



CHARACTERISTICS OF QUARTZ STONE POWDER BASED GEOPOLYMER MORTAR CURED AT AMBIENT CONDITION

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ABSTRACT

Development of self-curing geopolymers is a key consideration among the researchers. One of the challenges that face geopolymers to field application is applying of heat to enhance its mechanical properties. This study focuses on using self-cured, NaOH activated, quartz stone powder by using different cement dosages in producing geopolymer mortar. For this purpose twelve mixes were prepared. The base material, quartz stone powder, was replaced by Ordinary Portland Cement (OPC) in dosages of (0%, 5%, 10%, and 15%) by weight and different sodium hydroxide concentration variations were used. Compressive strength, water absorption and sorptivity were investigated. The results showed that 15% of OPC replacement has optimum influence on some properties of geopolymer mortar. At the same time Sodium hydroxide concentration of 14M achieves the optimum properties. The results revealed that incorporation of OPC and utilization of different NaOH concentrations significantly affected the compressive strength and absorption properties of the mortar.

KEYWORDS: Self-Curing, Geopolymer; Quartz Stone Powder; Compressive Strength; Water Absorption; Water Sorptivity.

1. INTRODUCTION

Geopolymer is a new technology to replace ordinary Portland cement. Manufacturing process of cement is problematic to environment. Nearly 7% of emitted CO₂ to atmosphere is due to OPC, which by turn leads to global warming (Andrew, 2018).

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 (Fernandez-Jimenez et al. 2006; Sindhunata et al., 2006; Kong and Sanjayan, 2010; Nematollahi et al., 2017) and ground granulated blast furnace slag (Bakharev et al. 1999; Shrestha et al., 2013) and natural materials like metakaolin (Davidovits, 1994) are possible materials for this purpose. Alkaline solution is a mixture of either sodium hydroxide and sodium silicate or potassium hydroxide and potassium silicate.

Geopolymer materials act 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 (Behera et al., 2014). 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 natural raw materials that mainly contain silica and alumina to produce geopolymer materials. Portland cement production requires a double amount of energy as compared to activator preparation in alkali activated production (Kong et al. 2006).

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 reaction (Bakharev, 2006), some additives can be used to enhance the polymerization process like, OPC, high calcium fly ash, calcium hydroxide and slag, as additional calcium sources in geopolymer mixes (Palomo et al., 2007; Chindaprasirt et al., 2011; Nath et al. 2012; Canfield et al., 2014; Suwan and Fan, 2014; Nath and Sarker, 2015; Aliabdo et al. 2016; Assi et al., 2016; Shehab et al. 2016). The reaction between cement and water is exothermic reaction, so it is an appropriate material to be used as an admixture for improving the polymerization process. Nano-silica incorporation in another way of geopolymerization improvement (Saini and Vattipalli, 2020).

Most commonly alkali activator is mixture of sodium silicate and sodium hydroxide, however preparing the sodium silicate needs 1300-1500°C that consumes a huge amount of energy (Kalapathy et al. 2002; Foletto et al., 2006), so developing geopolymer by utilizing just sodium hydroxide is an attempt to reduce the geopolymer energy consumption.

Effect of OPC inclusion with levels of 5, 7.5 and 10% by weight of fly ash was explained by (Kaja et al. 2018). 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., (2004) 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. Nath and Sarker, (2015) reported the influence of OPC inclusion to low calcium fly ash on the compressive strength of geopolymer mortar and concrete. It was achieved that the increase OPC content increases the compressive strength. Phoo-ngernkham et al. (2013) 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. Suwan and Fan (2014) studied the effect of OPC inclusion at levels of 5%, 10%, 30%, 50% and 70% of weight of fly ash and showed that the compressive strength continuously increased as replacement of OPC increases. Askarian et al. (2018) 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 was higher than the control geopolymer mixes furthermore it was reported that when OPC content increased from 10% to 60% the compressive strength also increases (Shehab et al. 2016) examined the impact of OPC inclusion in fly ash based geopolymer concrete. The authors concluded that 50% of OPC replacement retained the highest mechanical properties at 28 day. This study has been performed in order to examine the feasibility of quartz stone powder as a base material of geopolymer. Literatures regarding the utility of quartz stone powder in producing geopolymer concrete are rare. So it is necessary to investigate the properties of geopolymers made by quartz stone powder as a base material. In this study quartz stone powder was used as a starting material and it was replaced by OPC at levels of (0, 5, 10 and 15) % to enhance the hardened properties of geopolymer mortar.

