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Characteristics of Different Type of Coarse Aggregate on Properties of High Performance Concrete

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ABSTRACT. *The weakest links of conventional cement concrete is often occurred at the transition zone around coarse aggregate particles and the bulk of the compressive load is also borne by the cement paste. However, in special concrete such as High Strength Concrete (HSC) and High Performance Concrete (HPC) where, the water/cement ratio is low and high content of cement constitute their characteristics, the bulk compressive load is borne by the aggregate. Therefore, the failure in such concrete is mostly through the aggregate. This study discussed the characteristics of different type of coarse aggregate with distinct size range, 20-14mm and 10-5mm on properties of high performance concrete. In this project, investigation such as Slump test and Unit weight were carried out on fresh properties, and also compressive strength and water absorption on hardened properties, in which, readings were taken at curing days of 7 days, 14 days, and 28 days. The water to cement ratio used is 0.35, 1% super plasticizer of Conplast SP-430 were added, and the dosage of meta kaolin added was 0%, 7.5% and 15%. The HPC mix, grade M40concrete is designed as per ACI method. The result of the study indicated that the compressive strength increases with an increase in percentage of Metakaolin between 0% to 15% replacements. Basalt-mixed concrete gives higher compressive strength, followed by gneiss-mixed concrete, then granite-mixed concrete. It was also discovered that larger aggregate sizes (20mm-14mm) gives high compressive strength than smaller sizes (5mm-10mm). Therefore for optimum performance up to 15% replacement of Metakaolin can be used with 20mm-14mm sizes of basalt aggregate.*

Keywords: Granite, Basalt, Gneiss, Coarse Aggregate, High Performance concrete

1. INTRODUCTION

Concrete is a composite material that consists essentially of a binding medium in which are embedded particles or fragments of aggregates. It presents technological advantages: it can be made from local inexpensive materials and it can be cast in any shape [1]. Aggregates constitute a skeleton of concrete. Approximately three-quarter of the volume of conventional concrete is occupied by aggregate [2], [3]. The amount of aggregate is usually between 60 and 85% of volume fraction in all kind of concrete-like composites. It is inevitable that a constituent occupying such a large percentage of the mass should contribute important properties to both the fresh and hardened product. However, in concrete-like composites natural stone aggregate is used in the form of gravel or crushed rock and sand. They are obtained from all kinds of rocks as a result of the natural process of abrasion and weathering [4]. The aggregates are of two size groups always used in manufacture of good concrete. The main division being between Fine Aggregate (FA), often called sand, not larger than 5mm and coarse aggregate (CA), which comprises material at least 5mm [5]. Aggregate with undesirable properties cannot produce strong concrete, but the properties of aggregate greatly affect the durability and structural performance of concrete [3]. The internal structure, surface nature and shape of aggregates are also significant factors on which concrete greatly depends on, in terms of strength [6].

Moreover, standard concrete can be characterized solely by its compressive strength because that can be directly linked to the water-cement ratio, which still is the best indicator of paste porosity. Most of the useful mechanical characteristics of concrete can then be linked to compressive strength with simple empirical formulas. This is the case with elastic modulus and the modulus of rupture (flexural strength), because the hydrated cement paste and the transition zone around coarse-aggregate particles constitute the weakest links in concrete [1]. Though, the aggregate interface is not the limiting factor governing the strength requirement , because in concrete produced with low water/cement ratio and high cement content, the strength is influence by the quality of aggregate [7]. The quality and properties of the aggregate use also have significant effects on the final product of the concrete either in fresh or hardened state. All natural aggregate particles originally formed a part of a larger parent mass. This may have been fragmented by natural processes of weathering and abrasion or artificially by crushing. Thus, many properties of the aggregate depend entirely on the properties of the parent rock [3]. Thus, this study intends to evaluate the effect of different aggregate characteristics on the properties of High performance concrete (HPC).

