Effect of Tea Waste Particles on Chloride Ion Penetration in Cement-Based Mortars

Sadam Hussain Jakhrani[1], Shamotra[2], Arun Kumar[3], Jawad Akhter
Siddique[4] and Jabir Ali Keryio[5]

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Abstract

The durability of high-strength mortars is a critical factor in their long-term performance, especially in aggressive environments. This study evaluates the impact of different internal curing agents on the chloride-ion penetration in high-strength mortars. For this research, twelve (12) different mixes were prepared, adding tea-waste particles (as internal curing agent), perlite particles, and super-absorbent polymers (SAPs) (for comparison with tea-waste particles) as internal curing agents. The tea-waste and perlite particles were used in two different sizes and were tagged as TW30 and TW50, and P30 and P50, respectively, with 3% by vol. of the binder. The results indicated that the specimens induced with tea waste and SAP exhibited a slightly higher chloride penetration than perlite particles. The coarser particles showed higher penetration compared to finer particles. The findings suggest that the perlite particles can be effectively used as an internal curing agent in high-strength concretes combined with silica fume as supplementary material compared to tea-waste particles to resist chloride-ion penetration in high-strength mortars.

Keywords: High-strength Mortar; Internal Curing; Tea Waste Particles; Chloride Penetration

Introduction

High-strength concrete composites and ultra-high-performance concretes are the most frequently used materials in production due to their excellent durability performance (Ranjbar et al., 2018). To overcome the problems of these composites, shrinkage-reducing admixtures and internal curing agents have been recommended (Castro et al., 2011). Jakhrani et al. (Jakhrani et al., 2019) used tea waste and perlite particles as admixtures to regulate early hydration in these composites.

Internal curing attracted notable consideration by researchers and is experimentally proven to reduce or considerably lessen early-age shrinkage (Kovler & Jensen, 2007); Lura & Van Breugal, 2000; Schwesinger, 2002). It is established that internal curing (IC) can be successfully applied to obtain enhanced concrete performance with reduced cracking sensitivity. The essential purpose of adding internal curing agents (ICAs) in HSCCs was to work as water reservoirs. The internal curing agents are typically very permeable and porous; therefore, they can store extra water before adding it to the mixer (Jakhrani et al., 2019).

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[1] *The Benazir Bhutto Shaheed University of Technology and Skill Development, Khairpur Mirs, Sindh, Pakistan. Corresponding Author Email: dr.shj@bbsutsd.edu.pk*

[2] *The Benazir Bhutto Shaheed University of Technology and Skill Development, Khairpur Mirs, Pakistan. PhD Scholar, Department of Civil and Construction Engineering, Swinburne University of Technology, Melbourne, Australia.*

[3] *The Benazir Bhutto Shaheed University of Technology and Skill Development, Khairpur Mirs, Sindh, Pakistan.*

[4] *The Benazir Bhutto Shaheed University of Technology and Skill Development, Khairpur Mirs, Sindh, Pakistan.*

[5] *The Benazir Bhutto Shaheed University of Technology and Skill Development, Khairpur Mirs, Sindh, Pakistan.*

