

Effect of Fine Quarry Waste on the Mechanical and Microstructures of Green Cement and Geopolymer Concrete

Ashraf M. A. Heniegal

Industrial Education, Suez University, Suez, Egypt.

ARTICLE INFO

Article history:

Received: 28 June 2016;

Received in revised form:
27 July 2016;

Accepted: 2 August 2016;

Keywords

Hardened,
QLSW,
Materials,
Sand,
Cement Concrete,
Geopolymer Concrete,
LSS.

ABSTRACT

This paper studies the behavior of both green cement and Geopolymer concrete. Twenty-seven concrete mixes were prepared and tested in the fresh and hardened state. The properties of both Ordinary Portland Cement Concrete (OPCC) and Geopolymer concrete (GC) incorporating quarry limestone waste as a replacement of fine aggregate were studied. It was found that quarry waste fine aggregate increased the slump of fresh cement and Geopolymer concrete up to 50% as a replacement for fine aggregate. Improvements of properties of both cement and Geopolymer concrete were detected when quarry waste fine aggregate was replaced up to 50% of fine aggregate. The overall test results revealed that quarry limestone waste fine aggregate can be consumed efficiently in both cement and Geopolymer concrete up to 50%.

© 2016 Elixir All rights reserved.

Introduction

In recent years, green concrete has drawn serious attention of researchers and investigators because the concept of thinking in the environment (Environmentally friendly). The materials used in the production of concrete poses the problem of acute shortage in many areas. There are many wastes of some industries and quarries that can be used as a full or partial substitute for concrete materials [1]. M. S. Hameed et. al., [2] studied that the Green concrete capable for sustainable development is characterized by the application of industrial wastes to reduce consumption of natural resources, energy and pollution of the environment. Green concrete is very cheap to produce, because, waste products are used as a partial substitute for cement, charges for the disposal of waste are avoided, energy consumption in production is lower and durability is greater. Green concrete gives an excellent result in strength and quality aspect. Waste can be used to produce new products or can be used as admixes so that natural sources are used more efficiently and the environment is protected from waste deposits. Green concrete is generally composed of recycling materials as full or partial percent substitute for aggregate, cement and admixture in concrete. H. Binici et. al., [3] reported that the use of industrial residual products in making concrete will lead to sustainable concrete design and greener environment. There is an urgent need to develop concrete with non-conventional aggregates for environmental as well as economic reasons. It is necessary to explore new pathways for fly ash-based Geopolymerization and improve the properties of the materials. High CaO content decreases the microstructural porosity as well as strengthens the Geopolymer by establishing amorphous structure Ca–Al–Si gel during Geopolymerization [4]. This is also supported by the investigation [5] that ground granulated blast furnace slag which explains that calcium containing compounds such as

calcium silicates, calcium aluminate hydrates, and calcium-silico-aluminates are formed during Geopolymerization of fly ash, that affects the setting and workability of the mix [6]. Jaarsveld et al. [4] reported anomalous result; greater strength was obtained for the Geopolymers containing kaolin. Temuujin et al. [7] suggested that the accumulation of calcium compounds CaO and Ca(OH)₂ improves mechanical properties of the fly ash-based Geopolymers cured at ambient temperature. A thought of blended Geopolymer came out by the sense to improve the porosity as well as the strength and other properties. The addition of moderate amount of minerals to a Geopolymer can have significant improvements on the Geopolymer structure and properties. Debabrata Dutta et al. [8] abstracted that the compressive strength of Geopolymer paste specimens with 15% Limestone dust was increased about 44% when cured for 48 hours at 65°C. Specimens incorporated with Limestone dust showed better microstructure and exhibited lesser porosity.

Research Program

The experimental test program was scheduled to appreciate the research objectives of the study. One mix was a control Ordinary Portland Cement Concrete (OPCC) mix; four cement concrete mixes incorporating limestone waste 25%, 50%, and 75% and 100% replacement from sand. Two cement concrete mixes containing LSS as a coarse aggregate. Six mixes (in Geopolymer concrete) containing crushed stone, sand and limestone waste by 0.0%, 50% and 100% as a replacement for sand where the fly ash as a 100% replacement of cement, with concentration of sodium hydroxide (Molarity) M10, and using ratios of sodium hydroxide to sodium silicate by 1:2 and 1:2.5 respectively. Another six mixes (in Geopolymer concrete) containing crushed stone, sand, limestone waste by 0.0%, 50% and 100% as a replacement for

sand and fly ash as a 100% replacement of cement, with concentration of sodium hydroxide (Molarity) M12, and using ratios of sodium hydroxide to sodium silicate by 1:2 and 1:2.5 respectively. Also, four mixes of Geopolymer concrete containing limestone waste as a fine aggregate (0%, 50% and 100% as replacement of sand), and local steel slag as a coarse aggregate with a concentration of sodium hydroxide (Molarity) M10, and using ratios of sodium hydroxide to sodium silicate by 1:2 and 1:2.5 respectively. Four mixtures of Geopolymer concrete were prepared as the same of the previous four mixes but with concentration of sodium hydroxide (Molarity) M12

The mechanical properties of concrete were recorded in terms of compressive strength, indirect tensile (splitting tensile) and flexural strengths, and physical properties in terms of water absorption test, Los Angeles test (called Cantabro test method) and sorptivity test.

Materials Properties

Test samples were prepared from available local materials. These include natural siliceous sand, crushed stone from Suez governorate, Egypt, ordinary Portland cement OPC Suez Cement Company, tap drinking water, and quarry limestone waste from Suez as a raw material without any process as shown in Fig. 1. The chemical properties of the LSW used are shown in table1. Table 1 shows the physical and mechanical properties of LSW used where Table 2 and Table 3 indicate the chemical characteristic of LSW and LSS respectively. Available materials are complying with Egyptian Code No. 203-2008 [9]. The used local steel slag was obtained from Ezz steel industry factory in Suez. The local steel slag is obtained as a by-product during melting of steel scrap from the impurities and fluxing agents, which form the liquid slag floating over the liquid crude iron or steel in electrical arc furnaces. Table 4 illustrates the physical and mechanical properties of local steel slag used.

Sodium silicate solution "NS" was delivered from Egypt Global Silicates Company. The chemical and physical properties of the "NS" are illustrated in (Table 5). Sodium hydroxide "NH" was in flake form (NaOH with 98-99% purity). The fly ash used in this research is classified as class F fly ash according to the requirement of ASTM C618 Class F [10]. Its physical properties and XRF analysis are shown in Table 6 and Table 7, respectively.



(A) Raw LSW (B) LSW (C) Sand

Figure 1. (A) Raw LSW, (B) sieve analysis for limestone waste, (C) sieve analysis for Sand.

Mixing, Molding, and Curing

Table 8 represents the mix proportions by weighing for all mixes of ordinary Portland cement concrete (OPCC) and Geopolymer concrete (GC). Mixing was done in a standard drum-type mixer.

The preparation of chemicals and the mixing of fly ash based-Geopolymer concrete include two alkaline products, one of them (sodium hydroxide) which classified as a corrosive product which has the potential to seriously burn eyes, skin and internal organ, therefore, distinct care has been taken during handling and working with that material. These protections included using a fume cabinet during the preparation of the sodium hydroxide solution and the mixing of concrete specimens, using high density polyethylene container for storage, and wearing rubber gloves and goggle when handling the chemical and wet mix [12].