2. METHODOLOGY

2.1. Materials

2.1.1. Quartz stone

The quartz stones were collected and brought from Makok Mountain located west of Ranya city, cleaned by metal brush, crushed to a fine powder and sieved such that all the particles passed through 300 μ m sieve. The particle size distribution for the used quartz stone powder are shown in Fig. 1.

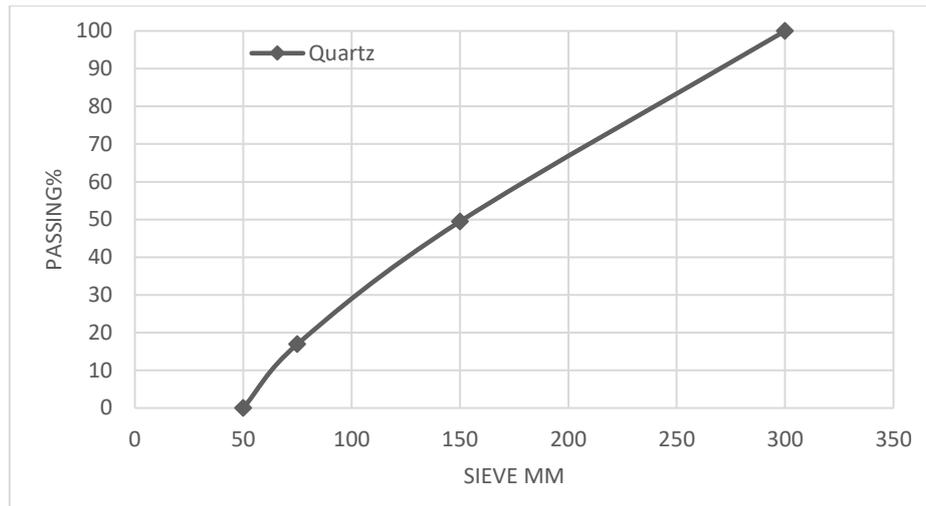


Fig. 1. Particle size distribution of quartz stone powder.

2.1.2. Ordinary Portland cement

Ordinary Portland cement was used for the entire experimental mixes of the study. The specific gravity of the cement was 3.14. The chemical and physical properties of the cement are shown in [Tables 1](#) and [2](#) respectively, which are conformed to IQ.S 5/1984 standard for ordinary Portland cement.

Table 1. 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 SO ₃) %	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 2. Physical properties of cement (OPC).

Physical Requirements	IQ.S 5/1984 Standard for Ordinary Portland Cement	
	Limitation	Test Result
Fineness (Blaine) kg/m ²	≥ 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/m ²)	≥ 15.0	35.7
	≥ 23.0	46.0

2.1.3. Fine aggregate

Locally available river sand that conformed to ASTM C33 was used as a fine aggregate in saturated surface dry state. The specific gravity of the sand was 2.64.

2.1.4. Sodium Hydroxide

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

2.1.5. Water

Distilled water was used for preparing the NaOH solution.



Fig. 2. Materials used in this research.

2.2. Mix design

Twelve geopolymer mixes were prepared. The quartz stone was replaced by ordinary Portland cement in percentages of 0%, 5%, 10% and 15% for each molar concentration (M10, M12 and M14) of sodium hydroxide. The solution of NaOH to binder ratio was remained constant 0.40. Fine aggregate was used as 20% of the total weight of the mix. The mix proportions for the samples are shown in [Table 3](#).

Table 3. Mix proportion of the geopolymer mortar (Kg/m³).