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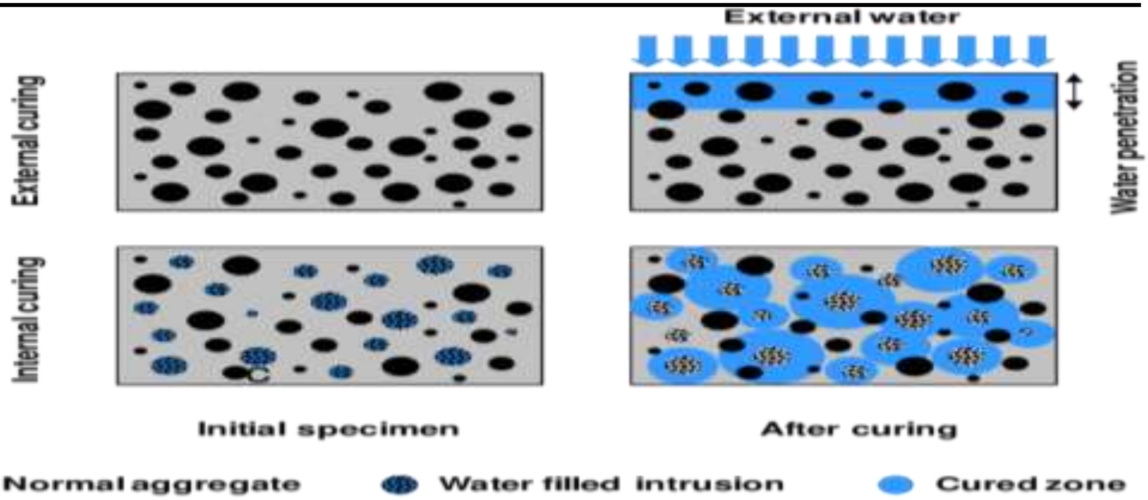
Introducing extremely porous weak materials into impermeable concretes will change concrete's mechanical and durability characteristics (Zhutovsky & Kovler, 2012). The unfavorable effect of internal curing agents on the strength of composites at an early age is reported by (Jakhrani et al., 2019). The effect of internal curing on the strength of hardened and long-term matured concrete fluctuates due to the type and amount of curing agent, content of other ingredients, and w/b ratio in the mix (Zhutovsky & Kovler, 2012). Since the efficiency of internal curing depends on the permeable nature of the cement matrix and w/b ratios (Zhutovsky et al., 2004), the w/b is reported to be the primary factor. Most researchers made HSSCs with w/b ratios ranging between 0.18-0.42 (Bentur et al., 2001). Fig.1. illustrates the mechanism of external and internal curing in cement composites.

Figure 1: Mechanism of external and internal curing



The use of agro-based waste material was also recommended by (Saman et al., 2017). Ozturk et al. (2019) used tea waste in varying quantities for manufacturing brick clay mixes to investigate the effect of tea waste on the characteristics of these bricks, and recommended that the of tea waste particles up to 10% has no adverse impact on structural properties of bricks. In addition, only minor changes on permeability were notices by addition of internal curing (Bentz, 2007). Bentz (2009) evaluated mortar specimens with 0.4 w/c and 8 % of internal curing water per mass of cement in mixes, and discovered that the chloride diffusion coefficient reduced to a value ranging 55% to 75% of that of the control specimens. The reduction in the chloride diffusion coefficient in internally cured specimens were attributed to significant reduction in the volume fraction of the percolated paste of the interfacial transition zone (ITZ) around the light-weight aggregates (LWAs), and the improved long-standing hydration. In a study, Cusson and Margeson (2010) revealed that the cement hydration elongates by internal curing. They witnessed 20 % higher calcium-silicate-hydrate (C–S–H) content after 28 days through thermo-gravimetric analysis (TGA), and revealed that’s this high content of C-S-H resulted about 10% higher compressive strengths. In the same study, water permeability and chloride permeability of high-performance concrete were found to be reduced by 20% and 25%, respectively. The effect of fractional replacement of normal weight aggregates with pre-saturated lightweight aggregates was studied. It was established that the higher replacement percentage resulted in lower chloride diffusivities by (Lam, 2005). In addition, the size of used LWA influenced the chloride diffusivity. High strength mortars were made with expanded shale aggregates (ESA) by (Bentz, 2009).

Furthermore, the studies Jakhrani et al. (2009) show that enormous quantity of tea plant are being grown in different part of the World, resulting in waste generation after consumption, making residents in surrounding unhealthy and dirty. Tea production is geographically restricted to little areas around the world and its proper growth is highly sensitive to the growing areas because of special climatic conditions for its growth. The Secretariat of the Inter-Governmental Group (IGG) on tea by Food and Agriculture Organization (FAO) reported that the selected tea markets have inelastic prices for two major types of tea i.e. black and green teas. Tea growth increased due to large production of tea by major tea producing countries throughout the world. China stands the first in the ranking of producing with about 1.9 million tons that accounts for 38% of total tea production in the world, while India stood the second in the list for tea production by producing 1.2 million tons of tea in the world as of 2013. Tea growth also increased in the two largest tea-exporting countries i.e. Kenya and Sri Lanka. Tea production in other tea-producing countries, such as, Indonesia, Bangladesh, Uganda, Malawi, Tanzania, Rwanda, Burundi, Zimbabwe and South Africa also increased. World tea production increased significantly by 6% that reached around 5070.00 thousand tons in 2013 as compared to 2006. The increase in the black tea production was found increased by 5.4%, while the increase in green tea production was about 5.1% (Chang, 2015). The tea production in the last decade i.e. from 2006 to 2013 is given in Table-1.

