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Research Article

Teleconnection between the Low Index Phase of Southern Oscillation and Precipitation Patterns over the Southeastern United States

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Abstract: A major byproduct begot from industries is Granite Powder (GP) generated from the granite polishing and milling industry in the form of powder. The byproduct is left predominantly untouched and is harmful material to the health of humans because it can be easily inhaled as it is an airborne material. GP was used as an additive to the concrete to explore the possibility of increasing the mechanical properties (compressive strength) of the concrete. The slump, compressive strength and water absorption test were performed on fresh and hardened concrete. The addition of GP to concrete to serve as an additive shows an improvement in the compressive strength of the concrete. The highest 3-day compressive strength (23.03 N/mm2) was recorded at 10% GP addition level while the lowest 3-day compressive strength (20.47 N/mm2) was recorded at 2.5% GP addition level. The highest 28-day compressive strength (28.29 N/mm2) was recorded at 10% GP addition level while the lowest 28 days compressive strength (27.40 N/mm2) was recorded at 2.5% GP addition level. Peak compressive strength of 33.40 N/mm2 was obtained at 56 days when 10% GP was added in the concrete production. The workability of the concrete decreased with increase in GP replacements. Therefore a higher water to cement ratio will be required to maintain a certain level of workability. In conclusion, employing GP as an additive in concrete helped in boosting the mechanical properties of concrete. The GP at 10% addition is the best choice among other concrete mixtures as it is equivalent to grade 30 concrete suitable for producing post tensioned concrete.

***Keywords*:** granite powder; river sand; mechanical properties; compressive strength

1. Introduction

The material that is most extensively employed for construction in the world today is concrete. Concrete is employed in structures, parking lots, road pavements, sidewalks concrete dam and lots more applications. The fulcrum of concrete strength and durability is the mix ratio between the various concrete constituents. Smaller cement paste results to more pores, thus yielding concrete of weaker strength and poor durability properties while more cement paste results to concrete that less durable as a result of high shrinkage. The grade of fine and coarse aggregates as well as mix ratio can affect concrete porosity and strength. Achieving desired workability should be one of the key factors in the mix design in other to allow for easy concrete placement without segregation. Normally concrete constitutes about 10% to 15% cement, 25% to 30% fine aggregate, 40% to 45% coarse aggregate and 15% to 20% water. Concrete should have strong mechanical and durability properties to ensure it can effectively carry applied loads and also have a useful life

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span to minimize maintenance cost [1] and compressive strength is the major concrete property that determines the other characteristics of the concrete. Generally, a concrete with good durability characteristics will display sufficient defiance to alkali-silica reaction, sulphate and abrasion reactions, seawater, chlorides, freeze and thaw and ultraviolet radiation. A very good material from the waste of polishing industry; Granite powder has shown great qualities as a material that can be employed in concrete production which resembles some pozzolanic materials such as slag, fly ash, silica fume etc. These products can be employed as surrogate materials for fine aggregate to lessen the void content of the concrete. The crushing of granite stone and granite stone polishing in the industry yields a waste product know as granite powder. It can also be obtained from granite pavers, terrazzo, stone scraps, and marble tops etc. when recycled. If its collection and disposal is not well managed the fine granite powder possesses tendencies of being airborne causing environmental problems and health hazards. Inhaling fine particles of granite powder affects human health as it negatively affects the lungs. The efficient re-use of granite powder will prevent the waste from been dumped in landfills providing economical and environmental friendly granite powder for various applications. For flooring, countertops and walls, recycled tiles made from recycled glass or factory waste have been adopted [2]. Industrial wastes otherwise known as post-industrial waste derived from the manufacture of standard tiles can also be used to make ceramics tiles. Fireclay tiles 'Dirt' series combines recycled materials from the post-industrial and post-consumer sectors. The granite dust recovered from the cutting operation makes up 26% of the material in the trash series tiles. Additionally, it has 26% recycled glass (post-consumer waste).

Binici and Aksogan [3] studied the durability properties of concrete incorporated with natural occurring granular granite, waste marble and basalt powders as fine aggregate replacement. The experiment recorded that concrete with constituents of natural granite, waste marble, silica sand and basalt powders showed superior durability qualities to the nominal concrete. It was concluded that incorporation of waste marble and basalt powders, natural granular granite and silica sand produces concrete that is less permeable. Shao and He [4] looked into the possibilities of using sandstone powder as a mineral additive to replace cement. It was noted that there could be a gain in concrete and decrease in alkali silica reaction as a result of the decrease in specific surface area of the sandstone powder and the pozzolanic behaviour of sandstone coarse aggregate respectively. The behaviour demonstrated that compressive strength might reduce by 35% if 50% of cement is replaced with sandstone powder but the strength could be enhanced with addition of 5% silica fume to the hybrid sandstone powder. Ashish [5] investigated the feasibility of partially replacing sand and cement amalgam with waste marble powder. The results showed that marble powder played no part in the hydration process but acted as filler. Maximum replacements were recorded at 10% sand and cement amalgam by 20% powder of marble. Tavakkolizadeh and Taji [6] studied the properties of marble and granite waste dust (MGWD) resulting from marble and granite stone processing. The results indicate that20% replacement of cement by MGWD does not show any significant influence in the concrete's mechanical properties. Furthermore, open circuit potential investigation showed that employing 10% granite and 10% marble waste dust in place of cement promotes the corrosion resistance of the reinforcements in the concrete. Ashish [7] partially replaced sand with up to 15% of marble powder and replaced cement partially with supplementary cementitious material in nine different concrete mixtures. The results showed that metakaolin and silica fume enhanced th durability properties of concrete with 15% of sand replaced by marble powder and metakaolin been more effective than silica fume. In addition, the cement paste showed no negative behavior in terms of expansion or setting due to cement replacement with marble powder.