Mixes	Proportion of binders	Quartz powder	Ordinary Portland Cement	Fine Sand	NaOH Molarit y	NaOH Solutio n	Binder/ Solution
M1	Q100-C0	1215	0	467	10	486	0.40
M2	Q95-C5	1154.25	60.75	467	10	486	0.40
M3	Q90-C10	1093.5	121.5	467	10	486	0.40
M4	Q85-C15	1032.75	182.25	467	10	486	0.40
M5	Q100-C0	1215	0	467	12	486	0.40
M6	Q95-C5	1154.25	60.75	467	12	486	0.40
M7	Q90-C10	1093.5	121.5	467	12	486	0.40
M8	Q85-C15	1032.75	182.25	467	12	486	0.40
M9	Q100-C0	1215	0	467	14	486	0.40
M10	Q95-C5	1154.25	60.75	467	14	486	0.40
M11	Q90-C10	1093.5	121.5	467	14	486	0.40
M12	Q85-C15	1032.75	182.25	467	14	486	0.40

2.3. Mixing, Casting and Curing

Sodium hydroxide flakes were dissolved in tap water to get the require concentration of solution. The binder materials (quartz stone powder partially replaced by cement by 0%, 5%, 10%, 15%) were manually blended, and then mixed with sand. The solution added to the dry materials and the mixture poured with two layers into (25x25x25) mm size molds. The moulds were manually compacted to remove the entrapped air. The samples were covered by a plastic bag to avoid moisture losing. After 24hrs the samples were de-molded and kept in ambient temperature. The samples were tested for compressive strength after 14, 28 and 56 and days of curing. For water absorption and water sorptivity 56 day cured samples were used. A total of 180 samples were prepared as shown in Fig. 3.



Fig. 3. Mixing, casting, and ambient curing of geopolymer mortar samples.

2.4. Testing

2.4.1 Compressive Strength

The compressive strength test is conducted according to ASTM C109 (Standard, 2008) for cement mortar. For each mix three samples were tested by a digital compression machine with the capacity and sensitivity of 2000kN and 0.1kN respectively, (Fig. 4). The average of the results of three samples were calculated and reported.



Fig. 4. Compression machine.

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 was performed on 56 day cured samples. For each mix, three samples were dried to a constant mass in an electrical oven at 105°C for 24 hrs. The samples were kept to cool to room temperature, then immersed in water for 24 hrs. to get the saturated mass of the samples.

2.4.3 Water sorptivity

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, 2011) standard. In this test three samples of (25x25x25) mm were used. In this study for each mix three samples were dried to a constant mass at 105°C in oven at 56 day, then the samples were taken out, and coated with silicone sealing to avoid entering of 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 Fig. 5. 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.

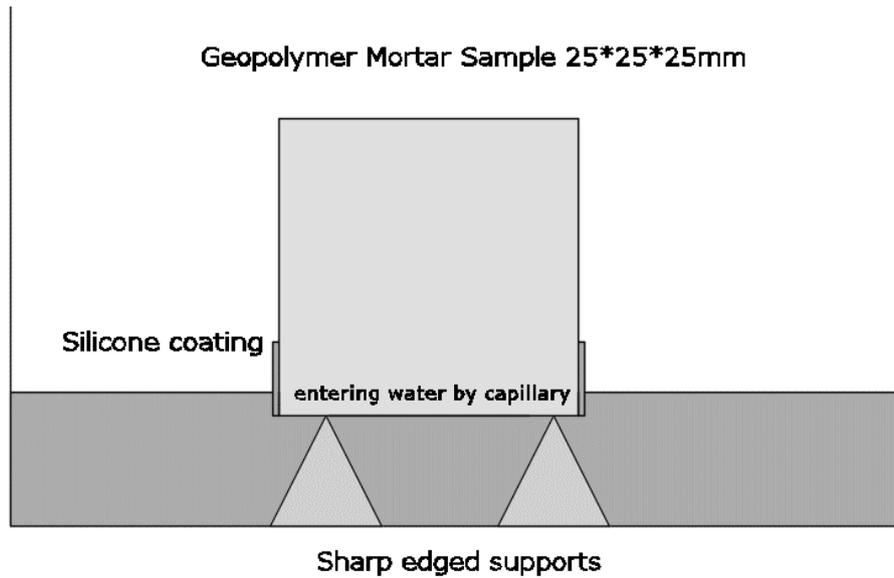


Fig. 5. Water sorptivity test for geopolymer mortar.