2. LITERATURE REVIEW

Several research works have been conducted on different type of aggregates in concrete for performance evaluation. Aginam et al., [6], reported that crushed granite performed best in compression than those made with natural gravels of similar grading. Highest compressive strength was achieved from concrete containing crushed quartzite, followed by concrete containing river gravel which indicated that aggregate type also has effect on the compressive strength of normal concrete [8]. Similarly the study by Bhavya and Sanjeev [9] but for different grades of concrete revealed that highest compressive strength was achieved from all grades of concrete containing 12mm Quartzite, followed by concrete containing Granite and river gravel. While according to Kalra and Mehmood [10], the type of coarse aggregate used has a great influence on the strength and elasticity modulus of high performance concrete. However, in high strength concrete the compressive strength is affected by the type of aggregate used whereas in normal strength concrete, compressive strength is independent of aggregate type.

Huynh et al.,[11] use four different maximum particle sizes (Dmax) of coarse aggregates (9.5 mm, 12.5 mm, 19 mm, and 25 mm), test results indicated that the workability of concrete increases with increasing the coarse aggregate size. Concrete made with Dmax of 12.5 mm shows the highest compressive strength, whereas concrete made with Dmax of 25 mm shows the lowest compressive strength.

Beshr et al., [7], evaluated the effect of four types of coarse aggregates (Calcareous, Dolomite, Quartzitic limestone and Steel slag) on compressive strength, tensile strength and elastic modulus of high strength concrete. The result showed that the highest and lowest strength compressive strength was obtained in the concrete specimens produced with steel slag and calcareous limestone aggregates, respectively. Also for the split tensile strength of steel slag concrete was the highest, followed by that of dolomitic, quartzitic limestone and the lowest is calcareous limestone aggregate concretes.

Wu et al., [12], carried out study on the effect of the coarse aggregate type on compressive strength, splitting tensile strength, fracture energy, characteristic length and elastic modulus of concrete produced using crushed quartzite, crushed granite, limestone and marble coarse aggregate. A higher compressive strength and splitting tensile strengths were obtained with crushed quartzite compared to marble aggregate. Conclusively, the results showed that the strength, stiffness and fracture energy of the concrete for a given water/cement ratio (W/C) depend on the type of aggregate, especially for High strength concrete.

Kalra [13] studied the effect of coarse aggregate size on strength of high performance concrete (HPC). Three sizes of coarse aggregates 10mm, 12.5mm and 16mm with two types of fine aggregate with fineness modulus 2.65 and 2.88 were used in the study. It was concluded that concrete made with 10mm size coarse aggregate showed higher compressive strength and the sand with 2.88 FM also yielded higher compressive strength.

Khaleel et al., [14], presented the effect of three types of coarse aggregate, namely crush gravel, uncrushed gravel and crush stone on fresh and hardened properties of self-compacting concrete (SCC) containing metakaolin. It was observed that the flow ability decreases with the increase in the maximum size of coarse aggregate and using crushed aggregate with same Water/binder ratio and super plasticizer. The mechanical properties of SCC mixes containing the 10mm maximum size of coarse aggregate are higher than in mixes with the 20mm maximum size of coarse aggregate. They also concluded that concrete mixes made with crushed limestone give higher strength and elasticity than that made with crushed gravel, and concrete mixes made with crushed gravel gave higher strength and elasticity than that made with uncrushed gravel.

Ekwulo and Eme [15], studied four concrete specimens made from aggregate size of 9.5mm, 12.7mm, 19.1mm and graded aggregate specimen and concluded that workability (slump) of fresh concrete decreases with increase in aggregate size and that compressive strength increases with increase in aggregate size.

Woode et al., [16], investigated the strength ability of varying sizes of gneiss (10, 14,20mm) on compressive strength of concrete by which the result indicated that gneiss of maximum aggregate size 10mm provide a higher compressive strength than the rest. While in another work by Vilane and Sabelo [17] on varying size of crushed stone (9.5, 13.2 & 19mm). The result demonstrated higher compressive strength by concrete containing 19mm crushed stone.

