



Properties of Self-Compacting Mortar Containing Slag with Different Finenesses

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Received 29 January 2021; Revised 10 April 2020; Accepted 15 April 2021; Published 01 May 2021

Abstract

It is well established that Self-Compacting Concrete (SCC) contains large amounts of fines including mineral admixtures, such as fly ash and slag, in order to avoid segregation and to increase cohesion. The use of these materials in concrete reduces CO₂ emissions and contributes towards sustainable construction. To overcome the negative effect of slag on the strength development slag was ground to three finenesses. Therefore, this paper examines the rheological, compressive strength, total and autogenous shrinkage and capillary water absorption of Self-Compacting Mortars (SCM) containing ground granulated blast furnace Slag (S). A total of seven mortar mixes were prepared. The control mix had a proportion of 1 (cement): 1.8 (sand): 0.38 (water). In the other mixes, the cement was partially replaced with 15% and 30% slag of different fineness of 350, 420, and 500 m²/kg. The other constituents remained unchanged. Testing included slump flow, V-funnel flow time, yield stress and viscosity, compressive strength, total and autogenous shrinkage, and capillary water absorption. The presence of slag was found to reduce the plastic viscosity and yield stress of SCM mixtures as the content and the fineness increase. The higher the fineness (specific surface) of the slag the less the rheological parameters (i.e. slump flow and viscosity). The results show also a reduction in compressive strength of SCM at early ages of curing in the presence of slag. However, in the long-term, the compressive strength of SCM mixtures containing slag was higher than that of control mortar. Generally, there is reduction in the total shrinkage and an increase in the autogenous shrinkage of SCM mixtures as the content and fineness increase.

Keywords: Slag; Fineness; Self-compacting Mortar; Rheology; Shrinkage; Autogenous Shrinkage; Capillary Water Absorption.

1. Introduction

Concrete is widely used material in construction because of its many advantages. It can be used as noncombustible material for multifunctional building [1] and for construction of complex architectural elements using SCC. Self-Compacting Concrete (SCC) is known of its high fluidity and its capacity to be placed and passed through narrow spaces under its own weight without any vibration. The high workability is not the only required property, but SCC

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 <http://dx.doi.org/10.28991/cej-2021-03091694>



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must present a good resistance to segregation [2]. Hence, the use of high content of fine materials and the use of superplasticizer is necessary for the production of SCC.

The use of supplementary cementitious materials (SCM) such as ground granulated blast furnace slag, natural pozzolana, fly ash and silica fume on the performance of SCC is widely investigated [3-6]. However, few studies have examined the effect of surface area of SCM on the properties of SCC or self-compacting mortar (SCM). The use of SCM in concrete production is becoming a common practice for their positive impact on the economy and environment [7]. They can also improve the performance of concrete by modifying its pore structure due to the reaction of SCM with the products of cement hydration. Furthermore, the fineness of SCM will have an effect on the various properties of concrete. The larger the fineness, the more available surfaces to react with the products of cement hydration. The inclusion of slag was found to increase the workability [8, 9]. Her and Lim [10] reported an increase in fluidity of concrete with increasing Blaine fineness of Nano ground slag. Partial replacement of cement with slag leads to a lower plastic viscosity and yield stress compared with traditional concrete [11]. Increasing the surface area of the slag causes a decrease in plastic viscosity and yield stress [12]. The long-term compressive strength of concrete with slag was found to be similar to that of the reference concrete [12, 13]. However, other researchers reported a reduction in compressive strength of SCC when slag is incorporated [14-16]. Sharmila and Dhinakaran [17] showed an improvement in compressive strength when ultrafine slag was incorporated in concrete. An enhancement in compressive strength of mortars with increasing slag fineness from 400 to 800 m²/kg was reported [18].

The use of SCM in concrete may cause an increase in shrinkage, thus the risk to cracking [19]. It is estimated that the shrinkage of SCC did not show a significant difference from that of traditional vibrated concrete [20]. However, others showed a higher shrinkage of concrete containing slag [21]. They attributed this effect to the high volume of binder in the SCC. The drying shrinkage of mortar was found to decrease in the presence of SCM [22]. This is in agreement with results reported elsewhere [23, 24]. The partial substitution of cement with slag resulted in an increase in the long-term autogenous shrinkage of concrete [25]. The higher the fineness of slag the larger the autogenous shrinkage [26]. The presence of SCM in concrete can improve its durability performance. Traditional concrete was found to have lower rate of water absorption by capillary action due to the incorporation of slag [27]. The finer the slag, the further the reduction in capillary water absorption [17].

It appears that the combined effect of slag content and fineness on the fresh and hardened properties of mortar is not well documented. Grinding slag to a higher fineness in cement plants could be performed at a very low cost and low energy consumption. Little research exist on the effect of fineness on the performance of SCC at both the fresh state and hardened state. A Preliminary study was conducted by the authors on slag and natural pozzolan with various finenesses but the study was limited to slump flow and v-funnel at the fresh state and compressive strength and drying shrinkage at 28 days only at the hardened state [28]. In addition, few studies are available on the effect of fineness on the development of autogenous shrinkage of SCC and on the rheological properties using rheometer. Therefore, in the current investigation, local medium hydraulicity slag with different finenesses was used in self-compacting mortars (SCM). These properties of SCM included; rheological properties using one point tests and a rheometer, compressive strength from 1 days up to 180 days, total and autogenous shrinkage up to 90 days and capillary water absorption at 90 days. The study demonstrated the positive effects of grinding slag to a higher fineness so that negative effect of slowing strength gain by slag is overcome and the durability is improved.

2. Experimental Procedure

2.1. Materials

The cement used was Portland cement type CEMII/B according to EN197-1 with a strength class of 42.5 N/mm² and a specific surface area of 310 m²/kg. The slag used has a specific gravity of 2.85 and was ground in a laboratory mill to a specific surface Blaine (SSB) of 350, 420 and 500 m²/kg. Table 1 presents the chemical and mineralogical composition of the binders used in the study. River sand with granular size of 0-5mm was used as fine aggregates. The sand has a specific gravity of 2.53, water absorption of 1.70% and fineness modulus of 2.80. The size distribution of river sand is shown in Figure 1. The superplasticizer (SP) used was a Polycarboxylate (MEDAFLOW30) with a specific density and solids content of 1.07 and 30%, respectively.

Table 1. Binder composition (%)

Composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	C ₃ S	C ₂ S	C ₃ A	C ₄ AF
Cement	21.06	3.6	4.47	63.4	1.85	2	67.4	9.89	1.98	13.59
Slag	40.1	6	2	42.2	4.7	0.15	–	–	–	–

