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Development of one part, Self-Cured, Fine Soil/ Quartz Stone Powder Based Geopolymer Mortar

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Abstract - One of the critical challenges in the practical application of geopolymers lies in the necessity of heat treatment to enhance their properties. Consequently, the development of self-curing geopolymers has emerged as a focal area of research. In this study, fine soil was utilized as the primary raw material. Two series of mixes were prepared: in the first series, without (%0) Ordinary Portland Cement (OPC) replacement, fine soil was replaced by quartz stone powder at varying proportions (0%, 20%, 40%, 60%, 80%, and 100%). In the second series, with a 10% OPC replacement, fine soil was replaced by quartz stone powder in increments of 0%, 15%, 35%, 55%, 75%, and 90%. Key properties such as compressive strength, water absorption, and sorptivity were investigated. The results revealed that the mix with 10% OPC replacement achieved better the geopolymer properties. Furthermore, in both series, increasing the quartz stone powder content consistently improved the mortar performance.

***Keywords*:** self-curing, sodium hydroxide, fine soil, quartz stone powder, compressive strength, water absorption water sorptivity.

1. Introduction

Geopolymer is a new technology to replace Ordinary Portland cement OPC. Manufacturing process of cement is problematic to environment. Nearly 7% of emitted CO2 to atmosphere is due to OPC, which leads to global warming [1].

Geopolymers are produced by activating a source material containing silica and alumina with alkaline solutions. Industrial by-product materials and natural materials can be used as source geopolymer material. Industrial by-products like fly ash [2–4], and ground granulated blast furnace slag [5, 6] and natural material like metakaolin [7]. Alkaline solution is a mixture of either sodium hydroxide and sodium silicate or potassium hydroxide and potassium silicate. Geopolymer materials acts as a sustainable material in two ways, recycling industrial by-product materials and reducing the exploitations of OPC like energy consumption, pollution and the area used to waste landfills [8]. Most of the researchers mainly depend on industrial by-products to develop geopolymer materials, while these materials are not in sufficient amount to totally replace OPC, and not available in some countries. So it is so essential to examine different raw materials that mainly contains silica an alumina to produce geopolymer materials. Portland cement production requires a double amount of energy as compared to activator preparation in alkali activated production [9].

External heat supply is one of the limitations in the application of geopolymer because the chemical reaction of source material with alkaline solution is endothermic reaction10, some additives can be used to enhance the geopolymerization like , such as OPC, high calcium fly ash, calcium hydroxide and slag, as additional calcium sources in geopolymer mixes [11–19]. The reaction between cement and water is exothermic reaction, so it is an appropriate material to be used as an admixture.

Most commonly alkali activator is mixture of sodium silicate and sodium hydroxide, however preparing the sodium silicate needs 1300-1500C that consumes a huge amount of energy [20, 21], so developing geopolymer with utilising just sodium hydroxide is an attempt to reduce the geopolymer energy consumption.

A.M. Kaja et al. [22] explained the effect of OPC inclusion with levels of 5%, 7.5, 10% to weight of fly ash. The results show that the optimum OPC substitution to fly ash is 7.5% at which the compressive strength is the highest.

Wang et al [23] reported the impact of NaOH addition and curing temperature on the mechanical properties of hybrid binder composed of fly ash and cement kiln dust in paste sample. It was concluded that curing temperature was more effective for 50/50 fly ash/ cement kiln binder on strength enhancement than NaOH addition. Pradir N. et al.[17] reported the influence of OPC inclusion to low calcium fly ash on the compressive strength of geopolymer mortar and concrete. It is achieved that the increase OPC content increases the compressive strength. Tanakorn P. et al. [24] studied the impact of OPC addition to high calcium fly ash on mechanical and porosity properties of geopolymer concrete. It was revealed that the use of OPC as an additive to replace part of FA leads to improve compressive strength. Teewara S. et al.18 studied the effect of OPC inclusion at levels of 5%, 10%, 30%, 50% and 70% of weight of fly ash, the compressive strength continuously increase as replacement of OPC increases. Mahya A. et al. [25] investigated the mechanical properties of one-part geopolymer fly ash replaced by 10%, 20% 30% and 60% of OPC. It was concluded that the compressive strength of hybrid binder is higher than the control geopolymer mixes furthermore it was reported that when OPC content increases from 10% to 60% the compressive strength also increases. Shehab et al [19] examined the impact of OPC inclusion in fly ash based geopolymer concrete. The author concluded that 50% of OPC replacement had highest mechanical properties at 28 day.

In order to examine the feasibility of fine soil as base material of geopolymer, This study contains two series of mixes, first one was six mixtures that was designated of fine soil and 0% OPC were blended with quartz stone powder in different ration (0%, 20%, 40%, 60%, 80% and 100%). second one was also six mixtures that was designated of fine soil and 10% of OPC were blended with quartz stone powder in different ration (0%, 15%, 35%, 55%, 75% and 90%). With constant concentration of NaOH solution 12 M. Compressive strength and absorption properties of the mortar. Fine soil was used as base material. The binder to solution ratio was kept constant 0.40. 20% of the total weight for fine sand was used. The results revealed that fine soil can be utilized as a base material to geopolymer, the quartz stone powder replacement and OPC inclusion can improve the hardened properties.