Table 1. Physical and mechanical properties of (LSW)

Property	Results	Limits
Specific Weight	2.61	----
Bulk Density (t/m ³)	1.65	----
Water Absorption %	18.5	ECCS limit ≤ 2.5
Fine Dust Content %	3.4	ESS limit ≤ 4
Flakiness Index %	37.5	ESS limit ≤ 40
Abrasion Index %	18.3	ESS limit ≤ 30

Table 2. The Chemical characteristics of the (LSW)

Property %	Results %
SiO ₂	6.5
Al ₂ O ₃	0.75
Fe ₂ O ₃	0.33
CaO	35.01
MgO	15.42
SO ₃	0.66
Na ₂ O	0.11
K ₂ O	0.38
CL	0.72
Loss on Ignition (L.O.I)	40.02

Table 3. Chemical Analysis of LSS Aggregates

Constituent	Composition %*
SiO ₂	13.10
Fe _x O _y	36.80
Al ₂ O ₃	5.510
CaO	33.00
MgO	5.030
MnO	4.180
Cr ₂ O ₃	0.775
P ₂ O ₅	0.743
TiO ₂	0.598
V ₂ O ₅	0.104
SO ₃	0.140

Table 4. Physical and Mechanical Properties of local Steel Slag Aggregates

Property	Results	% Limits
Specific Weight	3.48	----
Bulk Density (t/m ³)	1.97	----
Water Absorption %	1.0	ECCS limit ≤ 2.5
Crushing Coefficient %	11.40	ESS limit $\leq 30\%$
Abrasion Index (loss Anglos apparatus) %	13.5	ECCS limit ≤ 30

Table 5. Chemical and physical Properties of Sodium Silicate Solution

Product Name	Data
SiO ₂ /Na ₂ O ratio	2.00
%Na ₂ O	14.70
%SiO ₂	29.70
% Total solid	44.40
% Water content	55.55
% Water insoluble	0.05
Baume	50
Specific gravity at (20°C) g/cm ³	1.526
Color and appearance	Clear white liquid
PH	12.7

The mixing for all specimens was undertaken using manual mixing as:

1. Adding fly ash to sand then mixing dry materials for about 2 minutes.
2. Sodium hydroxide and sodium silicate are added to dry materials with a good mixing for 5 minutes.
3. Adding the needed water and mixing for 3 minutes again.
4. The mixes were then placed in 10 cm cubic molds and compacted manually. The surface of the samples was covered with plastic bags before placing in the oven to prevent rapid evaporation of liquids at different temperatures. Duplicating sets of specimens were then subjected to heat curing at 60 °C in the oven for 24 hours.
5. All specimens were stored at the room temperature prior to testing.

Table 6. Physical Properties of the Used Fly Ash

Property	Test Results
Specific surface area (cm ² /gm)	3959
Bulk density (kg/m ³)	1252
Specific gravity	2.5
color	Light gray

Table 7. X-Ray Analysis for the Used Fly Ash

Oxide	Content %	Limitation % *
SiO ₂	61.32	Min. 70
Al ₂ O ₃	29.38	
Fe ₂ O ₃	3.25	
CaO	1.23	--
MgO	0.73	--
K ₂ O	1.22	--
SO ₃	0.004	Max. 3
TiO ₂	0.01	--
Na ₂ O	0.74	Max. 1.5
Cl	0.03	Max. 0.05
LOI	0.669	Max. 6

* ASTM C 618 Class F[10].

Details of Specimen

Compression test was carried out at 3, 7, and 28 days on 100x100x100 mm cubes. Splitting test was carried out at 28 days on 150 × 300 mm cylinder. Flexural strength test was carried out at 28 days on 100 × 100 × 500 mm beams. All test specimens were demolded after 24 hours and then stored under water in curing tanks at room temperature (25±2°C). The test was carried out according to Egyptian Code No. 203-2008 [9].

1-Test results

Properties of Fresh Cement and Geopolymer Concrete

The fresh properties were studied after mixing immediately. Concrete slump test was measured as in Egyptian Code No. 203-2008 [9], and the Geopolymer concrete in the fresh state was observed to be highly viscous and good at working.

The investigation outcomes revealed that the Geopolymer concrete is highly viscous and workable. Moreover, the use of LSW as a replacement for fine aggregate in cement and Geopolymer concrete up to 50% increases the slump value of the mixes and more than 50% reduce may this value. However, the effect of molarity reduce the slumpvalue as shown in Table 9, the slump was 195 mm for the mix containing 50% LSW and M10-50-1:2.5 to, 170 mm for the mix containing 50% LSW and M12-50-1:2.5. From Table 9, it can be observed that the concentration of molarity has an effect on the slump value decrease by about 12%.

The visible notes for the fresh concrete were that the color of geopolymer concrete was the same as ordinary cement concrete, dark in its color.

Compressive strength

Effect of limestone waste on the cement concrete.

Table 9 and Fig. 2 indicate the compressive strength results of Ordinary Portland Cement Concrete (OPCC) incorporating LSW with different replacement ratios of 0.0, 25, 50, 75% and 100%, respectively. Compressive strength of Ordinary Portland Cement Concrete (OPCC) has increased by about (16%, 11%, 7%)25, (30%, 22%, 11%)50 at 3, 7 and 28 days respectively at LSW levels of 25% and 50%, when compared with the normal cement concrete mix N.

Table 8. The Mix Proportions of the Tested Mixes by Weight Quantities for Cement and Geopolymer Concrete.

Mix ID:	FA (kg)	cement (kg)	Total Aggregate (kg)				Alkaline Liquid (kg)	
			Fine A.		Coarse A		NS	HS
			s	LSW	CS	LSS		
N	0	350	767	0	1151	0	175 tap water	
N25	0	350	575	191	1151	0	175 tap water	
N50	0	350	383	383	1151	0	175 tap water	
N75	0	350	191	575	1151	0	175 tap water	
N100	0	350	0	767	1151	0	175 tap water	
M10-1:2	350	0	767	0	1151	0	118 59	
M10-50-1:2	350	0	383	383	1151	0	118 59	
M10-100-1:2	350	0	0	767	1151	0	118 59	
M10-1:2.5	350	0	767	0	1151	0	126.5 50.5	
M10-50-1:2.5	350	0	383	383	1151	0	126.5 50.5	
M10-100-1.:2.5	350	0	0	767	1151	0	126.5 50.5	
M12-1:2	350	0	767	0	1151	0	118 59	
M12-50-1:2	350	0	383	383	1151	0	118 59	
M12-100- 1:2	350	0	0	767	1151	0	118 59	
M12-1:2.5	350	0	767	0	1151	0	126.5 50.5	
M12-50- 1:2.5	350	0	383	383	1151	0	126.5 50.5	
M12-100- 1.:2.5	350	0	0	767	1151	0	126.5 50.5	
N-LSS	0	350	767	0	0	1151	175 tap water	
N-LSS-50	0	350	383	383	0	1151	175 tap water	
M10-LSS-1:2	350	0	767	0	0	1151	118 59	
M10-LSS-50-1:2	350	0	383	383	0	1151	118 59	
M10-LSS-1:2.5	350	0	767	0	0	1151	126.5 50.5	
M10-LSS-50-1:2.5	350	0	383	383	0	1151	126.5 50.5	
M12-LSS-N-1:2	450	0	767	0	0	1151	118 59	
M12-LSS-50-1:2	450	0	383	383	0	1151	118 59	
M12-LSS-N-1:2.5	450	0	767	0	0	1151	126.5 50.5	
M12-LSS-50-1:2.5	450	0	383	383	0	1151	126.5 50.5	

However, at level of 75%, and 100%, compressive strength of Ordinary Portland Cement Concrete (OPCC) incorporating LSW lost about (3.9%, 11%, 9%)75, (10.7%, 20%, 23%)100 at 3, 7 and 28 days respectively, when compared with the normal cement concrete mix N. This loss of the compressive strength for 75-100% LSW is related to its physical effects for limestone powder that fills the pores between cement particles due to formation of carbo-aluminate, which may accelerate the setting of cement pastes. Furthermore, the free calcium hydroxides during the reaction of cement increase when powder content in LSW increases. The compressive strength for 28 days age, meets the strength requirement of concrete, which shows that limestone waste has not opposing influence on the strength of concrete. The obtained results are matching with the published literatures [4].