Table 1: World tea production 2006-2013 (thousand tons), adopted from (Chang, 2015)

Description	**2006-08**	**2009**	**2010**	**2011**	**2012**	**2013**
Far East	2892.30	3089.70	3280.30	3579.10	3753.30	3965.60
Africa	535.90	520.50	616.10	591.70	580.20	649.50
Latin America and Caribbean	97.70	89.80	107.40	107.80	98.30	95.00
Oceania	7.10	7.20	7.20	6.60	6.40	6.50
Others	358.20	332.60	353.40	341.70	346.00	347.10
Total (World)	**3891.20**	**4040.00**	**4364.70**	**4627.00**	**4784.50**	**5063.90**

Therefore, it is essential to develop methods that may work in reducing the adverse impact of this waste on environment by making it green and getting rid of this waste. Hence, to extend the use of tea waste as an admixture in the works related to construction and enhancing the approach of earlier studies made by (Jakhrani et al., 2009) this work was conducted to assess the effect of tea waste particles on chloride-ion penetration in cement-based composites.

Materials and Methods

This section comprises the information of used materials, namely ordinary Portland cement, silica fume, fine aggregate (natural river sand), internal curing agents i.e. earl-grey black tea waste, perlite and superabsorbent polymer particles, superplasticizer, and water. Table-2 to Table-5 shows the composition/properties of used materials, and Fig.2. to Fig.4. depicts the materials that were used in making samples.

Ordinary Portland Cement: Ordinary Portland Cement (OPC) was used as a primary binder for all types of mortar specimens throughout the research work. The used OPC confirmed to ASTM C150 [18] with a specific gravity of 3.15 g/cm^3 and Blaine fineness of *325 m^2/kg.*

Silica fume: Silica fume (SF) was used as secondary binder. It was used to compensate the physical, microstructural and durability related properties.

Fine Aggregate: The river sand was used in all mortar specimens. The sand particles were first sieved before utilization. The particles were passed through 4# and retained on 200# ASTM sieve.

Internal Curing Agents: Three different types of curing admixtures / agents were used in this work. The use of tea waste particles as an internal curing admixture / gent was the sole purpose of this work, though the other two curing agents i.e. perlite and superabsorbent polymers were added to compare their efficiency with tea waste particles.

Tea waste: Tea waste particles were used as primary internal curing agent in mortar specimens. After collecting the TW particles, they were initially air and sun dried for 24 hours. Then, one kilogram (kg) of dried particles were washed with tap water for thirty (30) times. After that, these washed particles were boiled in boiling water again for thirty (30) minutes. The washing and boiling processes were carried out to have an approach for removing the impurities and leftover coloring agents from the waste particles. After boiling, the particles were put in a cloth piece by pressing the particles to remove extra water. Then these particles were dried in open sun light and in room temperature to remove remaining moisture for complete drying. However, before utilization of black TW particles in mortar mixes, these were sieved into two different sizes, such as coarser and finer particles. The coarser particles were named as TW30, because the particles of this group were retained on ASTM sieve No. 30 and passed through ASTM sieve No. 4, whereas, the finer particles were labeled as TW50, because these particles were retained on ASTM sieve No. 50 and passed through ASTM sieve No. 30. After grouping of particles, these were ready to be used in the mixes.

Perlite particles: Perlite particles were used in conjunction with tea waste particles. Perlite contained high percentage of silica. Before adding these particles in different mixes, the particles were characterized in two different sizes as did for tea waste particles. The coarser particles were named as P30, while the finer particles were labeled as P50.

Super-absorbent polymer: Super-absorbent polymer (SAP) used in this study were Acrylamide-based polymer. The SAP was purchased from a Korean company named TPY. According to the specifications, the used SAP was categorized as grade MG-2600. Its color is white and featured for high strength composites. The sole purpose of using the SAP particles was to compare the results obtained from the mixes made with other two curing agents.