2. Methods and materials

2.1 materials

2.1.1 Fine soil

The fine soil was collected and brought from Mirabag village, cleaned, dried and sieved such that all the particles passed through sieve 300µm, the particle size distribution is shown in the figure 1. And the chemical composition test XRF is conducted and the test results are shown in the table 1.

2.1.2 Quartz stone

The quartz stones were collected and brought from Makok mountain located near Ranya city, cleaned, dried crushed to a fine powder and sieved such that all the particles passed through sieve 300µm, the particle size distribution is shown in the figure 1. And the chemical composition test results are shown in the table 1.

Table 1: Chemical composition of XRF test result of fine soil, quartz stone powder and glass powder.

Oxides	SiO2	Al2O3	CaO	MgO	Na2O	K2O	Fe2O3	SO3	Mn
Fine Soil	13.926	4.49	60.277	5.892	0.762	0.564	2.737	0.187	10.262
Quart Stone	99.0	0.05	0.03	0.01	0.762	0.564	0.03	0.03	0

2.1.3 Ordinary Portland cement

Ordinary Portland Cement (OPC) was used for the entire experimental mixes of the study. The chemical and physical properties of the cement were shown in Tables 2 and 3 respectively, which are conformed to IQ.S 5/1984 Standard for Ordinary Portland Cement. The specific gravity of the cement is 3.14.

Table 2: Chemical properties of cement (OPC)

Chemical requirements	IQ.S 5/1984 Standard for Ordinary Portland Cement	
	Limitation	Test Results
Lime saturation coefficient %	0.66-1.02	1.0
Magnesium Oxide (as MgO)%	≤5	3.6
Sulfate content (as SO3) %	2.5 if C3A ≤ 5	2.2
	2.8 if C3A ≥5	
Loss of ignition (as LOI)%	≤4.0	3.5
Non soluble substance %	≤ 1.5	0.8

Table 3: Physical properties of cement (OPC)

Physical Requirements	IQ.S 5/1984 Standard for Ordinary Portland Cement	
	Limitation	Test Result
Fineness (Blaine) kg/m2	≥230	343
-Initial setting time minute	≥45	150
-Final setting time hour	≤10	3:20
Soundness (expansion) %	≤ 0.8	0.2
Compressive strength is not less than (MN/m2)	≥15.0	35.7
	≥ 23.0	46.0

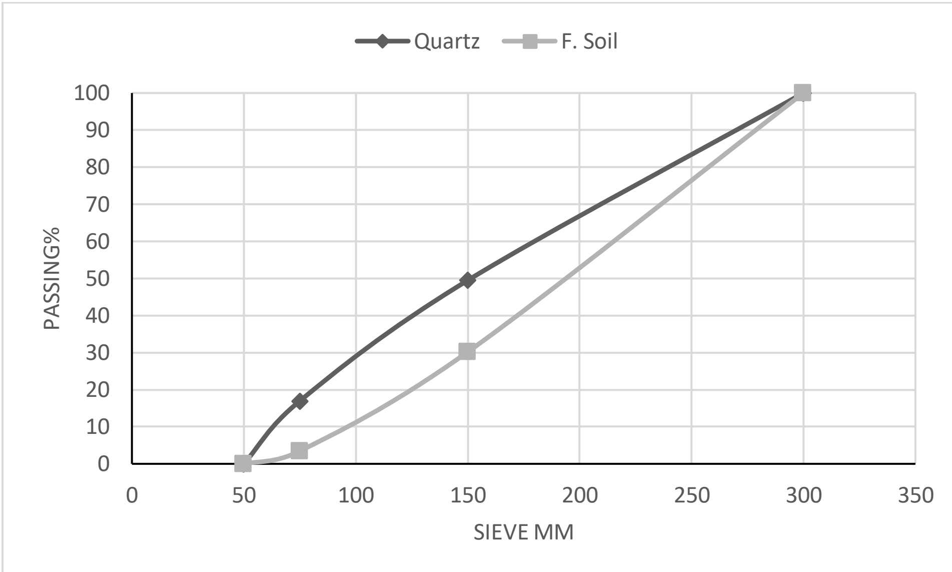


Fig. 1: Particle size distribution of fine soil, quartz stone powder and glass powder.

2.1.4 Fine river sand

Locally available river sand was used. That is conformed to ASTM C33. Specific gravity is 2.64.

2.1.5 Sodium Hydroxide

Sodium hydroxide in flakes with purity (99%) was used for all of the experimental mixes of the research.

2.1.6 Water

Distilled water was used for preparing the NaOH solution for investigation.

Fig. 2: Materials used in the experimentation.

2.2 Mix design

This study contains two series of mixes, first one was six mixtures that was designated of fine soil and 0% OPC were blended with quartz stone powder in different ration (0%, 20%, 40%, 60%, 80% and 100%). second one was also six mixtures that was designated of fine soil and 10% of OPC were blended with quartz stone powder in different ration (0%, 15%, 35%, 55%, 75% and 90%). With constant concentration of NaOH solution 12 M. Compressive strength and absorption properties of the mortar. Fine soil was used as base material. The binder to solution ratio was kept constant 0.40. 20% of the total weight for fine sand was used. The mix proportions are presented in the table 4.