Lu et al. [8] investigated the flexural strength, crystallization and densities of concrete with glass-ceramics additives. Flexural strength of 125 MPa was recorded which was more superior than that of natural granite with increase in crystallinity as the content of boehmite was increased. The sintered glass-ceramics with high flexural strength and artistic patterns indicates better reusability of granite waste for the purpose of ornamental tiles. Boukhelkhal et al. [9] investigated self-compacting concrete properties when waste marble (WMP) is employed as partial replacement

of cement regarding the effect on the concrete's durability and strength characteristics. The results showed that WMP increased the water capillary absorption of the concrete and water absorption at immersion. In addition, increase in WMP yielded decrease in compressive strength of concrete. Higher sulphate resistance and lower expansion were recorded for self-compacting concrete containing WMP. Zainuddin et al. [10] examined the geotechnical properties of marine clay in a bid to improve its qualities with the use of granite powder derived from tiles that were destroyed. The inclusion of DTM reduced the water holding capacity i.e. the plasticity of the soil from 33% - 29% and optimum water content from 32% to 22% with corresponding increase in maximum dry density from 1.34 to 1.48 Mg/m3. Furthermore, the micro-structural analysis observed that DTM acts majorly as filler and that at 5% significant increase in strength was recorded as curing age increased. Jain et al. [11] analyzed the self-compacting concrete's characteristics in wet and dry form containing granite cutting waste (GCW). The incorporation of GCW in the self-compacting concrete resulted to increase and decrease at 20% and beyond 20% replacements for both compressive and flexural strengths respectively. And at 40% replacement the flexural strength and ultrasonic velocity values of modified SCC was found higher than that of the control specimen. It was concluded that GCW could be efficiently employed for sustainable SCC mixes. Lu et al. [12] altered waste granite powder and sintered to produce durable, high-strength ceramics. Results indicate optimum flexural strength of 143 MPa and fracture toughness of 2.1 MPa m1/2 recorded at a heating rate of 500C min-1 which is much higher than that of natural granite. The sintered glass-ceramics showed major crystalline phase of anorthite in the crystal structure.

Lots of researches have done on the use of granite powder waste as partial replacement of cement or fine aggregate in concrete but very little has been on the use of granite powder as an additive. The concrete constituents that is the most expensive and key determinant factor in concrete strength is cement. Increasing cement content in concrete in a bid to increase the strength properties makes construction of civil projects uneconomical; on the other hand, these same strength properties can be enhanced by adding a certain percentage of granite powder to the concrete mix. In the current work, different percentages of granite powder are added to concrete as an addition, and the resulting compressive strength of the concrete has been assessed. The health risk posed by these industrial wastes is reduced as a result. If it is possible to use this granite fines to increase the mechanical properties of concrete particularly its compressive strength, then this will help promote the usage of granite powder waste in bigger civil projects where higher resistance to structural loading is required and at the same time will solve waste disposal problems.

2. Experimental programme

2.1 *Materials*

2.1.1 *Cement*

Dangote brand of Ordinary Portland Cement was used throughout the project. Cement was tested for its consistency and soundness as prescribed in BS EN 196-3 [13].

2.1.2 *Water*

Water obtained from tap in the concrete laboratory was used for producing the concrete. Note: water was free from dirt and impurities in order not to negatively affect the properties of the concrete.

2.1.3 *Fine aggregates*

Aggregate size passing 5 mm sieve and settling on 0.063 mm was employed for the research. Table 1 and Figure 1 shows that passing percentage complies with the Grading Zone II of B.S 882 [14] as shown as is suitable for use as fine aggregate for concreting.