Effect of limestone waste on Geopolymer concrete.

Compressive strength test results of Geopolymer concrete with LSW are presented in Table 9 and Fig. 3 for ratios of 50% and 100%, respectively. The use of LSW with levels of 50% and 100% with M10 and NH:NS (1:2), has increased the compressive strength of normal Geopolymer concrete by about (24%, 6%, 6%)_{50%} (22%, 3%, 6%)_{100%} at 3, 7 and 28 days respectively, when compared with Geopolymer concrete mix M10-1:2. Furthermore, the use of LSW with level of 50%, and 100% at M10 and NH:NS (1:2.5) has increased the compressive strength of normal Geopolymer concrete by about (15%, 14%, 19%)_{50%}, (-1%, 7%, 13%)_{100%} at 3, 7 and 28 days respectively, when compared with the Geopolymer concrete mix M10-1:2.5. The obtained results are matching with the published literatures [8], [13].

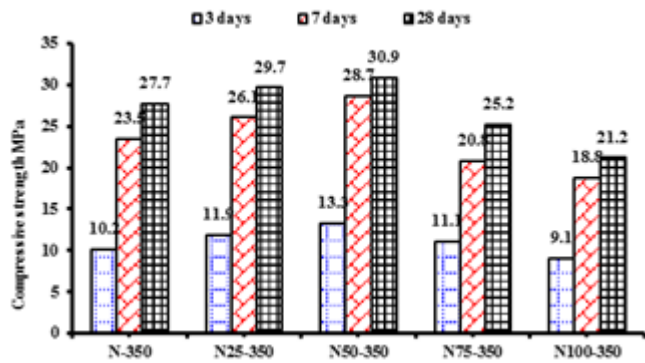


Figure 2. Effect of 25%, 50%, 75% and 100% LSW as a replacement from sand, as compared to normal strength concrete.

Effect of limestone waste on the local steel slag cement concrete.

Table 9 and Fig. 4 illustrate the compressive strength values of cement concrete with 50% LSW as a replacement of fine aggregate and local steel slag as a complete coarse aggregate. The use of LSW with levels of 50% for local steel slag as coarse aggregate has increased the compressive strength by about (4%, 11%, 10%)₅₀ at 3, 7 and 28 days respectively, when compared with the normal local steel slag cement concrete N-LSS.

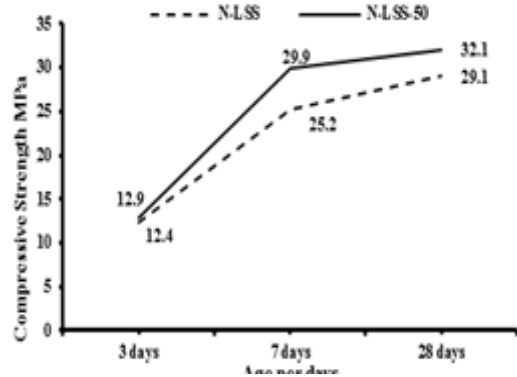


Figure 4. Effect of age on the compressive strength of cement concrete containing LSS with 50% LSW as a replacement for fine aggregate.

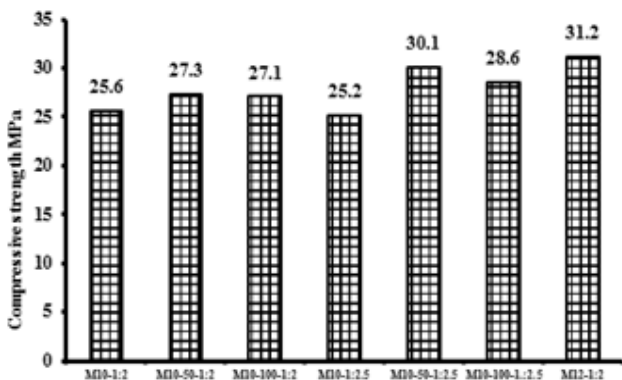


Figure 3. Effect of 50% and 100% LSW as a replacement from sand, as compared to normal strength Geopolymer concrete at 28 days

Effect of limestone waste and NS:HS on local steel slag Geopolymer concrete.

Test results of compressive strength for Geopolymer concrete which contains LSW with different replacement percentages are presented in Table 9 and Fig. 5. The Adding of LSW by 50% as a replacement of fine aggregate and complete local steel slag as a coarse aggregate using M10 and

NH:NS (1:2), has improved the compressive strength of Geopolymer concrete containing local steel slag by about (20%, 12%, 8%)_{50%} at 3, 7 and 28 days respectively, as compared with the local steel slag Geopolymer concrete M10-LSS-1:2. The use of M10-LSS-50-1:2.5 has increased the compressive strength of Geopolymer concrete containing local steel slag by about (8%, 7%, 8%)_{50%} at 3, 7 and 28 days respectively, when compared with the local steel slag Geopolymer concrete M10-LSS-1:2.5. On the other hand, it is obvious that the NS:HS enhanced the compressive strength when increased from 1:2 to 1:2.5

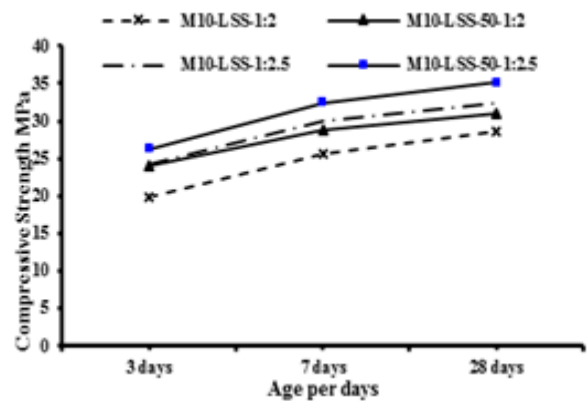


Figure 5. Effect of age on the compressive strength of Geopolymer concrete containing LSS with 50% LSW as a replacement for fine aggregate.

The remarkable increase in the compressive strength, especially when using local steel slag as a coarse aggregate can be attributed to the enhanced mechanical properties of the used steel slag as well as the high angularity and roughness of the steel slag which increase the bond between the aggregate and the cement paste. Similar results have been reported in earlier studies [15], [16], and [17].

Effect of Molarity on Compressive Strength

From Table 9 and Fig. 6, it can be observed that the compressive strength of Geopolymer concrete was increased with increasing the molarity of NaOH up to a value of 12. Fig. 6 illustrates the effect of sodium hydroxide concentration on the compressive strength of Geopolymer concrete. Fig. 6 demonstrates that the compressive strength test results of Geopolymer concrete increase with the increase of sodium hydroxide concentration, increasing sodium hydroxide concentration from M10 to M12 enhances Geopolymerization process resulting in an increase in the compressive strength of Geopolymer concrete.