Table 4: Mix Proportion of the geopolymer mortar (Kg/m^3)

Mixes	Proportion of binders	Fine Soil	Quartz powder	Ordinary Portland Cement	Fine Sand	NaOH Molarity	NaOH Solution	Binder/ Solution
M1	S100Q0-C0	1215	0	0	467	10	486	0.40
M2	S80Q20-C0	972	243	0	467	10	486	0.40
M3	S60Q40-C0	729	486	0	467	10	486	0.40
M4	S40Q60-C0	486	729	0	467	10	486	0.40
M5	S20Q80-C0	243	972	0	467	12	486	0.40
M6	S100Q0C0	0	1215	0	467	12	486	0.40
M7	S90Q0-C10	1093.5	0	121.5	467	12	486	0.40
M8	S75Q15-C10	911.25	182.25	121.5	467	12	486	0.40
M9	S55Q35-C10	688.25	425.25	121.5	467	14	486	0.40
M10	S35Q55-C10	425.25	688.25	121.5	467	14	486	0.40
M11	S15Q75-C10	911.25	182.25	121.5	467	14	486	0.40
M12	S0Q90C10	0	1093.5	121.5	467	14	486	0.40

2.3 Mixing, Casting and Curing

Sodium hydroxide flakes were dissolved in distilled water to get the require concentration of solution, for first series, fine soil partially and 0% of OPC replaced by quartz stone powder 0, 20, 40, 60, 80, 100) % were blended, for the second series, fine soil and 10% of OPC partially replaced by quartz stone powder 0, 15, 35, 55, 75, 90)% were blended then mixed with quartz stone powder, 20% of sand was also add to the binder material. The solution added to the dry materials, the mixture poured with two layers into the moulds with size (25*25*25) mm, then the moulds were manually compacted to remove the entrapped air. A total of 180 samples were prepared. The samples were covered by a plastic bag to avoid losing of moisture, after 24hr the samples were demoulded and kept in ambient temperature until the time of testing. The samples were tested for compressive strength at 14, 28 and 56, day and for water absorption and water sorptivity at 56 day of age.

2.4 Testing

2.4.1 Compressive Strength

Is the ability of material to resist failure under the action of compression load. Compressive strength test is conducted according to ASTM C109 for cement mortar. For each mix three samples were tested by a digital compression machine with the capacity of 2000KN. the average of the three results of three samples were calculated and reported. The results of the compression strength of 14, 28 and 56 day of age were presented in the relevant tables and graphs.

Fig. 3: Compression machine test.

2.4.2 Water absorption

Water absorption is the ability of material to absorb water and retain under specific condition. Durability of materials can be evaluated by conducting water absorption test, in this research water absorption test is taken at 56 day of age, for each of the mixes three samples were dried to a constant mass in oven at 105 °C for 24 hr. then the samples kept to cool to room temperature after that the samples were immersed in water for 24 hr to get the saturated mass of the samples. The increase in mass to the dry mass by percentage is the water absorption Eq. (1).

$$WA\% = \frac{M2 - M1}{M1} * 100 \tag{1}$$

M1=dry mass and M2 =saturated mass of the sample

2.4.3 Water sorptivity

Is the ability of material to absorb water by suction. It is one of the tests related to the durability of the material to evaluate the ingress of water through the material. Water sorptivity of geopolymer mortar was carried out according to ASTM C1585 standard [22]. In this test three samples of (25*25*25) mm were used. Water sorptivity measures the amount of water absorbed by the mortar by suction. In this study for each mix three samples were dried to a constant mass at 105C in oven at 56 day, then the samples were taken out, and coated with silicone sealing to avoid entering water from the sides, then the samples kept in water with depth not more than 4mm above the bottom of the samples as shown in the figure 4. Wetted height of the sample can be evaluated by dividing the increase of the mass of the sample weighed at different time intervals, by the bottom surface area of the sample and density of water. Then, the square root of time versus these values was plotted and the sorptivity index of mortar was calculated by the slope of the line of the best fit.

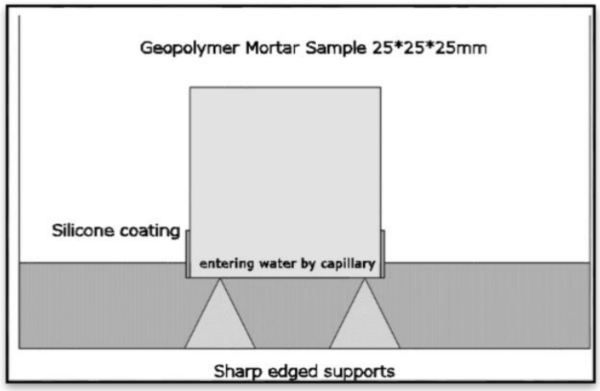


Fig. 4: Water sorptivity test for geopolymer mortar.

3. Results and discussion:

3.1 Compressive strength

Figure 5 and table 5 show the results of compressive strength of 0 and 10% of cement replacement and 0 to 100% of quartz stone powder for first series and for second series 0 to 90% of quartz stone powder.

For first series, increasing the quartz stone powder content in the mixes compressive strength also increases.

For the second series the compressive strength results are higher compared to the correspondence result of the first series means increasing 10% of OPC to the mixes increased the compressive strength. At the same time increasing the quartz stone powder increases the compressive strength.

Table 5: Effect of OPC and quartz stone replacement and NaOH concentration variation on compressive strength of fine soil based mortar.