3. RESULTS AND DISCUSSION

3.1 Compressive strength

Table 4 and Fig. 6 show the results the compressive strength. It is obvious that with increasing the OPC content from 0% to 15% the compressive strength increases from 6.15MPa to 7.93MPa at 28 days for 14M concentration of NaOH. The study conducted by Phoo-ngernkham *et al.*, (2013) who partially replaced OPC up to 15% by weight of high calcium fly ash, supports obtained results.

Previous studies agree with this investigation (Guo *et al.*, 2010; Garcia-Lodeiro *et al.*, 2011) Cement contains high amount of Ca which results in high compressive strength, this because of formation of additional of C-S-H and C-A-S-H gels that alters the microstructure of the material. New gels of geopolymeric binder CS-H and C-A-S-H work as a micro-aggregate, thereby improved the durability and compressive strength (Yip and Van Deventer, 2003; Yip, Lukey and Van Deventer, 2005). The reaction with SiO₂ and Al₂O₃ of binder reduced the Ca(OH)₂ content of the system, and the pore structure was refined in a similar way as the pozzolanic reaction in the blended cement paste (Kroehong *et al.*, 2011).

At the same time increasing the concentration of NaOH up to 14M led to additional increase in compressive strength. This is due to the high degree of geopolymerization as a result of increased leaching of alumina and silica (Hanjitsuwan *et al.*, 2014).

Table 4. Effect of OPC replacement and NaOH concentration variation on compressive strength.

Mixes	Compressive Strength MPa								
	14 Day			28 Day			56 Day		
	M10	M12	M14	M10	M12	M14	M10	M12	M14
Q100C0	4.08	4.36	4.81	5.12	5.48	6.15	5.41	5.94	7.47
Q95C5	4.31	5.73	5.98	5.35	5.86	6.2	5.44	6.88	7.91
Q90C10	5.57	6.02	6.09	6.53	6.75	6.78	7.47	7.58	8.2
Q85C15	5.67	7.04	7.16	7.23	7.89	7.93	8.35	8.99	9.06

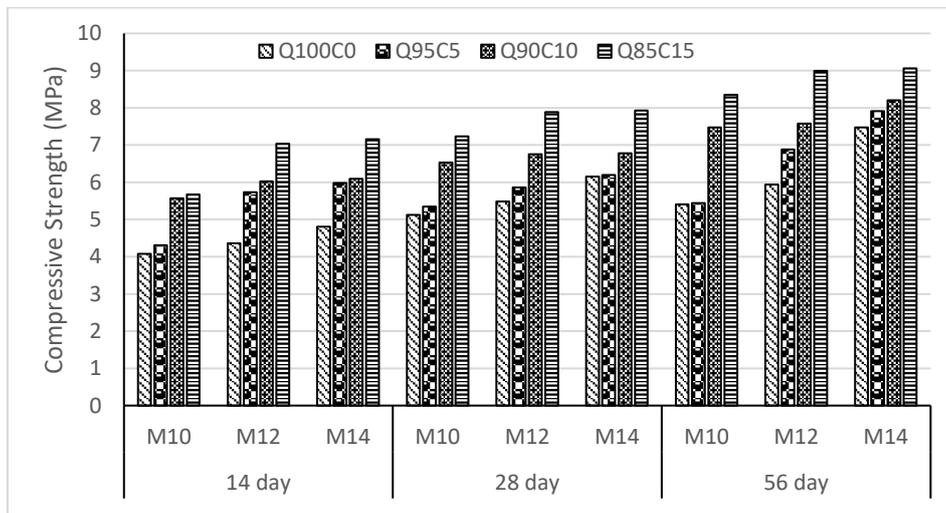


Fig. 6. Effect of OPC replacement and NaOH concentration variation on compressive strength of quartz stone powder- based mortar.

3.2 Water absorption

The results of the water absorption are shown in the Table 5 and Fig. 7. Increasing OPC content resulted in a better gel formation that led to a denser microstructure. This is the result of the reduction of water absorption when OPC content increased from 10.87% to 7.19% for M14 concentration of NaOH at 56 day. The reaction with SiO_2 and Al_2O_3 of binder reduced the $\text{Ca}(\text{OH})_2$ content of the system, and the pore structure was refined in a similar way as the pozzolanic reaction in the blended cement paste (Kroehong *et al.*, 2011). The results well corresponded with the mechanical behavior.