Table 9. Result of the Fresh and hardened properties specimens.

Mix ID:	Slump (mm)	LSW %	Compressive Strength (MPa)			flexural strength (MPa)	tensile strength (MPa)
			3 days	7 days	28 days		
N	95	0	10.2	23.5	27.7	2.9	4.2
N25	110	25	11.9	26.1	29.7		
N50	120	50	13.3	28.7	30.9	3.6	4.5
N75	85	75	9.8	20.8	25.2		
N100	70	100	9.1	18.8	21.2	1.9	4.7
M10-1:2	165	0	17.1	23.5	25.6	2.8	4.3
M10-50-1:2	180	50	21.3	25.1	27.3	3	4.5
M10-100-1:2	130	100	20.9	24.1	27.1	2.3	4.1
M10-1:2.5	175	0	19.2	24.3	25.2	2.9	4.8
M10-50-1:2.5	195	50	22.1	27.9	30.1	3.8	4.9
M10-100-1:2.5	135	100	19	26.2	28.6	2.2	4.1
M12-1:2	150	0	20.3	28.6	31.2	3.2	4.9
M12-50-1:2	160	50	23.9	29.3	32.5	3.5	5.1
M12-100-1:2	125	100	22.2	27.6	29.1	2.5	4.7
M12-1:2.5	165	0	21.3	32.5	33.6	3.9	5.2
M12-50-1:2.5	170	50	23.9	34.2	35.6	4.2	5.3
M12-100-1:2.5	155	100	24.2	33.6	34.9	3.2	4.8
N-LSS	95	0	12.4	25.2	29.1	3.1	4.6
N-LSS-50	80	50	12.9	29.9	32.1	3.4	4.8
M10-LSS-1:2	145	0	19.9	25.6	28.7	3.4	5
M10-LSS-50-1:2	150	50	24	28.9	31.1	3.6	5.3
M10-LSS-1:2.5	140	0	24.3	30.1	32.4	3.9	5.2
M10-LSS-50-1:2.5	130	50	26.3	32.5	35.1	4.1	5.4
M12-LSS-N-1:2	150	0	23.8	30.5	32.7	4.2	5.2
M12-LSS-50-1:2	155	50	27.2	31.9	33.2	4.3	5.4
M12-LSS-N-1:2.5	145	0	25.3	32.3	34.2	4.5	5.6
M12-LSS-50-1:2.5	140	50	28.3	35.6	36.9	4.7	5.8

Tensile Strength

Table 9 shows the results of the splitting tensile strength for Ordinary Portland Cement Concrete (OPCC) and Geopolymer concrete (GC) specimens.

From Table 9, Fig. 7 and Fig. 8 It can be observed that the splitting tensile strength is noticeably increased at 28 days; the highest increase was at 50% LSW. The use of 50% LSW has increased the splitting tensile strength by about 24% when compared with Ordinary Portland Cement Concrete (OPCC), mix N. On the other hand, the use of 50% LSW at M10 has increased the splitting tensile strength for Geopolymer concrete by about 7% when compared with Geopolymer concrete, mix M10-1:2. The same trend has happened at molarity M12. The achieved results are in agreement with the published literatures [4].

Flexural Strength

Table 9 indicates the results of the flexural strength for Ordinary Portland Cement Concrete (OPCC) and Geopolymer concrete beams.

From Table 9, Fig. 9 and Fig. 10, it can be observed that the flexural strength was significantly increased at 28 days. Using 50% LSW exhibited a good enhancement for the flexural resistance. The use of 50% LSW has increased the flexural strength by about 7% when compared with Ordinary Portland Cement Concrete (OPCC), mix N. On the other hand, the use of 50% LSW at M10 has increased the splitting tensile strength of Geopolymer concrete by about 4% when compared with Geopolymer concrete mix M10-1:2. The same trend has happened at molarity M12. This development in flexural strength may be related to the chemical and physical effect of LSW. Moreover, this enhancement in flexural strength for cement concrete may be due to the SiO_2 content in LSW which can react with the $\text{Ca}(\text{OH})_2$ in concrete to form

secondary calcium silicate hydrate and make it chemically stable and structurally dense.

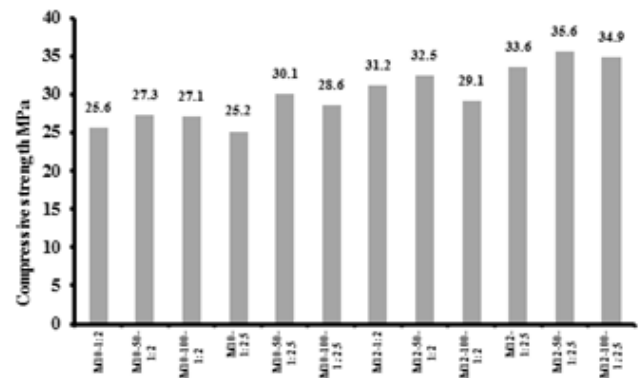


Figure 6. Effect of molarity of NaOH in compressive strength of Geopolymer concrete, at 28 days.

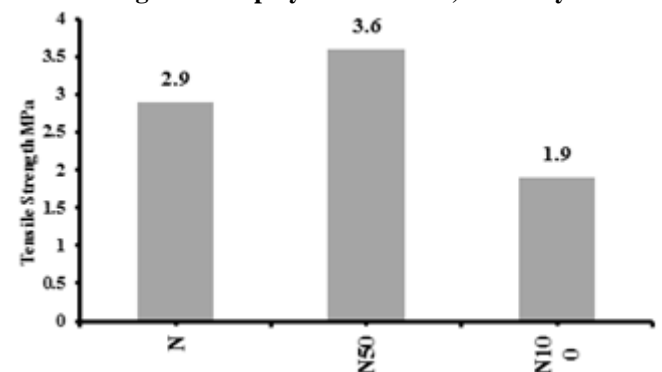


Figure 7. Effect of LSW on the tensile strength of cement concrete at 28 days.

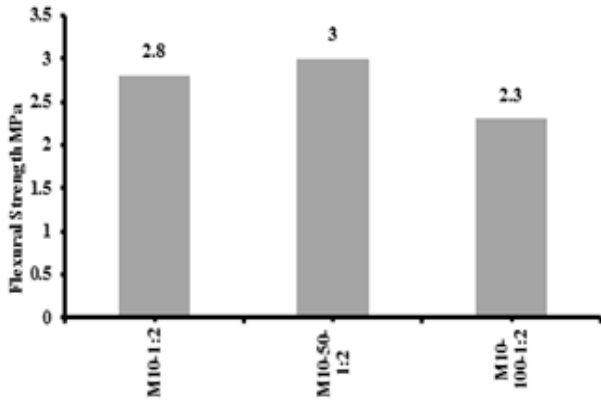


Figure 8. Effect of LSW on the tensile strength of Geopolymer concrete M10 at 28 days.

