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The influence of mineralogical composition and alkali reactivity for utilization of some Egyptian crushed granites as a concrete aggregate

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Abstract. Egyptian Eastern Desert is rich in many areas that contain granites masses throughout the geological era; some of them show good characteristics of the rock hardness, durability, density and mineralogy. This current research aims to utilize three main types of granite aggregates based on their mineralogical composition and Alkali reactivity with cement during concrete production. The studied granite aggregate can be also classified into red younger granite aggregate, white older granite aggregate and grey older granite aggregate. Evaluating these granite rocks as aggregate used in concrete mixture is interesting by produced three mixes using the three studied granite aggregate symbolized (Red GA), (White GA) and (Grey GA), tested mechanically to give a more detailed for the obtained results to be not restricted for only studied granite aggregate criteria but also to follow the actual reaction of this studied granite aggregate with cement. It was obtained that all studied granite aggregates within acceptable limits of concrete aggregate by following Egyptian code (ECP-203) although their variation on its mineralogical composition. Some reflections produced from change in mineralogical composition between the three studied granite aggregates exhibited by relative regression in the average physico-mechanical values for both (White and Grey GA) than (Red GA). On the other hand, slight reactive for (Red GA) than others at the age of 28 day. In addition, all produced (Red GA), (White GA) and (Grey GA) mixes were acceptable mechanically with limits of (ECP-203) giving benefit for using all of the studied granite aggregate after their detailed study involving its mineralogical composition and alkali aggregate reactivity (AAR).

Key words: Aggregates, Granite, Mineralogical composition, Alkali reactivity, Compressive strength.

1. Introduction

Generally, aggregate encompasses a wide variety of naturally occurring or manmade materials of different sizes and physical properties (Langer, 1993). Engineering definition of aggregate considered as particles of rock which when brought together in a bound condition form units of engineering structure, (Neville, 2011). Nature aggregate type essentially refers to the geological origin of the aggregate under investigation. The main distributed aggregate types could be classified into igneous, sedimentary, and metamorphic rocks as discussed by many authors (Tsado, 2013; Shahien et al., 2014; Petrounias et al., 2018; El-Fakharany et al., 2019). Locally, igneous aggregates are further subdivided on the basis of their mineralogy to granite and basalt according to the Egyptian specification.

Aggregate should be selected for adequate durability and workability for concrete application. Limited resources and huge demand of local aggregates needed to investigate an alternative to other locally traditional aggregates such as basalt, limestone and dolomite (Abd-Allah et al., 2018;

Masoud et al., 2020). Granite aggregate is very hard rock mainly of granular structure and angular shape due to the crushing preparation. It is wide distribute on earth forming most of the igneous basement rocks. Soundness properties of granite rocks acquired their aggregate a good compressive strength with the concrete mix and make it serve as an adequate building material (Ubi et al., 2020; Sharma et al., 2016). It is regarded as the best aggregate for high grade concrete by Szczesniak et al. (2019).

Mineralogical and Chemical composition of aggregate can affects the quality of concrete and its reactivity (Shahien et al., 2014; El Sayed et al., 2014; Antolik & Niedzwiedzka, 2021). Feldspars, quartz and mica crystals are the main minerals content of granites which reflect the soundness and stability of the concrete (Rutkauskas et al., 2017). Since aggregate filled most of the conventional concrete volume. It is inevitable that the physical characteristics and chemical compositions of such a large percentage of occupying mass should contribute important properties to both the fresh and hardened product. (Jackson & Dnir, 1991; Kabir et al., 2019). Concrete strength found to depend on the quality, type, surface and internal structure of the aggregates besides the properties of interfacial transition zone close to aggregate surface (Beshr et al., 2003; Sorensen & Kristensen, 2007). Reactive siliceous aggregate with high alkali content of cement may cause the alkali silica reaction (ASR) as documented by Shahien et al. (2014). It was known that the mechanism of ASR proceeds first through the hydrolysis of reactive silica from harmful minerals impurities by OH ions from sodium and potassium hydroxides in presence of moisture of the surrounding media (Rutkauskas et al., 2017). Then formation of a hygroscopic gel involves absorption of water which increases the concrete volume and finally causes a type of concrete deterioration and damage (Ramachandran, 1998; Wakizaka, 2000).

Granites rocks are widely distributed in Egypt deserts all over the Egyptian Shield, constituting approximately 60% of its plutonic assemblage (El Ramly, 1972). The igneous rocks especially granites could be a good source of concrete aggregate. The recent research focused on evaluation the role of mineralogical composition and alkali reactivity of the crushed granites as a concrete aggregate, particularly in some areas such as the Egyptian Eastern Desert where rare other aggregate sources. Although the high cost of quarry-crushed granite due to high energy consumption during rock blasting and transportation as discussed by Nduka et al. (2018), but locally it is still highly preferable in case of the excavated granites did not used as ornamental stone and considered as useless rock masses. From this stand point, the available crushed granite aggregate will be used as an alternative and investigate its behavior with cement paste.

2. Sampling and experimental program

Different samples of granites were collected to evaluate the possibility of using some types of crushed granite as a concrete aggregate and the influence of their mineralogical composition on aggregate properties. The studied samples represent three types of local granite (red, white and grey granite) spread in Egyptian Eastern-Desert quarries (Fig.1). In the recent research, the studied samples of crushed granites chosen carefully to achieve the aim of the current research. The studied crushed granite samples can be divided to two different main geological origin, red granite originated to younger granites while on the other hand, older granites is represented by the grey and white colored granites, based on the classification of the previous Egyptian geological studies (El Ramly, 1972; El Gaby, 1975; Greenberg, 1981; Gharib & Obied., 2004). All studied samples were crushed by using a laboratory jaw crusher to prepare granite aggregates (GA) with a maximum size of 10mm. While natural quartz sand with a maximum size of 4.75 mm was used as fine aggregate. Portland Cement Type II was used for all concrete mixes in this study (Portland Cement-CEMII-Rank42.5N, Suez Cement Company, Egypt) with 3.15 specific gravity that fulfils the requirements of Egyptian standard (ES 4756, 2009).