Mixes	C0			Mixes	C10		
	14 day	28 day	56 day		14 day	28 day	56 day
S100Q0C0	3.64	4.59	5.88	S90Q0C10	4.00	5.33	6.88
S80Q20C0	4.51	4.84	6.31	S75Q15C10	4.56	6.00	7.00
S60Q40C0	4.38	5.62	7.10	S55Q35C10	4.86	6.12	7.34
S40Q60C0	4.74	6.05	8.30	S35Q55C10	4.93	6.22	8.43
S20Q80C0	5.06	6.87	9.12	S15Q75C10	5.82	7.05	9.48
S0Q100C0	6.18	8.00	10.31	S0Q90C10	6.28	8.36	12.39

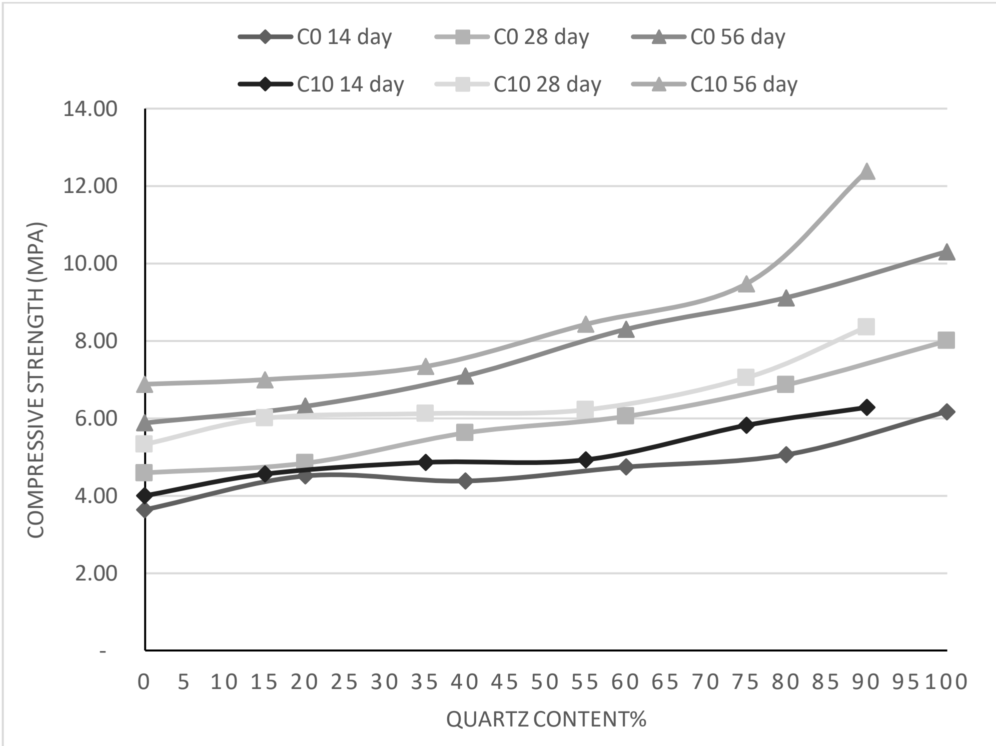


Fig. 5: Effect of OPC and quartz stone replacement and NaOH concentration variation on compressive strength of fine soil based mortar.

3.2 Water absorption

Table 6 and figure 6 show the results of water absorption of 0 and 10% of cement replacement and 0 to 100% of quartz stone powder for first series and for second series 0 to 90% of quartz stone powder.

For first series, increasing the quartz stone powder content in the mixes form 0 to 100% water absorption also decreases.

For the second series, the water absorption results are lower compared to the correspondence results of the first series means increasing 10% of OPC to the mixes decreased the water absorption. At the same time increasing the quartz stone powder decreases the water absorption.

Table 6: Effect of OPC and quartz stone replacement and NaOH concentration variation on water absorption of fine soil based mortar.

C0		C10	
S100Q0C0	14.20	S90Q0C10	12.87
S80Q20C0	13.40	S75Q15C10	11.32
S60Q40C0	12.80	S55Q35C10	10.12
S40Q60C0	11.60	S35Q55C10	9.87
S20Q80C0	10.50	S15Q75C10	9.65
S0Q100C0	10.00	S0Q90C10	8.30