Superplasticizer: Liquid-type poly-carboxylate-based superplasticizer (SP) was used in this study as a chemical admixture to reduce water requirements in the mixture. The used SP was confirmed to ASTM C494 , which describes the type and properties of the used admixtures in detail.

Table 2: Chemical composition of binders

Description	**Results (wt. %)**	
Chemical composition	**OPC**	**SF**
CaO	62.00	1.50
SiO_2	20.80	88.70
Al_2O_3	6.30	1.80
Fe_2O_3	3.20	1.80
MgO	3.30	0.80
SO_3	2.20	0.10
Na_2O	0.60	0.33
LOI	1.30	1.10

Table 3: Physicochemical properties of sand

Description	**Results**
Physiochemical properties	**Sand**
Specific Gravity (g/cm^3)	2.65
Fineness Modulus	2.70
Absorption Ability (%)	4.5
Moisture Content (%)	0.2

Table 4: Chemical composition of curing agents

Description	**Unit**	**Internal curing agents [3, 4]**	
Elemental Composition		**Tea Waste Particles**	**Perlite particles**
Carbon	mass %	49.34	-
Oxygen	mass %	39.60	47.50
Nitrogen	mass %	7.89	-
Calcium	mass %	1.31	0.60
Phosphorous	ppm	3802.00	-
Sulphur	ppm	3443.00	-
Potassium	ppm	2829.00	-
Silicon	mass %	0.202	33.80
Iron	ppm	1564.00	-

Table 5: Physicochemical pproperties of curing agents

Physical Properties	**Unit**	**Internal curing agents [3, 4]**			
		TW30	**TW50**	**P30**	**P50**
Specific Gravity	g/cm^3	0.342	0.465	0.345	0.650
Absorption Ability	%	215	110	75.0	47.0
Moisture Content	%	3.5	2.1	2.1	1.5
BJH adsorption cumulative surface area	(cm^2/g)	1.307	1.773	0.832	1.107
BJH adsorption cumulative pore volume	(cm^2/g)	0.000819	0.001055	0.00694	0.00376

Figure 2: Pictorial view of OPC particles (left), and SF particles (middle), & fine aggregates (right)

Figure 3: Pictorial view of tea waste particles, TW30 & TW50 (left), and perlite particles P30 & P50 (right)

Figure 4: Pictorial view of SAP particles

Mix Design

Twelve (12) different mixes were made with different mix proportions (Table-6) for the evaluation of chloride-ion penetration test after initial curing of 28 days. This proportion was based on higher contents of curing agents except control mix and mix SF-10. Among the prepared mixes, six (06) mixes are made with OPC as only primary binder, and six (06) mixes are made with partial replacement of OPC with silica fume as secondary binder. The twelve mixes included; Control Mix, OPC/TW30-3, OPC/TW50-3, OPC/P30-3, OPC/P50-3, OPC/SAP-0.3, SF-10, SF-10/TW30-3, SF-10/TW50-3, SF-10/P30-3, SF-10/P50-3 and SF-10/SAP-0.3. Furthermore, cylindrical mortar specimens were tested for the evaluation of chloride ion penetration.

Table 6: Detailed mix proportion

MIX ID	OPC Content	SF Content by wt. of OPC	B/S	TW30 % by vol. of binder	TW50 % by vol. of binder	P30 % by vol. of binder	P50 % by vol. of binder	SAP % by wt. of binder	W/B	SP/B
Control Mix	1.0	-	1.25	-	-	-	-	-	0.2	0.01
OPC/TW30-3	1.0	-	1.25	3.0	-	-	-	-	0.2	0.01
OPC/TW50-3	1.0	-	1.25	-	3.0	-	-	-	0.2	0.01
OPC/P30-3	1.0	-	1.25	-	-	3.0	-	-	0.2	0.01
OPC/P50-3	1.0	-	1.25	-	-	-	3.0	-	0.2	0.01
OPC/SAP-0.3	1.0	-	1.25	-	-	-	-	0.3	0.2	0.01
SF-10	0.9	0.1	1.25	-	-	-	-	-	0.2	0.01
SF-10/TW30-3	0.9	0.1	1.25	3.0	-	-	-	-	0.2	0.01
SF-10/TW50-3	0.9	0.1	1.25	-	3.0	-	-	-	0.2	0.01
SF-10/P30-3	0.9	0.1	1.25	-	-	3.0	-	-	0.2	0.01
SF-10/P50-3	0.9	0.1	1.25	-	-	-	3.0	-	0.2	0.01
SF10/SAP-0.3	0.9	0.1	1.25	-	-	-	-	0.3	0.2	0.01