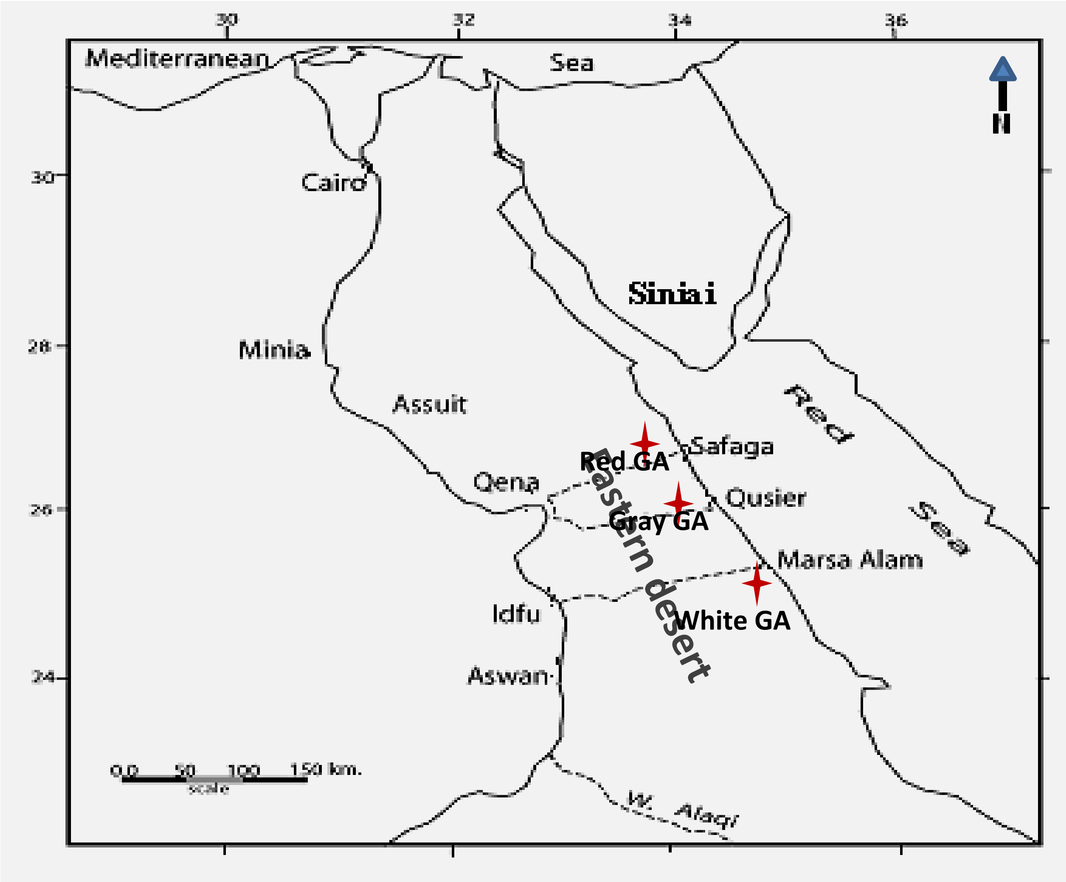

Fig 1. Location map of the different studied granitic aggregates (GA)

Analyzing by X-ray diffraction [XRD (model X'Pert Pro- Phillips MPD– PANalytical Manufacturing B.VCo., Netherlands - ISO 9001/14001 KEMA, 0.7516) provided with (Cu) anode at 40 kV&30 mA with a scanning speed of 2º /minute), Axios (PW4400) WD-XRF Sequential Spectrometer (Panalytical, Netherland)] with the aid of Petrography to identify crushed granitic aggregates composition. The three main types conducted to polarizing microscope to investigate not only the main mineralogical composition and crystals relations (texture), but also to help in identifying the presence of any altered minerals which may cause detectable effect on the main alkali silica reactivity of the studied different granites. Alkali silica reaction (ASTM C1260-21), also some physico-mechanical tests water absorption (ASTM C127-15), aggregate crushing value (ACV) and Aggregate Specific Gravity are performed on GA samples to know their suitability for use in concrete meet the ASTM C33 specification. The concrete mix design according to (ECP 203, 2017) is followed. The proportion by mass 1:1.8:2.9 (cement: sand: aggregate) of the concrete mix with 0.45 W/C ratio was used. The representative samples then casted in 0.1X0.1X0.1 m cubes to determine its compressive strength at ages of 14 and 28days according to the Egyptian Code (ECP-203, 2017).

3. Results and discussion

3.1 X-Ray Diffraction analysis

The XRD analyses of the aggregate elaborated with the studied granites are illustrated in Fig. 2. The predominant minerals within granitic aggregate types are quartz, plagioclase, and K-feldspars with minor amounts of biotite and traces of actinolite minerals. Quartz mineral showed the highest intensity between all minerals in all the granitic samples especially the white and grey granite samples. The three granitic aggregates show minor variables between feldspars content.

Relatively Red granite shows the highest intensity of the total feldspars (both plagioclase and K-feldspar) than grey and white granite samples, although the red granitic aggregate type showed relatively the lowest Biotite mineral content between all samples. There is not an indication of any mineralogical alteration within the studied granite aggregates except traces of Kaolinite within the grey granite indicated begin of hydrolysis type of feldspars. Traces of actinolite mineral were also detected within the studied grey granite sample.