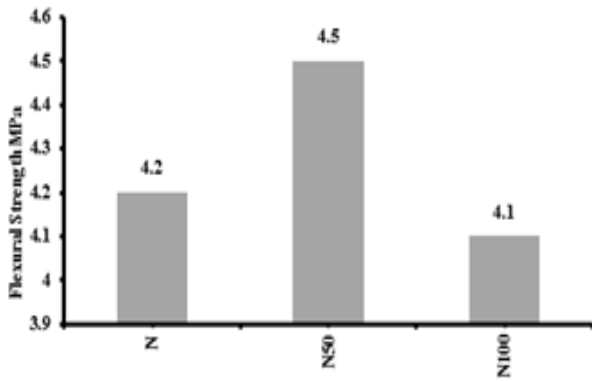


Figure 9. Effect of LSW on the flexural strength of cement concrete at 28 days.

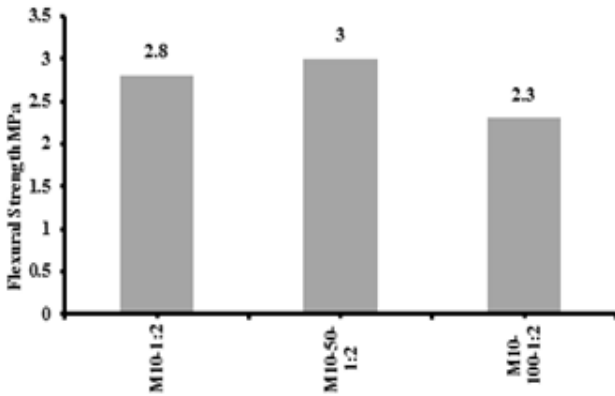


Figure 10. Effect of LSW on the flexural strength of Geopolymer concrete M10 at 28 days.

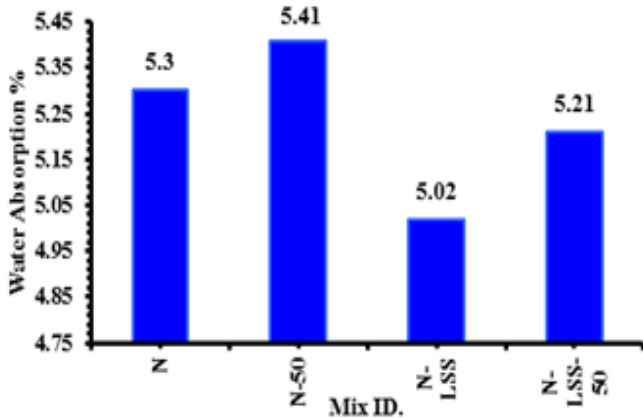


Figure 11. Effect of LSW and local steel slag on the water absorption of cement concrete at 28 days.

Water Absorption

Figure 11 shows the results of water absorption for Ordinary Portland Cement Concrete (OPCC) which indicate that the absorption for (OPCC) has increased by about 2% if LSW replaces sand by 50% whereas the presence of LSS aggregates reduced this absorption of OPCC by about 5%. In general replacement of sand by 50% LSW increases the absorption for OPCC. In addition, Fig. 12 shows that Geopolymer concrete with crushed stone (CS) as coarse aggregate was affected by the replacement of LSW where replacement of sand by 50% LSW increased the absorption by about 16% and 13% at M10-1:2 and M10-1:2.5 respectively. On Other hand, the increase of the molarity has no effect on the absorption.

Figure 13 indicates the results of the effect of both molarity and NH:NS concentration on the Geopolymer concrete with LSS as coarse aggregate. Results illustrates that there is a slight increase in the absorption of Geopolymer concrete with LSS when 50% LSW was replaced and that the effect of increasing NH:NS may be negligible, however, the rise of molarity from M10 to M12 also has a slight effect on water absorption.

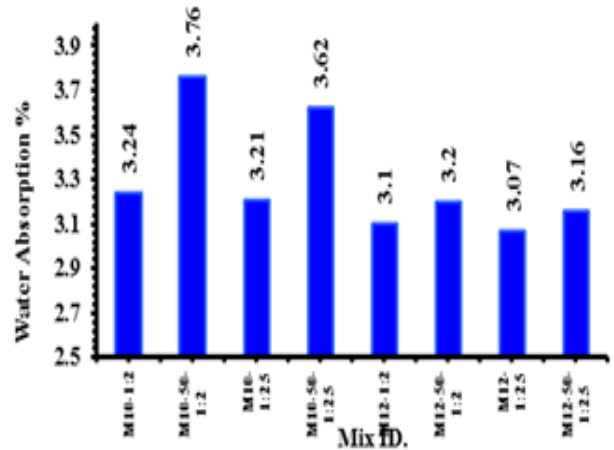


Figure 12. Effect of LSW on the water absorption of Geopolymer concrete at 28 days.

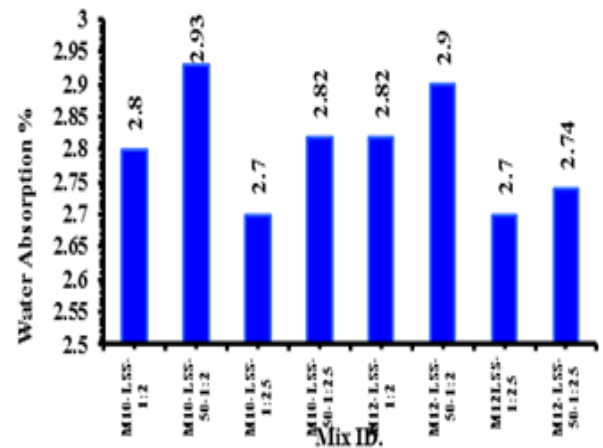


Figure 13. Effect of LSW and local steel slag on the water absorption of Geopolymer concrete at 28 days

This rise of water absorption at a replacement level of 50% LSW may be related to the physical effects of limestone powder. Moreover, the percentage of free calcium hydroxide during the reaction of cement is increased, when powder content of LSW increases, the water absorption of LSW increases more than fine aggregate as indicated in Table 1.



Figure 14. Los Angeles (LA) abrasion machine called Cantabro Test method.

Weight loss with Los Angeles (LA) abrasion machine called Cantabro Test method

The Cantabro testing involves recording the initial weight of the separate sample, placing it in the Los Angeles abrasion, and then rotating it for 300 revolutions at the rate of 30 revolutions per minute. A cylindrical sample 150 mm diameter by 100 mm height was used in the test as displayed in Fig. 14. The weight loss after the Cantabro test (called Cantabro Loss) is calculated in percentage using Equation (1).

$$\text{Cantabro Loss \%} = [(W1 - W2) / W1] * 100 \quad (1) \quad [14]$$

Where,

Cantabro Loss = Weight loss, %;

W1= Initial sample weight, g;

W2= Final sample weight, g.

Fig. 15, Fig. 16 and Fig. 17 show Cantabro loss results. It can be observed that the results could clearly show the difference among the tested Portland cement concrete with or without local steel slag as a coarse aggregate mix, this test was sensitive enough to separate local steel slag cement concrete mixes with different properties. In general, using small local steel slag size as a coarse aggregate (10 mm) and/or replacement of fine aggregate for quarry limestone waste reduced the Cantabro loss, which approved well with the compressive strength results.