Nduka et al., [18], studied the comparative analysis on concrete produced with quarry crushed and locally sourced coarse aggregate. They encouraged the use of granite over gravel for higher strength concrete application, otherwise the gravel should be sieved and the coarse content washed before use.

The aim of the present study of the HPC is to investigate the effects of aggregates types and sizes (Basalt, Gneiss and Granite) on the characteristics of high performance concrete made with Metakaolin and super plasticizer (Conplast Sp-430).

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Cement

Rapid hardening Portland Cement, Grade 42.5R (Dangote Cement 3X) which complied with BS EN 197-1[19] was used for casting all the sample. The cement has a specific gravity of 3.15 and the fineness modulus of 2.90.

3.1.2 Fine Aggregate

Natural river sand complying with BS EN 12620 [20] was used for the study. It has specific gravity of 2.60 and fineness modulus of 2.60 conforming to zone II of BS882 [5]

3.1.3 Coarse Aggregate

The types of coarse aggregate used in the study are granite, basalt and gneiss of different aggregate sizes (20mm-14mm, 10mm- 5mm). The aggregate are crushed rock complying with BS EN 12620[20]. The Physical properties of the aggregates are given in table 1.0 and Figure 1-3 depict the sample of the three aggregate type used.

Table-1: Physical property of aggregates

S/N	Properties	Granite	Gneiss	Basalt
1	Specific gravity (SG)	2.52	2.83	3.0
2	Water absorption	2%	1.6%	1.6%
3	Aggregate impact value (AIV)	20.3%	22.38%	25.4%
4	Aggregate crushing value (ACV)	25.25%	26.8%	35%
5	Bulk density	1528.7kg/m^3	1686.35kg/m^3	1752.0kg/m^3

Fig-1: Basalt

Fig-2: Gneiss

Fig-3: Granite

3.1.4 Mineral Admixture

The mineral admixture adopted for this research is metakaolin, which is a dehydrated form of clay mineral kaolinite stone that are rich in kaolinite known as China clay. Meta-kaolin used for the study has a PH of 6.9, and a specific gravity of 2.67. The oxide composition of metakaolin is given in table 2.0.

Table-2: Oxides Composition of Metakaolin

Chemical	Percentage Composition
SO_2	67.83
Al_2O_3	18.60
Fe_2O_3	1.15
CaO	1.71
MgO	0.41
SO_3	0.04
K_2O	0.67
Na_2O	0.13
P_2O_5	0.08
MnO_3	0.03
TiO_2	1.86
LOI	6.12

3.1.5 Water

Water fit for drinking is suitable for mixing concrete, therefore water available in the college campus conforming to the requirements of water for concreting and curing.

3.1.6 Chemical Admixture

High performance super plasticizing admixture Conplast SP 430 which is sulphonated napthalene polymers from Fosroc, Fars Iran limited which conforms with BS EN 934[21] and with ASTM C494[22] was used for this investigation.

3.2 Method

3.2.1 Mix design

In this work, a mix proportion of 1: 1.5: 2: 0.35 was used for aggregates size of range 20mm-14mm. Also, a mix proportion of 1:1.42:1.49:0.35 was used for aggregates sizes of range 10mm-5mm. Grade M40 was designed to have the above mix proportioning based on ACI method. Table 3.0 below shows the constituent of each material.

Table-3 Mix proportions used

Components	M40 (10mm-5mm)	M40 (20mm-14mm)
Cement (kg/m^3)	514.3	471.43
Coarse Aggregate (kg/m^3)	768	1024
Fine Aggregate (kg/m^3)	727.7	694.57
Water (kg/m^3)	180	165
Meta-kaolin (kg) for 0%, 7.577.5%, Repl cement	0, 0.38, 0.76	0, 0.35, 0.74
Admixture SP-430 (kg)	0.051, 0.0471, 0.0433	0.045, 0.039, 0.042
w/c	0.35	0.35
Mix proportion	1:1.5:2:0.35	1:1.42:1.49:0.35

3.2.2 Casting of Cubes

The mould of 100mm×100mm×100mm size was used to produce the test samples in accordance with BS EN 12390 [23].