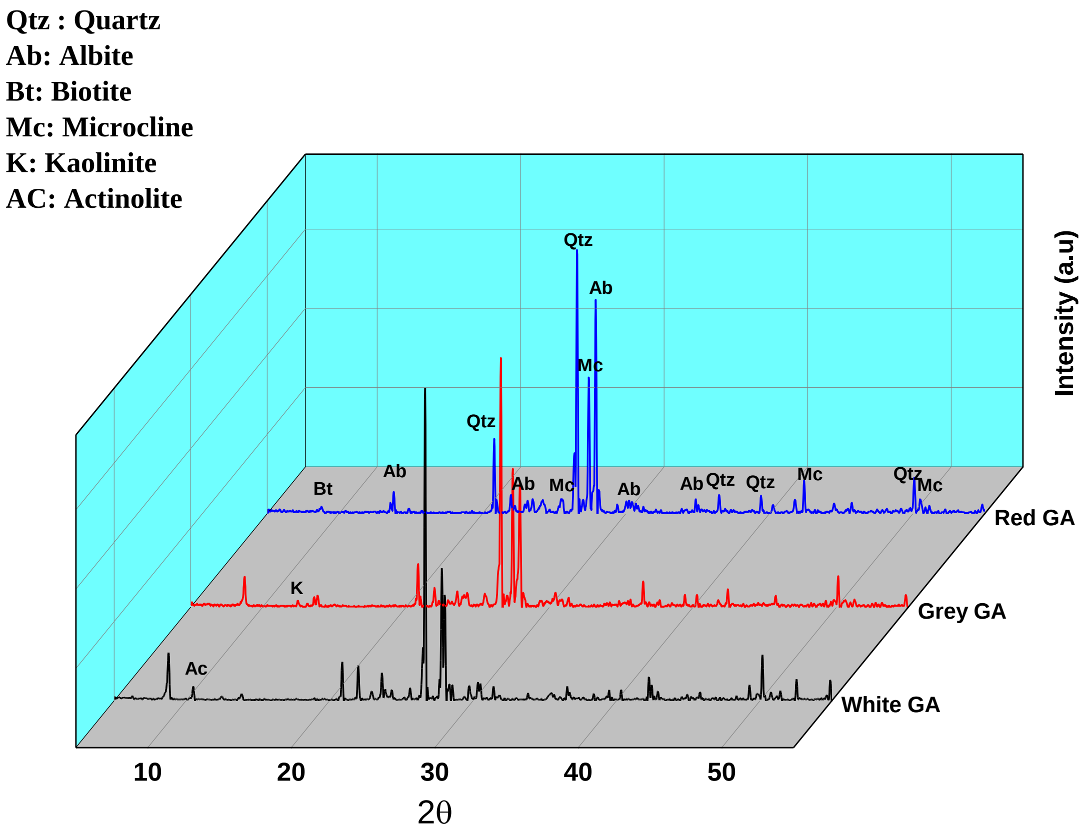

Fig 2. XRD patterns of the different studied GA

3.2 Petrographic analysis

In the recent research three main types of granites which can be divided into two main groups : the first one includes younger granites that represented by red GA while on the other hand, the second is older granites that represented by the grey and white colored GA. Petrographically, not only investigate the main mineralogical composition and the texture of the three main types but also to help in identifying the presence of any altered minerals which may cause detectable effect on the main reactivity of the studied different granitic aggregates. Firstly, the petrographic investigation of the studied red granite showed that spread and presence of microcrystalline quartz crystals between crosshatched microclne and perthite (Fig.3). Slightly to moderatly altered plagioclase(albite) surrounded by quartz crystals. The studied Red granite shows relative increase in alkali feldspare (Microcline) than the other studied granitioids. The (white and grey) exhibited similar mineralogical compostion which differs than the red as: biotite mineral more apperared in (white and grey). Thin section photomicrograph of grey granite aggregate showed simple altered coarse plagioclase crystals associated with biotite and surrounded by quartz grains (Fig.3c). The white granite showed quartz grains with medium biotite minerals intersected the coarse lamellar plagioclase crystals (Fig.3d).

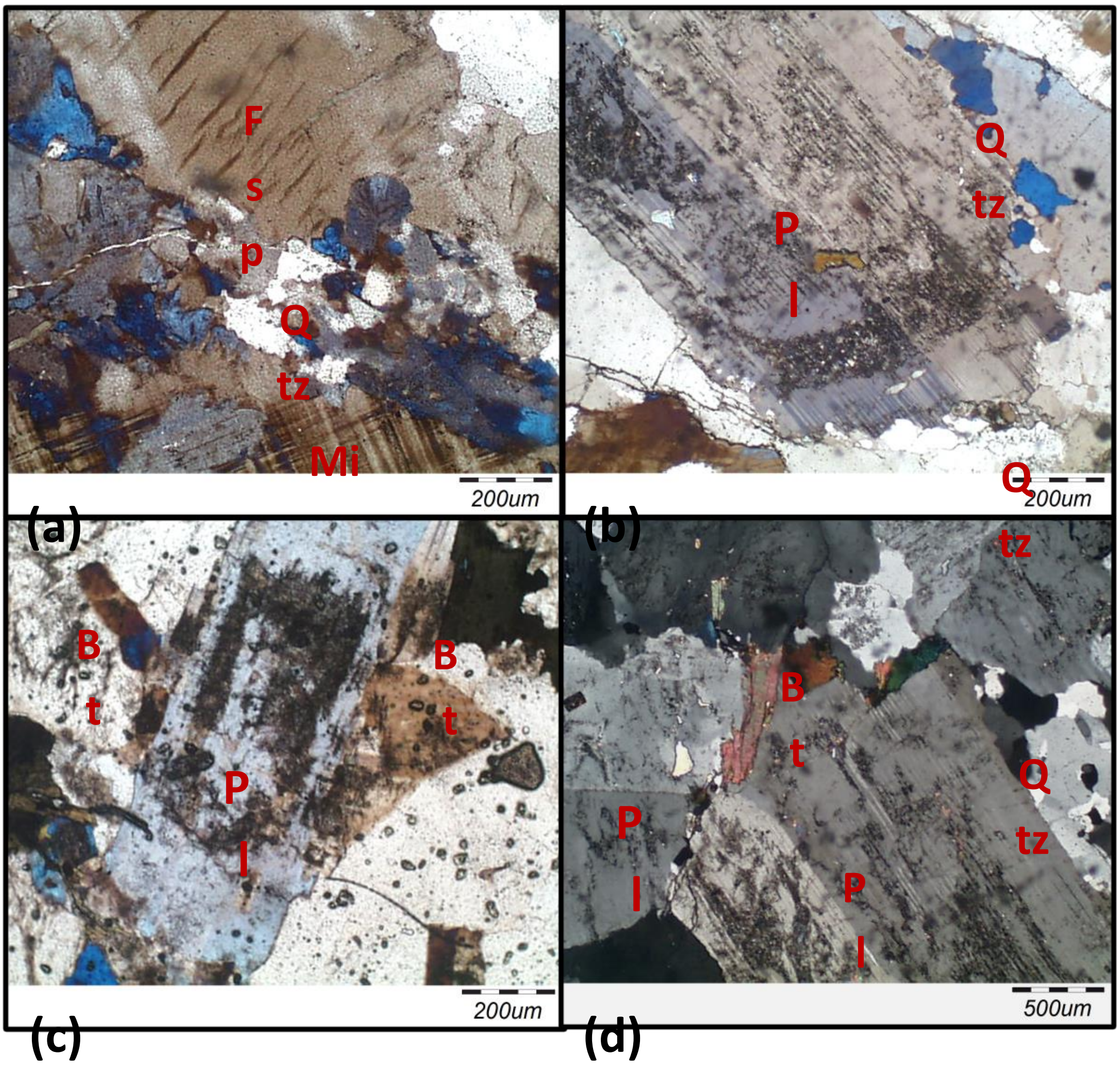

Fig 3. Photomicrographs of the three GA types, (a) the presence of microcrystalline quartz between crosshatched microcline and perthite of (Red GA). (b) Slightly to moderatly altered plagioclase (albite) surrounded by quartz crystals. (c) Moderate altered coarse plagioclase crystals associated with biotite and surrounded by quartz grains (Grey GA). (d) Quartz grains with medium biotite minerals intersected the coarse lamellar plagioclase crystals in (White GA) thin section. [Qtz:Quartz, Fsp:Feldspare, Mi:Microcline, Pl:Plagioclase, Bt:Biotite].