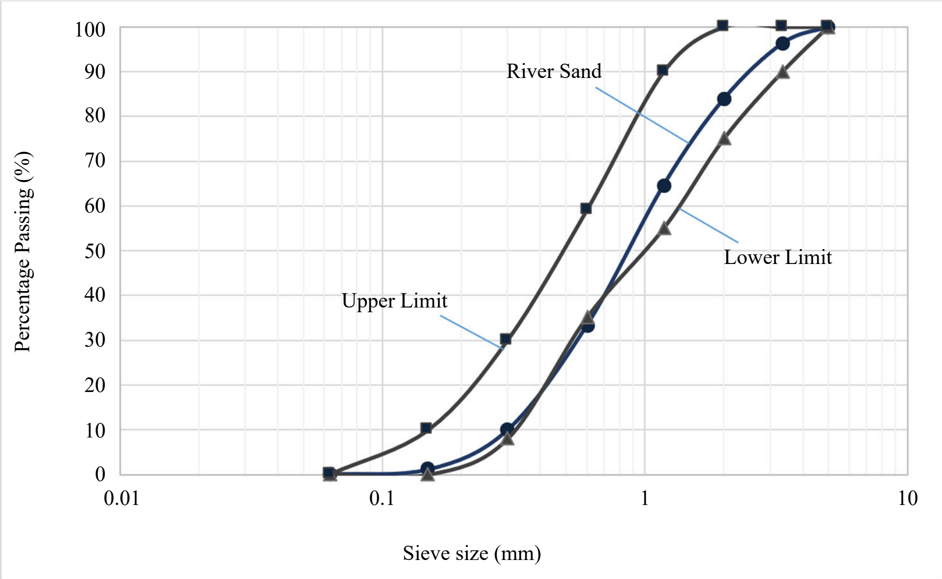

Figure 1. Grading curve of River Sand (RS)

2.1.4 *Coarse Aggregate*

Maximum coarse aggregate size 20 mm was employed for the experiment. Figure 2 shows that passing percentage complies with the Grading Zone II of B.S 882 [14] as shown as is suitable for use as coarse aggregate for concreting.

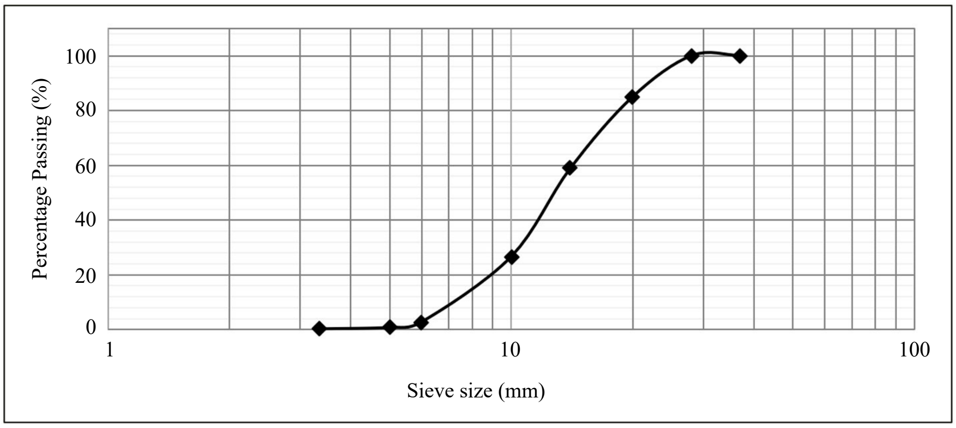

Figure 2. Grading curve of Coarse Aggregate

Bulk density of coarse aggregate

Bulk density is the mass of the substance (together with any solid particles and water that may be present) per unit volume, voids included. The bulk density is influenced by the particle size and shape as well as how tightly the aggregate is packed. The method for the determination of bulk density is given by BS 812 – 2: 1995 [15].

Table 1. Bulk Density of Coarse Aggregate

S/N	Wt. of empty cylinder W^1 (kg)	Wt. of cylinder + sample W^2 (kg)	Wt. of Cylinder + Water, W^3 (kg)	Volume $\frac{W_3 - W_1}{1000}$ (m^3)	Bulk density $\frac{(W_2 - W_1)}{v}$ (kg/m^3)	Average Bulk Density (kg/m^3)
1	2.40	3.29	2.95	0.00055	1618.20	
2	2.40	3.30	2.97	0.00055	1578.90	1571.40
3	2.40	3.28	2.98	0.00055	1517.20	

The average bulk density of coarse aggregate is 1571.40 kg/m3 as presented in Table 1.

2.1.5 *Granite Powder*

The granite powder was obtained from granite polishing unit at Sahelian Granite Engineering Limited Bauchi, within Bauchi metropolis. The material is dump as waste within the premises.

Table 2. Chemical composition of granite powder

Chemical compound	Weight (%)
MgO	0.53
Fe2O3	5.72
Al2O3	11.92
TiO2	0.65
SiO2	63.5
P2O5	0.59
K2O	5.16
Na2O	5.89
CaO	4.70
MnO	0.37

The chemical composition of granite powder as indicated in table 2 shows large content of alumina and silica which were pivotal to the formation of aluminosilicate phases, regular with the faces of the microcline and anorthite. Figure 3 show the grading curves for granite powder and river sand.

