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THE EFFECT OF BRICK AND GLASS POWDER ON THE MECHANICAL PROPERTIES AND POROSITY OF SELF-COMPACTING MORTAR

Yasmina Bouleghebar [a*], M. Bentchikou [b], O. Boukendakdji [a], K. El-Hadj[c], F. Debieb [a], Ali Maisarah [d]

[a] Material and Environment laboratory (LME), Faculty of Technology, University of Médéa, Algeria, E-mails: [*]yasminebouleghbar.93@gmail.com, boukendakdji_o@yahoo.fr, fdebieb89@gmail.com
[b] Laboratory of Mechanic Physics and Mathematical Modeling (LMP2M), Faculty of Technology, University of Médéa, Algeria, E-mail: bentchikou_moham@yahoo.com
[c] Laboratoire de Mécanique et Matériaux du Génie Civil (L2MGC) - EA 4114, Université de Cergy-Pontoise 5, France, E-mail: el-hadj.kadri@u-cergy.fr
[d] Civil Engineering Department, Kulliyyah of Engineering, International Islamic University Malaysia (IIUM), Kuala Lumpur, Malaysia, E-mail: maisarah@iium.edu.my

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ABSTRACT:

The use of glass and brick powder waste as supplementary cementious material provides an effective approach to produce concrete in order to effectively save resources and solve environmental pollution problems. This study shows the evolution of the preparation of an eco-friendly self-compacting mortar (SCM) with various fineness levels and replacement ratios of crushed glass and crushed calcined brick waste. Cement was replaced by weight, by 8, 12, 16, 20, 24% of glass powder (GP) and 4, 8, 12, 16 and 20% of crushed brick powder (BP), with three specific surface Blaine (SSB) fineness measurements (F1=3300cm^2/g,F2=4400 cm^2/g and F3=6000 cm^2/g) for both wastes. Mini-slump and V-funnel flow time tests of fresh SCM were evaluated. Compressive and flexural strength developments of cured SCMs were determined on 7, 14, 28, 5 6, and 90 days. In addition, porosity of SCM was also evaluated. The results revealed that the (SCM-GP) mix increases workability and reduces superplasticizer dosage, while the (SCM-BP) mix reduces workability with a slight increase in superplasticizer. When the GP fineness is higher than the cement fineness, the compression strength with GP contents up to 16% is superior to without the GP, whereas for the BP the strength improvement is up to 8%, while the compression strength decreases when the GP and BP fineness is close or lower than the cement fineness. The porosity diminishes with the increase of the fineness; the 12% of the GPF3 indicated the lowest porousness at 400 days, whereas for SCM-BP the 8BPF3 is the least porous mixture.

1. INTRODUCTION

The construction industry has been one of the largest sectors in the world, it is responsible for the consumption of 40% of natural resource extracts (Angulo et al. 2013), for that reason solutions must be found to help minimize the environmental problems generated, due to both the negative impact on the environment and the excessive use of natural resources (Matias et al. 2004). Concrete is one of the most used construction materials with a global consumption rate of 25 gigatons per year (Petek et al. 2014), knowing that the CO2 emitted by the production and transportation of concrete could represent about 10% of the global human production (Henry et al. 2011).

In that order, various strategies and methods have been followed to improve the sustainability of concrete in terms of reducing CO2 emissions and conserving non-renewable natural resources to develop green and ecological concrete (Long et al. 2015). These strategies consist of using industrial by-products such as waste from construction sites, building demolition and factory waste (Falmata et al. 2020). These wastes cause significant environmental problems worldwide, especially for the waste management system due to the low rate of recycling compared to the amount produced each year.

Recently, the amount of glass waste has increased due to industrialization and the living standards improvement; The worldwide volume of landfilled glass is estimated to be 200 million tons per year with very little recycling (Mirzahosseini et al. 2015). For instances, China produced 20.25 million tons of WG in 2017, however, only less than half of this was recycled (Z. H. Liu 2018) Less than 25% of the more than 11.5 million tons of WG produced in the United States in 2013 were recycled (Afshinnia et al.2016).

The use of waste glass in concrete is one of the proposed solutions that can recycle a large amount of glass, minimize landfill space and save energy and money.

Several researches have been interested on the use of waste glass as aggregates in mortars and concretes (Tan H. et al. 2013;Soliman N. et al. 2017). The results found showed a reduction in workability and a decrease in mechanical properties due to the flat and angular nature of glass (Cheeseman et al.2014). In addition, coarse and fine glass aggregates cause the alkali-silica reaction (ASR) in concrete, while the glass powder could mitigate and suppress the expansion of ASR (Patel et al.2012) . Glass contains more than 70% amorphous silica, which makes it pozzolanic, thus it is an ideal choice for use as supplementary cementitious materials (SCMs) (Tohoué et al. 2018). The incorporation of waste glass powder, as a replacement for cement has been studied by several authors, most of the results obtained show that the compressive strength decreases with the increasing of the content of glass powder (Idir al. 2011; Li et al. 2019).

Many studies it was recommended that 10–20 wt.% WGP can be utilized as a cement replacement (Islam et al. 2017;D. Patel et al. 2019) Previous studies have shown that concrete's compressive strength increased up to 10% GP content (Khatib et al. 2012;Kumarappan et al. 2013). Use of glass powder in the production of self compacting concrete is recommended by (Rehman et al.2018), where the combined effect of glass powder with granular steel slag as replacement to cement and fine aggregate on mechanical properties is studied. According to the results, replacing cement with 20% glass powder and fine aggregate with 80% steel slag improves the mechanical properties of concrete.(Du et al. 2021) conducted a laboratory study in which glass powder was used with metakaolin and limestone filler as replacement to cement for studying the thermal conductivity of the cement paste. The literature review conducted suggests the extensive use of glass powder in conjunction with different SCMs to produce concrete with improved mechanical and durability properties.

Clay brick is another source of alternative material, it is classified as the second most used construction material after concrete and it is treated as construction and demolition waste C & D if there is damage during manufacturing, construction and demolition activities (Ge et al. 2012;Wong et al. 2018). Approximately 80% of C&D waste is concrete and clay brick waste, and these wastes can be recycled into secondary building materials (Siad et al. 2017;Liang et al. 2020).

During demolition work, a large amount of clay brick is produced, it is estimated that there will be at least 5 billion tons of construction waste in the next 5-10 years, while brick waste accounts for 30-50% (J Lu et al. 2012). This waste must be transported to landfills.

Crushed clay brick can be used as aggregate, fine aggregate (sand) and mineral admixture (J Lu et al. 2012). According to several authors the use of brick waste as aggregate (coarse and fine) leads to a reduction in workability and mechanical strength (Bektas et al. 2009:Poon et al. 2006) In accordance to (Khatib 2005;Debieb et al. 2008), the reduction in compressive strength is due to the porous nature of brick aggregates which promotes water consumption during mixing and thus leads to a reduction in strength. In addition, brick waste used as sand decreases the modulus of elasticity and increases the physical shrinkage of concrete (Vieira et al. 2016;H. Li et al. 2016). They recommend using brick waste as a mineral admixture in place of cement because it contains amorphous silica (SiO2) and alumina (AL2O3). In addition, there are many benefits associated with the use of brick waste as pozzolanic materials such higher reuse rate of brick waste, reduced cement content and thus carbon footprint with also strength and durability increase (Naceri et al. 2009;L. G. Li et al. 2020).

