a large impact on the strength, durability, workability, and economy of concrete. These different properties of aggregate allow designers and contractors great flexibility in meeting their design and construction targets.

2.0 LITERATURE REVIEW

Aginam et al (2013) investigated the effects of coarse aggregate type on the compressive strength of concrete. The results of this investigation showed concretes made with crushed granite performed better in compression than those made with natural gravels of similar grading.

Bhikshma and Annie (2013) studied the effect of maximum size of aggregate in high grade concrete with volume fly ash. The result showed that the workability of concrete decreased from 0% to 20% of fly ash replacement and then increased for further replacements of 30%, 40% and 59% (irrespective of the size of the aggregate). The workability of concrete increased as the size of the aggregate increased from 10 mm to 20 mm for all percentages of replacements of the fly ash.

Panda and Bal (2012) studied properties of self-compacting concrete, using recycled coarse aggregate. The test results indicated that the compressive strength, flexural strength and split tensile strength of SCC are less than the NVC. The compressive strength, flexural strength and split tensile strength of SCC decreased with increase in the amount of RCA. The 28 day-test SCC marginally achieved the required compressive strength (up to 0.30 replacement ratio). NVC with 100% NCA, had the highest flexural strength and more than the theoretical value at 28 days and 90 days, respectively. The 28-day flexural strength of SCC obtained from experimental investigation, is less than the theoretical flexural strength in all the replacement ratios of RCA.

RCA showed higher water-absorption compared with conventional NCA, due to old mortar attached to the original concrete, and has relatively lower specific gravity.

Ahmed (2015) studied the properties of recycled concrete aggregate under different curing condition. From his results, it can be concluded that:

- In all the studied cases of curing (air, water, paint), increasing the concrete age led to an increase in its compressive strength;
- The best ratio of recycled aggregates to natural aggregates is the mixing ratio of 50%, and when the concrete is cured in air, or painted, the maximum value of the compressive strength and tensile strength was obtained at age of 28 days;
- In moist curing, full replacement of coarse aggregates gave the highest compressive strength, at 28 days;
- Curing with paint is more beneficial in all cases (and for all ages of concrete) than water or air curing, except in the case of full replacement (where the maximum value of the compressive and tensile strengths in this case, was obtained with curing using water);

- Increasing the recycled aggregates ratio caused a decrease in the concrete permeability by ISAT (in case of curing in air);
- In all cases of recycled aggregates ratios, curing in water caused a decrease in the concrete's permeability.

3.0 METHODOLOGY

3.1 SAMPLE COLLECTION AND PREPARATION

The coarse aggregates used for the concrete were collected from gneiss rock deposits from L-Adisa area, opposite the International Institute of Tropical Agriculture (IITA), along Ojoo – Moniya Road, within the Ibadan geopolitical zone (7° 22′ 39″ N, 3° 56′ 49″ W) of Oyo State of Nigeria. Naturally-occurring sand (fine aggregate), used for the experimental work, was obtained from the pits within the same area. The aggregates were then transported to the Department of Civil Engineering, after which they were sun-dried. This was in order to eliminate water from the aggregates, before the mixing to generate concrete.

3.2 MATERIALS

Fine and coarse aggregates: The sieved coarse aggregates used for the concrete were 6.7mm, 9.5mm, 13.2mm and 19mm (maximum sizes), commercially-crushed stones, obtained from garnet gneiss rock-deposit found within the Ibadan. Naturally-occurring fine aggregate (sand) of maximum size of 2mm, obtained from pits in the Ibadan region was used for the concrete.

Cement: Commercially-available Ordinary Portland Cement was used in this project. This cement has a specific gravity of 3.15, 32.5 Grade and conforms to Nigerian Industrial Standards (NIS). The Dangote brand of Ordinary Portland Cement was used in the work. It was taken to the laboratory in 50kg bags, and was carefully kept away from damp (to prevent lumps).

Water: Potable water was obtained from the Civil Engineering Laboratory was used for the work. This water met the requirements of BS 3148, 1980.

Other materials: Cube mould (100mm x 100mm x 100mm), cylinder mould (100mm diameter x 200mm), hand trowel, shovel, weighing balance, set of sieves, and a UTM (Universal Testing Machine).

3.3 METHODS

Sieve Analysis: The fine and coarse aggregates were sieved to various sizes, in accordance with BS 812:103. BS sieve 19mm, BS sieve 13.2mm, BS sieve 9.5mm, BS sieve 6.7mm, BS sieve 4.75mm and BS sieve 2.36mm, specifically, were used to sieve the coarse aggregates and fine aggregates, respectively.