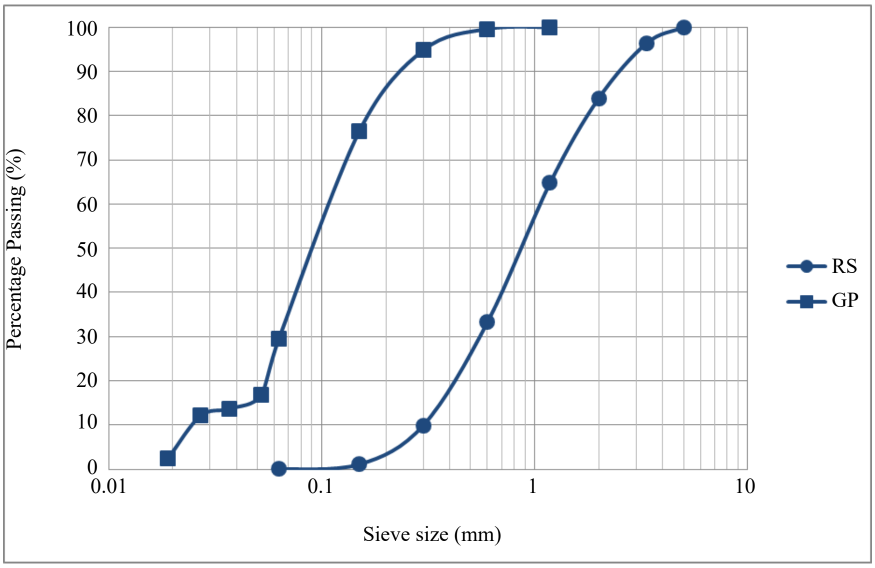

Figure 3. Grading curve of River Sand (RS) and Granite Powder (GP)

2.2 *Experimental tests*

Sieve analysis was conducted on the aggregates in accordance to BS EN 933-1 [15]. After which the specific gravity of the aggregates were determined as prescribed in BS EN 1097 - 3 [16]. Furthermore, the aggregates resistance to impact and crushing load (AIV & ACV) were then determined respectively [17, 18]. After mixing each batch, slump test was conducted as stipulated in BS EN 12350-2 [19] to ensure the mix was uniform throughout. After casting the concrete cubes, the density of each cube was determined BS EN 1097-3 [20] and submerged in a water tank i.e. curing. The measure of concrete resistance to failure due to loading is referred to as the compressive strength test was conducted in accordance to BS EN 12390-1 [21].

2.3 *Mix proportions*

Concrete cubes of size 150 mm x 150 mm x 150 mm were produced at designed mix ratio using the granite powder as an additive. The granite powder was at different percentages ranging from 0%, 2.5%, 5%, 7.5% and 10% by weight of cement to serve as additive. The required quantities of materials used in producing the concrete are presented in Table 3.

Table 3. Chemical composition of granite powder

% of GP Added	GP (kg)	Cement (kg)	Water (kg)	Fine Aggregates (kg)	Coarse Aggregates (kg)
0	0	1.18	0.68	2.44	3.66
2.5	0.029	1.18	0.68	2.44	3.66
5	0.059	1.18	0.68	2.44	3.66
7.5	0.088	1.18	0.68	2.44	3.66
10	0.118	1.18	0.68	2.44	3.66

3. Results and Discussions

3.1 *Cement*

Dangote brand of Ordinary Portland Cement was used throughout the project. Cement was tested for its consistency and sound

Table 4. Result for setting time and soundness of cement

Consistency (%)	Initial Setting Time (minutes)	Final Setting Time (minutes)	Soundness (mm)
31	50	655	1.5

The standard consistency test was carried out to determine the water content required for a given cement to produce a paste of standard consistency which is also used for finding out the initial setting time, final setting time and soundness of the cement. The results for consistency, setting time and soundness of cement are presented in Table 4. The cement had an initial setting time of 50 minutes, final setting time of 655 minutes and a soundness of 1.5 mm. The cement brand met the BS EN 197-1:2000 [22] requirement with regards to setting time; that is $\nless$ 45 minutes for initial setting time and $\nless$ 10 hours for final setting time and $\ngtr$ 10 mm for soundness.

Table 5. Specific gravity of granite powder

			Granite			
Sample No.	M_1 (g)	M_2 (g)	M_3 (g)	M4 (g)	G_S	Average G_S
1	23.70	33.70	78.70	72.40	2.70	2.70
2			78.70	71.50	2.70	
			River sand			
1	23.70	33.70	78.60	72.40	2.63	2.63
2	20.40	30.40	77.70	71.50	2.63	

$$G_s=(M_2\text{-}M_1)/(M_4\text{-}M_1)\text{-}(M_3\text{-}M_2) \quad (1)$$

Table 5 present the specific gravity results for both granite powder and river sand. The specific gravity of river sand is found to be 2.63 with the fineness modulus is 3. This falls within the range of values 2.6 – 2.7 and 2 – 3 as recorded by Neville [23] for specific gravity and fineness modulus respectively. In addition, granite powder gave specific gravity 2.7 which is also within the range of values 2.7 – 3 as obtained by Neville [23]. These values qualify it for use in the mix design and thus concrete production.

3.3 *Aggregate strengths*

Toughness can be defined as the resistance of aggregate to failure by impact and crushing, and it is usual to determine the aggregate impact value (AIV) and aggregate crushing value of bulk aggregate (ACV).

Table 6. Aggregate Crushing & Impact Value (ACV) of Coarse Aggregate

AGGREGATE CRUSHING VALUE						
S/No.	Wt. of empty cylinder W_1 (kg)	Wt. of cylinder + sample W_2 (kg)	Wt. of sample passing sieve 2.36mm W_3 (kg)	Wt. of sample $W_2 - W_1$ (kg)	ACV	Average (%)
1	2280	2925	125	645	19.30	
2	2280	2920	120	640	18.75	18.72
3	2280	2915	115	635	18.10	
AGGREGATE IMPACT VALUE						
1	2280	2920	115	640	17.97	
2	2280	2900	90	620	14.52	15.59
3	2280	2910	90	630	14.28	

$$ACV=AIV=\left(W_3/W_2-W_1\right)\times 100 \quad (2)$$

The aggregate crushing and impact values were 18.72% and 15.59% respectively as shown in Table 6. These values are within the range of crushing value and impact value of (9 – 35%) specified for crushed granite [17, 18], hence its suitability for application in civil works e.g. used for construction of rigid pavement.