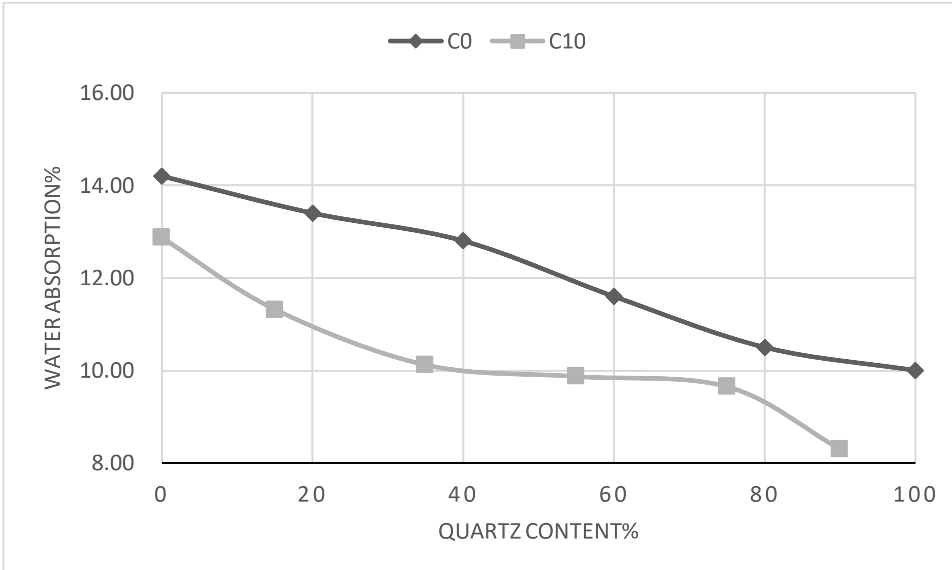


Fig. 6: Effect of OPC and quartz stone replacement and NaOH concentration variation on water absorption of fine soil based mortar.

3.3 Water Sorptivity

Figure 7 show the results of water sorptivity of 0 and 10% of cement replacement and 0 to 100% of quartz stone powder for first series and for second series 0 to 90% of quartz stone powder.

For first series, increasing the quartz stone powder content in the mixes form 0 to 100% water sorptivity also decreases.

For the second series, the water sorptivity results are lower compared to the correspondence results of the first series means increasing 10% of OPC to the mixes decreased the water sorptivity. At the same time increasing the quartz stone powder decreases the water sorptivity.

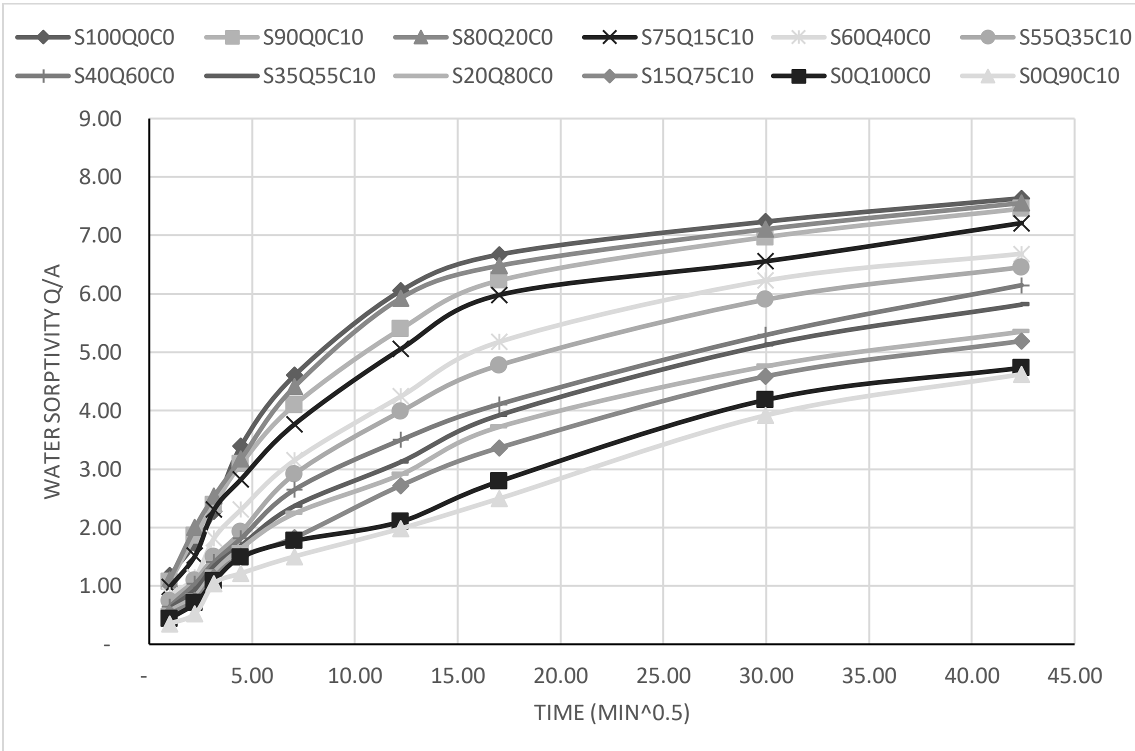
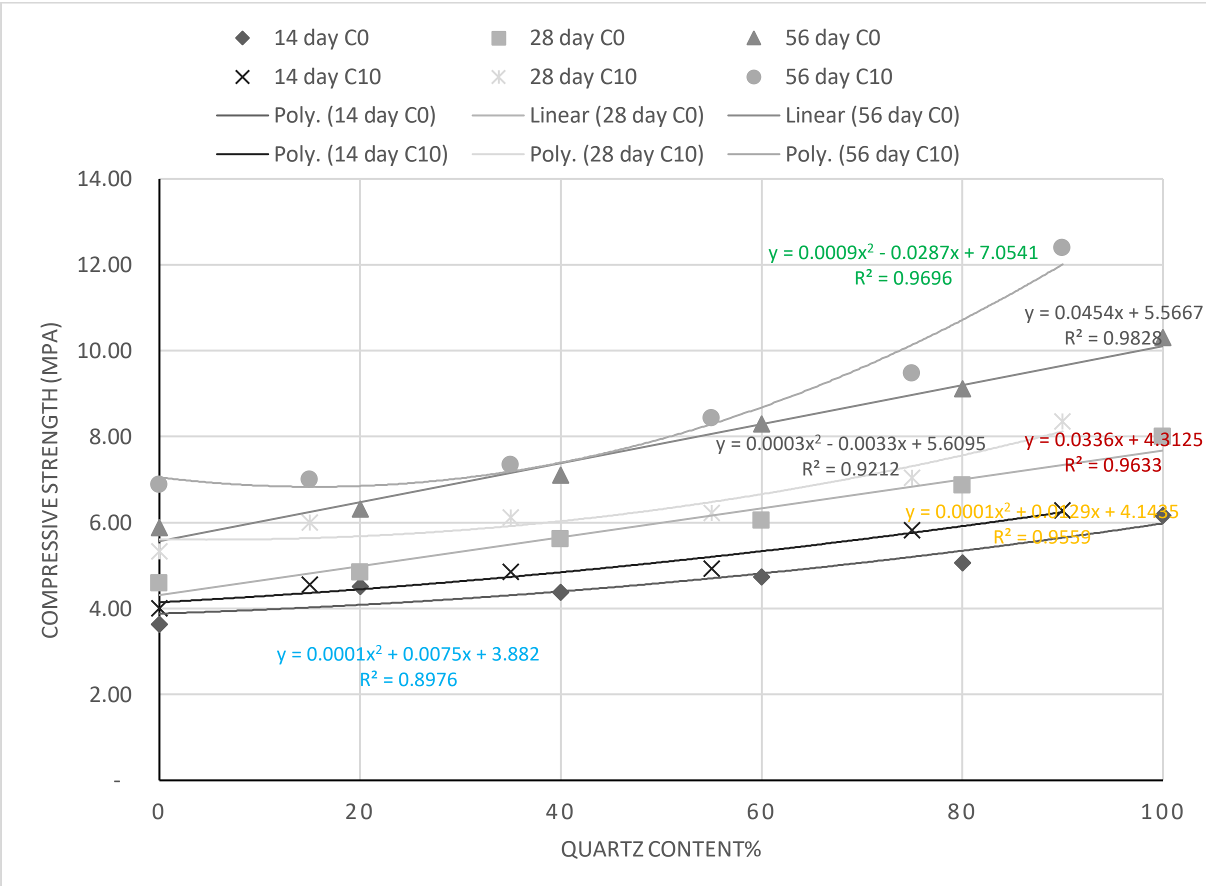