Chloride Penetration Test

Chloride penetration test was carried out using NT BUILD 492 [19] method. The cylindrical specimens were taken out from the curing tub (after curing) and were dried for 24 hours at the room temperature. The next day, each cylindrical specimen was cut into three equal sizes of Φ100x50mm. Then, the specimens were put in a vacuum container that contained a solution of calcium hydroxide $Ca(OH)_2$. Subsequently, $Ca(OH)_2$ solution was made in a separate container (before putting the specimens) and was allowed to remain undisturbed for 3 hours. The cut specimens were allowed in the vacuum container in fully submerged condition for 18 hours under an appropriate pressure as prescribed in the standard. After 18 hours, the specimens were taken out from the vacuum container and were fixed in rubber sleeves (secured with two clamps in order to prevent leakage). Then, these specimens were put on a steel stand in a big plastic container (box) as shown in figure 5. After fitting the specimens in rubber sleeves, two different solutions, i.e. the sodium hydroxide (0.3M NaOH solution), i.e. approximately 12 gram NaOH powder in 1 liter de-ionized water) and (10% NaCl solution), i.e. approximately 12 gram NaCl powder in 900 gram de-ionized water) were made separately in separate containers. The sodium hydroxide (0.3M NaOH) solution was placed on the top surface of the specimens in the rubber sleeves, whereas, 10% NaCl solution was placed in the plastic box and was allowed to contact with the sleeves/specimens from the bottom. In the meantime, an anolyte charge was passed through the (0.3M NaOH) solutions and a catholyte charge was passed through 10% NaCl solution. The test was initiated for a specific voltage adjustment and an appropriate duration for each specimen. After the designated period, the specimens were taken out from the solution and were allowed to dry for 1 hour at the room temperature. After that, they were broken into two halves with the help of a UTM machine. The broken exposed surfaces were then sprayed with a liquid silver nitrate (0.1M $AgNO_3$). After few minutes of spraying, a clear exposure layer was exposed on the surface of specimens. Then, the depths of penetrations were measured through a laboratory-based small Vernier caliper. After measuring the penetration depths, a non-steady-state migration coefficient for each specimen was calculated using the equation 1.

$$\mathrm{Dnssm} = \frac{0.0239\,(273+T)L}{(U-2)t}\left(x_d - 0.0238\sqrt{\frac{(273+T)Lx_d}{U-2}}\right) \qquad (1)$$

Where Dnssm is the non-steady-state migration coefficient (×10-12 m^2/s), T is the average value of the initial and final temperatures in anolyte solution (ºC); L is the thickness of the specimen (mm), U is the absolute value of the applied voltage (V), t is the test duration in hours (h), and the xd is the average value of the penetration depths for each mix specimen (mm).

Figure 5: Pictorial view of specimens during chloride penetration test

Results and Discussion

Chloride Penetration Resistance

The obtained results from chloride penetration test for T, U, t, L and X_d of all are given in Table-7. The results of non-steady-state migration coefficient (D_{nssm}) are depicted in Fig. 6, and the pictorial view of specimens after chloride penetration is shown in Fig. 7 and 8. The average D_{nssm} for control mix and mix SF-10 were found to be 5.99×10^{-12} m^2/s and 2.14×10^{-12} m^2/s, respectively. The higher and lower D_{nssm} values were noted for the mixes OPC/TW30-3 and SF-10/P50-3 as 6.04×10^{-12} m^2/s and 1.41×10^{-12} m^2/s, respectively. The results show that the incorporation of 3% tea-waste particles has no mush adverse impact on the permeability of chloride ions. Though the addition of tea waste particles and other curing agents with some content of silica fume performed better against the penetration of chloride as compared to the mixes made with OPC as the only binder. The addition of ICAs along with silica fume particles is suitable and can be used without any harm. It was presumed that the available extra moisture in fine pores of curing agents released the water for formation of more hydration products. Similar to the outcomes of this research, Cordeiro et al. [20], and Qudoos et al. [21] found reduction in the penetration of chloride ions in concretes that were made with wheat straw ash (WSA) and silica fume (SF). They attributed the reduction to pore refinement of specimens to form a denser structure in the presence of wheat straw ash and silica fume particles.