3.4 *Concrete tests*

Concrete with expected 28 days characteristics strength of 25 N/mm2 was designed for concrete with granite powder as an additive.

3.4.1 *Workability test*

Slump test was carried on the freshly mixed concrete to determine the concrete workability. Workability is the amount of useful internal work necessary to produce full compaction. One of the major parameter on which concrete finished surface appearance, durability and strength is dependent on is the concrete's workability. As concrete strength is negatively affected by voids in the compact mass of the concrete achieving maximum density is very important. To this regards, sufficient workability is required to enable full compaction under all working conditions. Voids in concrete bring about reduction in the density and strength of the concrete. Concrete workability depends on the ratio water to cement content in the mix and the capacity of the aggregates to absorb water. The test was carried out in accordance with BS EN 12350-2 [19].

Table 7. Workability test results

S/N	Sample Identity	SLUMP (mm)
1	A2.5%	38
2	A5.0%	38
3	A7.5%	36
4	A10%	35

The workability result for the concrete mix is presented in Table 7. It can be observed that 2.5% and 5.0% granite powder additions have the same workability value of 38 mm. 10% granite powder additions has the least workability with a slump value of 35 mm. There is also a slight decline in workability as the percent addition of GP in increased. In smaller percentage the power of granite powder as filler is more effective and its power reduces with increase in percentage. At 2.5% and 5% addition the concrete void was adequately filled by the granite powder and equally matched by the cement content and water/cement ratio in terms of concrete bond. But as the percentage of granite powder increased to 7.5% and 10% the binding strength of the cement paste became less i.e. insufficient leading to reduction in workability. However, all the slump values are within the design range (i.e. 30 – 60 mm).

3.4.2 *Water Absorption*

Bar graph of water absorption against curing age is presented in Figure 4 to compare the variations of water absorption of control concrete (i.e. 0% GP addition) and concretes at 2.5%, 5.0%, 7.5% and 10% GP additions levels. Peak water absorption recorded as 2.20% for 10% addition at 28 days of curing while the lowest recorded is 0.56% for 7.5% addition at 3 days of curing. The water absorption of 0% GP and 10% GP concrete samples increased steadily from 1.29 to 2.89% and 1.09 to 2.20% at 3 days and 28 days but dropped to 2.59% and 1.69% at 56 days curing. Concrete samples with 7.5% GP addition showed the least water absorption at all ages recording 0.56, 0.68, 1.0, 1.52 and 0.98% at 3, 7,14, 28 and 56 days respectively.