(Al-Kroom et al. 2022) reported that the use of CBP as a filler material increases the concrete workability. It also caused an increase in the concrete dry density, compressive strength, UPV values, and thermal conductivity with the increase in the CBP content as it filled the pores and therefore enhanced the mechanical and durability properties of the concrete.

One of the novelties of construction materials in the 80s is the development of self-compacting concrete (SCC), which constitutes a real revolution in concrete. The SCC contains a high amount of fines (mainly cement), which refines the microstructure and therefore the network of pores of the material. This gives a better durability potential compared to traditional concrete (Kanellopoulos et al. 2012).

The self compacting mortar (SCM) is the basis of formulation for self-compacting concrete (the work on the mortar is more controllable compared to concrete). In addition, it is intended to be used for the rehabilitation and the repair of structures (Mohseni et al. 2015; Tuaum et al. 2018). It has many advantages including high fluidity,deformability and its ease of placement without vibration. These properties require a specific composition which is characterized by using superplasticizer and high content of powder materials (Boukendakdji et al. 2012).

In recent years, many mineral additives or admixtures have been incorporated into SCC in order to improve its performance (Sua-iam et al. 2017)and even to reduce its production cost if it is used as waste (Gesoğlu et al. 2012)However, few studies have examined the effect of the SCM surface on the properties of SCC or self-placing mortar (SCM).

Although glass and brick as a global replacement has already been the focus of many investigations, there has been less study on the partial substitution of cement with glass & brick specifically in Algeria. In addition, concentrated study on the effect of fineness of glass and powder brick on the fresh and hardened properties of concrete or mortar is limited. The performance of glass and brick powder self compacting mortar in terms of fresh (slump flow, V-funnel) and hardened properties (compressive and flexural strength, porosity) were studied.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Ordinary Portland cement type I 42.5R with a minimum compressive strength of 42.5 MPa according to EN 197-1:2000 (EN 2000) was used in this study. In addition, glass waste and crushed calcined brick waste of different fineness were adopted to replace the cement. The glass waste was cleaned and placed in an oven at 105 C° to remove moisture before grinding. The

grinding was done with a ball mill of 20 kg capacity, and then sieved through 80 µm screen openings. Afterwards they were ground for the second time with a disc mill to get the desired finenesses. The finenesses of the powders were determined using the Blaine air permeability apparatus.

Figure 1 summarizes the recycling, crushing and grinding procedure for glass waste (the same procedure was followed for calcined brick waste).

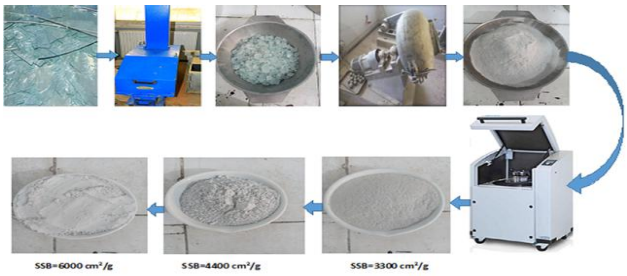


Figure 1. Crushing procedure and grinding of waste glass

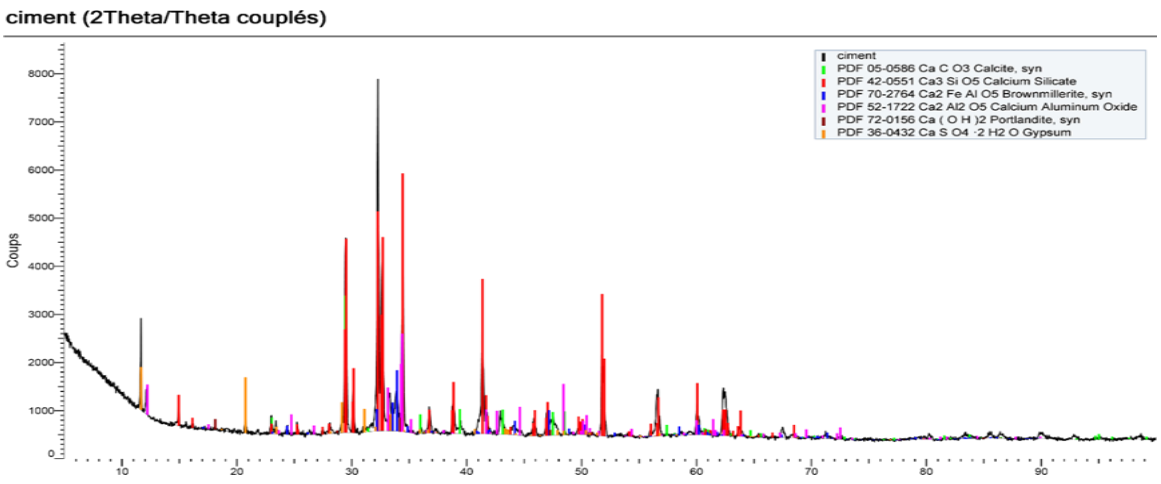
The chemical and physical compositions of waste glass, crushed calcined brick and cement are determined using X-ray fluorescence spectrometry analysis (XRF) and are grouped in Table 1.

Composition (%)	Cement	GP	BP
SiO2	20.83	72.68	57.43
AL2O3	4.13	1.11	15.45
Fe2O3	5.58	0.74	5.80
CaO	62.19	9.47	11.26
MgO	1.42	1.74	2.09
K2O	2.30	0.46	2.46
Na2O	0.38	12.52	1.44
TiO2	0.028	0.07	0.68
SO3	-	0.25	0.32
P2O5			
Specific gravity (g/cm^3)	-	0.01	0.20
Blaine fineness (cm^2/g)			
	3.12	2.5	2.6
	3300	3300	3300
		4400	4400
		6000	6000

Table 1. Chemical and physical properties of cement glass and brick

The mineralogical compositions of cement, glass and calcined brick were determined by X-ray diffraction (XRD) and the results are shown in Figure 2.

This figure shows that the main mineral composition of glass is quartz (SiO2) and calcite (CaCO3) and for brick is quartz (SiO2) and Albite (NaAl-Si3O8). Calcite (CaCO3) and dolomite (CaMg(CO3)2)) were also detected for the brick with small amounts. Other composition like Sodium (Na2O) and Iron (Fe2O3) are also present in the glass powder but with moderate amounts.