3.3 Chemical characteristics

The XRF analysis of oxides content in granitic aggregates is shown in Table 1. It can be noticed that SiO_2 content values vary between 67.41% (white GA) and 69.82% (Red GA). The higher value in Red granite may be related to the abundance of more feldspars and quartz minerals than others. Aluminum oxide content of Red and white samples are slightly similar reached to 14.78% than the least Al_2O_3 value in grey granite sample (11.73%). Both of the Red and White granites characterized by enrichment in alkalis (K_2O+Na_2O) content which attributed to the relatively higher contents of alkali feldspars. The percents of iron oxide (3.5, 4.0 and 4.9%) for (red, white and grey GA) respectively with approximately 1% of magnesium oxide indicate to presence of biotite mineral especially in the white granite aggregate. There is a direct relation between increasing of calcium oxide content and increasing of loss among all studied aggregate samples. To some extent the relatively high value of the loss on ignition as in case of grey granite aggregate since it reached to 4% loss may be related to the water loss of altered minerals. The used cement show high percent (58.71%) of Calcium oxide and insoluble residue reach 0.82%. Also, the sodium equivalent calculated from Portland cement oxides content equal 0.54 which considered in limits of the ASTM C1260 (2021) requirements.

Table 1. Chemical composition of the used materials

Oxide content (wt,%)	Cement	Red GA	Grey GA	White GA
SiO_2	21.21	69.82	68.51	67.41
Al_2O_3	5.42	14.00	11.73	14.78
Fe_2O_3	5.65	3.50	4.89	4.01
CaO	58.71	1.50	5.00	2.00
MgO	2.17	1.06	1.30	1.39
SO_3	2.76	0.20	0.12	0.10
Na_2O	0.41	3.37	1.53	4.10
K_2O	0.20	3.82	2.42	3.10
TiO_2	0.44	0.48	0.27	0.67
P_2O_5	0.17	0.18	0.13	0.18
Mn_2O_3	0.23	0.08	0.06	0.04
Loss of Ignition (LOI)	2.47	1.98	4.00	2.20
Total	99.94	99.99	99.96	99.98
Ins.Res	0.82			
Na_2OEq	0.54			
C_3A	4.81			
C_3S	25.33			
C_2S	41.79			
C_4AF	17.18			

3.4 Water absorption (WA)

There is affinity for WA values of the studied granite aggregates as shown in Fig. 4. It varies between 0.13 and 0.18% for red and white aggregate samples respectively where White GA shows relatively the highest percent between the studied granitic aggregate. That may attribute to abundance of biotite mica than other samples. To achieve durable concrete mix, aggregate with low water absorption classification (less than 0.2%) should be used besides avoid aggregate with high abundance of biotite mica as mentioned by Ahmad et al. (2016). Increase of WA percent will not be more safely in concrete due to the mechanical adherence with high water absorption may be weakening as discussed by El-Fakharany et al. (2019).

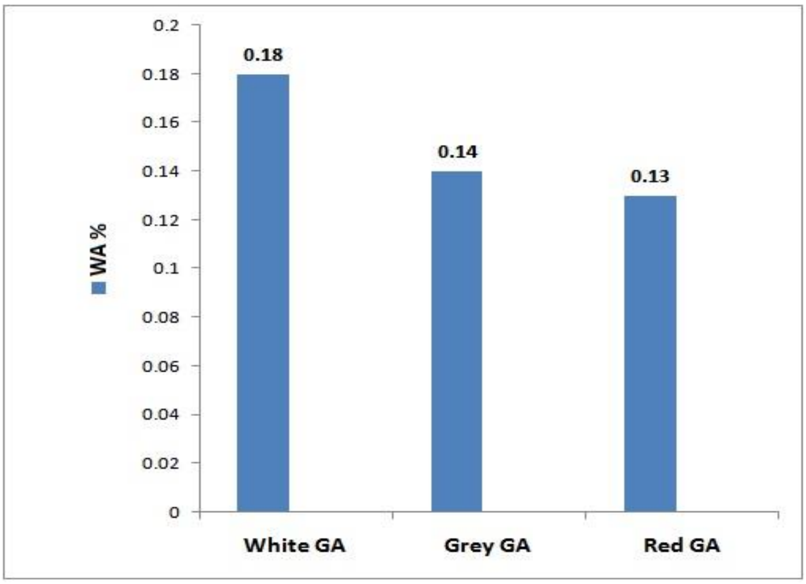

Fig 4. Water absorption (WA) values of the studied GA.

3.5 Aggregate crushing value (ACV)

The ACV gives a relative measure of the resistance of the aggregate applied to erosion or friction effect. From the results, the ACV is ranged between 18.98 and 23.11% (Fig. 5). It was noticed that there was an increase in loss percent (as detected by XRF) within increasing of ACV. Grey granite showed the highest value and therefore the lowest resistance aggregate between the studied granitic aggregates. The highest value may be related to the presence of friable clay mineral (kaolinite) or the high percent of elongated shape biotite mineral as detected from the XRD analysis of this aggregate sample. However, these ACV results were considered acceptable in normal concrete (the maximum limit is 30%) and in especial concrete which exposed to the friction (the maximum limit is 25%) according to the Egyptian code for concrete (ECP-203, 2017).

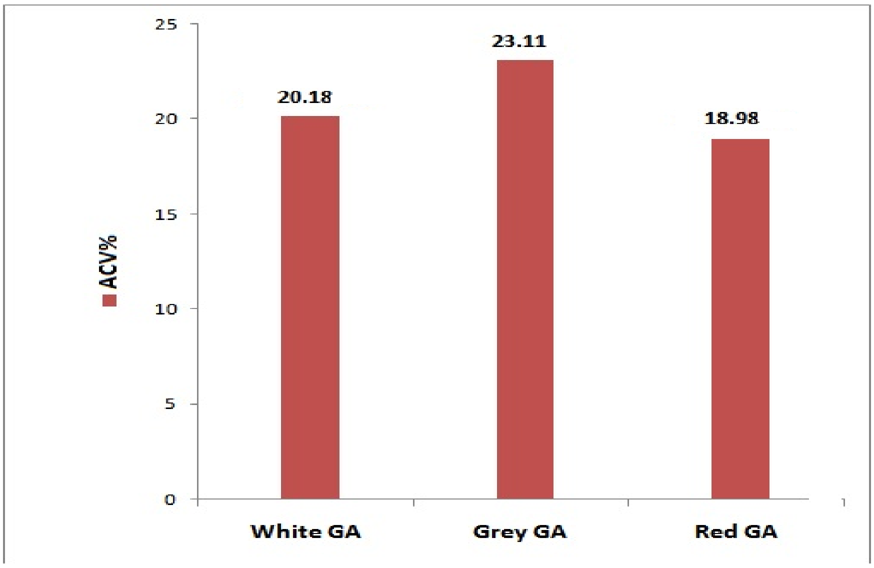

Fig 5. Aggregate crushing values (ACV) of the studied GA.