Mix Proportion: A nominal mix ratio of 1:2:4 (Cement: Fine Aggregate: Coarse Aggregate) was adopted for the purpose of this work and a water-cement ratio of 0.6 was used. Three cubes were cast for each aggregate size, for a particular age of curing, namely: 7 days, 14 days, 21 days, and 28 days.

Curing of Test Specimens: The concrete cubes were cured in a curing tank for 7 days, 14 days, 21 days and 28 days, respectively, before carrying out split tensile test on them.

Split Tensile Strength: The split tensile strength tests were also carried out on the Universal Testing Machine – UTM in accordance with the procedures outlined in BS1881-116: (1983)

3.4 PRODUCTION OF SPECIMENS

3.4.1 PREPARATION OF MIX DESIGN FOR CONCRETE CUBES AND CONCRETE CYLINDERS

The constituents that make up the concrete were weighed in accordance with the mix proportion for each batch of the concrete. Using the mix proportion as calculated using the absolute volume method, the weighed sand was poured on the prepared surface. Similarly, a proportionate measure of cement was poured on the fine aggregate. The sample was thoroughly mixed by using hand mixing method (i.e. a shovel to mix it properly, to obtain uniformity in the mix). Right proportions of granite and water followed in their order. Thereafter, the concrete was placed.

3.5 TESTING OF SPECIMENS

All cube specimen and cylinder specimens were removed at their appropriate days (i.e. 7, 14, 21 and 28 days, respectively) for crushing.

3.5.1 SPLITTING TENSILE STRENGTH TEST

The methods involve applying a diametric compressive force along the length of the cylindrical specimen which is placed between the platens of the compressive testing machine, with its axis horizontal. Force is applied along a vertical diameter through thin plywood strips interposed between the cylinder and the machine plates. Plywood strips were used, so that the load is applied uniformly along the length of the cylinder. The loading induces tensile stresses on the plane containing the applied load; therefore instead of compressive failure, tensile failure occurs by splitting along the loaded diameter. The formula that captures this procedure (and generates the desired result is): Splitting tensile strength = crushing load x 10^3/ Area of the cylinder.

4.0 RESULTS AND DISCUSSIONS

4.1 CLASS OF SPECIMEN FOR SPLITTING TENSILE STRENGTH

Tables 4.1-4.4 below show the results of the splitting tensile strength tests, while figures 4.1-4.4 show the bar chart representation of the results of different aggregate sizes.

Table 4.1: 7 days Splitting Tensile Strength Result

Aggregate size (mm)	Cylinders specimen	Weight (kg)	Maximum load (KN)	Splitting tensile strength (Mpa)	Average compressive strength (Mpa)
19	E1	4.12	45.2	5.76	5.71
	E2	3.42	39.1	4.98	
	E3	3.64	50.2	6.39	
13.2	F1	3.94	44.0	5.60	5.11
	F2	3.86	33.2	4.23	
	F3	3.72	43.2	5.50	
9.5	G1	3.52	36.4	4.64	4.56
	G2	3.49	33.6	4.28	
	G3	3.58	37.3	4.75	
6.7	H1	3.38	28.6	3.64	3.56
	H2	3.39	26.4	3.36	
	H3	3.44	28.9	3.68	