(a)

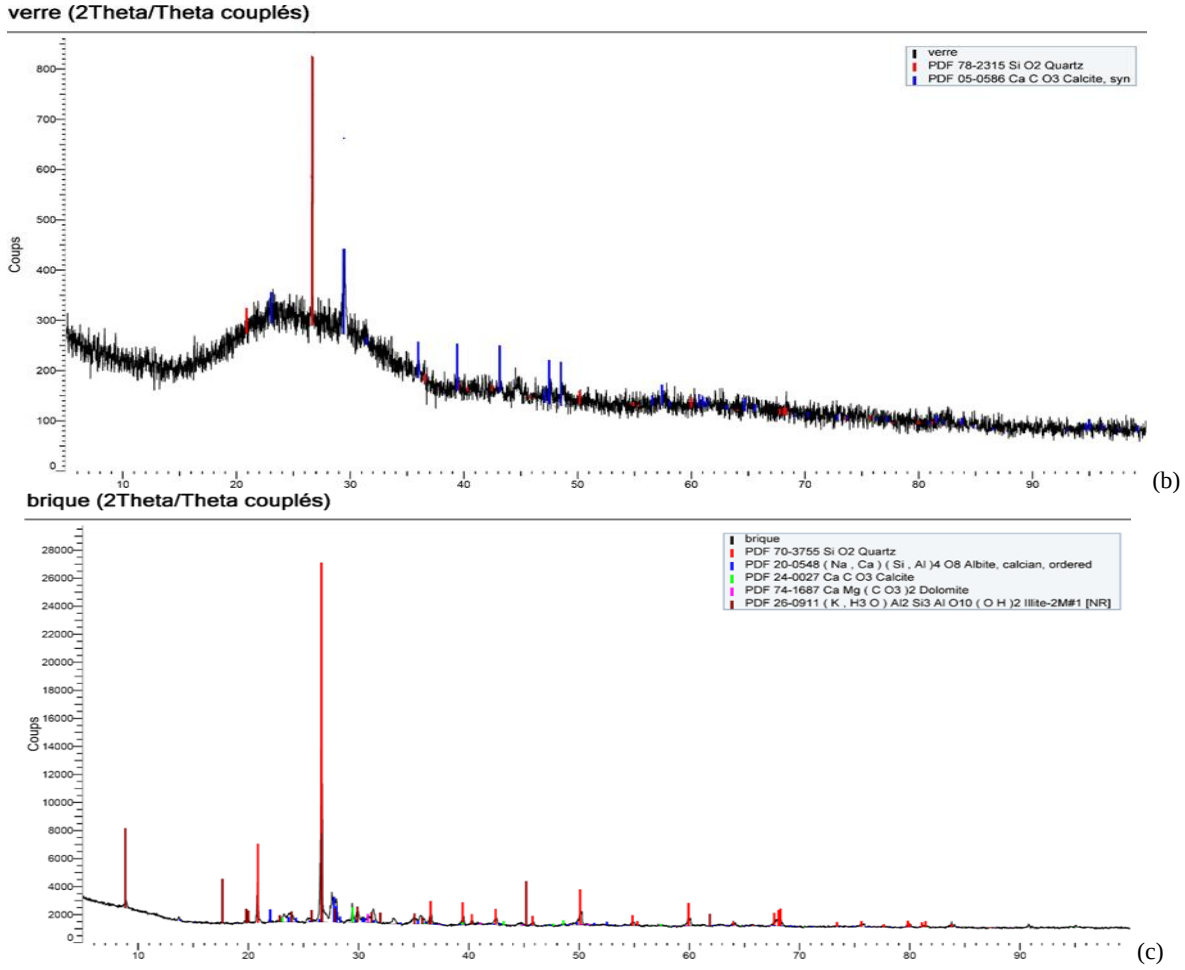


Figure 2. XRD of (a) cement, (b) glass and (c) brick

These results were also confirmed by energy dispersive X-ray (EDX) tests as presented in figure 3.

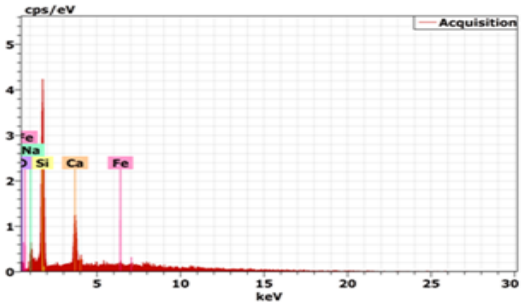


Figure3. EDX for glass powder

The morphology of the glass and brick powders determined by scanning electron microscopy (SEM) is almost the same; the particles have an angular and irregular shape.

A dune sand that comes from the region Oued-Souf (Algeria) was used; the grains are generally isometric and rounded shape. It was cleaned and dried for 24 hours at a temperature of 105 °C. The physical properties and the particle size characterization of the sand are given in table 2. The mixing water used is the tap water of the laboratory. In order to achieve the desired workability, a new generation of superplasticizer MEDAFLOW 145 high water reducer was used.

Proprieties	Types of aggregates
	Sand
Specific density (g/cm^3)	2.63
Finesses modulus	2.5
Sand equivalent (%)	83.33
Water absorption (%)	0.7

Table 2. Physical properties of the used aggregates

It is designed based on the modified poly ether carboxylates with a specific density and solids content of 1.065 and 30% respectively and a pH of 5 to 6 with chloride content of 1.17 g/l.

2.2 Mortar compositions

The proportions of the mixtures are based on the Okamura method (Okamura et al.2000) with some modifications made in the determination of the sand content in the mortar (S/M). The water/binder ratio (W/B) as well as the super plasticizer ratio (SP/C) were adjusted in order to be adapted to the requirements of the local materials and to obtain good fresh mortar characteristics. The tests on mortar were carried out

for a constant water / powder ratio (W/P) of 0.4 by weight and a sand / mortar ratio (S/M) of 0.5 by volume. The workability of the mixtures was obtained by increasing the dosage of SP. Appropriate adjustments were made to the superplasticizer (SP) for all mixes to achieve the slump flow value of 270 to 330 mm (Domone et al. 1999, Benabed et al. 2012). The proportions of different mixtures are presented in table 3.

Mixtures	Cementitious materials [kg/m^3]				sand	W/B	SP(%)
		Cement	Glass powder (GP)	Brick powder (BP)			
SCM-Control	100% CEM I	694.26	-	0	1315	0.4	0.85
SCM-GP	8% GP	633.92	55.12	0	1315	0.4	0.80
" "	12% GP	603.9	82.35	0	1315	0.4	0.80
" "	16% GP	574.61	109.45	0	1315	0.4	0.80
" "	20% GP	545.22	136.31	0	1315	0.4	0.80
	24% GP	516.26	163.03	0	1315	0.4	0.80
SCM-Control	100% CEM I	694.26	0	-	1315	0.4	0.85
SCM-BP	4% BP	664.11	0	27.67	1315	0.4	0.90
" "	8% BP	635.01	0	55.22	1315	0.4	0.90
" "	12% BP	605.47	0	82.56	1315	0.4	0.90
" "	16% BP	575.57	0	109.53	1315	0.4	0.90
	20% BP	546.62	0	136.66	1315	0.4	0.90

Table 3. Mix Composition of Self Compacting Mortar (SCM)

A total of thirty-two SCM mixes have been prepared and presented in two series. In series I, cement was replaced by 8%,12%,16%, 20% and 24% GP by weight. In series II, the cement was replaced by 4%,8%,12%,16% and 20% of BP by weight too. For each series three different finenesses were used (F1=3300 cm2 /g, F2=4400 cm2/g and F3=6000 cm2/g).

2.3 Mixing procedure and curing of samples

The mixing procedure consisted of dry mixing the cement and sand for 30 seconds at a slow speed to homogenize the mixture and then 70% of the water was added and mixed for 1 min. The remaining water (30%) was mixed with the superplasticizer for another 1 min at a fast speed. At the end the mixture formed was stirred for another 3 min. This mixing procedure takes 5.5 minutes in total.After casting, samples were sealed in a plastic bag to cure at room temperature for 24 h. Once that period finished, the specimens were de-moulded and kept immersed in water at a temperature of 20±2 C° for one series and at laboratory air regulated at a temperature of 20±2 C°.