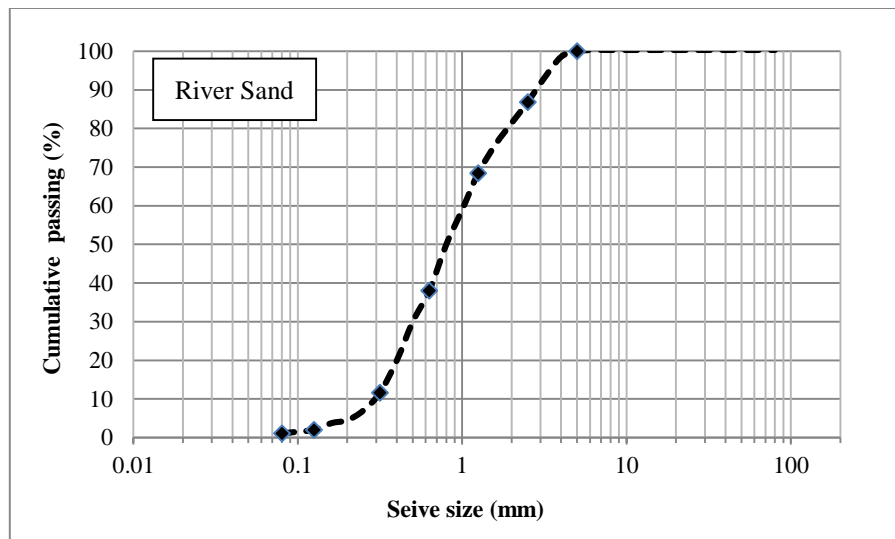


Figure 1. Size distribution of river sand

2.2. Mix Proportions

Mortar mixes were prepared according to Okamura and Ozawa's recommendations [29]. For each fineness, three different SCM mixes were prepared with 0% (SCM0), 15% (SCM15) and 30% (SCM30) (by weight) of slag as partial substitution of cement. The level of substitution of the cement by slag was limited as the local slag has a medium to low activity and previous studies showed that higher than 30% could be detrimental to the performance of concrete [3, 11, 27]. The tests conducted were; rheology, compressive strength, capillary water absorption and shrinkage. The water-binder (w/b) ratio, sand-mortar (s/m) ratio and superplasticizer content were kept unchanged at 0.38, 0.5 and 1.5% (by weight of binder), respectively. The choice of different parameters of the mix was based on previous studies on similar materials to obtain SCC mixes [3, 11]. The details of the composition of the self-compacting mortar mixes studied are given in Table 2.

Table 2. Mixture proportions for self-compacting mortars (SCM)

Mixture	w/b (%)	SP (%)	Slag (%)	Cement (kg/m ³)	Sand (kg/m ³)	Slag (kg/m ³)
SCM0	0.38	1.50	–	705.00	1253.80	–
SCM15S	0.38	1.50	15	602.50	1253.80	99.40
SCM30S	0.38	1.50	30	498.80	1253.80	198.80

2.3. Testing

The following flow chart (Figure 2) summarizes the research methodology.

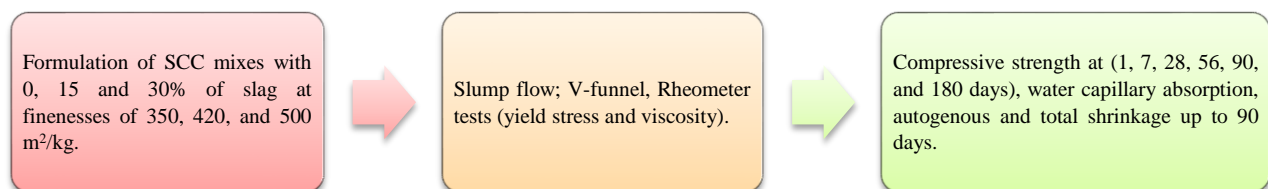


Figure 2. Flowchart of research methodology

2.3.1. Workability

The slump flow and V-funnel flow tests were made according to EFNARC recommendations [30]. For the measurement of rheological parameters, a rheometer composed of an agitator, a cylindrical container (13 cm in height and 10 cm in diameter) and a steel vane (10.5 cm in height and 5 cm in diameter) was used (Figure 3). A computer software was employed to control the movement of the agitator [31]. In the first step, the cylinder is filled with mortar. Thereafter, the vane is placed in the center of the container and immersed in the mortar and the rheological parameters are measured [31].



Figure 3. Rheological test

2.3.2. Compressive Strength

The compressive strength was measured using specimens of dimensions $40 \times 40 \times 160$ mm³ according to NF P 18-406 [32]. All specimens were demolded after 24h. Then, they were cured in water at $20 \pm 2^\circ\text{C}$ until testing. The testing ages were 1, 7, 28, 56, and 90 days so that the effect of slag on both early age and long term could be investigated. At each age, three samples were tested and the average value was taken to represent the strength at each age.

2.3.3. Shrinkage

The total and autogenous shrinkage were measured on prismatic specimens of dimensions $40 \times 40 \times 160$ mm³ for a period of three months as shown in Figure 4. The procedure is based on NF P 15-437 [33]. Weight loss was also measured. Specimens for autogenous shrinkage were demolded after 24 hours and then sealed with aluminum adhesive tape. For total shrinkage, all specimens were stored at a temperature of $20 \pm 1^\circ\text{C}$ and humidity of $55 \pm 5\%$.

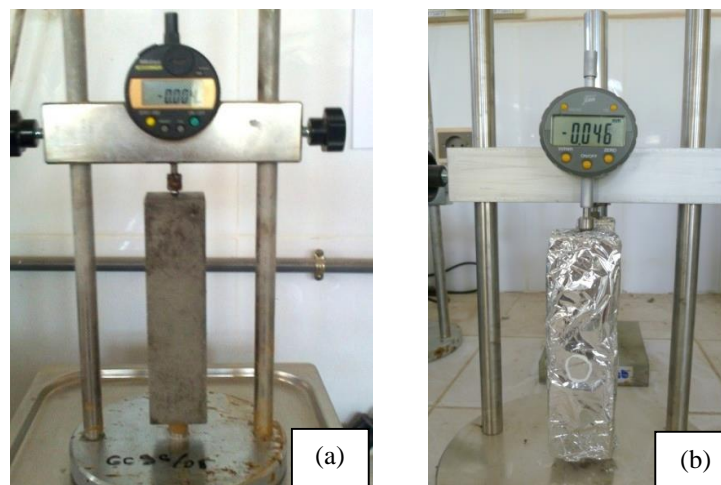


Figure 4. Shrinkage test: (a) total shrinkage (b) autogenous shrinkage

2.3.4. Capillary Water Absorption

Capillary water absorption test was measured on prismatic mortar specimens $40 \times 40 \times 160$ mm³ in size according to ASTM C-1585 standard [34]. After 90 days of water curing, the samples were oven dried at 80°C and then sealed laterally by a layer of epoxy resin to guarantee water flows in one direction and then the unsealed face of the specimens was subjected to water. The initial water absorption of specimens was measured frequently during the first 6 hours, then less frequently until 7 days.

3. Results and Discussion

3.1. Fresh Properties of Self-compacting Mortars

Table 3 presents the slump flow and V-funnel values for SCM with and without slag. The results indicates that the use of slag in mortar provides better workability compared to that of control mortar, which is in agreement with others researchers [35, 36]. The characteristics of the surface of slag grains with a better intergranular slip and very low water

absorption may explain this increase in workability. Other studies [37, 38] of fresh SCC have shown an improvement of fresh properties of concrete with increasing slag content. Shi et al. [39] reported that increases in slump flow with increasing slag content for substitution higher than 50%. It was also noted that the workability of mortar increases when the specific surface area of slag increases. This could be attributed to the filling of voids by the higher fineness of slag particles in the mixtures.