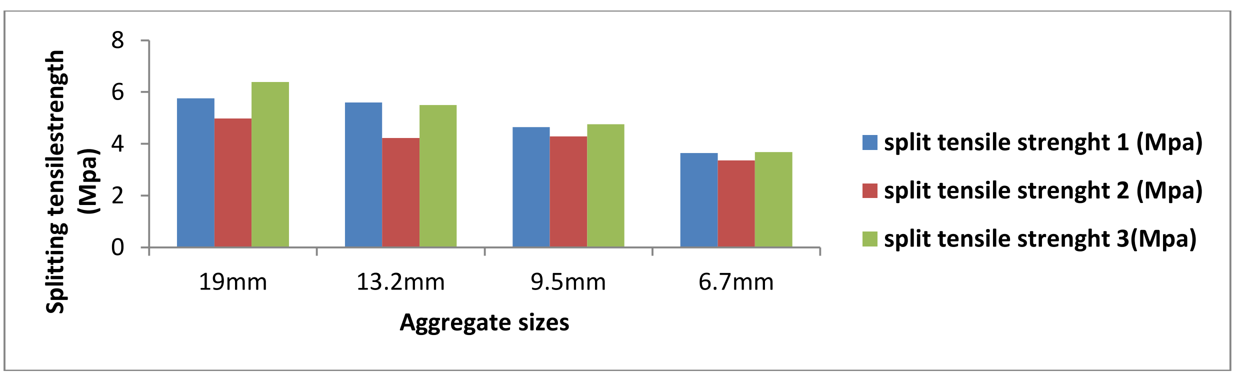


Figure 4.1: 7 days Splitting Tensile Strength Result

Table 4.2: 14 days Splitting Tensile Strength Result

Aggregate size (mm)	Cylinders specimen	Weight (kg)	Maximum load (KN)	Compressive strength (Mpa)	Average compressive strength (Mpa)	Percentage increase after 14 days
19	E4	3.12	33.0	4.20	6.17	8.06%
	E5	3.46	52.9	6.74		
	E6	4.05	59.4	7.56		
13.2	F4	3.97	45.7	5.82	5.71	11.74%
	F5	3.68	40.8	5.20		
	F6	3.70	48.1	6.12		
9.5	G4	3.48	36.2	4.61	5.12	12.28%
	G5	3.69	47.5	6.05		
	G6	3.34	37.1	4.72		
6.7	H4	3.52	37.7	4.80	3.95	10.96%
	H5	3.61	25.4	3.23		
	H6	3.87	30.0	3.82		

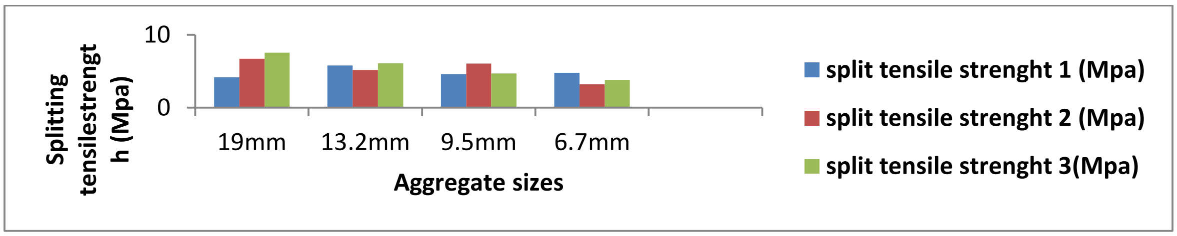


Figure 4.2: 14 days Splitting Tensile Strength Result

Table 4.3: 21 days Splitting Tensile Strength Result

Aggregate size (mm)	Cylinders specimen	Weight (kg)	Maximum load (KN)	Compressive strength (Mpa)	Average compressive strength (Mpa)	Percentage increase after 21 days
19	E7	3.34	44.7	5.69	6.23	9.11%
	E8	3.39	54.9	6.99		
	E9	3.66	47.2	6.01		
13.2	F7	3.19	41.9	5.34	5.74	12.33%
	F8	3.37	52.0	6.62		
	F9	3.28	41.3	5.26		
9.5	G7	3.58	36.2	4.61	5.48	20.18%
	G8	3.62	49.0	6.24		
	G9	3.52	43.9	5.59		
6.7	H7	3.60	46.7	5.95	5.37	50.84%
	H8	3.36	44.0	5.60		
	H9	3.47	35.7	4.55		