2.4 Test methods

2.4.1 Fresh mortar: The fresh properties of the SCM mixtures were conducted using a Mini-slump flow and V-funnel flow time test. The spread test consists of filling a truncated cone mold placed on a smooth horizontal surface, once the mold was lifted, the spread diameter of the mortar was measured along two perpendicular directions, and the average of the measurement is retained (Benabed et al. 2012).

The flow capacity of the SCM mixtures was examined by a simple V-funnel flow test. The flow capacity of the SCM is measured by the time from the opening of the funnel orifice to the time when the first light is visible through the opening (Belaidi et al. 2012).

2.4.2 Hardened mortar:

A Series of tests were performed to determine the compressive strength, flexural strength and porosity.The flexural strength was performed using prismatic samples with dimensions (4*4*16 cm^3) at 7, 14, 28, 56 and 90 hardening ages according to ASTM C348 (ASTM 2000), then the compression test was determined according to ASTM C349 (ASTM 2002) on the half-prisms obtained after the flexural test. The porosity accessible to water is evaluated at 28 days and 400 days, according to standard NF P18-459 (NF 2010) . The test pieces were completely dried and then immersed in water until saturation. The volume porosity was determined according to the following formula:

$$\text{Porosity } (\%) = \frac{Mair - M\,dry}{Mair - M\,water} \times 100 \qquad (1)$$

where:

- M air: Mass of the saturated test specimen, superficially dried, weighed in air (g)
- M dry: Mass of the dried test piece (g)
- M water: Mass of the saturated test specimen, weighed in water (g)

3. RESULTS AND DISCUSSION

3.1 Fresh properties of self-compacting mortars

The effect of glass and brick as partial cement replacement at different percentages and fineness measurements on the workability of self-compacting mortar is investigated based on two fresh mortar tests, namely, slump spread and V-funnel.

The discs obtained show that all SCM mixtures are fluid and homogeneous and do not show signs of bleeding or segregation this by visual control during the slump flow test Table 3 shows the results of the fresh properties for all self-compacting mortar mixes. The values are within the recommended values of EFNARC of 270–330 mm for slump spread and 2–10 s for v-funnel time.

For the first mix (SCM-GP), the results clearly show that the spread ability increases with the rate of substitution of cement by glass powder for both SCM-GPF1 and SCM-GPF2.

It is noticed that the workability is more than that of control for both finenesses, which is similar to the results reported in other research (N. A. Soliman et al. 2016; Nassar et al. 2012; Mafalda et al.2012).This improvement in workability in the presence of glass powder could be expressed by the low absorption of the glass powder and its smoother surface.

Fineness of glass and brick powder (cm^2/g)						
	330		4400		6000	
Content (%)	Slumps flow (mm)	V-funnel time (s)	Slump flow (mm)	V-funnel time (s)	Slump flow (mm)	V-funnel time (s)
SCM- 0 (Control)	298	5.62	298	5.62	298	5.62
SCM-8GP	300	4.94	298	5.25	295	5.5
SCM-12GP	302	4.8	300	5.09	292	5.8
SCM-16GP	305	4.57	302	4.79	290	6.03
SCM-20GP	307	4.42	304	4.55	288	6.14
SCM-24GP	309	4.2	304	4.35	287	6.47
SCM- 0 (Control)	298	5.62	298	5.62	298	5.62
SCM-4BP	298	5.7	297	5.9	291	6.44
SCM-8BP	297	5.95	295	6.22	287	6.73
SCM-12BP	296	6.08	294	6.95	285	7.53
SCM-16BP	295	6.3	294	7.25	280	7.94
SCM-20BP	292	7.05	291	7.54	280	8.00

Table 3. Results of fresh mortars test

For the second mix (SCM-BP), it is evident that as the percentage of cement substitution by PB increases, the flowability decreases; as well as when the fineness of the brick powder is greater than that of cement, a decrease in workability is observed as also reported by other researchers (Schackow et al. 2015; Ge et al. 2015; L. G. Li et al. 2019; L. G. Li, Zhuo, et al. 2020). SCM-BPF1 with low BP content had the highest spreadability. For SCM with 4% and 8%BP, the spread was similar to the control SCM. The high water absorption, angularity and rough surface of BP resulted in the reduction of spread.

Table 3 shows that all SCM mixtures gave flow time values in the recommended range of 2 to 10 S. Besides, the introduction of more and more GP lead to reduce the flow time and plastic viscosity of SCM mixtures, except for SCM-GP with F3, where a slight increase in flow time is noticed, due to the high specific surface area of the powder which require more time to spread. This is well correlated to results of slump test. On the other hand, the presence of the glass powder leads to a slight decrease in the demand for superplasticizer, thus confirming the results obtained previously by the spreading test.

For the mixture with BP an increase in flow time with the increase of BP content is observed and this is also the case for the 3 fineness; the more we increase the Blaine fineness the more the mixture (SCM-BP) takes more time to flow and this increase the plastic viscosity. Similar results have been reported in other research (Zeghad et al. 2017;Irki et al. 2018) and the reason is that the powders used have a high specific surface area, which requires excess water.

3.2 Compressive strength

For samples cured in water and for the both mixes the compressive strength is plotted versus GP/BP content and time for the three fineness (F1=3300 cm2 /g, F2= 4400 cm2 /g and F3=6000 cm2 /g), in figures 4 and 5.

3.2.1 Compressive strength of SCM-GP: Figures 4 and 5 express the compressive strengths of (SCM-GP) and (SCM-BP) with three different finenesses (F1=3300 cm2 /g, F2= 4400 cm2 /g and F3=6000 cm2 /g) keep in water at 7, 14, 28, 56 in 90 days.