On the other hand, increasing the concentration of NaOH led to high degree of geopolymerization (Hanjitsuwan *et al.*, 2014) this produce a denser gel that minimize the amount of absorbed water by the samples.

Table 5. Effect of OPC replacement and NaOH concentration variation on water absorption of quartz stone powder- based mortar.

Mixes	Water Absorption%		
	M10	M12	M14
Q100C0	11.21	10.97	10.87
Q95C05	10.55	10.20	9.80
Q90C10	10.01	9.71	8.06
Q85C15	8.45	8.12	7.19

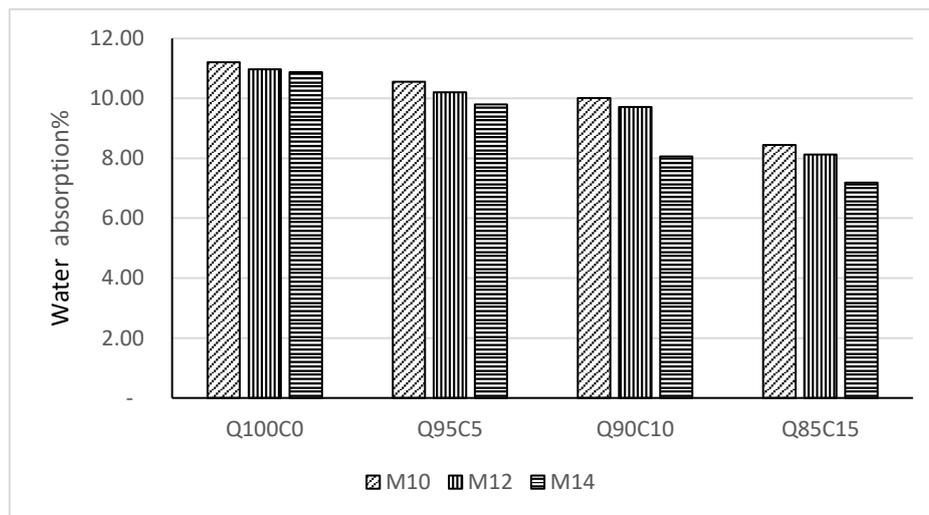


Fig. 7. Effect of OPC replacement and NaOH concentration variation on water absorption of quartz stone powder- based mortar.

3.3 Water Sorptivity

The results of the water sorptivity are shown in the Figs. 8. a, b and c. Increasing OPC content resulted in a better gel formation that led to a more dense microstructure. This is the result of the reduction of water absorption when OPC content increased. The reaction with SiO_2 and Al_2O_3 of binder reduced the $\text{Ca}(\text{OH})_2$ content of the system, and the pore structure was refined in a similar way as the pozzolanic reaction in the blended cement paste (Kroehong *et al.*, 2011). The results well corresponded with the mechanical behavior.

On the other hand, increasing the concentration of NaOH led to high degree of geopolymerization (Hanjitsuwan *et al.*, 2014) this produce a denser gel that minimize the amount of suction water by capillary action.