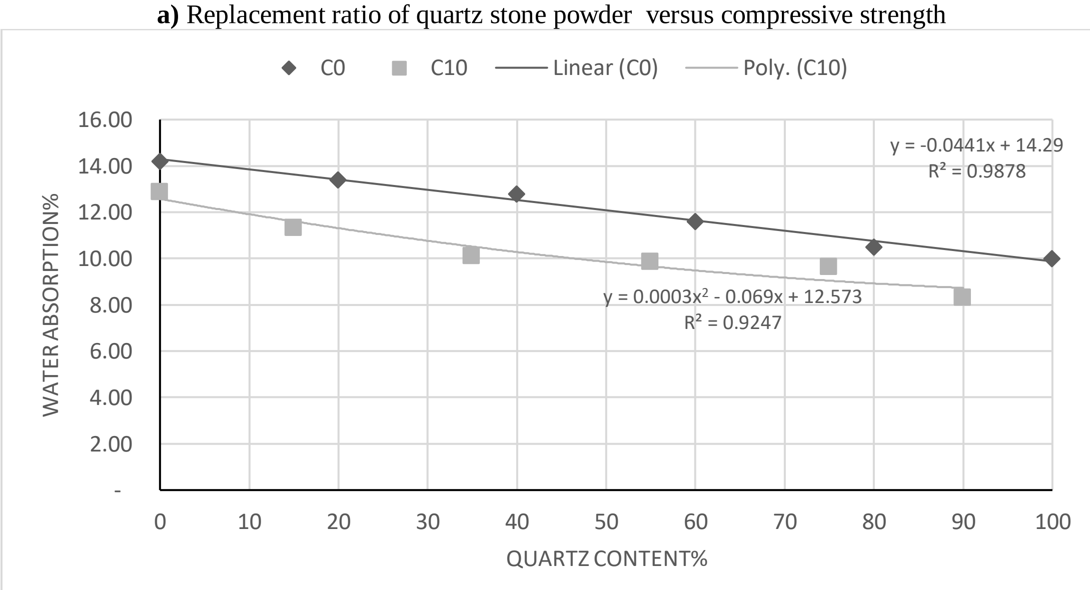
Fig. 7: Effect of OPC and quartz stone replacement and NaOH concentration variation on water sorptivity of fine soil based mortar.