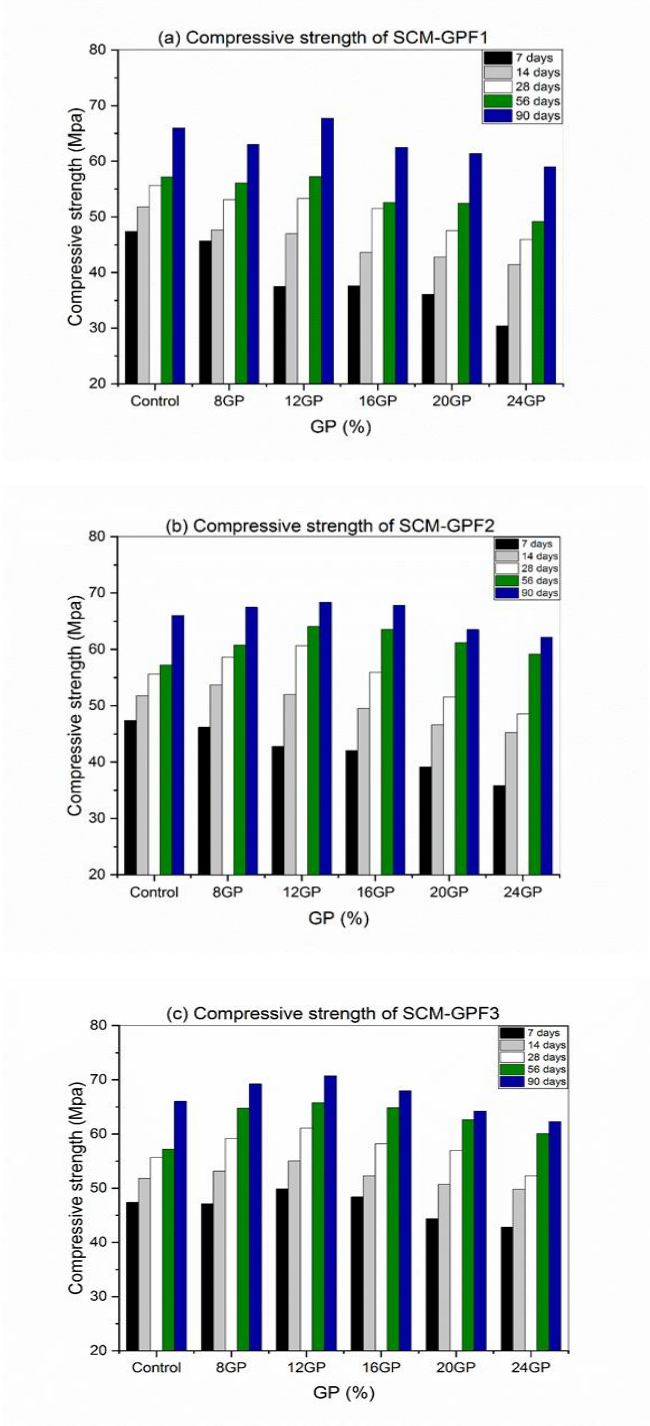


Figure 4. Compressive strength of SCM-GP mixes with three fineness a) F1, b) F2, c) F3

As can be seen from figure 4 the compressive strength of SCM-GP increases with age and with fineness and decreases with increasing GP content. The lowest value is obtained at 24% GP. The same tendency was observed by researches in other studies (Li et al. 2019b; Lee et al. 2008). Contrary to the values of SCM-GPF1, the strengths of SCM-GPF2 and SCM-GPF3 develop quickly and were higher.

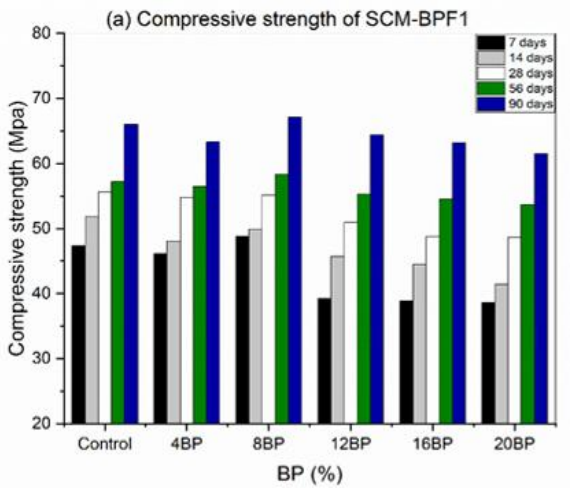
Between 7 and 14 days, whatever the percentage of GP incorporated, the compressive strength of SCM-GPF1 is lower than that of the control except for 12GP mixture, while for SCM-GPF2 and SCM-GPF3 mixtures with 8GP, 12GP and 16GP, the compressive strength is higher than that of the control.

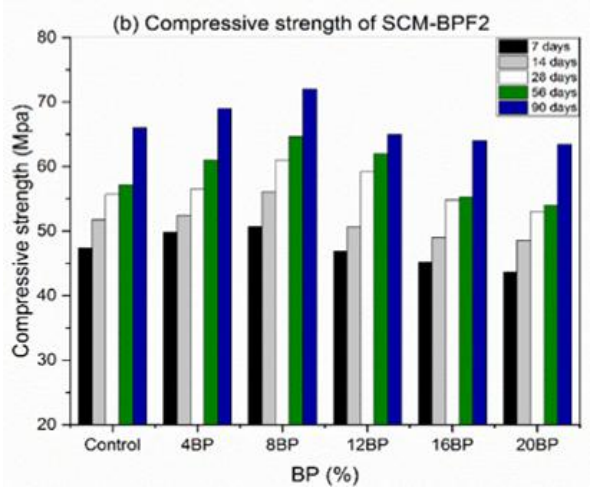
Beyond 28 days, it is noticed that the compressive strength of SCM mixtures containing GP with all three finenesses continues to improve, and 12GPF3 showed a resistance of 61 MPa. These results are also proved by other studies; the study of (Du et al. 2021) showed that 5% GP is the optimum content with a compressive strength of 60 MPA at 28 days. In addition, (Öznur et al. 2017) found results of a compressive strength in the range.

At 56 days the 12GP mixture had the highest compressive strength of 64 MPa and 65 MPa which increased by 4% and 5% over the control mixture for SCM-GPF2 and SCM-GPF3 respectively while at 90 days, 8GP and 12GP mixes show the highest strengths which are higher than the control ones. However, it is worth noting that SCM containing 12% GP can be considered as the optimum as it had the highest compression ratio; the increase is about 5%, 3%, 10%, 15% and 7% respectively, compared to the control mix at 7, 14, 28, 56 and 90 days for SCM-GPF3.

The increase in compressive strength of GP mixes at later stages can be explained on the one hand by the increase in pozzolanic reaction between SiO2 and CaO of the glass powder present in the porous solution and unreacted CH, C3S and C2S grains as reported by (Elaqra et al.2018) and by the filling effect that leads to a denser microstructure by reducing the total porosity of the mortar.

3.2.2 Compressive strength of SCM-BP: As it can be seen from figure 5, the compressive strength of SCM-BP decreases with increasing BP content, but it improves with the fineness. On the other hand, early strengths development of SCM-BP are low compared to that developed later which mean that BP cannot participate in hydration at young ages because of their low pozzolanic activity, except for 4BP and 8BP mixtures, which showed a slight increase in strength compared to the control mixture at 7 and 14 days for SCM-BPF2 and SCM-BPF3. This slight improvement for cement replacement with 5% and 10% of BP is confirmed also by (Karatas et al. 2010).





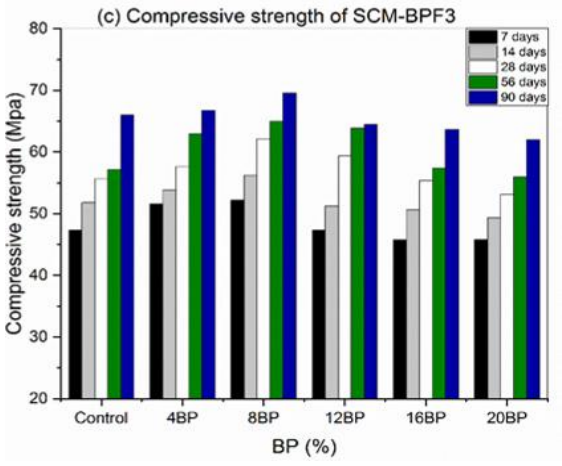


Figure 5. Compressive strength of SCM-BP mixes with three fineness a) F1, b) F2, c) F3

Under the same conditions, the compressive strength of SCM-BPF2 and SCM-BPF3 mixtures is higher than that of SCM-BPF1, which may be due to the large specific surface area of the brick powder, in addition, it has a higher pore filling effect which makes the microstructure of cement pastes with brick powder more dense and less porous, this also led to an improvement in compressive strengths (Liu et al. 2017).

According to (Li et al. 2016), there are amorphous phases in BP. These amorphous phases and active SiO2 are activated by the hydration of cement produced Ca(OH)2 and (CH), with which they then react. The pozzolanic BP effect also comes into play, when more BP is mixed; there are more amorphous phases and active SiO2 available. Thus, the pozzolanic reaction occurs to a greater extent and more new hydration phases are formed.