Table 3. Results of fresh mortars tests (SCM with slag)

Content (%)	Fineness of slag (m^2/kg)					
	350		420		500	
	Slump-flow (mm)	V-Funnel time(s)	Slump-flow (mm)	V-Funnel time(s)	Slump-flow (mm)	V-Funnel time(s)
SCM0	296.5	2.52	296.5	2.52	296.5	2.52
SCM15S	299.5	2.43	304.5	2.11	319.5	2.06
SCM30S	302.0	5.11	310.5	3.90	321.5	2.58

3.2. Rheological Parameters

The effect of slag as cement replacement on the plastic viscosity and yield stress is given in Figures 5 and 6. It can be clearly seen that an increase in slag content decreased the plastic viscosity as well as the yield stress of SCM regardless of the slag fineness. For a slag fineness of $350 \text{ m}^2/\text{kg}$, a reduction of viscosity from 6.08 to 4.73 and 4.65 Pa.s is noted for substitution of 15 and 30%, respectively. This effect was more pronounced for higher specific surface area. Also, the yield stress decreases from 19.11 to 12.31 and 9.8 Pa for slag contents of 15 and 30%, respectively. Other researchers reported similar results on the rheological properties of SCC when slag was used [11]. Moreover, Boukendakdji et al. [3] also demonstrated that plastic viscosity and yield stress are lower for higher slag contents. In another investigation Adjoudj et al. [31] stated that plastic viscosity of cement mortars decreases with the increase in blast furnace slag content, but, they noted that increasing the substitution rate of slag leads to an increase of mortars yield stress. The results also demonstrated that increasing the fineness of slag affects significantly the rheological properties of self-compacting mortars. For substitution of 30%, an increase of fineness from 350 to 420 or $500 \text{ m}^2/\text{kg}$ decreases the plastic viscosity of SCM with slag from 4.65 to 3.23 and 2.06 Pa.s, respectively.

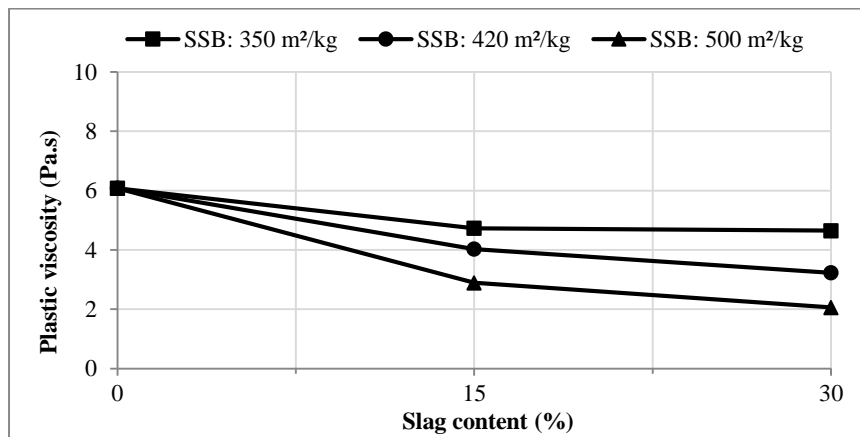


Figure 5. Effect of content and fineness of slag on plastic viscosity

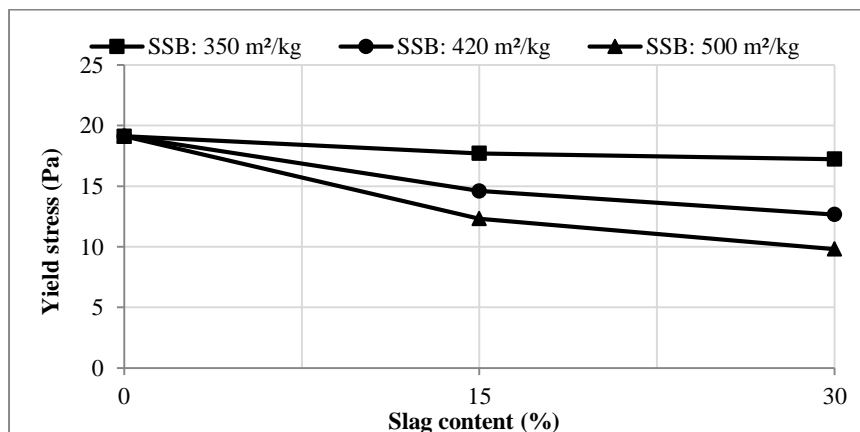


Figure 6. Effect of content and fineness of slag on yield stress

Figure 7 shows the correlation between slump flow and plastic viscosity for the different replacements and surface areas. A reduction in plastic velocity is observed when slump flow increases. If a linear relationship is plotted between plastic viscosity and slump flow, correlation coefficients of 0.83, 0.97 and 0.98 for slag with fineness of 350, 420 and 500 m^2/kg , respectively indicate a good correlation.

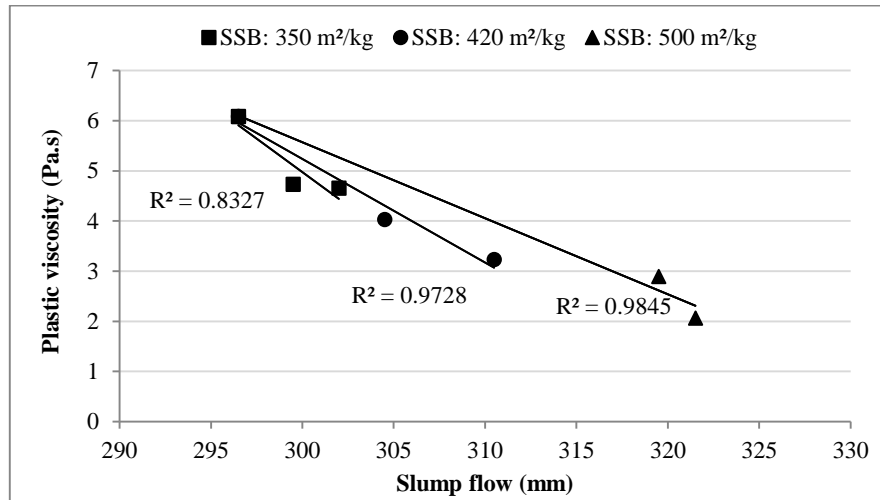


Figure 7. Correlation between plastic viscosity and slump flow (SCM with slag)

3.3. Effect of Slag Content on Compressive Strength

Figure 8 presents the results of compressive strengths of SCM containing slag with 350 m^2/kg fineness. The compressive strength of SCM with slag is lower than that of control mortar at early age. The decrease in strength is about 18 and 43% at the age of 1 day, 9 and 22 % at the age of 7 days and 3 and 7% at the age of 28 days for SCM mixtures containing 15 and 30%, respectively. The low reactivity of slag at early age and the dilution effect when slag is present could partially explain these results.

At longer term (more than 90 days of curing), mortar specimens with slag presented a higher compressive strength than that of the control. An increase of 2 and 3MPa at the age of 90 days, 5 and 5MPa at the age of 180 days was observed for SCM mixes containing 15 and 30% of slag, respectively. The pozzolanic reaction of slag which consumes calcium hydroxide, leads to the formation of additional hydration products and hence improves the microstructure which is the main reason for the increase in compressive strength [40]. Other researchers [41], reported increases in the amount of C-S-(A)-H gel, with the continuous hydration of slag which improves the pore structure of hardened paste as the hydration age increases. Some researchers [3, 15], also reported similar results when slag was added in SCC mixtures causing a decrease in compressive strength at the age of 7 days and an improvement at later ages of curing. Gupta and Siddique [38] found that mixes containing up to 60% of copper slag develop higher strength compared to control concrete. In another investigation [42], it was observed that after two weeks of hydration, the mortar strength containing 10% of slag is similar to the cement concrete mix. As concluded by Jaffar and Shah [43], the compressive strength of concrete specimens with 30% slag replacement ratio is higher than that of control concrete. Dordi et al. [44], stated that the hardened characteristics of high performance concrete are improved with incorporating slag in concrete mixtures.