3.2.3 Curing of Cubes

The sample were completely immersed in water for curing age of 7days, 14days and 28days in accordance with BS EN 12390 [23].

3.2.4 Workability

Slump test was carried out in accordance with BS EN 12350 [24].

3.2.5 Unit weight
It was carried out in accordance with ASTM C138 [25].

3.2.6 Compressive Strength

The test specimens (cubes) were removed from water after specified curing time and excess water was wiped out from the surface. The dimension of the specimen was taken to the nearest 0.2m.The bearing surface of the testing machine was cleaned. The loading was carried out in accordance with BS EN 12390-3 (2002).

3.2.7 Water Absorption
The test was conducted in accordance with BS 1881 part 122 (1983).The cubes were removed from the curing tank; they were then weighed under saturated surface dry condition and after air dried for 24 hours. Finally the percentage difference in weight between the air dried and weight (SSD) is the water absorbed.

4. RESULTS AND DISCUSSION

4.1 Workability
Incorporation of meta-kaolin has reduced the workability as shown in Chart-1 and Chart-2 below, the higher the percentage replacement the lower the workability. Also, comparing the slump results of aggregate sizes ranging between (20mm-14mm) and (10mm-5mm) it was observed that the smaller the aggregate sizes the greater the workability and Basalt is more workable followed by Gneiss and then Granite. Therefore, the better the workability of concrete the more ability to develop strength, as that related to the self-compacting ability.

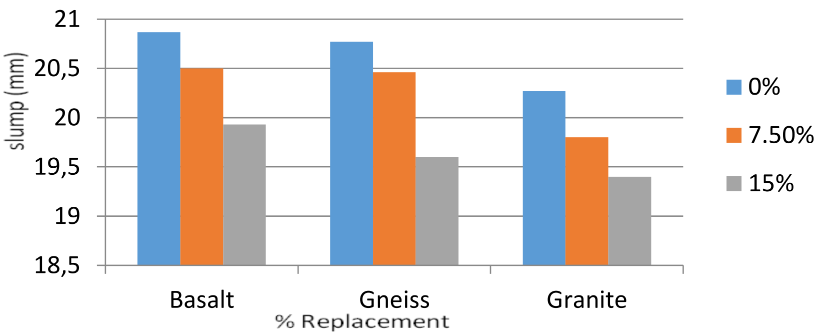

Chart-1: Slump (mm) versus percentage replacement (20mm-14mm)

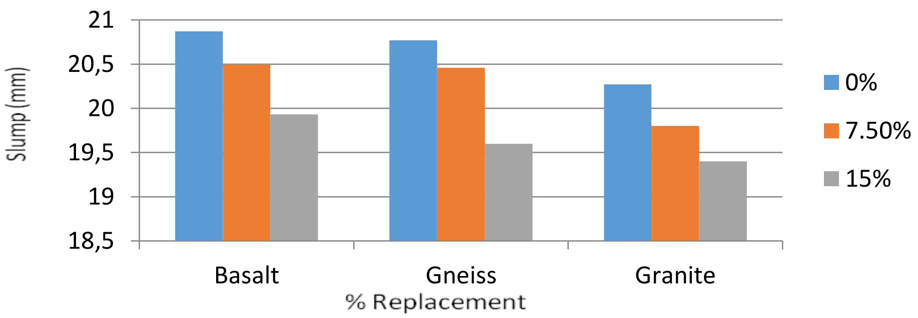

Chart-2: Slump (mm) versus percentage replacement (10mm-5mm)

4.2 Unit Weight
The bulk density of mixes with aggregate of sizes (20mm-14mm) was designed for a density of 2355kg/m^3. The results have shown that the density decreased with increase in percentage replacement. From what was observed, basalt mixed concrete is denser than gneiss mixed concrete and granite mixed concrete, this is due to differences in their specific gravities. Also, the bulk density of mixes with aggregate of sizes (10mm-5mm) was

designed for a density of 2190kg/m^3 where concrete with (20mm-14mm) aggregates has higher bulk density than concrete mixed with (10mm-5mm) aggregates. Chart-3 and 4 show the bulk density results.