The incorporation of BP improved the compressive strength at 28 and 56 days compared to the control mixture, which helped it to gain strength (up to 90 days). According to Naceri and Hamina (Naceri et al. 2009) the brick powder (BP) reacts with the hydration products of cement (calcium hydroxide) and produces more gels, which will contribute to the increase in compressive strength.

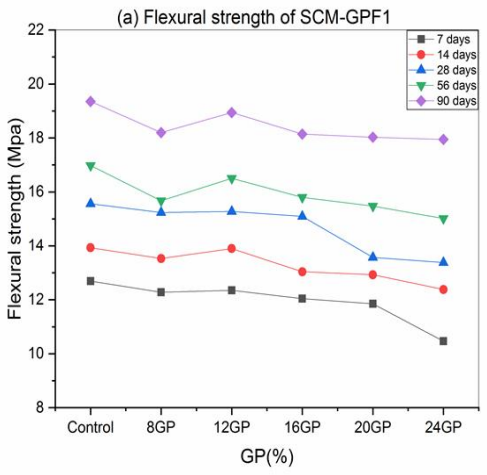
The 90-day compressive strength of the 4BP and 8BP mixtures is up to 69 MPa and 72 MPa for SCM-BPF2 and 67 MPa and 70Mpa for SCM-BPF3 respectively, which are higher than the control value of 66 MPa. The brick powder added to cement will show progressively higher increase in mechanical properties over time (up to 90 days) as proven by many researches (Demir et al.2011; Vejmelková et al. 2014).

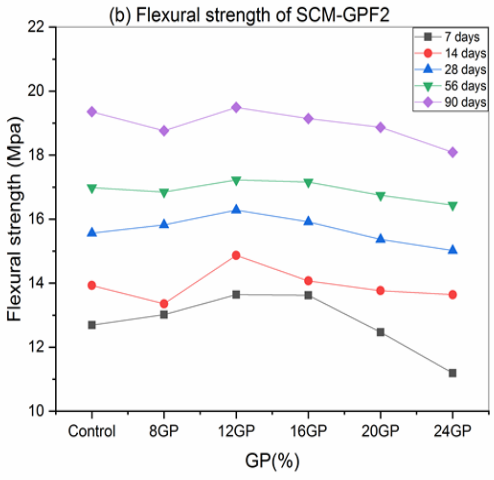
Moreover, it is seen that SCM-8BP had the highest compression ratio over all ages, the increase is 7%, 8%, 10%, 13% and 9% higher compared to the control mixes at 7, 14, 28, 56 and 90 days, respectively for SCM-BPF2; and 10%, 9%, 12%, 14% and 5% at 7, 14, 28, 56 and 90 days, respectively for SCM-BPF3.

3.3 Flexural strength

3.3.1 Flexural strength of SCM-GP mixtures

The flexural strengths of SCM-GP samples are presented in Figure 6.





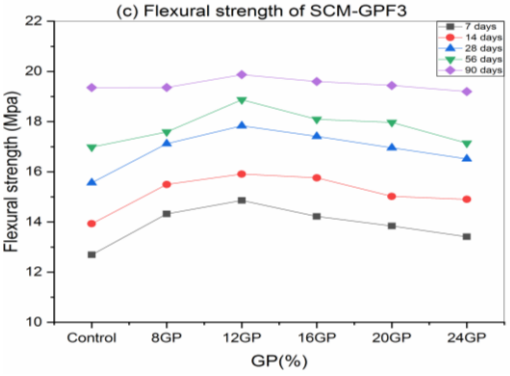


Figure 6. Flexural strength of SCM-GP mixes with three fineness a) F1, b) F2, c) F3

The flexural strength decreases with GP content and increases with age and fineness. The 12% GP blend gave the highest flexural strength, while the 24% GP gave the lowest for the three blends SCM-GPF1, SCM-GPF2 and SCM-GPF3. The flexural strength decreases with GP content and increases with age and fineness. The 12% GP blend gave the highest flexural strength, while the 24% GP gave the lowest for the three blends SCM-GPF1, SCM-GPF2 and SCM-GPF3.

At 90 days, the flexural strength of SCM with 12% GP reveals an increase up to 3.06 MPa compared to 7 days for SCM-GPF3.

The flexural strengths of all the SCM-GPF3 mixtures obtained for 7 to 90 cured days exceeded those of the control, while for SCM-GPF2 only 8%, 12% and 16% GP mixtures show higher strengths than the control. However, the SCM-GPF1 composition gives lower flexural strengths than that given by the control one for the period of 7 to 28 days.

The increase in flexural strength can be attributed to the increased bonding of the interface transition zone between cement paste and aggregates and the refinement of porosity (H. Elaqra et al.2018; H.Elaqra et al.2019).

3.3.2 Flexural strength of SCM-BP mixtures:

Figure 7 shows the results of the flexural strength of SCM-BP with three fineness's for samples retained in water for 7, 14, 28, 56 and 90 days.

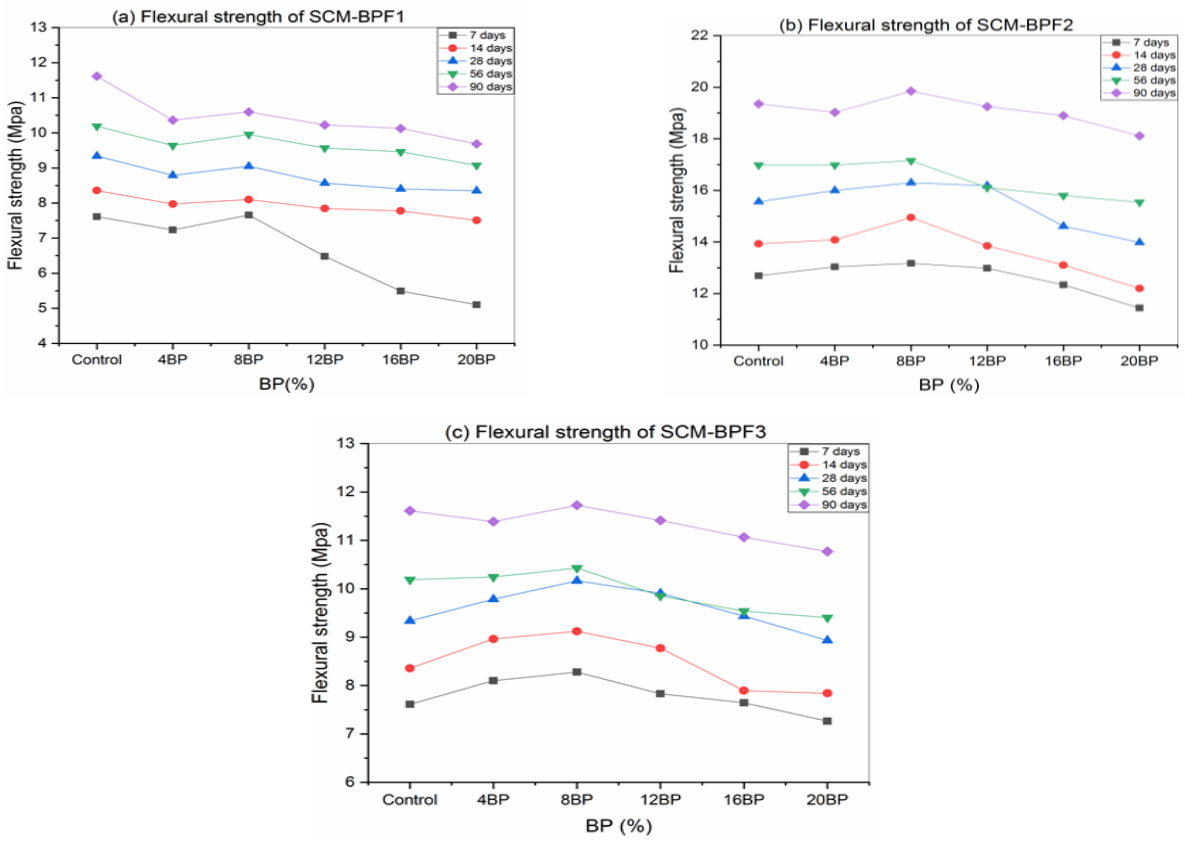


Figure 7. Flexural strength of SCM-BP mixes with three fineness a) F1, b) F2, c) F3