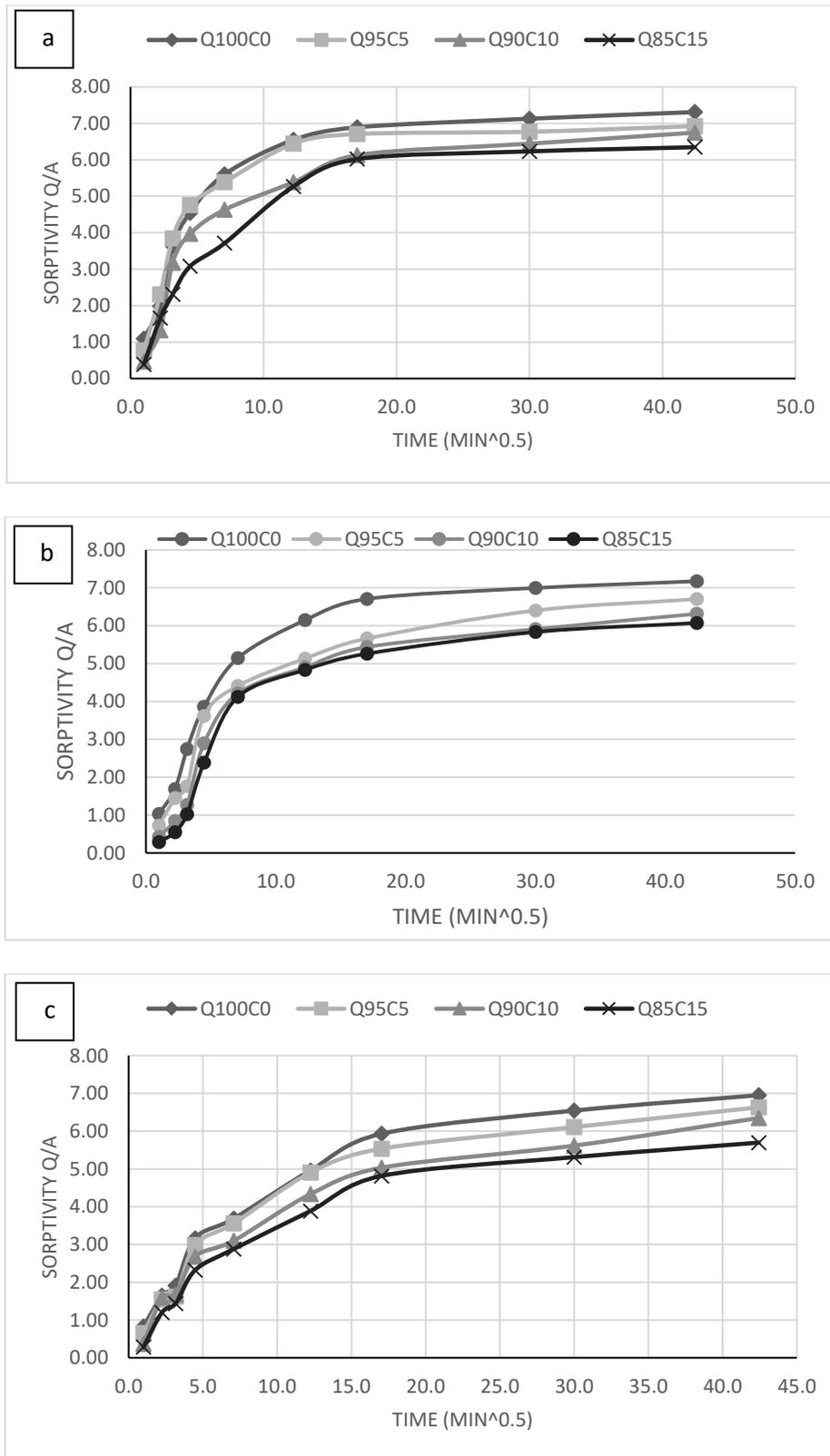


Fig. 8. Effect of OPC replacement and NaOH concentration variation on compressive strength of quartz stone powder- based mortar. a) 10M, b) 12M, c) 14M.

4. CONCLUSION

On the basis of the results achieved in this study, the followings can be concluded.

1. The incorporation of OPC increases the compressive strength of geopolymer mortar. This is due to the formation of additional gel C-S-H and C-A-S-H which alters the microstructure of the mortar. When OPC content increased from 0% to 15%, compressive strength approximately increased by 41%. Simultaneously, increasing NaOH concentration leads to increase compressive strength. When NaOH molarity increased from 12M to 14M, compressive strength approximately increased by 20%
2. The use of OPC to partially replace quartz stone powder in the mixes leads to decrease water absorption. When OPC content increased from 0% to 15%, water absorption approximately decreased by 28%. That is well corresponded with mechanical behavior. At the same time increasing NaOH concentration leads to lower water absorption. When NaOH molarity increased from 12M to 14M, water absorption approximately decreased by 11%
3. Increasing OPC content in the mixes leads to lower water sorptivity. At the same time increasing NaOH concentration leads to decrease water sorptivity.

5. RECOMMENDATION

The authors recommend researchers to take beyond 15% of base material replacement.

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