Table 7: Chloride penetration depth obtained results

Mix ID	Avg. Initial and Final Temp. (C)	Absolute applied voltage (volt)	Test duration (hour)	Thickness of specimen (mm)	Average penetration depths (mm)	Non-steady-state migration coefficient (×10^{-12} m^2/s),
	T	**U**	**t**	**L**	**X_d**	**D_{nssm}**
Control Mix	23	20	24	50	9	5.99
OPC/TW30-3	23	20	24	50	9.5	6.04
OPC/TW50-3	23	20	24	50	8.505	5.32
OPC/P30-3	23	25	24	50	8.665	4.396
OPC/P50-3	23	30	24	50	8.49	3.62
OPC/SAP-0.3	23	30	24	50	8.89	3.81
SF-10	23	60	96	50	36.2	2.14
SF-10/TW30-3	23	60	96	50	38.15	2.27
SF-10/TW50-3	23	60	96	50	29.77	1.76
SF-10/P30-3	23	60	96	50	28.16	1.66
SF-10/P50-3	23	60	96	50	24.13	1.41
SF-10/SAP-0.3	23	60	96	50	38.76	2.31

Figure 6: Chloride penetration depths (D_{nssm}) of mixes made with OPC as only binder

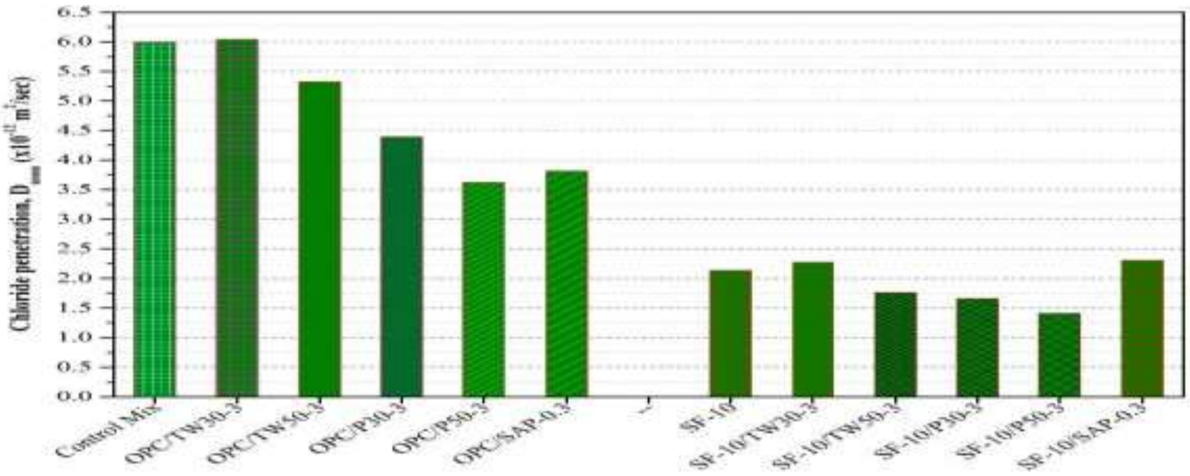


Figure 7: Chloride penetration depths of mix (a) Control mix, (b) OPC/TW30-3 and (c) OPC/TW50-3

Figure 8: Chloride penetration depths of mix (a) OPC/P30-3, (b) OPC/P50-3 and (c) OPC/SAP-3

Conclusion

From the obtained outcomes, it can be concluded that the;

- Penetration of chloride ions in presence of finer tea-waste particles had no much adverse impact though it was slightly higher than that of control mix.
- The finer tea-waste particles had a lower penetration rate of chloride ions I the specimens than the coarser particles.
- Perlite particles and superabsorbent polymers have also shown better results against resistance to penetration of chloride ions than tea-waste particles.
- In addition, the incorporation of silica fume up to 10% (by weight) had lowered the penetration rate of chloride ions in the specimens.
  Thus it is recommended that the; the replacing cement of cement has
- The addition of finer internal curing agents with a slight amount may not have any adverse impact on the chloride ion penetration into mortars in presence of silica fume than only OPC as primary binder.