3.6 Specific gravity

The specific gravity of all the studied granitic aggregate ranged between 2.59 and 2.64 gm/cm^3 with an average equal 2.62 gm/cm^3 (Fig.6). White granite sample showed the lowest value between those granitic aggregates (2.59 gm/cm^3) however, that value is considered reasonable to good concrete with normal weight. All values are within the acceptable limits which ranged between 2.50 and 2.75 gm/cm^3 for the natural aggregate according to(ECP-203, 2017).

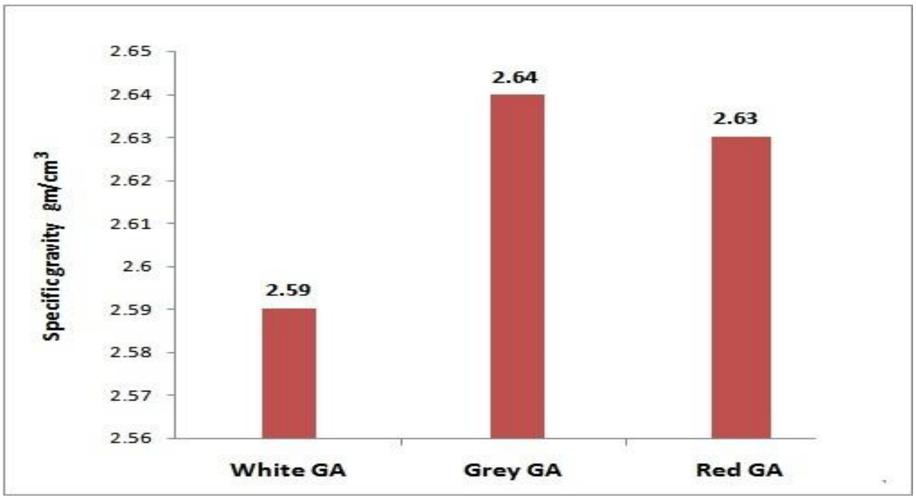

Fig 6. Specific gravity values of the studied GA.

3.7 Alkali silica Reaction

The tested granite aggregate samples contain few reactive silica/silicate minerals because the linear expansion after 14 curing testing days did not exceed 0.1 % (0.002 % for grey granite mix, 0.007 % for white granite mix and 0.03% for red granite mix) as the result curves showed in figure 7. Therefore, the studied samples can be considered as non alkali-reactive aggregate (if expansion after14 days < 0.10 %) according to ASTM C1260 test method. In case of soaking the mixes for the long period of 30days the expansion results of granitic aggregates showed slightly difference and still within the limits (expansion after 30 days < 0.2 %).

The determined insignificant difference between the tested samples (0.004 % for grey granite mix, 0.041 % for white granite mix and 0.102% for red granite mix) is expected due to the similarity of the predominant minerals content as identified by mineralogical composition. However, red granite can be distinguished to some extent expansible from others tested granitic aggregates. That noticed tendency of expansion may attribute to the high alkali feldspars content than others in addition to the texture behavior of such minerals. The expansion gel may be formed within microcrystalline quartz also associated to its microcracks, in addition to expansion can be more accused if the granitic aggregate contains perthite texture (Torres et al., 2010).