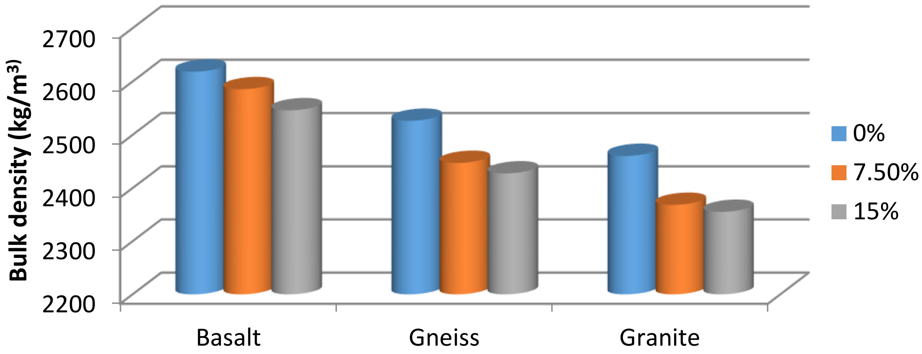

Chart-3: Plot of Bulk Density (20mm-14mm) aggregate sizes

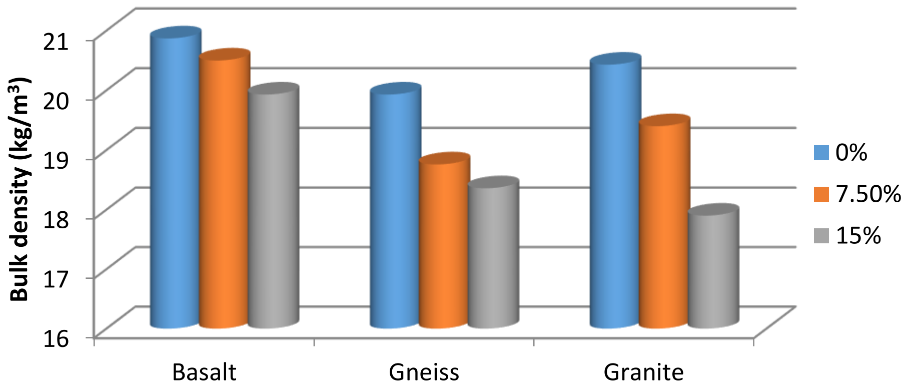

Chart-4: Plot of Bulk Density (10mm-5mm) aggregate sizes

4.3 Compressive Strength

After 7days, 14 days and 28 days of curing, three cubes each for designated mix were tested using the compression machine. The average value of the three cubes was taken as the compressive strength. Table-4 and 5 depict the compressive strength of 20mm-14mm and 10mm-5mm respectively with respect to the type of aggregate.

Table- 4: Compressive Strength Test Results (20mm-14mm) Aggregate Sizes

Curing days	Basalts (N/mm^2)			Gneiss(N/mm^2)			Granite(N/mm^2)		
	0%	7.5%	15%	0%	7.5%	15%	0%	7.5%	15%
7	39.9	43.9	44.8	38.3	40.5	41.5	37.5	38.2	39.6
14	42.4	45.3	46.03	39.3	41.95	43.6	37.65	39.1	41.4
28	43.8	46.7	47.2	40.52	43.13	44.74	39.5	41.1	43.4