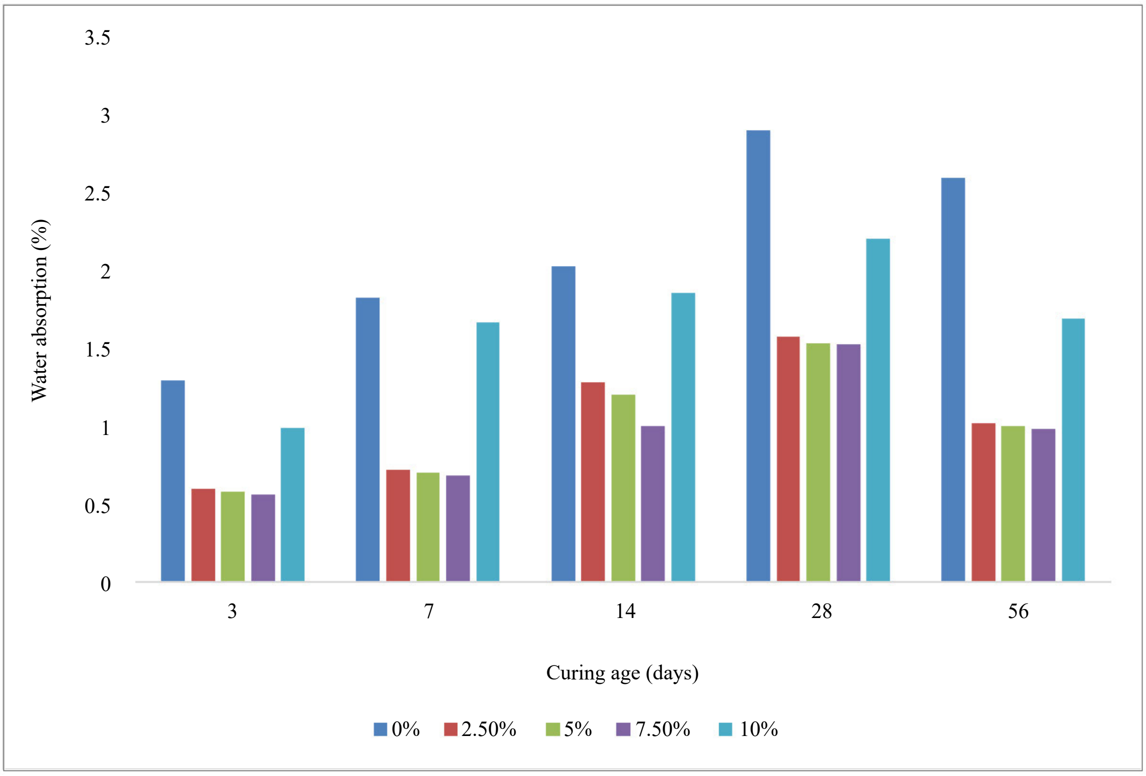

Figure 4. Bar chart of water absorption at different curing Age

From figure 4 it can be noted that the water absorption of the control specimen are higher than the specimens with granite powder and it steadily increased as curing age increased up to 28 days implying that it had more void content. This also proves that granite powder is a good material for promoting concrete properties as it adequately fills voids in concrete and granite powder concrete yields better qualities than the conventional concrete when added to concrete at and below 10%. During compaction the silicate oxide in the granite powder facilitates a greater bond between 2.5% to 7.5% thereby filling most of the voids contained in the concrete and preventing the concrete from absorbing much water, which is why the water absorption of the specimens reduced with percentage increase of GP from 0% to 7.5%. However, at 10% cement paste became insufficient to bond the excess granite to other concrete constituents giving room to some voids in the concrete and thus increasing the water absorption. The water absorption properties of the concrete cubes recorded reductions at age 56 days; this is because after maximum hydration must have taken place after 28 days the flow of water into concrete will reduce as most of the voids have already been filled with water as a result of the reaction between water and particles of cement in the concrete mixture. Prokopski [24] recorded decrease in water absorption by 32–38 % and water penetration by 60–70 % with the addition of granite dust into concrete.

3.4.3 *Density*

Bar graph of Density against Curing Age is illustrated in Figure 5 to compare the variations of dry density of control concrete (i.e. 0% GP addition) and concretes at 2.5, 5.0, 7.5 and 10% GP additions levels. The peak dry density recorded was 2508 kg/m3 for 10% addition at 56 days of curing while the lowest recorded was 2291 kg/m3 for control concrete (i.e. 0% replacement) at 3 days of curing. From these values, it can be deduced that the range of density is 2291 kg/m3 – 2508 kg/m3; This falls within the range of densities for normal concrete (i.e. 2200 kg/m3 – 2600 kg/m3) as stated by Shetty [25]. Aggregate specific gravity is the major factor that determines the density of concrete as well other properties of the concrete component. Experimental results showed that specific gravity of granite powder is 2.7 while that of river sand is 2.63; this proves the reason for the difference in densities of the control concrete and the granite powder concrete. Dead load of a structure is largely dependent on the density of the concrete which in the long run affects the general performance of the structure.