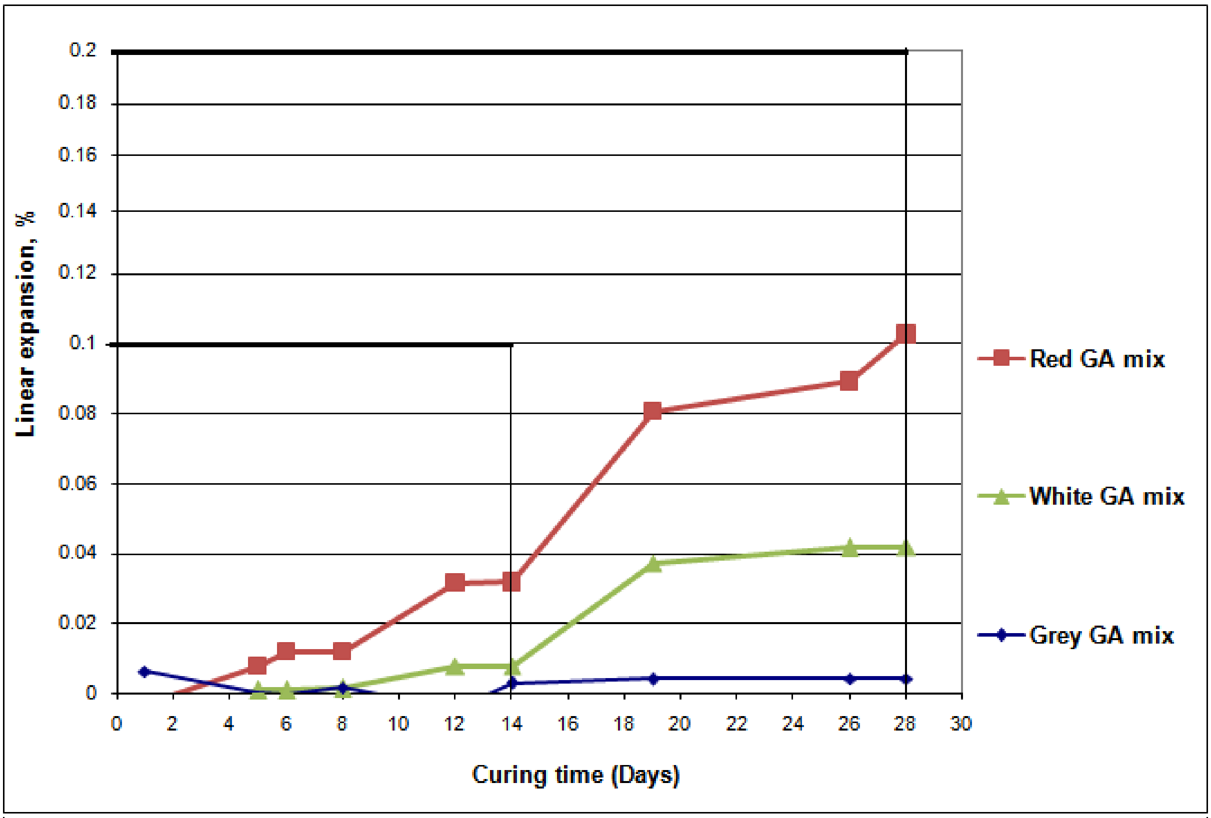

Fig 7. The alkali silica reaction curves of the studied GA mixes

3.8 Characterization of Granite aggregate (GA) mixes

Compressive strength at 14- and 28-days interval was evaluated by testing four moulded concrete cubes of each GA type. There is a simple variation in strength between all GA concrete samples (Fig. 8). This may relate to specific physical difference and mineralogical composition of the applied granitic aggregate. The strength ranges between 28.63 and 32.24 MPa in 14 days interval. Then strengths increase to the range between 40.91 and 50.38 MPa in the age of 28days. According to the Egyptian code that strength values are considered acceptable within the limit of traditional concrete after 28days. The strength of Red GA still the highest between the three GA concrete types till the later age, however its ability for more alkali silica expansion than (Grey and White GA). The relative high strength value in both early and later ages of the (Red GA) mix than studied mortars may due to the properties of crushed granite aggregate with lower content of biotite mineral give good performance within the concrete. The weak bond present between the cement paste and the soft crumble surface of flaky biotite particles, also their irregularity in shape was responsible for poor workability and lowering the compressive strength as reported by (Wakizaka et al., 2005).

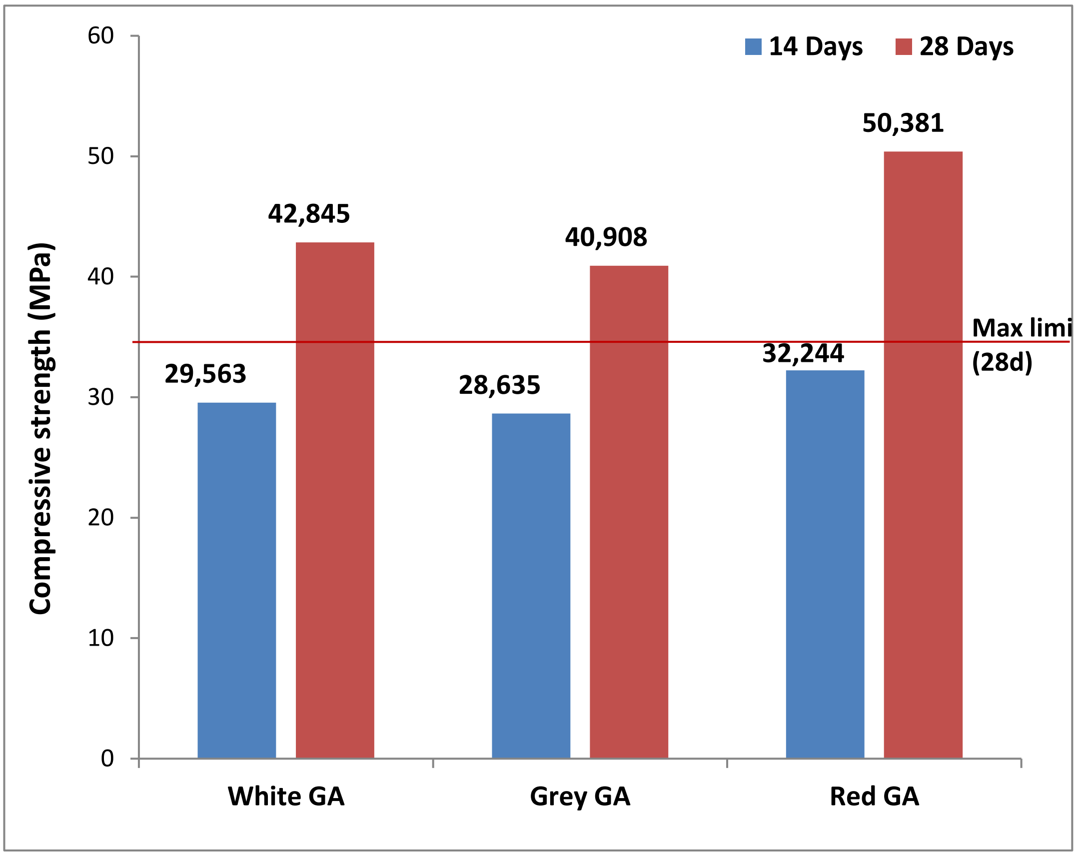

Fig 8. Correlation between 14 and 28 days compressive strength of the studied GA mixes

It showed that by mineralogical analysis the composition of casted concrete is influenced by the type and content of its aggregates in case of blended GA with Portland cement. Quartz and feldspars minerals are present in the form of fine and coarse aggregates added to the cement paste in addition to the cement phases of portlandite, and calcium silicate hydrate (Fig.9). The intensity of cementitious minerals has approach result between the studied samples and gives relatively poor diffractograms after 28 day. Further examination with the aid of stereo-microscope, the photomicrograph of the Red GA mortar reflects good compaction and gives dense appearance as noticed in (Fig.10). That indicates the high strength gained by Red GA mix between other studied GA mixes. Therefore, the strength quality of the concrete mix elaborated with the studied granitic aggregate cannot be judged from XRD analysis alone without petrography investigation under the polarizing and stereo-microscopes.