As for the SCM-GP, the results show that the flexural strength of SCM-BP is positively influenced by Blaine fineness and increases with age, but BP caused a gradual decrease in the flexural strength of SCM-BPF1 at 7 and 14 days compared to the control SCM. However, from 28 days the flexural strength is almost similar, while SCM-BPF2 and SCM-BPF3 showed a little bit higher strengths from the first days. Beside, the flexural strength of SCM with 4%, 8% and 12% BP is higher than control and the optimum is around 8% BP.

We record 11.73 MPa for SCM-BPF2 and 11.91 MPa for SCM-BPF3 at 90 days. The high flexural strength could be caused by the shape and surface texture of BP. The rough surface could result in higher bond strength between the BP and the cementitious matrix as reported by (Ge et al. 2015). Similarly, the larger specific surface area of BP fills the voids and pores and makes the microstructure of SCM dense, the pozzolanic reaction of BP also plays its role in increasing the strength. These results are in agreement with other experimental studies (Irki et al. 2018; Zhao et al. 2020).

3.4 Porosity

3.4.1 Porosity of SCM-GP mixtures (kept in air and water): Porosity is an important indicator of the durability of any cementitious material. The results of the water accessible porosity of the SCM-GP mixtures keep in open air and in water. At 28 and 400 days are shown in figures 8 and figure 9 respectively. It can be observed that glass powder has a positive influence on the reduction of total porosity, the decrease is caused by long-term storage and increase in fineness and the mixtures stored in water are less porous compared to those stored in open air at 28 and 400 days.

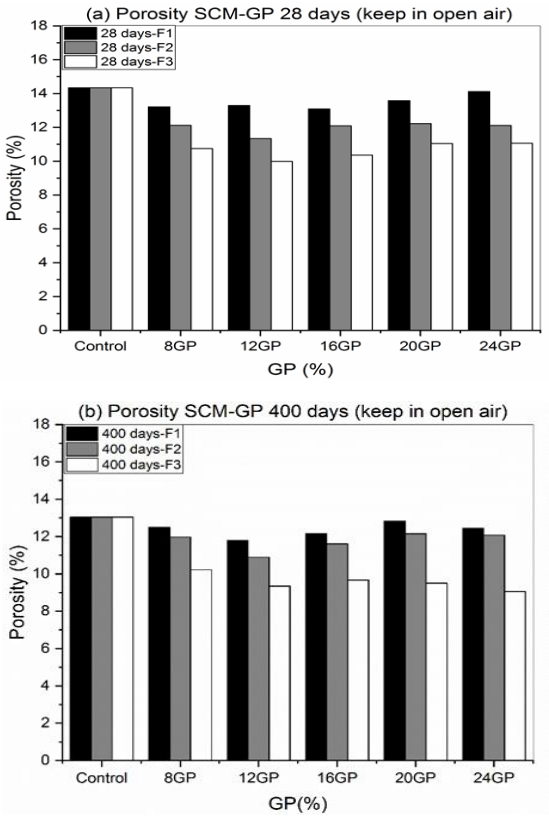


Figure 8. Porosity results of SCM-GP mixtures keep in the open air for 28 and 400 days

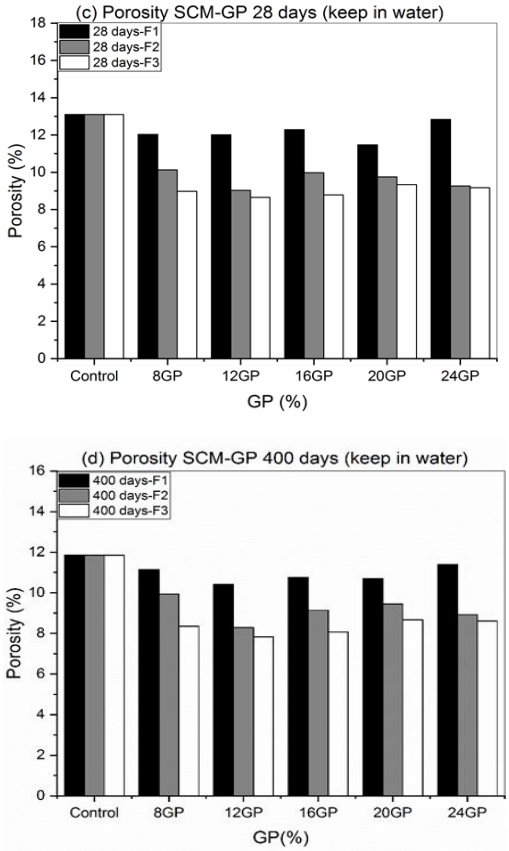


Figure 9. Porosity results of SCM-GP mixtures keep in the water for 28 and 400 days

Porosity decreases significantly with the increasing of GP fineness. This could explain why the mechanical properties of SCM-GP increased with the increasing fineness. Reducing the porosity can also improve the long-term compressive and flexural strength as also observed by (Nassar et al. 2012).

It is observed that the use of 12% and 16% GP reduces the total porosity of the specimens and the specimen containing 12% GP has the lowest total porosity, compared to that of control SCM. On the other hand, the SCM with 24% GP shows a slight increase in total porosity especially with SCM-GPF1; this could be due to the excess quantity of GP that does not react causing weak zones inside the SCM; while the porosity still remains lower than that of the control SCM.

The porosity of SCM-GP did not show significant changes from curing for 28 days or 400 days and varied in the range of 8 to 15%. It can be seen that SCM-GP with 12% GPF3 indicated the lowest porosity at 400 days; this may be due to the higher pozzolanic activity of GPF3 compared to GPF2 and GPF1.

At 400 days, the reduction in porosity compared to the control SCM for the air cured mixtures goes from 13.04 to 11.79%, 10.89% and 9.34% for SCM-GPF1, SCM-GPF2 and SCM-GPF3 respectively. Likewise for the water curing medium, the void volume decreases from 11.85% to 10.43%, 8.28% and 7.82% for SCM-GPF1, SCM-GPF2 and SCM-GPF3 respectively. This reduction in porosity is due to the high specific surface area of the glass powder, which fills the voids and improves the density of the SCM-GP mixtures, in

addition to the low water absorption of glass leading to use of a low W/B ratio as commented by (Lu et al. 2019) working on waste glass aggregates (WGA).

3.4.2 Porosity of SCM-BP mixtures (kept in air and water): The results of the water accessible porosity of the SCM-BP mixtures keep in open air and in water at 28 and 400 days are shown in figures 10 and figure 11 respectively.