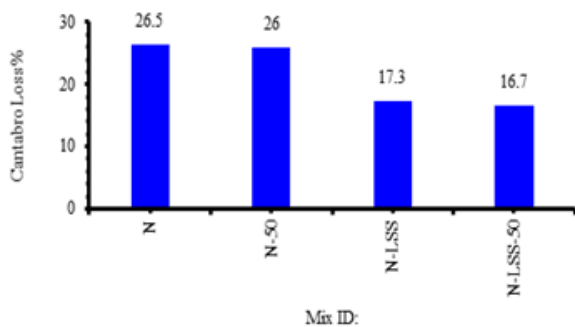


Figure 15. Effect of LSW and local steel slag on the Weight loss with Los Angeles abrasion (Cantabro Test method) of cement concrete.

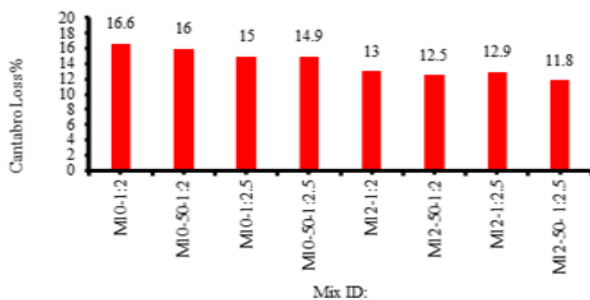


Figure 16. Effect of LSW on the Weight loss with Los Angeles abrasion (Cantabro Test method) of Geopolymer concrete.

Figure 16 also shows that the Cantabro loss range was within 11.8% and 16.6% (290~470 g), representing that less than quarter of the sample weight was lost during the test for all green Geopolymer concrete mixes. The probable reason for this was that some of the specimens were fallen apart due to the crash in the test rather than were abraded away because of their low strength in the Geopolymer mixes containing molarity M10 compared to mixes containing molarity M12. In this case, the test protocol (300 revolutions) may be too severe. Fewer revolutions will be investigated as a potential way to mitigate the weight loss value and to improve the effectiveness of the test. Cantabro loss range was within 9.8% and 13.1% (290~340g) for local steel slag as a coarse aggregate in Geopolymer concrete, demonstrating that more than 10% of the samples weight was lost during the test for all Geopolymer concrete mixes having local steel slag as a coarse aggregate as shown in Fig. 17

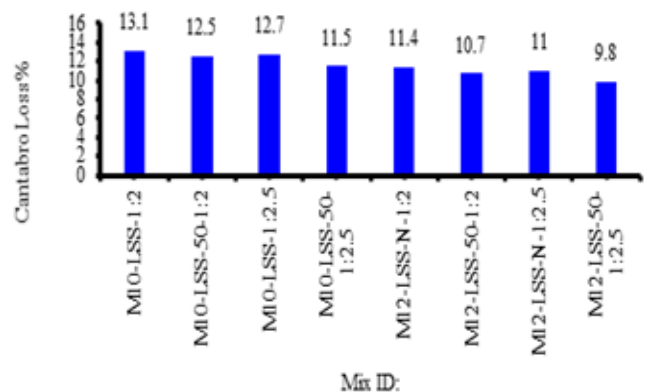


Figure 17. Effect of LSW and local steel slag on the Weight loss with Los Angeles abrasion (Cantabro Test method) of Geopolymer concrete.

Sorptivity

Sorptivity is an asset associated with capillary effects. It is defined as the gradient of the volume of water absorbed per unit area of the surface and the square root of the absorption time. The movement of water into concrete is described by the classical square-root-time relationship.

Fig. 19, Fig. 20, Fig. 21, Fig. 22 and Fig. 23 give the sorptivity results for the mixes (N, N-50, N-LSS, N-LSS-50) Portland cement concrete in Fig. 16, (M10-1:2, M10-50-1:2, M10-1:2.5, M10-50-1:2.5) Geopolymer concrete in Fig. 17, (M12-1:2, M12-50-1:2, M12-1:2.5, M12-50-1:2.5) Geopolymer concrete in Fig. 18, (M10-LSS-1:2, M10-LSS-50-1:2, M10-LSS-1:2.5, M10-LSS-50-1:2.5) Geopolymer concrete in Fig. 19, and (M12-LSS-1:2, M12-LSS-50-1:2, M12-LSS-1:2.5, M12-LSS-50-1:2.5) Geopolymer concrete in Fig. 20. Each set of schemes shown refer to the average of the three samples tested from each of the mixes.



Figure 18. Sorptivity test method.

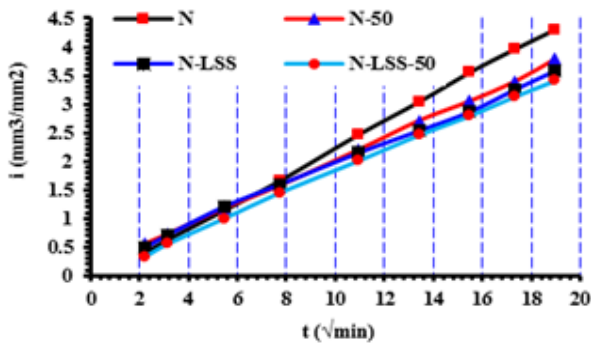


Figure 19. Cumulative sorptivity per unit area with square root time for OPC concrete with or without local steel slag as coarse aggregate in cement content 350kg/m³.

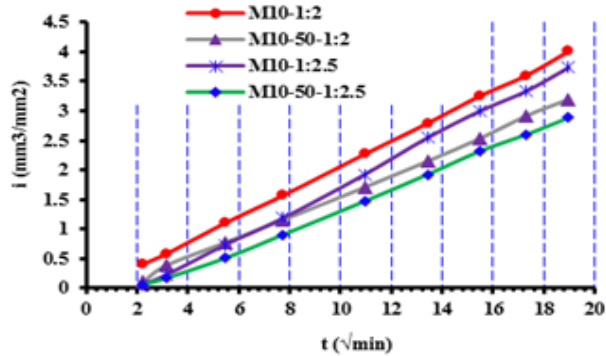


Figure 20. Cumulative sorptivity per unit area with square root time for GPC with or without 50% LSW as replacement for fine aggregate in molarity M10 and fly ash content 350 kg/m³.

In this relationship, water absorption into porous materials increases with the square root of the elapsed time (t). Assuming a constant supply of water at the inflow surface, the following relationship holds [20]. Typical plots of cumulative sorptivity against the square root of time are shown in Fig. 16, Fig. 17, Fig. 18, Fig. 19, and Fig. 20.

Water sorptivity test results of Ordinary Portland Cement Concrete (OPCC) with LSW with different replacement percentages are presented in Fig. 16 for 0.0, and 50% respectively. The use of LSW with levels of 50% has increased water sorptivity of Ordinary Portland Cement Concrete (OPCC) by about 13% when compared with the Ordinary Portland Cement Concrete (OPCC) N50-350. The use of 50% LSW and 100% local steel slag has decreased water sorptivity of Ordinary Portland Cement Concrete (OPCC) by about 3% when compared with the Ordinary Portland Cement Concrete (OPCC) N-LSS.

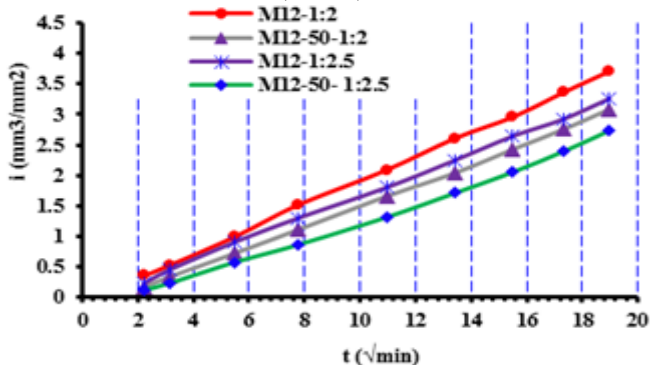


Figure 21. Cumulative sorptivity per unit area with square root time for GPC with or without 50% LSW as replacement for fine aggregate in molarity M12 and fly ash content 350 kg/m³.