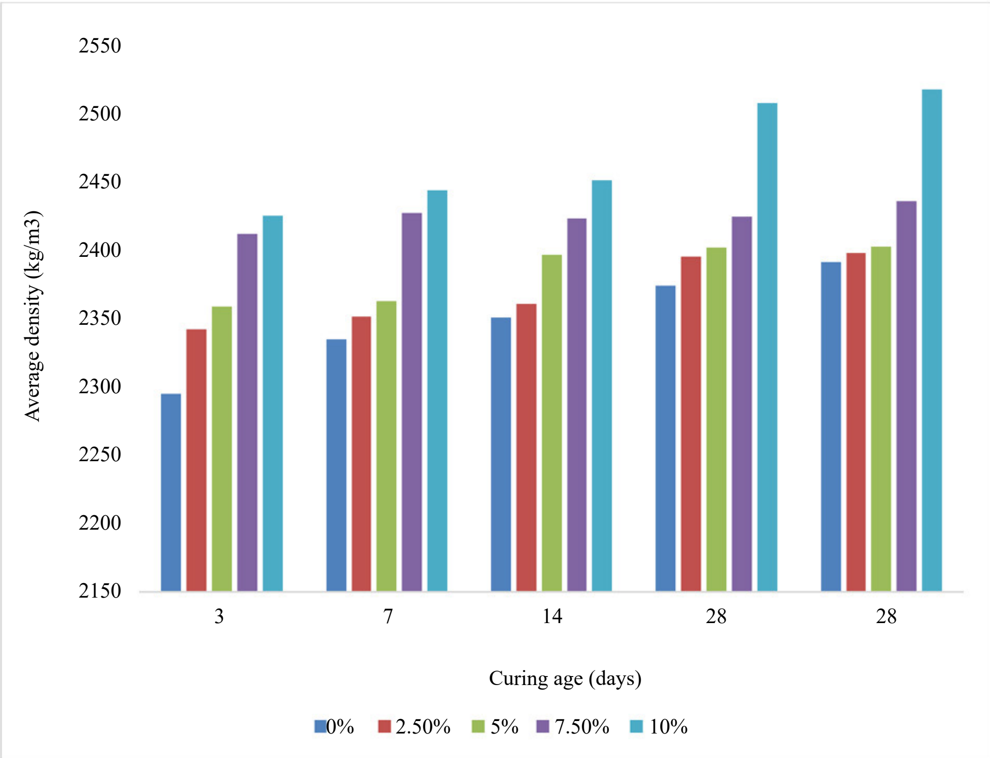

Figure 5. Bar chart of Density Vs Curing Age

3.4.4 *Compressive Strength*

Figure 6 show that there is an improvement in compressive strength of the concrete as the percentage addition of GP increases, the peak compressive strength (33.40 N/mm2) occurring at 10% GP addition and at 56 days of curing equivalent to grade 30 concrete which qualifies it as concrete for use with post tensioned tendons [26]. The highest 3-day compressive strength (23.03 N/mm2) was recorded at 10% GP addition level while the lowest 3-day compressive strength (20.47 N/mm2) was recorded at 2.5% GP addition level. The highest 28-day compressive strength (28.29 N/mm2) was recorded at 10% GP addition level while the lowest 28 days compressive strength (27.40 N/mm2) was recorded at 2.5%

GP addition level. Addition levels of GP for all of the concrete specimens showed greater results than that of the control specimen.

The 28 days design compressive strength of the control sample was 25 N/mm2 but at 28 days 10% GP addition yielded a compressive strength of 28.29 N/mm2, after further curing 10% GP yielded a compressive strength of 33.40N/mm2 as compared to that of the control specimen which was 26.96. The mix ratio for a grade 30 concrete will definitely require more cement content which will inflate the cost of the concrete, but this research as shown in figure 8 has proven that granite powder increases the strength and mechanical characteristics of concrete and also reduces the production cost thereby increasing its economic value and preferring solution to waste disposal problems of granite powder.

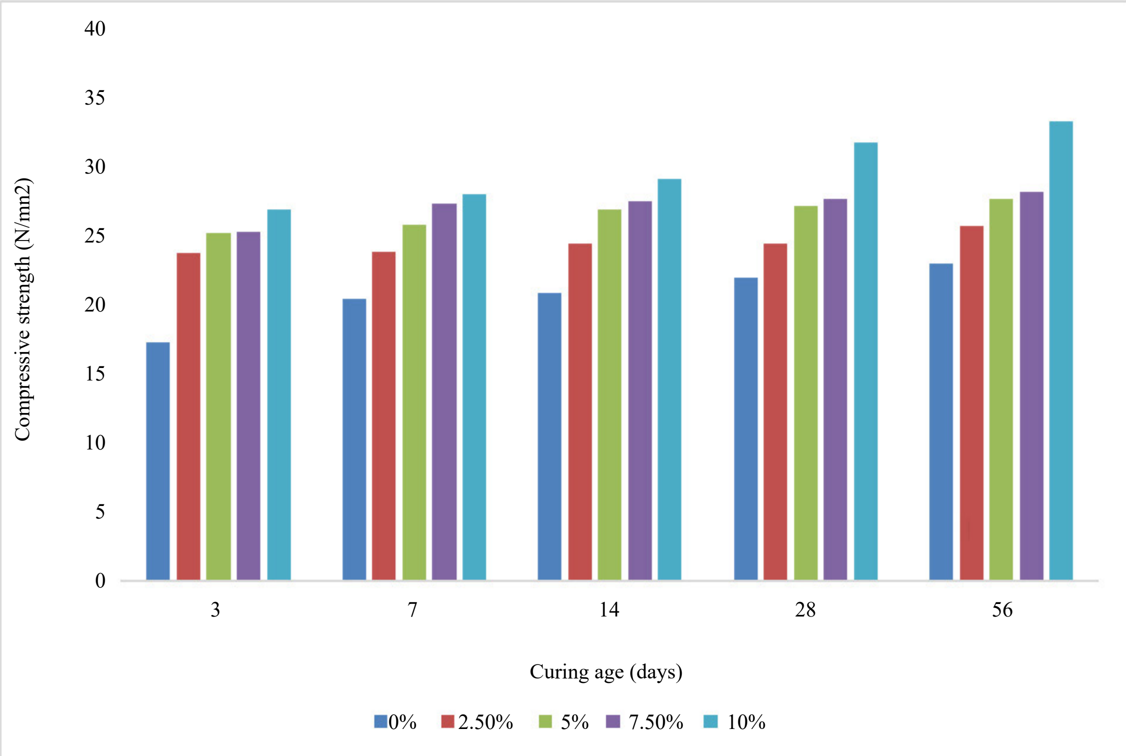

Figure 6. Plot of Compressive Strength against Curing Age for control (0%) and GP addition level