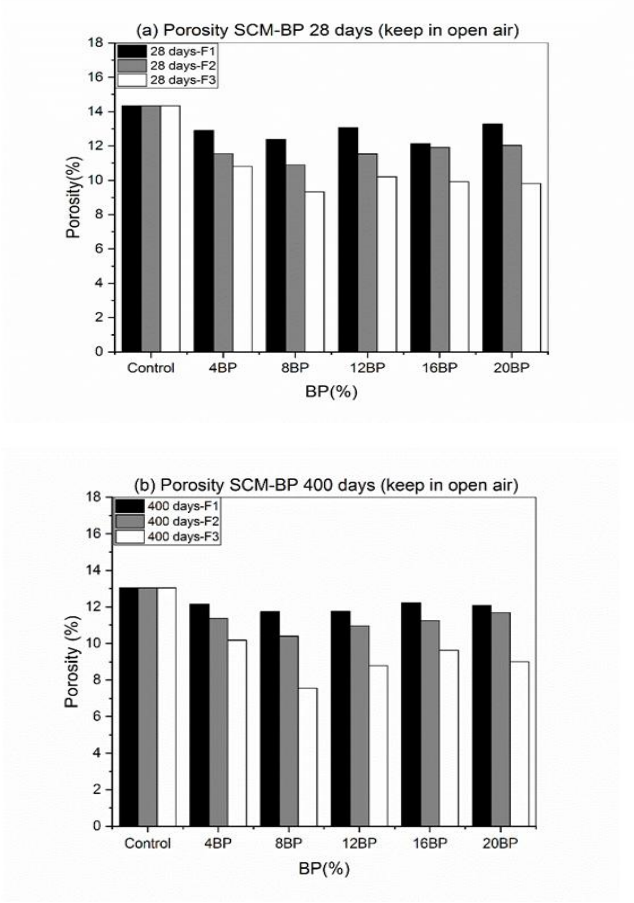
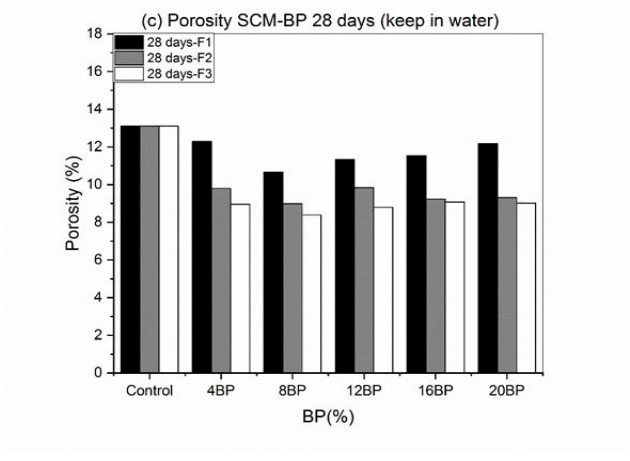


Figure 10. Porosity results of SCM-BP mixtures kept in the open air for 28and 400 days



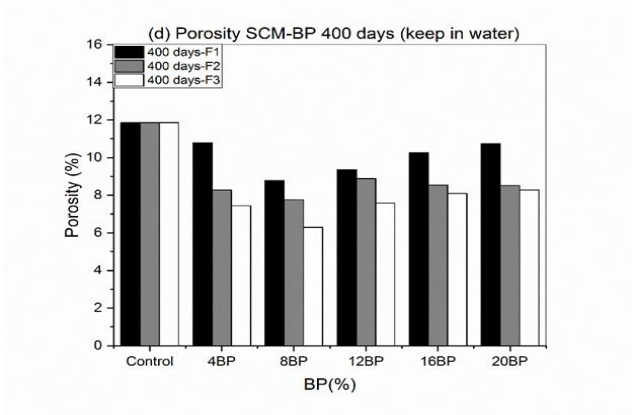


Figure 11. Porosity results of SCM-BP mixtures kept in the water for 28 and 400 days

From Figures 10 and 11, the water-accessible porosity values for the two cured medium are always lower than those of the control SCM. The decrease in porosity is also affected by age and fineness.

The porosity decreases from 28 to 400 days for all studied BP- SCM. At 400 days, the rate of pore refinement increases, leading to the decrease in porosity and the increase in density. For SCM-BPF1, decreases in average total porosity values were observed due to the replacement of cement with BP. This result is in accordance with that obtained by (Du et al. 2021), who have used metakaolin as partial substitution of cement and explained this trend by the consumption of calcium hydroxide in the interstitial solution of curing cement paste to generate additional C-(A-) S-H gel and C_2ASH_8 and these hydration products can fill the pores in cement paste.

For SCM-BPF1, decreases in average total porosity values were observed due to the replacement of cement with BP. For example, the inclusion of 8BPF1 and 12PBF1 in the mortar leads to a porosity of 11,73% and 11,77% respectively compared to the SCM-control whose porosity is 13,04% and for SCM-PBF2 with 8% and 12% BP, the porosity is lower with 10,4% and 10,96% respectively. The 8BPF3 is the least porous mixture with 7,54%; these are for mixtures kept in the open air. For the mixtures kept in water, the same trend of porosity reduction was observed but they are less porous compared to the mixtures kept in open air. The reduction for 8BPF3 goes from 11,85% for the SCM-control to 6,28% .

Comparing the porosity of the three series of SCM, it can be verified that, SCM-BPF3 presented lower porosity values than those observed for SCM-BPF2 and SCM-BPF1 and this for the two modes of cure. This behavior can be related to a refinement of the porous structure of SCM-BPF3 produced by the pozzolanic effect of the BP and its filling effect because of its great fineness. The ground clay powder improves the structure of the cement paste, filling the space, thus reducing the volume and number of pores in the curing matrix as also reported by (Zeghad et al. 2017).

4. CONCLUSION

The paper explore the effects of glass (GP) and (BP) brick powder with different fineness as alternatives to Portland cement in producing an environmentally friendly and economical self-compacting mortar (SCM). The major conclusions are:

1- The incorporation of (GP) in SCM mixes provides better workability compared to that of the control, while the incorporation of (BP) decreased the slump flow.

2- The pozzolanic effect of BP and GP is clearly noticed on the development of mechanical strength, especially with the increase of Blaine fineness.

3- When the GP fineness is higher than the cement fineness , the compression strength with GP contents up to 16% is superior than without the GP, whereas for the BP the strength improvement is up to 8%, while the compression strength decreases when the GP and BP fineness is close or lower than the cement fineness

4- The improvement of compressive strength of BP mixtures at 90 days is up to 72 MPa at 8% replacement rate with F2, while GP mixtures strength accounts for 70 MPa at 12% replacement rate with F3.

4- The flexural strength decreases linearly with increasing (GP) and (BP) content, and the flexural strength of mortar with high-fineness (GP) and (BP) is higher than that of mortar with low-fineness (GP) and (BP).

5- Incorporating an appropriate fineness level and replacement ratio of (GP) and (BP) reduces the total porosity comparing to the control, and for the two modes of preservation (water and air).This makes the cementitious matrix denser due to pores filling by the secondary generated C-S-H gel that causes the densification of SCM microstructure.

6- It is conclude that SCM-12 GP and SCM-8 BP mixtures with F2 are the most optimal ones as they are the least porous and the most resistant mixtures.

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