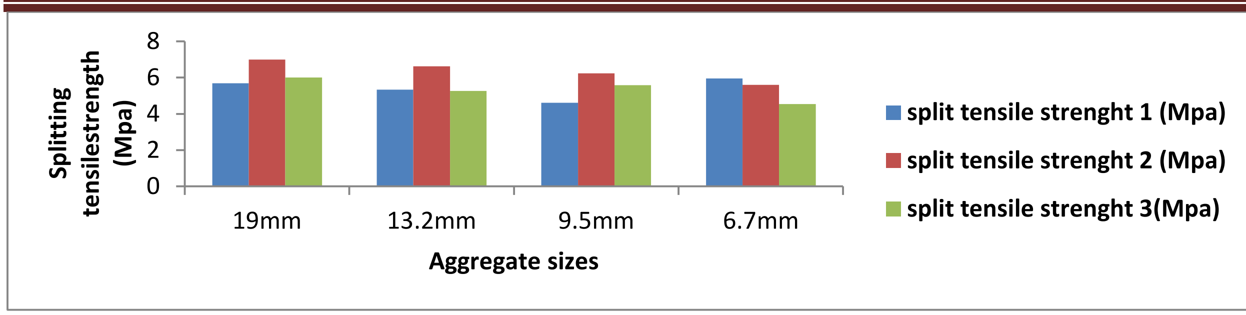


Figure 4.3: 21 days Splitting Tensile Strength Result

Table 4.4: 28 days Splitting Tensile Strength Result

Aggregate size (mm)	Cylinders specimen	Weight (kg)	Maximum load (KN)	Compressive strength (Mpa)	Average compressive strength (Mpa)	Percentage increase after 28 days
19	E10	3.45	46.8	5.94	6.94	21.54%
	E11	3.88	57.0	7.26		
	E12	3.73	59.9	7.63		
13.2	F10	3.82	49.0	6.24	5.90	15.46%
	F11	3.87	46.2	5.88		
	F12	3.64	59.5	5.58		
9.5	G10	3.84	45.8	5.83	5.49	20.39%
	G11	3.42	45.8	5.83		
	G12	3.50	37.6	4.79		
6.7	H10	3.52	35.6	4.53	5.40	51.69%
	H11	3.55	48.0	6.11		
	H12	3.49	43.6	5.55		

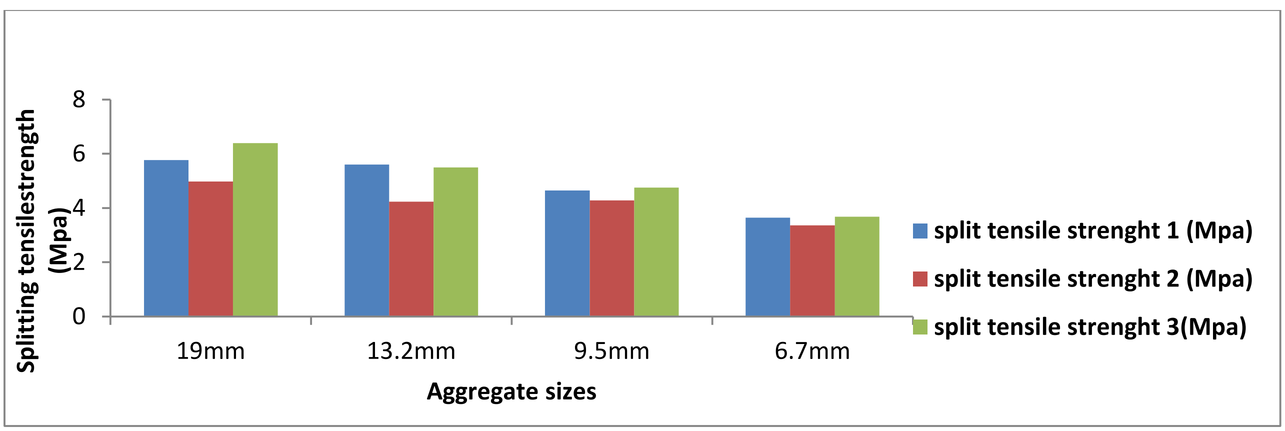
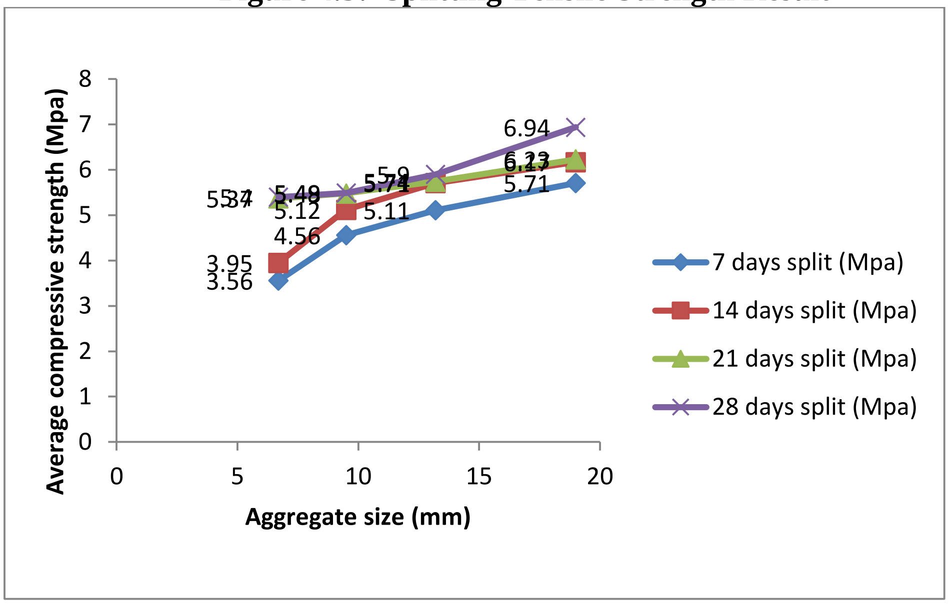