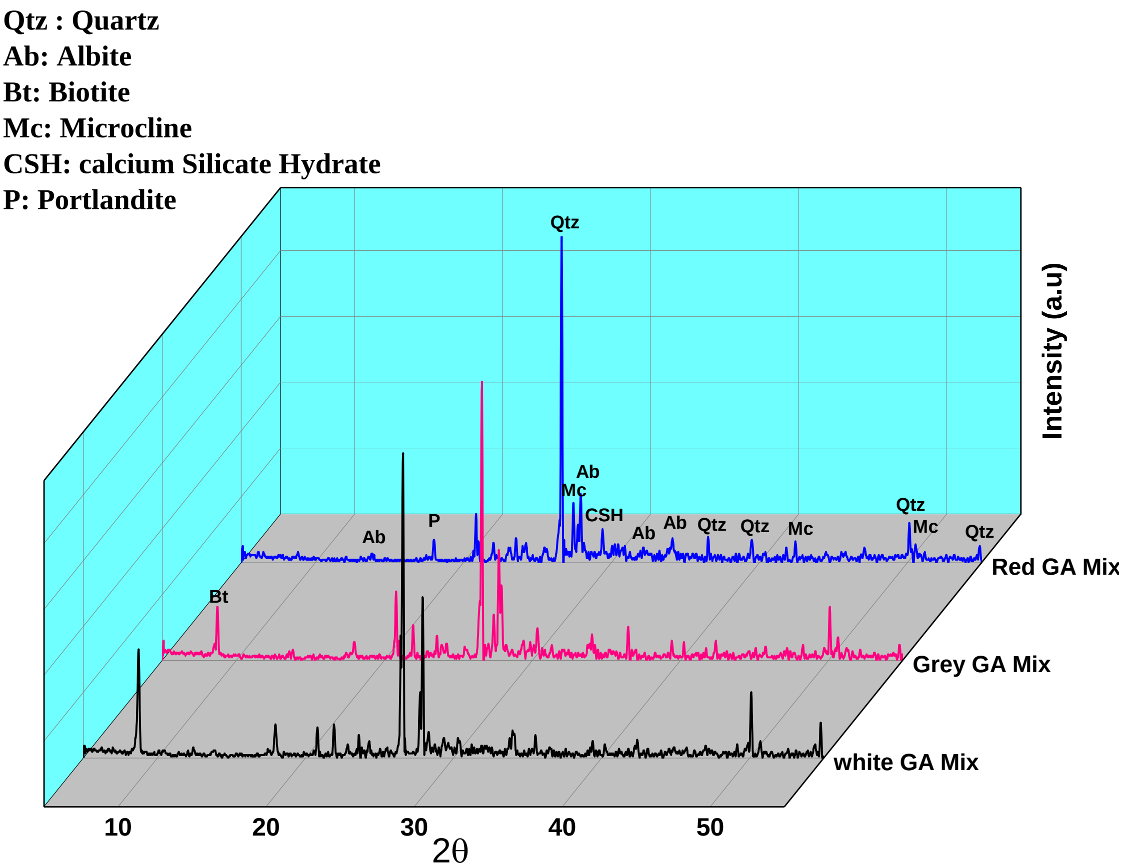

Fig 9. XRD patterns of the different studied GA Mixes.

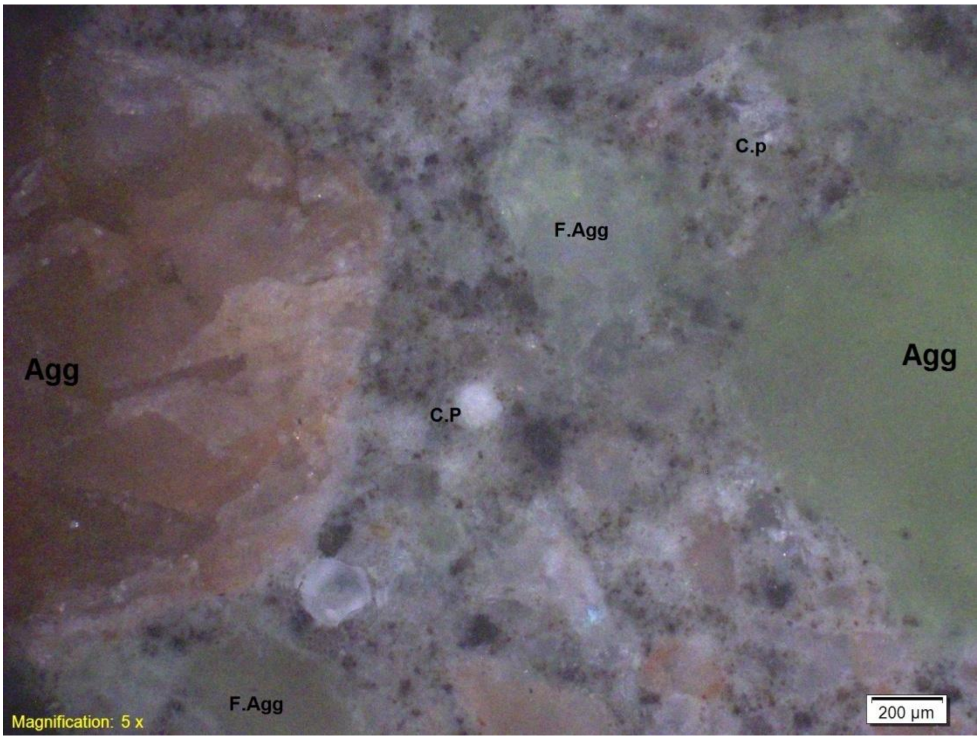

Fig 10. Photomicrograph of the studied Red GA Mix (Agg:Aggregate, F.Agg:Fine Aggregate, C.P:Cement paste).

4. Conclusions

Depending on the obtained outcomes of the recent study it can be concluded that:

- All of the studied crushed granitic aggregate achieved the requirements of the physico-mechanical average values for its using as a concrete coarse aggregate based on documented Egyptian code (ECP-203, 2017).
- The impact of mineralogical composition as important parameters in the evaluation and differentiation between the studied granite aggregates should be taken in to consideration during aggregate selection.
- Mineralogically, there is a similarity between white and grey granitic aggregates while red granitic aggregate shows excess of alkali feldspar mineral (microcline).
- The negative effect of the presence altered minerals (kaolinite and actinolite) in the studied older granite aggregates (White and Grey GA) besides mica (biotite) as all those minerals led to slight increase in water absorption average value associated with slight regression in the other different studied physico-mechanical values than younger granite aggregate (Red granite aggregate).
- The second important parameter within the current study is alkali silica reaction of the different studied granitic aggregate by which it can be concluded that; all of the studied granite aggregates are non-reactive up to the curing time 14 day. On the other hand, only the red granite aggregate show relatively raises in linear expansion curve up to 28days with a tendency to be in the slow reactive zone most likely to be as a reason for its excess of alkali feldspar mineral (microcline) and its specific texture described by the petrography examination. However, the standard method for identification ASR (ASTM C1260) classifies the studied three types of local Egyptian granitic aggregate as a non reactive aggregate.
- Although Granitic aggregate show some extent similar mineralogical and chemical composition but it may show differences in the behavior within cement paste. Characteristics of the studied granite aggregate play an important role in its possibility of their utilization as a concrete coarse aggregate. Granitic aggregate with excess presence of mica minerals may accompanied with slightly decrease of compressive strength. Moreover, granitic aggregate with higher altered minerals content or perthitic texture should be avoided and take into consideration in selection a high quality igneous aggregate.

The results clearly showed the need to study the changes in the mineral composition of the granite aggregate and its relationship to the alkali reactivity of it in concrete mixtures, as the mineral changes, even if they were slight have repercussions on the alkali activity of it and thus the quality of the concrete product elaborated with granite aggregate.

5. References

Abd-Allah, A. M, Baghdady, A.R., and Dawood, Y.H. (2018). Adequacy of carbonate aggregates as an alternative for chert aggregates in concrete manufacture, Construction and Building Materials, 181, 94–105.

Ahmad, M., Ansari, M., Singh, R., Sharma, L., Singh, k., Prashant, Singh, T. N., (2016). Mineralogical Control on the Water Absorption of Few Igneous and Metamorphic Rocks. INDOROCK2016 Proceeding MASHUD, 520-531.