3.4 Correlation between hardened properties

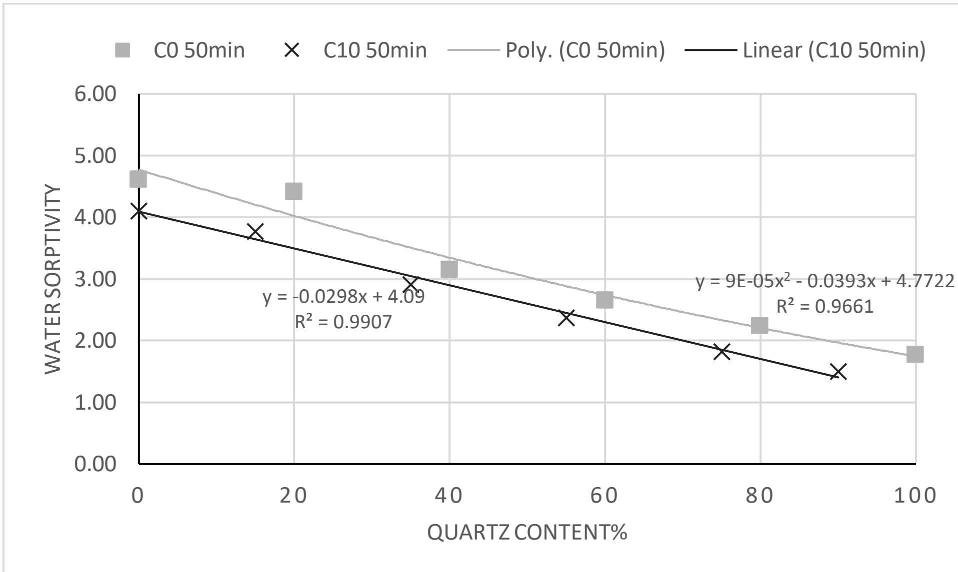
After obtaining the results, it is significant to determine the relationship between the properties. There are several factors affect the mechanical properties of concrete like w/c, aggregate. ect. As stated earlier, most of the mechanical properties of concrete related to compressive strength of concrete. In this study, the effect of quartz powder replacement and OPC inclusion n were investigated. Simultaneously the correlating and relationship between the achieved results was also studied. There are close relationship between quartz stone powder replacement and compressive strength (R2:0.9), (R2:0.96) and (R2: 0.98) at 0% of OPC replacement age of 14, 28 and 56 respectively. (R2:0.96), (R2:0.92) and (R2: 0.97) at 10% of OPC replacement age of 14, 28 and 56 respectively. At the same time, there is a close relationship between quartz stone powder replacement and water absorption (R2:0.99) and (R2:0.92) for 0% and 10% of OPC inclusion at age of 56 respectively. Furthermore, there is a close relationship between quartz stone powder replacement and water sorptivity (R2:0.97) and (R2:0.99) at 50minutes at age of 56 respectively. From the R2 values, it can be concluded that there is an excellent correlation between the quartz stone powder replacement ratio and mechanical and durability properties even at the age of 56 days as shown in Figure 8.



a) Replacement ratio of quartz stone powder versus compressive strength



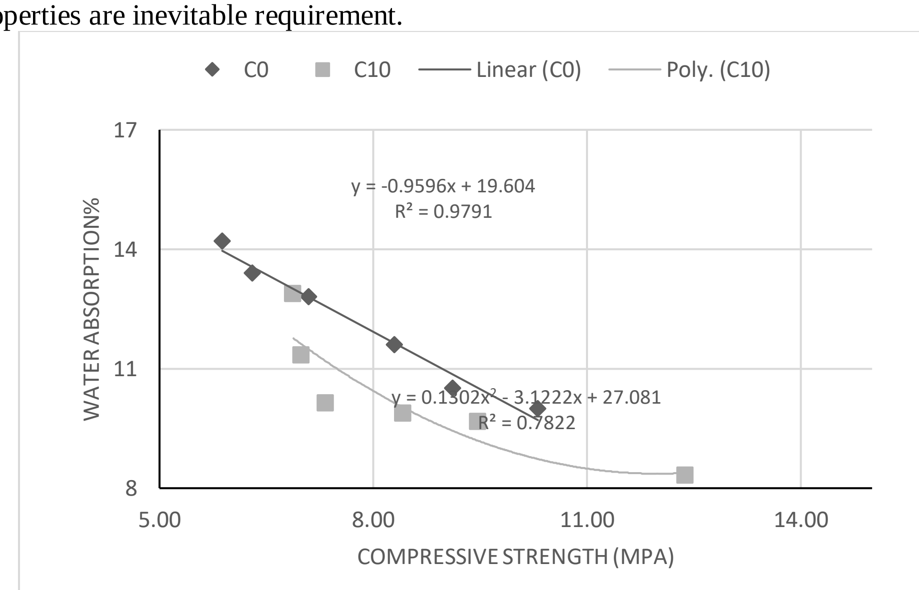
b) Replacement ratio of quartz stone powder versus water absorption