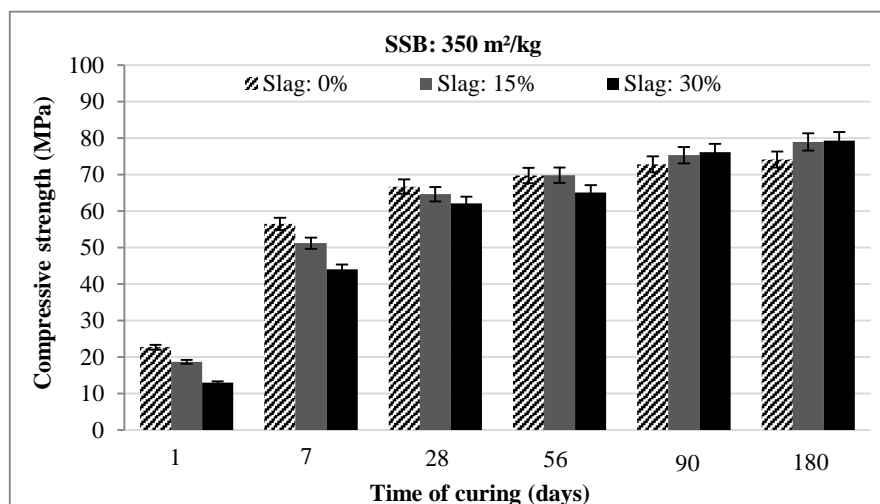


Figure 8. Compressive strength of SCM with slag (SSB: 350 m^2/kg)

3.4. Effect of Slag Fineness on Compressive Strength

Figures 9 and 10 show the variation of compressive strengths of SCM mixtures with different slag finenesses at 1, 7, 28, 56, 90 and 180 days of curing for 15 and 30% slag replacement, respectively. It can be seen that compressive strengths, especially at 15% slag replacement are similar for different finenesses. At later ages of curing (i.e. above 90 days), mixes with the highest slag fineness (i.e. 420 and 500 m²/kg) tend to have higher compressive strengths for 15% substitution level. However, for 30% substitution level, the compressive strengths of mortars are always comparable for the three finenesses used. It has been reported that both the chemical composition and specific surface area of slag affect significantly the reactivity of slag and that the pozzolanic reaction of slag increases with increasing its fineness [45, 46]. Zhou and Zhang [47] reported that at later ages, increasing slag fineness leads to an increase of pozzolanic reaction degree of about 40 to 70%. Furthermore, additional studies [48] showed that increasing fineness of slag from 400 to 565 m²/kg improves the compressive strength of mortars.

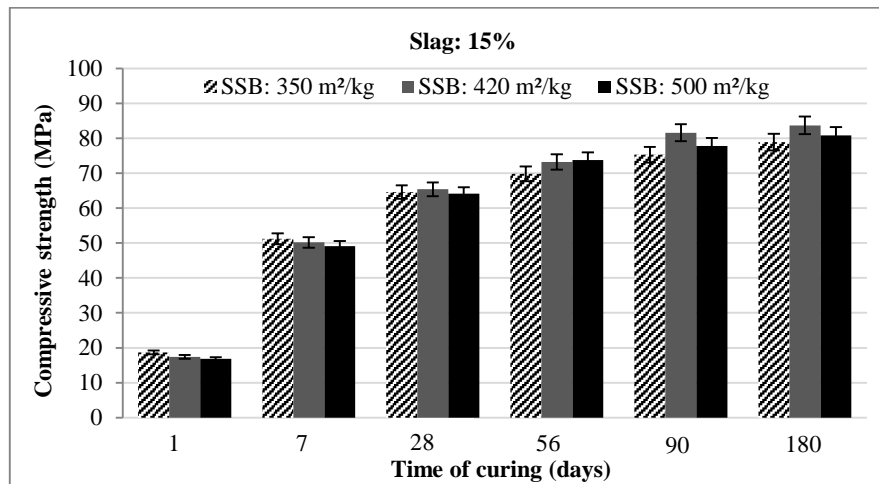


Figure 9. Effect of slag fineness on compressive strength of SCM (15% slag)

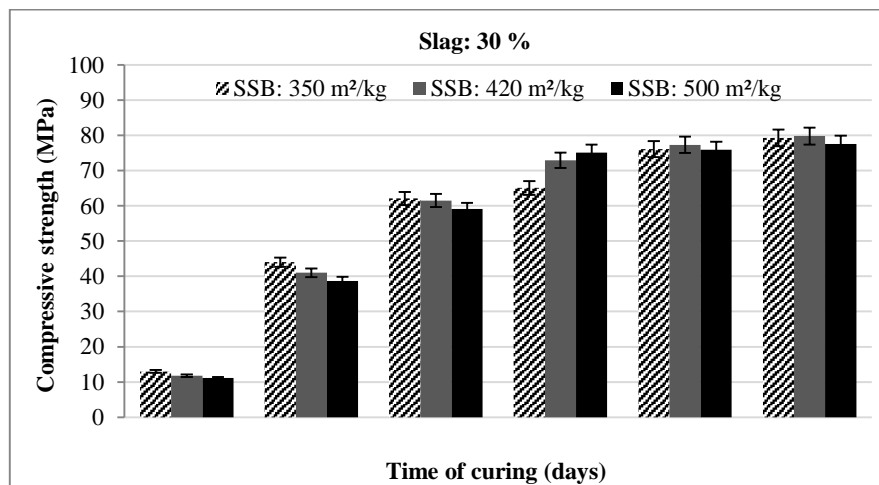


Figure 10. Effect of slag fineness on compressive strength of SCM (30% slag)

3.5. Influence of Slag Content on Total and Autogenous Shrinkage

Figures 10 to 12 show the evolution of the total and autogenous shrinkage for mortars containing 0, 15 and 30% slag with fineness of 350, 420 and 500 m²/kg respectively. Most of the drying shrinkage deformation occurred during the first 20 days; which is generally attributed to the reduced amount of free water present, as well as the contribution of autogenous shrinkage. As expected, the curves show that when slag content increases, the drying shrinkage reduces whatever the fineness of slag. For a fineness of 350 m²/kg, the decrease in shrinkage for mortar with 30% slag is about 20% compared to the control. This may be attributed to the densification of the microstructure and the associated lower permeability of mortars containing slag at later ages. In fact, as can be seen in Figure 14 where the mass loss of mortar mixes with age are plotted, the presence of slag has led to a reduction in mass loss, thus leading to lower shrinkage [49]. The addition of supplementary cementitious material such as slag affects significantly the shrinkage properties of concrete [50]. In addition, a reduction in drying shrinkage has been reported high volume of slag ($\geq 50\%$) is incorporated [51-53]. Palod et al. [54] reported a decrease in the rate of shrinkage with time with increasing slag replacement in mixes.

Autogenous shrinkage depends only on the intrinsic material parameters: chemical reactions, heat of hydration and composition of the mortar. The mixes investigated differ only in the content and fineness of slag. Typically slag is considered as a pozzolanic material with low reactivity and is effective in reducing the autogenous shrinkage of cements and concretes. Because of its latent hydraulicity, the slag does not have an effect on the evolution of autogenous shrinkage at early age, whatever the specific surface area of slag. After about 28 days, the pozzolanicity of slag begins to take effect causing a higher formation of hydrates than the control mortar and therefore a higher autogenous shrinkage (Figures 10 to 12). This effect is much more observed for the finenesses of 420 and 500 m^2/kg . This increase is on average 25 and 34% when cement is substituted by 15 and 30% slag, respectively. Liu et al. [25] noted that at long term, autogenous shrinkage increases with slag content. Some authors [55] pointed out that increasing autogenous shrinkage is caused by the finer porous structure in concretes with higher slag content, thus generating the tensile stress by the water menisci in the capillaries and consequently giving higher shrinkage. In addition, self-compacting concrete with slag as substitution of sand show a higher autogenous shrinkage. This is because of the chemical shrinkage caused by the slag reactivity and the higher self-desiccation due to slag hydration [56]. For a substitution of sand by slag of 10 and 60%, the increase is on average 11 and 33%. The effect on shrinkage of cement paste depends on the nature of the cementitious additions as fly ash, silica fume and blast furnace slag have different effects [57]. Fly ash drastically reduces the autogenous shrinkage whereas silica fume increases it, and the presence of slag resulted in values between those exhibited for fly ash and silica fume concretes.