Antolik, A., Niedzwiedzka, D. (2021). Assessment of Alkali Silica Reaction in Granitic Rocks, Construction and Building materials, 295, 12.

ASTM C127, (2015). Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate, ASTM International, West Conshohocken, PA, www.astm.org

ASTM C1260, (2021). Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method), Annual Book of ASTM Standards, 04 (02), Concrete and Aggregates, ASTM International, West Conshohocken, PA, www.astm.org

ASTM C33, (2018). Standard Specification for Concrete Aggregates, ASTM International, West Conshohocken, PA, www.astm.org

ASTM C642, (2013). Standard test method for Density, Absorption and Voids in Hardened Concrete, ASTM International, West Conshohocken, PA, www.astm.org

Beshr, H., Almusallam, A.A., Maslehuddin, M. (2003) Effect of coarse aggregate quality on mechanical properties of high strength concrete. Construction and Building Materials, 17, 97-103.

ECP-203, (2017). Egyptian Code for the design and implementation of concrete structures, Manual of testes, copy2017, HBNRC, Giza, Egypt

ES 4756–1 (2009) Cement part: (1) composition, specifications and conformity criteria for common cements. Egyptian Organization for Standardization and Quality, Egypt

El-Fakharany, M. E., Ezzat, M., Gad, A., Abdel-Ghafour, N. G., Baghdady, A. R. (2019) Performance of dolomitic cementitious mortars as a repairing material for normal concrete in Egypt, Építő anyag – Journal of Silicate Based and Composite Materials, 71 (2), 33–42.

El-Gaby, S. (1975) Petrochemistry and geochemistry of some granite from Egypt. N. Jb. Mineral. Abh., 125, 147- 189.

El-Ramly, M. F. (1972) A new geological map for the basement in the eastern desert and southwestern desert of Egypt, Ann. Geol. Surv. Egypt, 2, 1-18.

El-Sayed, M. I., Shahien, M. G., Abdel-Ghafour, N. G., Gharieb, S. E., Abou Bakr, A. (2014) Mineralogical Assessment of the Coarse Carbonate Aggregates of Gabal Ataqa to Predict Their Alkali Reactivity Behavior, Suez, Egypt. Egyptian journal of applied sciences, 29 (6) , 194-205.

Gharib , M. E. and Obied,M.A., 2004. Geochemistry and evaluation of the Neoproterozoic granitoids magmatism in the Wadi Shiekh-Gabal Saint Katherine area, SouthWestern, Sinai. 7th Int.Conf.,Geology of the Arab world, Cairo Univ.,Egypt, 53-73.

Greenberg, J. K. (1981) Characteristics and origin of Egyptian younger granites, Summary. Bull. Geol. Soc. Am., 92, 224-232.

Jackson, N., Dnir, R. K. (1991) Civil Engineering Material, (4th Ed). Addison Wesley Longman's Limited Edinburgh Gate, England

Kabir, N., Aliyu, S., Nasara, M., Chinade, A., Shehu, A. (2019) Characteristics of Different Type of Coarse Aggregate on Properties of High Performance Concrete, Sustainable Structure and Materials, 2 (1), 88-96.

Langer, W.H. (1993). Natural aggregates of the conterminous United States, U.S. Geological Survey Bulletin, Second Printing, 1-3, 1553-1560.

Masoud, M. A., Rashad, A. M., Sakr, K., Shahien, M. G., Zayed, A. M. (2020) Possibility of using different types of Egyptian serpentine as fine and coarse aggregates for concrete production Materials and Structures, 53, 1-17.

NDUKA, D. O., FABGENLE, O. I., JOSHUA, O., OGUNDE, A. O., Omuh, I. O. (2018) Comparative Analysis of Concrete Strength Utilizing Quarry-Crushed and Locally Sourced Coarse Aggregates, International Journal of Mechanical Engineering and Technology, 9(1), 609–617.

Neville, A.M. (2011). Properties of Concrete, Pearson Education Limited. Edinburgh Gate, (5th Ed) England.

Petrounias P, Giannakopoulou P, Rogkala A et al. (2018) The impact of secondary phyllosilicate minerals on the engineering properties of various igneous aggregates from Greece. Minerals, 8, 329.

Ramachandran, V.S. (1998). Alkali-aggregate expansion inhibiting admixtures, Cement and Concrete Composites, 20 (2-3), 149-161.

Rutkauskas, A., Nagrockienė, D., Skripkiūnas, G., Barkauskas, K. (2017). Determining Reactivity Level of Granite Aggregate for Concrete, Construction Science, 20, 33–37.

Shahien, M.G., El Sayed, M.I., Abdel Ghafour, N.G., and El-Fakhrany, M.E. (2014). Effect of Mineralogical Composition of some Egyptian Wadi Wash Aggregate on the Alkali Aggregate Reactivity. Egyptian journal of applied sciences, 29 (4),194-205.

Sharma, A. S., Vinoth Kumar, N., Harish J., and Sathish, A. (2016). Utilisation of Granite Chips as a Supplementary Coarse Aggregate Material. Indian Journal of Science and Technology, 9 (2), 1-4

Sorensen, E. V., Kristensen, L. F. (2007). Sea dredged Gravel Versus Crushed Granite as Coarse Aggregate for Compacting Concrete in Aggressive Environments, Nordic Concrete Research, 7 (1-2), 9-18.

Szczesniak, A., Siwinski, J., Stolarski, A. (2019). Experimental Study on the Use of Granite as Fine Aggregate in Very-High-Strength Concrete. IOP Conf. Series: Materials Science and Engineering, 471, 1-8

Torres, A. Alaejos, P. Soriano, J. (2010) Comparative Study of the Alkali Silica Reaction (ASR) in Granitic aggregates, Estudios Geol, 66 (1), 105-114.

Tsado. A, (2013). A comparative analysis of concrete strength using igneous, sedimentary and metamorphic aggregate as coarse aggregate, Zeszyty Naukowe Politechniki Częstochowskiej.19 (169), 179-191.

Ubi, S.E, Nkra, P.O, Agbor, R.B, Ewa, D.E, Nuchal, M. (2020) Efficacy of Basalt and Granite As Coarse Aggregate in Concrete Mixture, International Journal of Engineering Technologies and Management Research , 7 (9), 1-9.

Wakizaka, Y. (2000). Alkali-silica reactivity of Japanese rocks, Engineering Geology, 56 (1–2), 211-221.

Wakizaka, Y, Ichikawa K, Nakamura Y, Anan S (2005). Deterioration of concrete due to specific minerals, Environ Econ, 2, 331–338.