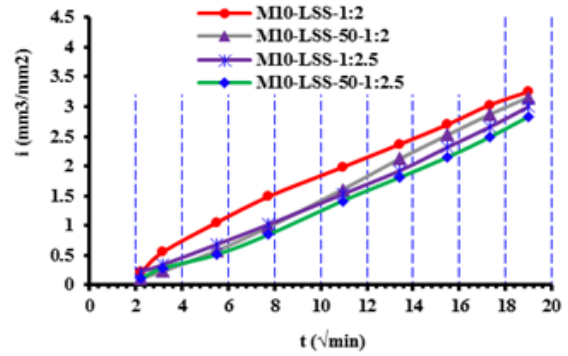


Figure 22. Cumulative sorptivity per unit area with square root time for GPC with and without LSW containing local steel slag as coarse aggregate in molarity M10 and fly ash content 350 kg/m³.

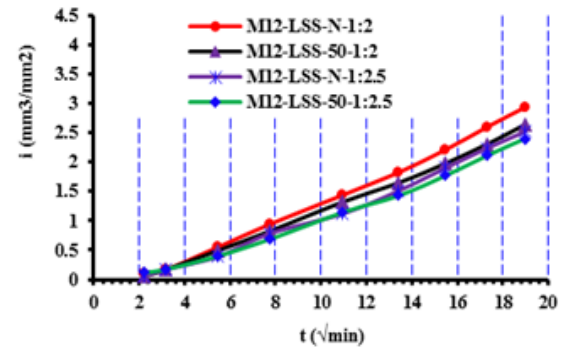


Figure 23. Cumulative sorptivity per unit area with square root time for GPC with and without LSW containing local steel slag as coarse aggregate in molarity M12 and fly ash content 350 kg/m³.

Fig. 17, Fig. 18, Fig. 19, and Fig. 20, represent the curve of cumulative mass gained per exposed surface area against square root of time where the slope of the linear portion is the measurement of sorptivity. They show that the value of sorptivity decrease for Geopolymer concrete containing local steel slag as coarse aggregate. Also, water sorptivity decrease for Geopolymer concrete containing 50% LSW as a replacement for fine aggregate because the powder in the quarry limestone waste fills the pores in the Geopolymer matrix. Furthermore, as the concentration of NaOH increases in Geopolymer concrete, the pore area become non-permeable for molarity M12. Similar findings have been reported in earlier studies [15].

Microstructure Analysis

Scanning electron microscopy was familiar determining the microstructure and the phase distribution of the models. In order to innovation high-quality images by means of a backscattering scanning electron detector, the models had to be prepared carefully, cutting, grinding and polishing in order to become high contrast pictures to be clear for analysis. In Figure 24, shown Pore size and pore shape are considerably affected by LSW percent. Slight pores can be detected in the models, especially in the model containing 50% LSW. There are some pores in the samples containing 50% LSW which are mostly located around coarse aggregates

Figure 25, shows the features morphology of the samples with 10M and 12M NaOH solution of the Geopolymer concrete containing 50% LSW. Original fly ash consists of a series of spherical vitreous particles of different sizes. When the Geopolymerization reaction arises, the spherical particles begin to break. The development of a porous heterogenous matrix is detected. From Fig. 26 (a) (b) (c) and (d), a big amount of fly ash still did not totally dissolve.

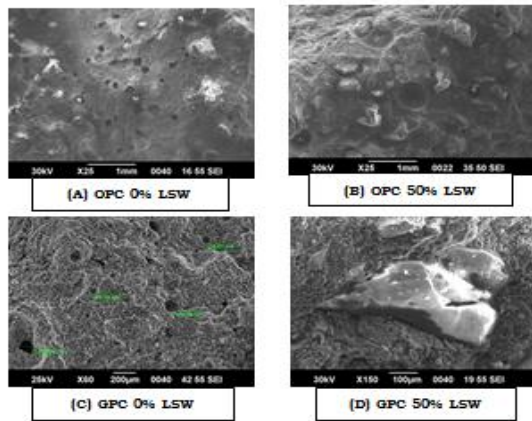
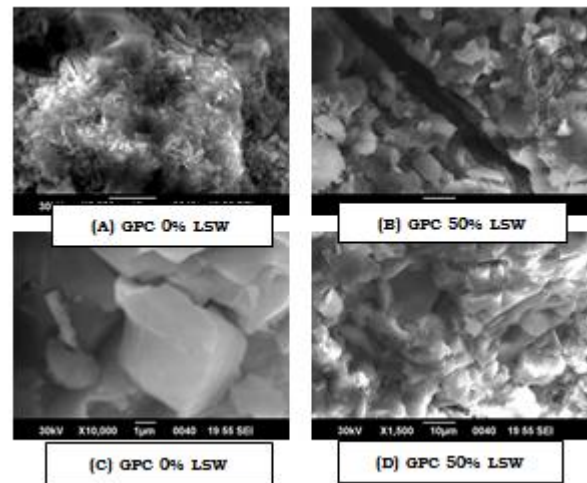


Figure 24. Shown Pore size and pore shape are significantly influenced by 50 % LSW content.

Fig. 26 (b) displays the smallest unreacted fly ash with alkaline activator and more gel covered and connected fly ash particles together that gave the highest compressive strength 36.9 MPa at 28 days age. This suggests that the dissolution of silica and alumina in Geopolymerization process that form aluminosilicate gel is very significant in determining the stability of Geopolymer during the hardening stage which enhances the compressive strength of Geopolymer. The pores and cracks are also found in the matrix Fig. 26 (a) and (b) which bound the compulsory capacity and hence decreases compressive strength. Fig. 26 (c) shows a dense gel-like matrix with imbedded fly ash particles. However, this causes micro-cracks which also cause low compressive strength. Fig. 26 (a) and (c) displayed the microstructure morphology of Geopolymers with the best mix design (high compressive strength) for each type of fly ash/alkaline activator ratio (2.0 and 2.5). The microstructure of fly ash based Geopolymer for different mix design had been observed with SEM. It presented that the materials are heterogeneous which leads to incompletely unreacted fly ashes that occurred on the dense gel-like matrix. Among these three mix design, the sample with fly ash/alkaline activator ratio of 2.5 (Fig. 26 (b)) showed more dense matrix and less unreacted fly ash which contributed to maximizing compressive strength (36.9 MPa). The quantities of liquid in the schemes have an effect on the saturation rate of ionic species and strength of Geopolymer. When the fly ash is added with a small quantity of alkaline activator, a paste was formed and quickly transformed into a hardened solid. Thus, there is no space for the gel (product of reactions) to develop into a well-crystallised structure. It is well known that zeolites usually need some time for crystallization and minimum quantity of liquid. In this case, fly ash/alkaline activator of 2.5 is the greatest ratio and satisfies the requirement for increasing the strength of Geopolymer. The vertical hair type crack exists on the sample of ratio fly ash/alkaline activator of 2.5 which reduced the compressive strength of the sample as shown in Fig. 26 (c) .