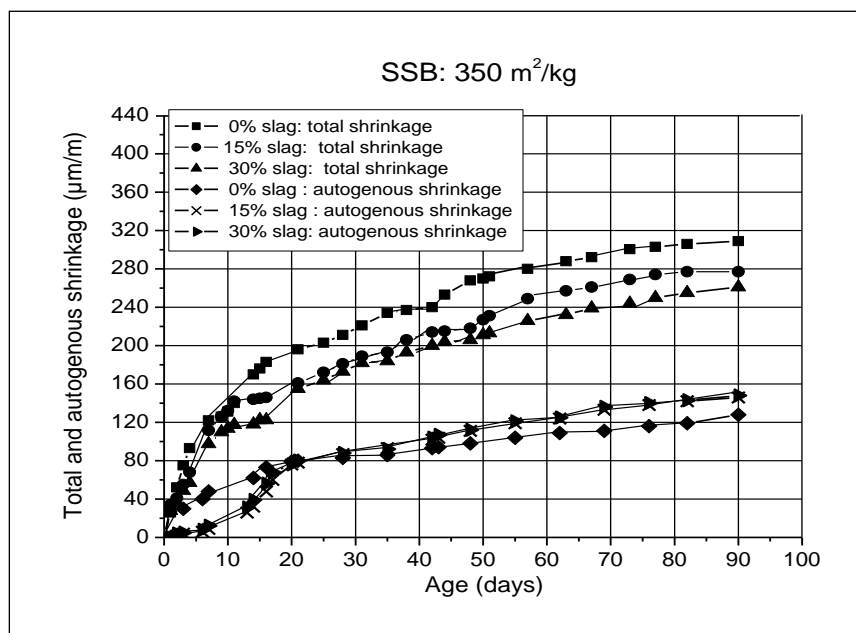


Figure 11. Total and autogenous shrinkage of SCM with slag (SSB: 350 m^2/kg)

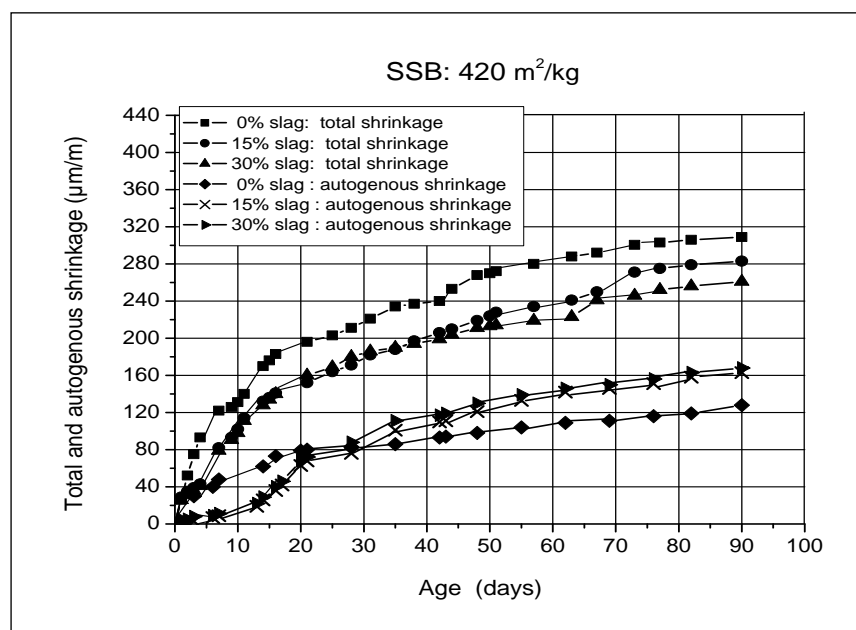


Figure 12. Total and autogenous shrinkage of SCM with slag (SSB: 420 m^2/kg)

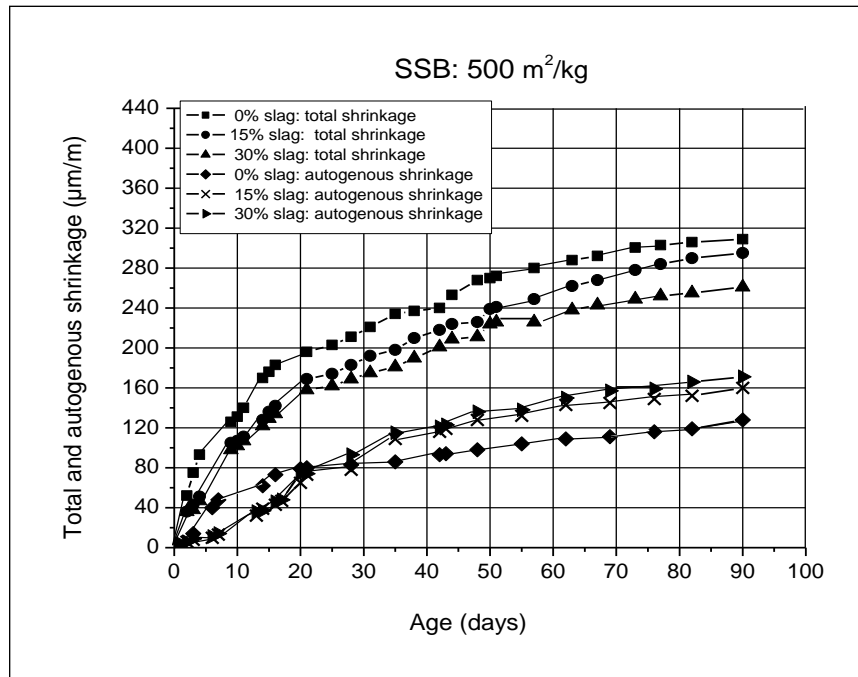


Figure 13. Total and autogenous shrinkage of SCM with slag (SSB: 500 m²/kg)