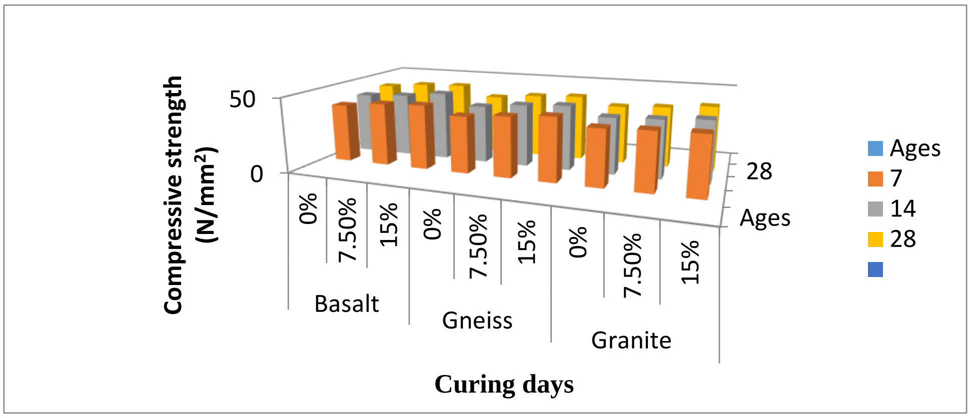

Chart-5: Plot of compressive Strength versus curing days/percentage replacement (20mm-14mm)

Table-5: Compressive Strength Test Results (10mm-5mm) Aggregate Sizes

curing days	Basalts(N/mm^2)			Gneiss(N/mm^2)			Granite(N/mm^2)		
	0%	7.5%	15%	0%	7.5%	15%	0%	7.5%	15%
7	38.94	41.87	43.0	37.75	40.04	42.27	37.34	38.39	39.0
14	40.95	42.53	45.66	38.59	41.55	43.27	37.64	38.78	40.72
28	43.1	45.8	46.69	39.89	42.69	44.03	39.02	40.63	43.13

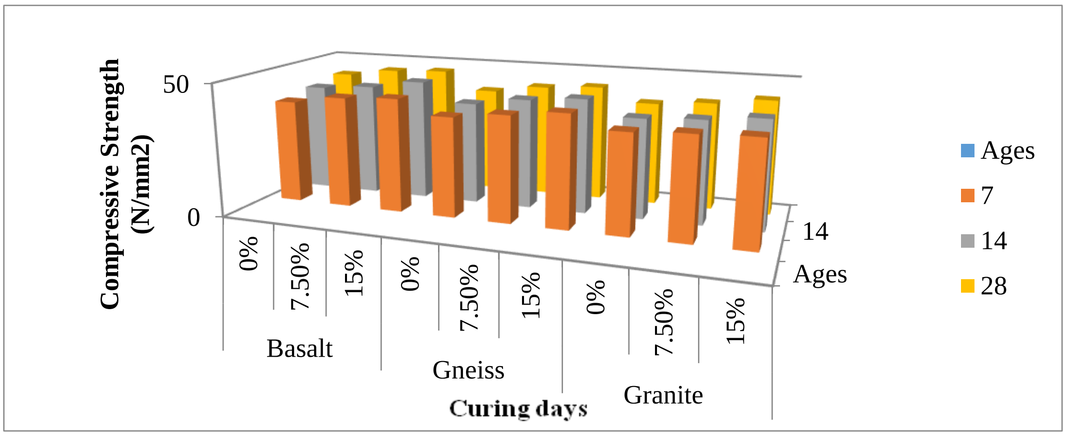

Chart-6: Plot of compressive Strength versus curing days/percentage replacement (10mm-5mm)

The highest compressive strengths for the control samples were found in concrete with basalt aggregate types and optimum for 28days for 20mm-14mm (43.3 N/mm^2). Moreover, the replacement of cement with metakaolin shows increase in compressive strength up to 15% with optimum in Basalt, followed by gneiss then granite. The large aggregate size of the study demonstrated better strength performance which is due to the fact that the size is not above 38.1mm (1/2in) maximum size for which the gain in strength due to the reduced water requirement is offset by the detrimental effects of lower bond area [3].

4.4 Water Absorption

Cahrt-7 and 8 show the results obtained from water absorption, which indicated that it increases with increase in curing ages, and also increases with the replacement levels of metakaolin. Basalt samples absorbs water more, followed by gneiss and granite, were samples made with smaller sizes aggregate (10mm-5mm) absorb water more.