References

- ASTM, B. (2012). 150/B 150M—12; Standard Specification for Aluminum Bronze Rod, Bar, and Shapes. *ASTM International: Conshohocken, PA, USA.*
- Bentur, A., Igarashi, S. I., & Kovler, K. (2001). Prevention of autogenous shrinkage in high-strength concrete by internal curing using wet lightweight aggregates. *Cement and concrete research*, *31*(11), 1587-1591.

- Bentz, D. P. (2007). Internal curing of high-performance blended cement mortars. *Materials Journal*, *104*(4), 408-414.
- Bentz, D. P. (2009). Influence of internal curing using lightweight aggregates on interfacial transition zone percolation and chloride ingress in mortars. *Cement and concrete composites*, *31*(5), 285-289.
- Castro, J., Keiser, L., Golias, M., & Weiss, J. (2011). Absorption and desorption properties of fine lightweight aggregate for application to internally cured concrete mixtures. *Cement and Concrete composites*, *33*(10), 1001-1008.
- Chang, K. (2015). World tea production and trade: Current and future development. *Food and Agriculture Organization of the United Nations, Rome*, 3-4.
- Cordeiro, G. C., Toledo Filho, R. D., & de Moraes Rego Fairbairn, E. (2009). Use of ultrafine rice husk ash with high-carbon content as pozzolan in high performance concrete. *Materials and structures*, *42*, 983-99.
- Cusson, D., & Margeson, J. (2010). Development of low-shrinkage high-performance concrete with improved durability. *CONSEC*, *10*, 8.
- Jakhrani, S. H., Kim, H. G., Jeon, I. K., & Ryou, J. S. (2019). Effect of saturated tea waste and perlite particles on early age hydration of high-strength cement mortars. *Materials*, *12*(14), 2269.
- Jakhrani, S. H., Ryou, J. S., Jeon, I. K., Woo, B. H., & Kim, H. G. (2019). Prevention of autogenous shrinkage in high-strength mortars with saturated tea waste particles. *Materials*, *12*(17), 2654.
- Kovler, K., & Jensen, O. M. (2007). Internal curing of concrete, state-of-the-art Report of RILEM Technical Committee 196-ICC. *Rilem Report*, *41*.
- Lam, H. (2005). Effects of internal curing methods on restrained shrinkage and permeability.
- Lura, P., & Van Breugel, K. (2000). Moisture exchange as a basic phenomenon to understand volume changes of lightweight aggregate concrete at early age. In *International RILEM workshop on shrinkage of concrete* (pp. 1-14). RILEM publications.
- Noordic cooperation, (1999). Concrete, mortar and cement-based repair materials: chloride migration coefficient from non-steady-state migration experiments.
- Ozturk, S., Sutcu, M., Erdogmus, E., & Gencel, O. (2019). Influence of tea waste concentration in the physical, mechanical and thermal properties of brick clay mixtures. *Construction and building materials*, *217*, 592-599.
- Qudoos, A., Kim, H. G., & Ryou, J. S. (2018). Effect of mechanical processing on the pozzolanic efficiency and the microstructure development of wheat straw ash blended cement composites. *Construction and Building Materials*, *193*, 481-490.
- Ranjbar, N., Mehrali, M., Maheri, M. R., & Mehrali, M. (2017). Hot-pressed geopolymer. *Cement and Concrete Research*, *100*, 14-22.
- Saman, N. S. M., Deraman, R., & Hamzah, M. H. (2017, December). Development of low thermal conductivity brick using rice husk, corn cob and waste tea in clay brick manufacturing. In *AIP Conference Proceedings* (Vol. 1901, No. 1). AIP Publishing.
- Schwesinger, P. (2002). Reducing Shrinkage in HPC by International Curing Using Pre Soaked LWA. *Control of Cracking in Early Age Concrete*, 333-338.
- Zhutovsky, S., & Kovler, K. (2012). Effect of internal curing on durability-related properties of high performance concrete. *Cement and concrete research*, *42*(1), 20-26.
- Zhutovsky, S., Kovler, K., & Bentur, A. (2004). Influence of cement paste matrix properties on the autogenous curing of high-performance concrete. *Cement and Concrete Composites*, *26*(5), 499-507.