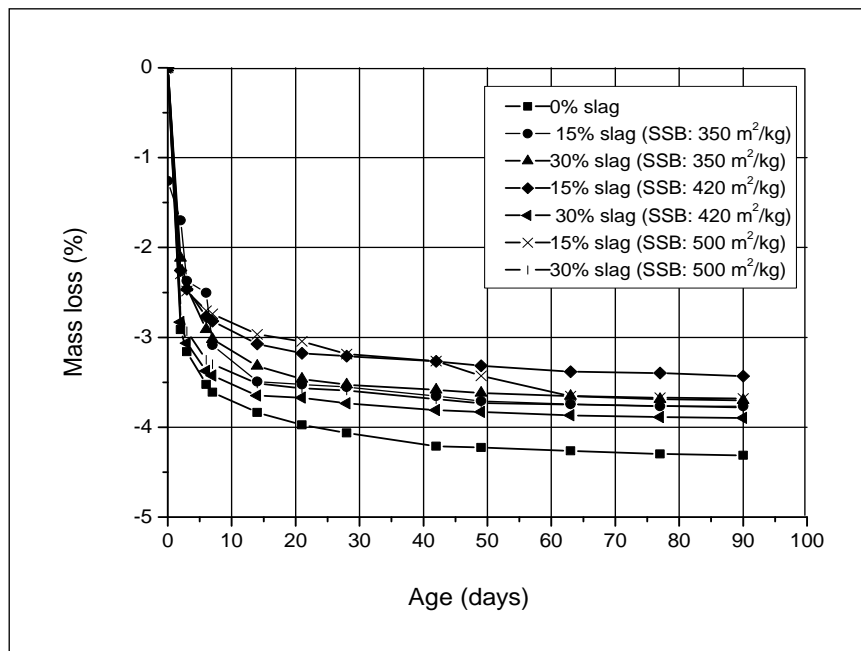


Figure 14. Mass loss of SCM with slag

3.6. Influence of Slag Fineness on Total and Autogenous Shrinkage

Figures 15 and 16 plot respectively the effect of fineness of slag on the drying and autogenous shrinkage of mortars at 15 and 30% slag replacement. These results show that the specific surface area of slag does not affect significantly the evolution of total shrinkage whatever the level of cement substitution. An increase of around 10% for mortars containing 15% slag with fineness of 420 and 500 m²/kg, compared with fineness of 350 m²/kg. Regarding the autogenous shrinkage, the results show that increasing slag fineness from 350 to 420 or 500 m²/kg results in a slightly higher shrinkage. This effect is much more observed for mortars with 30% replacement. This increase is about 12%. The trend of autogenous shrinkage can be explained by the accelerated hydration reactions generated by increasing the fineness of slag which leads to more surface areas of slag particles to react with water and more nucleation sites. This leads to an increase in the capillary tension because of the development of micro pores of the hardened cement paste and hence giving an increase in the consumption of crystal lattices of calcium hydroxide (Ca(OH)₂) [58]. Previous studies also reported increases in the autogenous shrinkage due to increase in fineness [59, 60].

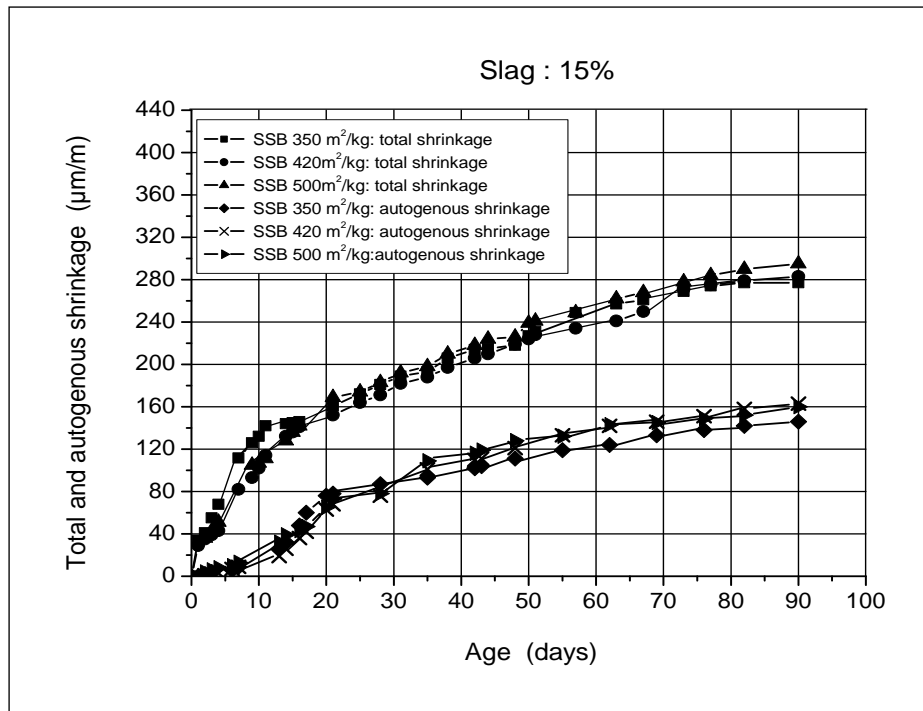


Figure 15. Effect of slag fineness on total and autogenous shrinkage of SCM (15% slag)

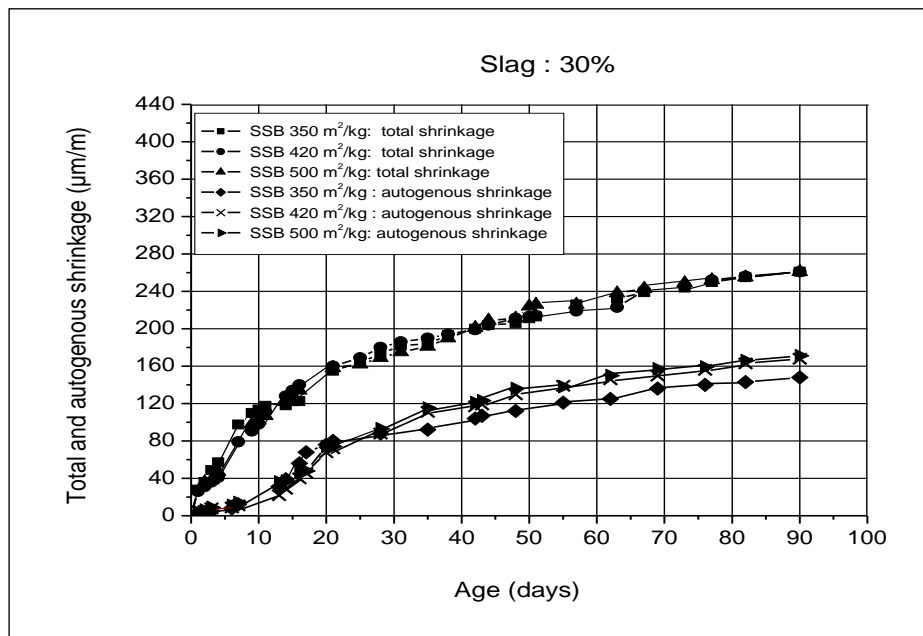


Figure 16. Effect of slag fineness on total and autogenous shrinkage of SCM (30% slag)

3.7. Effect of Slag Content on Capillary Water Absorption

Figures 17 to 19 summarize the effect of slag on water absorption of SCM for slag finenesses of 350, 420 and 500 m^2/kg , respectively. It was observed that the amount of absorbed water (initial and final absorption) decreased with the increase in slag content, whatever the slag fineness. The effect of slag on the initial absorption is clear even at the early stage of the test (less than 3 hours) indicating less large pores for slag mixes.