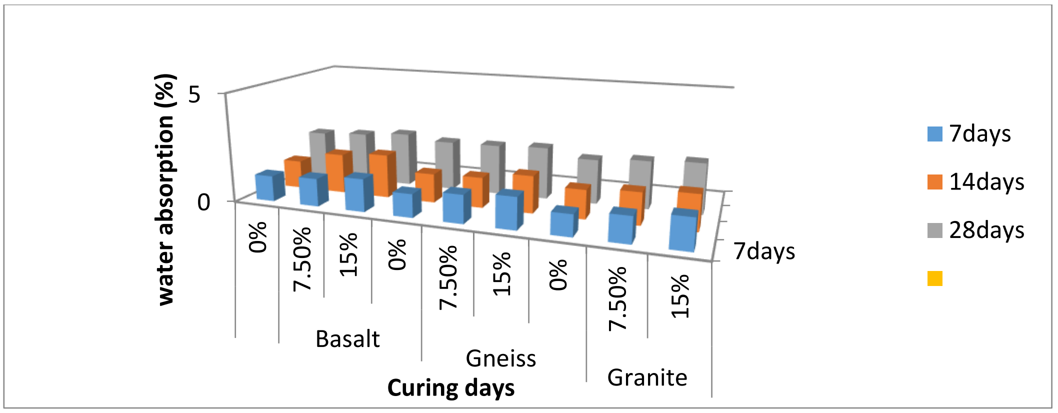

Chart-7: Plot of water absorption against curing days (20mm-14mm) aggregate sizes

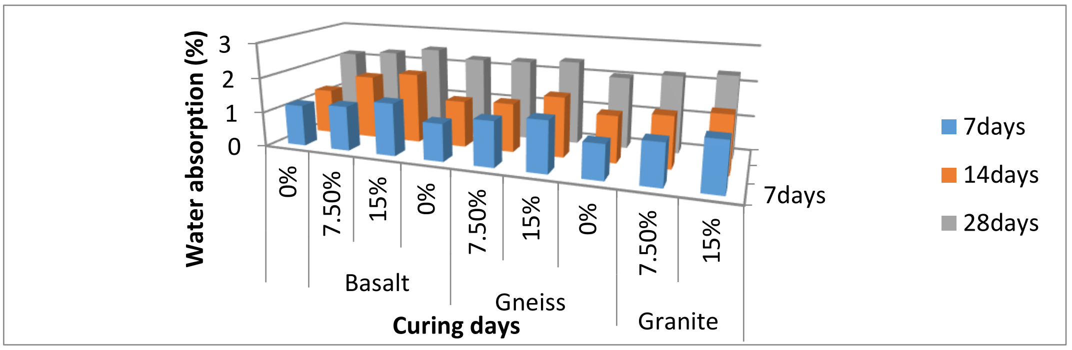

Chart-8: Plot of water absorption versus curing days (10mm-5mm) aggregate sizes

5. CONCLUSIONS

Constant water cement ratio was used throughout in studying the effect of different aggregate types and sizes on workability, density, water absorption and compressive strength of high performance concrete for various percentage replacements with Metakaolin (5%, 7.5% and 15%), using super plasticizer Complast SP-430 as chemical admixture. The following conclusions were made:

1. Workability of the mixes decreases with an increase in percentage of Metakaolin. Also, adding Super plasticizer Conplast SP-430 increases the workability of the mix.
2. The density test demonstrated that basalt-mixed concrete is denser than gneiss-mixed concrete, followed by granite-mixed concrete, and thus, concrete mixed with larger aggregate sizes is denser than those with smaller aggregate sizes, were an increase in percentage of mea-kaolin decreases the density of the mixes.
3. Water absorption of cubes increases with decreases in aggregate sizes, and basalts absorbed more water than gneiss and granite, also the water absorption of the samples increases with an increase in percentage of Metakaolin.
4. The study shows that compressive strength increases with an increase in percentage of metakaolin between 0% to 15% replacements. Basalt-mixed concrete gives higher compressive strength, followed by gneiss-mixed concrete, then granite-mixed concrete.

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