It can also be seen that there are small limestone waste particles exist in the concrete even after 28 days of hydration, the total volume of limestone waste is nearly not changing during the 28 days hydration. The powder in the quarry limestone waste fills the interfacial transition zone between the matrix and aggregate, leading to more dense matrix, and enhances the bond between cement paste and aggregate.



This may be due to the surface texture, and shape, of the quarry limestone waste, this result is in agreement with reference [13] which is the reason why the compressive strength of concrete incorporating limestone waste up to 50% is more than that of Ordinary Portland Cement Concrete(OPCC) but replacement of LSW more than 50% decreases the compressive strength because the mixes become low in homogenate see Fig. 2.

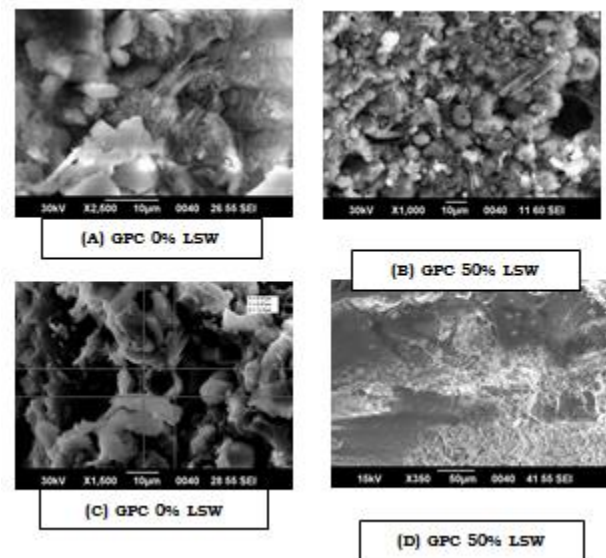


Figure 26. Shown microstructure properties of 0% and 50 % LSW content in Geopolymer connector.

Conclusions

The following annotations and conclusions can be made on the origin of the existing experimental consequences.

- 1-Lime stone powder can be used as a raw material without any processing for production of both green Ordinary Portland Cement Concrete (OPCC) and Geopolymer concrete (GC)
- 2-Lime stone powder reduced the slump of both OPCC and GC concrete up to about 50% replacement of used sand weight
- 3-Using replacement of LSW up to 50% enhances the compressive strength for both cement and Geopolymer concrete.
- 4-Molarity of the sodium hydroxide has an positive effect on the compressive strength especially in the presence of LSW in GC
- 5-Indirect tensile strength for cement and Geopolymer concrete increase by about 24% and 7% for both OPCC and GC respectively by using LSW by 50% instead of sand.

6-Slight flexural strength improvement was observed if sand was reduced by 50% LSW

7-Water absorption increases with LSW replacement for GC with a reasonable values where it increases slightly with OPCC whereas the effect of both molarity and NH:NS were slight. LSS coarse aggregate reduces the absorption for both OPCC and GC

8-Los Angeles abrasion test result indicates that the abrasion resistance of GC was more than OPCC by about 37% to 51% and increase to 40% to 55% if LSW used to GC as replacement of sand by 50%. Local steel slag aggregate increase the abrasion resistance for both OPCC and GC especially with LSW powder.

9-The filling effect of the powder in the quarry limestone waste can make the paste matrix and the interfacial transition zone between the matrix and aggregate more denser, which can improve the performance of concrete. Limestone powder does not have pozzolanic properties, but it is still un-hydrated at the age of 28 days.

References

[1] M. S. Hameed and A. S. S. Sekar, (2009) "properties of green concrete containing quarry rock dust and marble sludge powder as fine aggregate" India, *ARNP Journal of Engineering and Applied Sciences*, Vol. 4, NO. 4, pp. 83-89.

[2] R. Ilangovana, N. Mahendrana and K. Nagamanib, (2008) "Strength and durability properties of concrete containing quarry rock dust as fine aggregate" India, *ARNP Journal of Engineering and Applied Sciences*, Vol. 3, NO. 5, pp. 20-26.

[3] H. Binici, T. Shahb, O. Aksoganc, and H. Kapland (2008) "Durability of concrete made with granite and marble as recycle aggregates" Turkey, *journal of materials processing technology*, Vol.208, pp. 299-308.

[4] J.G.S. VAN Jaarsveld, J.S.J. VAN Deventer, and L. Lorenzen (1998) "Factors Affecting the Immobilization of Metals in Geopolymerized Fly ash" South Africa, *metallurgical and materials transactions*, VOL 29B, pp. 283-291.

[5] C. K. YIP, J. S. J. VAN Deventer, (2003) "Microanalysis of calcium silicate hydrate gel formed within a Geopolymeric binder" Australia, *Journal of Materials Science* VOL. 38, PP. 3851 - 3860.

[6] J.G.S. van Jaarsveld, J.S.J. van Deventer, G.C. Lukey (2003) "The characterisation of source materials in fly ash-based Geopolymers" Australia, *Materials Letters*, VOL. 57, PP. 1272 - 1280.

[7] J. Temuujin, A. van Riessen, R. Williams, (2009) "Influence of calcium compounds on the mechanical properties of fly ash Geopolymer pastes" Australia, *Journal of Hazardous Materials*, VOL. 167, PP. 82-88.

[8] Debabrata Dutta, and Somnath Ghosh (2012), "Effect of Limestone Dust on Geopolymerisation and Geopolymeric Structure" India, *International Journal of Emerging Technology and Advanced Engineering*, VOL. 2, PP. 757-763.

[9] Egyptian Code No. 203-2008.

[10] ASTM C618 Class F.

[11] ESS 1109/2002 Egyptian Standard Specifications "concrete aggregates from natural sources".

[12] A. A. Adam, (2009) "Strength and Durability Properties of Alkali Activated Slag and Fly Ash-Based Geopolymer Concrete" Ph. D, School of Civil, Environmental and Chemical Engineering, RMIT University, Melbourne, Australia.

[13] LIU Shuhua, YAN Peiyn, (2010) "Effect of limestone Powder on Microstructure of Concrete" China, *Journal of Wuhan University of Technology-Mater*, VOL. 25, PP. 328-331.

[14] Qiao Dong, Hao Wu, Baoshan Huang, Xiang Shu, and Kejin Wang, (2010) "Development of a Simple and Fast Test Method for Measuring the Durability of Portland Cement Pervious Concrete" *ASCE Journal of Materials in Civil Engineering*.

[15] D. Dutta, (2010), "Influence of Silicious and Calcious Material as an Additive on The Performance of Fly Ash Based Geopolymer Paste And Mortar" M.Sc Civil Engineering (Structural Engineering), Department of Civil Engineering Faculty of Engineering & Technology Jadavpur University - Kolkata.

[16] O. M. Omar, A. M. Heniegal, G. D. Abd Elhameed, H. A. Mohamadien, (2015) "Effect of Local Steel Slag as a Coarse Aggregate on Properties of Fly Ash Based-Geopolymer Concrete" Egypt, *World Academy of Science, Engineering and Technology*, VOL. 9, PP. 508-516.

[17] O. M. Omar, G. D. Abd Elhameed, A. M. Heniegal H. A. Mohamadien, (2015) "Effect of Crashed Stone on Properties of Fly Ash Based-Geopolymer Concrete with Local Alkaline Activator in Egypt" Egypt, *World Academy of Science, Engineering and Technology*, VOL. 9, PP. 957-966.