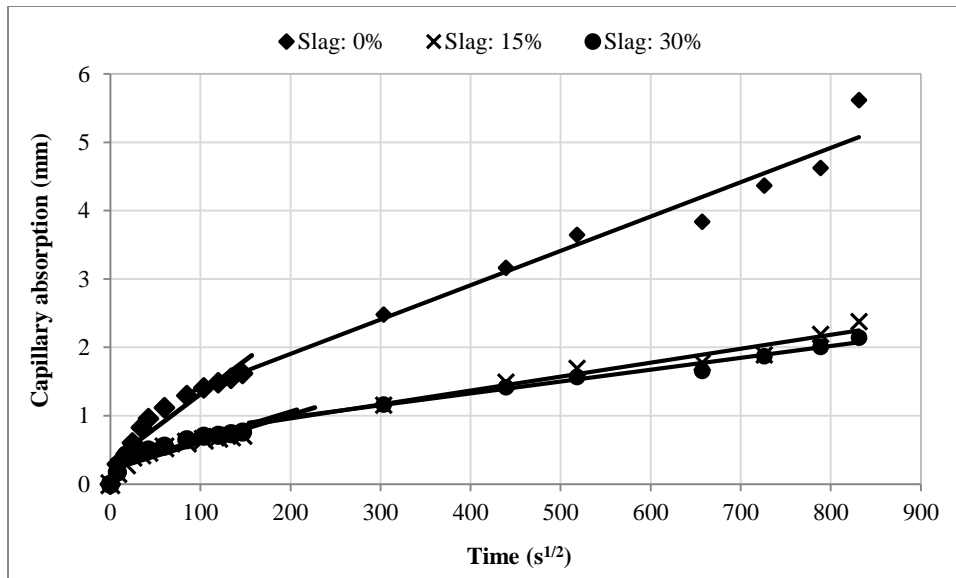


Figure 17. Effect of slag on capillary absorption of SCM (SSB: 350 m²/kg)

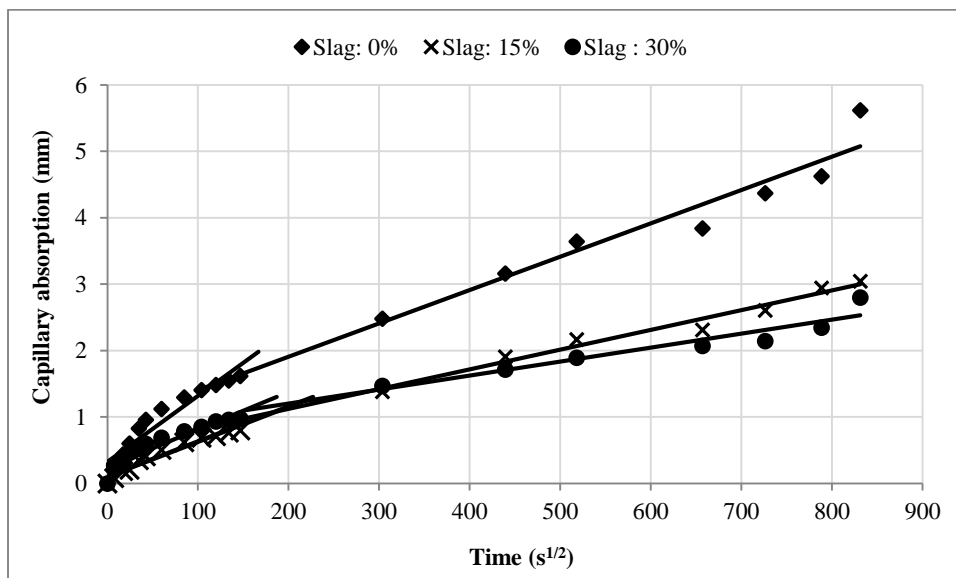


Figure 18. Effect of slag on capillary absorption of SCM (SSB: 420 m²/kg)

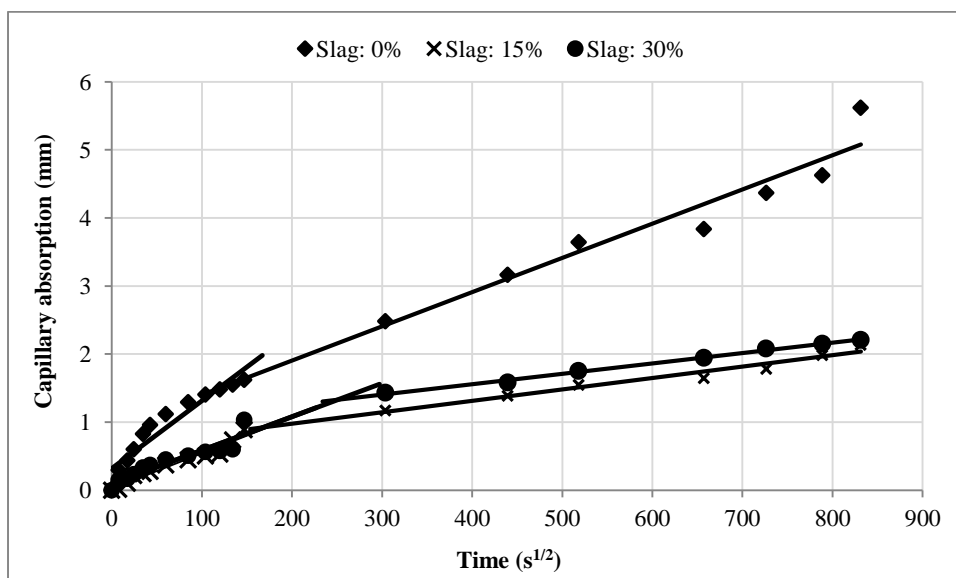


Figure 19. Effect of slag on capillary absorption of SCM (SSB: 500 m²/kg)

The sorptivity characterizes the rate of absorption of water by capillary suction of concrete. The sorptivity of SCM mixes with slag is shown in Figure 20. The results indicate a lower sorptivity of slag mortars compared to that of the control although many researchers have reported an increase of porosity and water absorption [61]. This reduction can be explained by the refinement of the porous structure of the SCM slag mortars which can be caused by the formation of additional CSH resulting from pozzolanic reaction of the slag. In addition to the microstructure which becomes denser, it was observed that micro-cracks decrease and connection between paste and aggregate is enhanced [62]. Similar reactions were reported by Deboucha et al. [63]. The substitution of cement with copper slag involves a reduction in sorptivity compared to the control [64]. Özbay et al. [65] reported a decrease in the sorptivity index of concrete when higher content of slag was used. Recent studies on the effect of mineral admixtures on properties of geopolymer concrete [66] indicated that increasing the replacement ratio of slag was seen to lower percentage of initial and final water absorption.

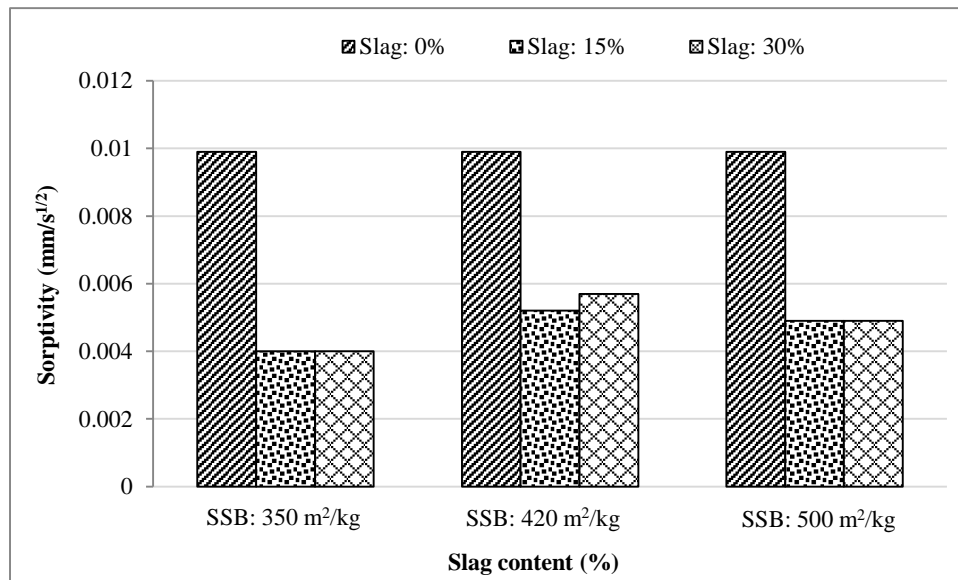


Figure 20. Effect of slag on sorptivity of SCM

3.8. Influence of Slag Fineness on Capillary Water Absorption

The effect of the fineness of slag on the capillary water absorption of SCM is shown in Figure 21. It can be seen that the water absorption (initial and final) results were comparable with the increase of the specific surface area of slag for both substitution levels of 15 and 30%. The sorptivity, which is the slope of the initial part of the curves in Figures 17 to 19, is plotted in Figure 20 for all SCM mixes. It can be seen that neither the increase in slag fineness nor the substitution levels have a significant effect on the sorptivity.