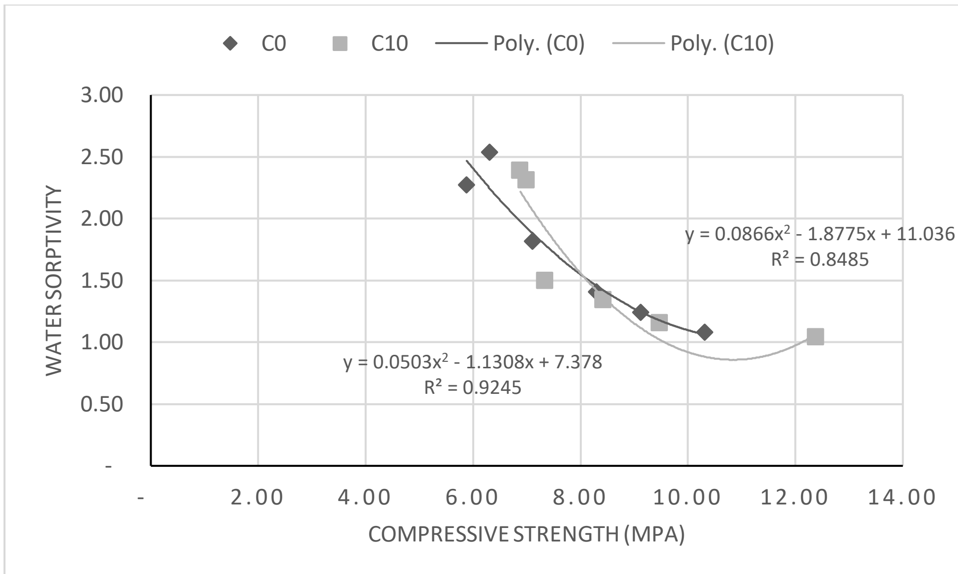
c) Replacement of quartz stone powder versus water sorptivity(50min)

Figure 8: Effect of OPC replacement ratio on the properties of alkali activated mortar.

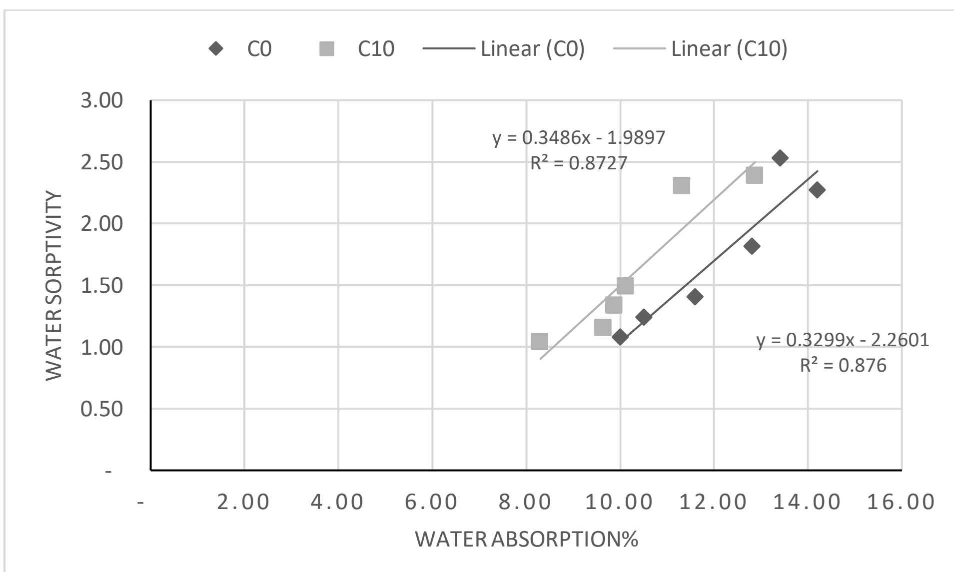
On the other hand, the results also shown noticeable close relationships between mechanical and durability properties of alkali activated mortar as illustrated in Fig. 9. The good correlation exhibits high coefficient (R2) values which indicate that the mechanical and durability properties of alkali activated mortar improved and deteriorated with similar factors or effects. Moreover, good relationships presence between the hardened performances of alkali activated mortar and the OPC replacement. The correlation between hardened performance and concentration of alkali activated exhibits high coefficient (R2) value as shown in Figure 9. Generally, it can be deduced that there are excellent relationships between hardened properties and quartz stone powder replacement despite the incorporation of OPC. OPC replacement had significant effect on the hardened properties. Therefore, in order to achieve superior alkali activated specimens exhibit good mechanical properties, good durability properties are inevitable requirement.



(a) Water absorption vs compressive strength



b)Water sorptivity (10min) vs compressive strength



c)Water absorption vs water sorptivity (10min)

Fig. 9: Correlation between the hardened properties of alkali activated mortar.

3.5 Statistical analysis

An analysis of variance model with a significant level of 0.05 is conducted to evaluate the variation of the alkali activated mortar performance with different level of OPC replacement ratio and/or quartz stone powder replacement in a quantitative form. For this, compressive strength, water absorption and sorptivity of the mortar were designated as the dependent variables while the OPC inclusion and replacement level of quartz stone powder were the independent factors. In order to determine significant factors with a p-level of smaller than 0.05, a statistical analysis was carried out. The P-level that is smaller than 0.05 showed that the related parameter is a significant parameter in the resulting performance. In addition, percent contribution was also determined to find out the degree of effectiveness of the parameter on the resulting performance. If this value is higher, then it can be accepted as the influence of the parameter is significant on the resulting performance. Meanwhile, the mechanical and durability performances of the specimens significantly improved with the replacement of OPC and quartz stone powder replacement.

4. Conclusion

The conclusion of this study can be briefly summarized

1- Increasing OPC content in the mixes leads to increase the compressive strength. At the same time increasing quartz stone powder content also leads to increase compressive strength.
2- Increasing OPC content in the mixes leads to decrease water absorption. At the same time increasing quartz stone powder content also leads to decrease water absorption.
3- Increasing OPC content in the mixes leads to decrease water sorptivity. At the same time increasing quartz stone powder content also leads to decrease water sorptivity.

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