Figure 4.4: 28 days Splitting Tensile Strength Result

The results showed that there was increase in the splitting tensile strength of the concrete for each of the coarse aggregate sizes from the 7 days testing which progressed after the 28 day testing. For the 19mm coarse aggregate-size, the split strength of 5.71Mpa (at 7 day testing) increased to 6.94Mpa after 28 days. For the 13.2mm coarse aggregate-size, the split strength of 5.11Mpa (at 7 day testing) increased to 6.90Mpa after 28 days. Similarly, at the 7 day split testing, the 9.5mm coarse aggregate-size (of value 4.56Mpa), and 6.7mm aggregate-size (of value 3.56Mpa) progressively increased to a value of 5.49Mpa and 5.40Mpa respectively. So, it can be deduced, generally, that the bigger the Mean Size of Aggregate (MSA), the greater the splitting tensile strength of concrete.

For the splitting tensile result, the 19mm aggregate-size showed 21.54% increase in strength after 28 days of testing. Meanwhile, the 13.2mm aggregate-size showed 15.46% increase in strength after 28 days of testing. Moreover, the 9.5mm aggregate-size showed 20.39% increase in strength after 28 days of testing. Nevertheless, the 6.7mm aggregate-size showed 51.69% increase in strength after 28 days of testing. This when compared to the compressive strength percentage increase value of 46.62%, 46.84%, 122.67% and 78.16% for aggregate-size of 19mm, 13.2mm, 9.5mm and 6.7mm respectively, showed less impart of splitting strength to compressive strength of different coarse aggregate sizes.

Figure 4.5: Splitting Tensile Strength Result



CONCLUSION

From the results obtained, the following conclusions can be arrived at:

- The 19mm and 13.2mm coarse aggregate sizes exhibited high splitting tensile strengths (of 6.94Mpa and 5.9Mpa respectively), at 28 days.
- It was observed that there was an increase in the splitting tensile strength of concrete from 7 days strength for each concrete of coarse aggregate sizes to maximum strength after 28 days.
- It was indicated from the research that there was decrease in the splitting tensile strength as concrete coarse aggregate sizes decreased.

It is further recommended that:

- All concrete works should be designed for **a**nd appropriate coarse aggregate size be specified by an experienced professional.
- The local authorities should include the aggregate size specification as part of projects involving concrete works.
- There should be improved awareness about the importance of aggregate sizes with the professionals in the construction industry in order to control failures in concrete.
- For concrete works, 19mm and 13.2mm coarse aggregate size could be adopted as they give appreciable splitting tensile strength and are also appropriate for minimum bar spacing in beam.
- Maximum size of aggregate used in the mix design should not be greater than 1/5th of the least dimension. If the maximum size of aggregate is greater than 1/5th of the least dimension, the chances of failure in shear are extremely high.

References

Aginam, C. H., Chidolue, C. A. and Nwakire, C. (2013), *Investigating the Effects of Coarse Aggregate Types on the Compressive Strength of Concrete*, International Journal of Engineering Research and Applications, Vol. 3, pp. 1140 – 1144.

Ahmed, E. M. (2015), *Hydrogel: Preparation, Characterization and Applications: A Review*, Journal of Advanced Research, Vol. 6, Issue 2, pp. 105 – 121.

Bhikshma, V. and Annie, F. G. V. (2013), *Studies on Effect of Maximum Size of Aggregate in Higher Grade Concrete with High Volume of Fly Ash*, Asian Journal of Civil Engineering, Vol. 14, No. 3, pp. 209 – 217.

Panda, K. C. and Bal, P. K. (2013), *Properties of Self Compacting Concrete Using Recycled Coarse Aggregate*, Procedia Engineering, Vol. 51, pp. 159 – 164.

www.engr.psu.edu, *Effect of Curing Temperature on the Durability of Concrete under Highly Geothermal Environment* (2017), (www./hindawi.com/journals/amse/2017), Retrieved: April, 2020.