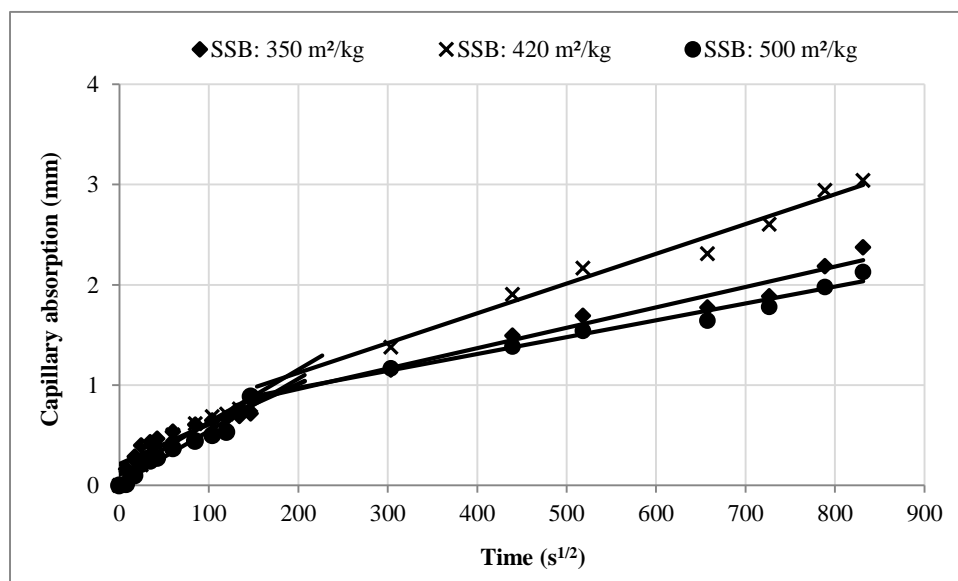


Figure 21. Effect of slag fineness on capillary absorption of SCM (15% slag)

Figure 22 presents the correlation between sorptivity and compressive strength of SCM with slag at 90 days of curing. It can be seen that, there is a good linear correlation (R^2 is more than 0.8) between the sorptivity and compressive strength values of SCM, regardless of the content and fineness of slag. The relationship shows an increase in compressive strength with decreasing sorptivity. It has been reported that incorporating micro-fine and ultra-fine slag in concrete leads to a better microstructure and thus a lower sorptivity and water absorption of concrete [17, 44].

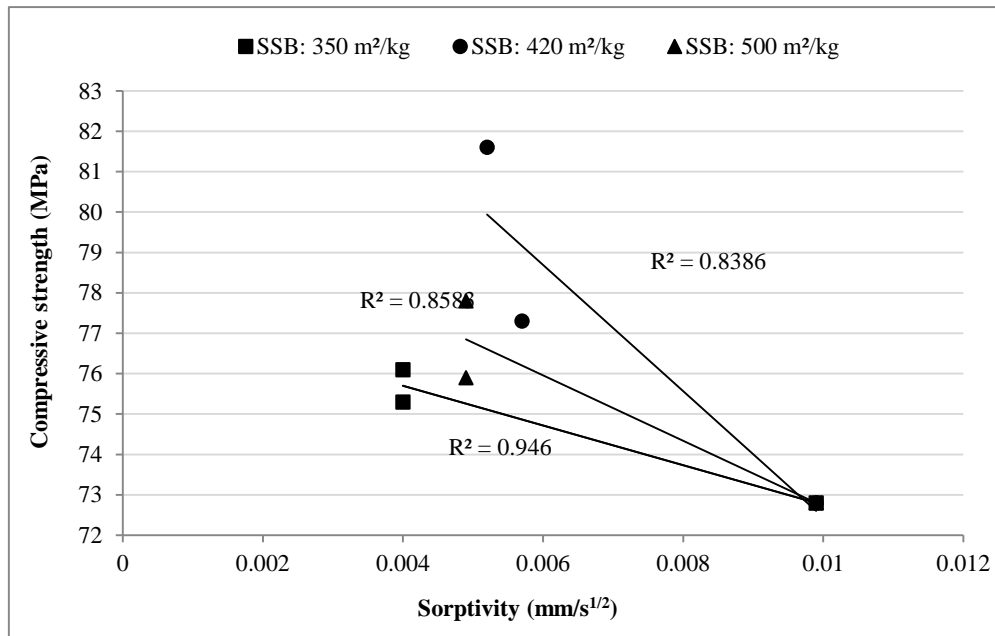


Figure 22. Relation between compressive strength and sorptivity in SCM with slag

4. Conclusions

This study examined the effect of substitution level and fineness of slag on fresh properties, compressive strength, total and autogenous shrinkage and capillary water absorption of SCM. The following conclusions can be drawn:

- The incorporation of slag in SCM mixes provides better workability compared to that of the control. The increase in slag fineness also improves the workability of SCM. For substitution of 30%, increasing specific surface area of slag from 350 to 420 or 500 m²/kg caused an increase of slump flow of 2.81 and 6.45%, respectively.
- Increasing replacement level of slag decreased the viscosity and yield stress of SCM mixes. The effect of fineness of slag is more significant. The plastic viscosity and yield stress were found to be lower for higher fineness of slag 420 or 500 m²/kg compared to those with a fineness of 350 m²/kg.
- Incorporating slag reduces the compressive strength at early age. The addition of slag in SCM mixes had a positive effect on the long-term compressive strength. At later ages, SCMs with higher slag fineness (420 and 500 m²/kg) tend to have higher compressive strengths for substitution of 15%. However, for 30% replacement, the compressive strengths of mortars are similar regardless of the slag fineness.
- Replacing cement with 15 and 30% slag in SCM mixes reduces the total (drying and autogenous shrinkage) shrinkage at all ages. For a fineness of 350 m²/kg, the decrease in later age shrinkage for mortar with 15 and 30% slag is about 10 and 20%, respectively compared to the control mortar.
- Incorporating slag in mortar mixes does not have a significant effect on the evolution of autogenous shrinkage at early age regardless of the fineness of slag. After about 28 days, the pozzolanic effect of slag begins to take effect causing a higher autogenous shrinkage. This effect is much more observed for finenesses of 420 and 500 m²/kg at 30% slag replacement. For specific surface area of 500 m²/kg, the increase is about 25 and 34% when cement is substituted by 15 and 30% slag, respectively.
- The capillary water absorption decreased with the increase in slag content regardless of the fineness of the slag. Increasing specific surface area of slag at 15% and 30% slag replacement does not affect the water absorption of mortars.

5. Declarations

5.1. Author Contributions

Conceptualization, B.M. and S.K.; methodology, B.M. and S.K.; validation, B.M., J.K., E.K. and S.K.; formal analysis, B.M.; investigation, S.H.; data curation, S.H.; writing—original draft preparation, S.H.; writing—review and editing, B.M., J.K., E.K. and S.K.; supervision, B.M. and S.K.; funding acquisition, S.K.. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding and Acknowledgements

The authors thank the funding agency "Directorate-General for scientific research and technological development, Ministry of higher education and scientific research, Algiers, Algeria" for their financial support.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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