Major factors that characterize the performance and properties of granite powder are the chemical composition, particle crystal structure and morphology. The particles which are micro-sized in nature showed cleaved surfaces and edges that were very sharp; clear reflection of the characteristics of granite stone. The particle size of the granite powder is very important in determining the physical and chemical properties of the concrete and how it positively affects the concrete quality. This is because the size of granite powder is very small, as a matter of fact much smaller than that of sand hence enables it to fill any void that may exist between fine aggregate, coarse aggregate and cement paste thus resulting in little or no void in the concrete thereby yielding concrete of higher density and very high compressive strength. Furthermore, because of the very small texture of the particle size it gives the granite powder a very large surface area of contact with all the other concrete constituents. For this reason, the concrete is expected to yield compressive strength that is higher than that of conventional concrete as a result of a more consistent sticky mixture and more bonded areas with hydrated cement. From figure 5 density of concrete increased with corresponding increase in granite powder meaning granite powder brings about increase in compressive strength. The addition of granite powder compacts the micro-structure of the cement matrix and this is the exactly reason granite powder is used for increasing the mechanical properties of concrete i.e. compressive strength and other strength properties. Granite dust has a positive effect on concrete strength both at 3 days, as well as the strength at 56 days of hardening. Even though the silicon oxide content of granite powder is not too high preventing the entire granite powder from reacting with the cement chemically, the effect as filler will most likely improve the compressive strength and thus the mechanical properties of the concrete. The experimental results indicate that the best gain in compressive strength was with 10% granite powder. Ghannam et al. [27] replaced sand by 5%, 10%, 15%, and 20% of GP by weight and recorded that 10% GP replacement had the best effect on increasing the mechanical properties of concrete as it showed 30% increase in compressive strength compared to the nominal concrete. It looks like beyond the 10% replacement, the power of granite powder waste as filler is not optimized. In most cases, maximum particle size distribution in concrete will produce concrete of higher density and less voids. For this reason, if the distribution of the particle is not optimal the concrete compressive strength and mechanical properties will be less as a result of high void content. It seems that increase in surface area will require more hydrating cement to bond these areas. If the ratios of water to cement including additional admixtures are not adequate to hydrate enough cement, then the increase in surface area of granite powder will not be properly covered by the cement matrix thereby increasing the adhesive bond and reducing cohesive bond of the concrete constituents. Thus, decreasing the strength properties of concrete with corresponding increase in ratio of granite powder.

Other researchers also obtained similar results [28, 29]. Vijayalakshmi et al. [30] prepared concrete by 0%, 5%, 10%, 15%, 20% and 25% of fine/natural aggregate replaced by GP waste. The obtained results showed that 15% replacement of river sand by granite powder waste of any mix ration is good for concrete production without negatively affecting the strength and durability properties. In Zhang et al. [31] investigation of the properties of ultra-high performance concrete (UHPC) replacing 0 to 25% of cement with ground granite powder (GGP). It was observed that GGP did not affect the chemical compositions and morphology of hydration product but changes were recorded in the pore structure over the replacement ratio ω_{GGP}. Maximum replacement ratios recorded were 15%, 10% and 5% for UHPC cubes cured under autoclaved, warm water and standard curing respectively. Autoclaved curing was noted as the curing type that enhanced the polymerization and hydration degrees of hydration product. Increase was also recorded in flexural and compressive strengths at the initial stage as ω_{GGP} increased. This proves that curing age and method of curing also affects the mechanical and durability properties of concrete. From the foregoing discussions, it can be seen that incorporating granite powder into concrete is beneficial. Thomas and Partheeban [32] replaced sand by 0, 25, 50, 75 and 100% of granite powder and partially replaced cement with 1% superplasticiser, 7·5% silica fume, 10% slag and 10% fly ash. The highest compressive strength was achieved in samples containing 25% granite powder. In the research carried out by Prokopski et al. [24] It was seen that adopting CEM I 32,5 R, the strength increased from 24% to 25% at the age of 3, 7 and 28 days, which is slightly higher compared to using CEM I 42,5 R, which increased 17% to 19 % compared to control specimens with no granite powder.

4. Conclusion and Recommendation

4.1 *Conclusiont*

Based on the results of the experimental investigation, the following conclusions are drawn.

1. The addition of GP to concrete to serve as an additive shows an improvement in the compressive strength of the concrete.
2. Peak compressive strength of 33.40 N/mm^2 was obtained when 10% GP was added in the concrete production at 56 days curing age. Therefore, GP at 10% addition is the best choice among other concrete mixtures equivalent to grade 30 concrete which qualifies it as concrete for use with post tensioned tendons.
3. The highest 3-day compressive strength (23.03 N/mm^2) was recorded at 10% GP addition level while the lowest 3-day compressive strength (20.47 N/mm^2) was recorded at 2.5% GP addition level. The highest 28-day compressive strength (28.29 N/mm^2) was recorded at 10% GP addition level while the lowest 28 days compressive strength (27.40 N/mm^2) was recorded at 2.5% GP addition level.
4. The workability of the concrete decreases with increase in GP replacements. Therefore, a higher water to cement ratio will be required to maintain a certain level of workability.
5. It is beneficial when GP is in used as an additive in concrete as it enhances the compressive strength and mechanical properties of concrete i.e. high strength concrete. The granite powder; a waste produced from the granite processing unit can be effectively utilized by incorporating it in the production of concrete thereby eradicating

waste management disposal problems of granite powder and make production of high strength concrete more economical.

4.2 *Recommendation*

This project focused mainly on the compressive strength of the concrete. However, studies on other properties of the concrete such as flexural strength, split tensile strength and durability can also be carried out for the production of suitable concrete with the inclusion of GP as a partial substitute and also as an additive.

Summary statement

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