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EFFECT OF MINERAL ADMIXTURE ON PLASTIC SHRINKAGE CRACKING IN CONCRETE- A REVIEW

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Abstract - *Plastic shrinkage cracking is a serious issue in fresh concrete which may affect the long-term durability, serviceability and strength of concrete. However, concrete design mainly focuses on environmental safety and economy while other parameters of concrete are often ignored. Very limited studies are available on the plastic shrinkage in blended concrete. A detailed review of the effect of mineral admixture on plastic shrinkage cracking in concrete based on the available studies is presented in this paper. This literature includes the comparison of methods to evaluate the plastic shrinkage cracking, different crack measuring techniques and influence on various types of mineral admixture and its dosages on plastic shrinkage cracking in concrete. Data including the type and size of specimens, the water-binder ratios used in different studies were analysed. Studies show that partial replacement of Ordinary Portland Cement (OPC) by mineral admixtures result in an increase in plastic shrinkage cracking in concrete. The crack length, average crack width and total crack area increase with the increase in dosage of mineral admixtures. However, there is still a need for a detailed study on the influence of mineral admixture on both the fresh and hardened properties of concrete.*

Key Words: Mineral admixture, Plastic shrinkage cracking, OPC, Total Crack Area

1.INTRODUCTION

In recent year, concrete has been one of the most widely used construction material worldwide because, it has many advantages like durability, strength, and economic efficiency. However, these properties are affected by environmental conditions, proportions of ingredients, admixtures etc. One of the most common problems in fresh concrete is "Plastic shrinkage". Plastic shrinkage means the shrinkage of concrete occurring in the first 24h after batching, caused by external drying and cement hydration effect(Kai et al. 2017). According to ACI Committee 305, this occurs mainly because of the loss of water by evaporation from the surface of the concrete(Almusallam, Maslehuddin, and Khan 1998). If the evaporation rate exceeds the bleeding water rising, it will result in plastic shrinkage cracking. In its plastic state, concrete undergo volume change that strongly influences the properties of hardened material. This volume change results in both plastic settlement and plastic shrinkage. There are mainly two different types of volume change that occurred in concrete in its fresh state. First, while the settlement of solid particles, bleeding water begins to rise to the surface results in plastic settlement. Secondly, the bleeding water layer gradually starts to evaporate result in plastic shrinkage deformation. It will result in the development of capillary pressure which helps to contract the plastic materials and if a critical limit is reached, cracks may start to form(Bertelsen, Ottosen, and Fischer 2020).

The cracks are mainly seen on horizontal surfaces. Plastic shrinkage cracking generally occurs in exposed surfaces due to more drying which in turn undergo plastic deformation(Matalkah, Jaradat, and Soroushian 2019). It is also seen in large surface area to volume ratios such as parking slabs, bridge decks, tunnel lining and industrial floors(Bertelsen, Ottosen, and Fischer 2020).

The formation of cracks mainly depends on the parameters like ambient temperature, relative humidity, wind velocity, concrete temperature and bleeding characteristics of concrete. From a material point of view, mix design, binder properties, higher binder content, low water to cement ratios and use of mineral admixtures will lead to plastic shrinkage cracking(Kai et al. 2017). Almost straight plastic shrinkage cracks are formed without any definite pattern. They have a varying length from several millimetres to few metres. The cracks not only affect the aesthetic nature of concrete but also affect the durability, strength and serviceability of the structure. Cracks permit the moisture entered into the concrete results in corrosion of reinforcement. This review only reports the effect of mineral admixture on the plastic shrinkage cracking of concrete.

2. RESEARCH OBJECTIVE AND OUTLINE

This study aims to review the existing literature on experimental testing of the effect of mineral admixture on plastic shrinkage cracking of concrete. This literature describes different types of mineral admixtures with varying dosages and experimental test methods. The properties of mineral admixtures include material composition and physical properties.

3.MATERIAL AND METHODS

3.1 MINERAL ADMIXTURES

Mineral admixtures refer to the finely divided material which is added to obtain the specific engineering properties of cement mortar and concrete(Lohtia and Joshi, n.d.). These are also used to improve the economical benefits and environmental safety. Most of the mineral admixtures are pozzolanic materials. These are abundantly available and cheaper. In past decades, natural admixtures such as volcanic earth, clays, shales etc are used in building structures(Lohtia and Joshi, n.d.). However, in recent years most of the industrial waste by-products are used as mineral admixtures. Commonly used mineral admixtures are fly ash, ground granulated blast furnace slag, silica fume, metakaolin etc.

The mineral admixtures are either used in blended form or replacing the ordinary cement. The utilisation of these materials will result in the conservation of energy and natural resources. It also helps to reduce the carbon footprints. At the same time, it will adversely affect the concrete, such as retarding the setting time, slower the early strength gain and formation of plastic shrinkage cracks(Sirajuddin 2018). The plastic shrinkage occurs when the fineness of mineral admixture is lower than that of ordinary cement. Therefore it is important to study the effect of mineral admixture on adding to concrete.

Various mineral admixtures with different properties have been studied to evaluate the effect of mineral admixture on plastic shrinkage cracking on concrete. The chemical compositions of mineral admixture investigated in the studies included in this review are shown in Table 1. Most of the study investigated the effect of Fly Ash, GGBS and Silica Fume. The different dosages are studied in some journals(Al-amoudi, Abiola, and Maslehuddin 2006)(Al-amoudi, Maslehuddin, and Abiola 2004).

Table -1: Details of Chemical Composition of Mineral Admixture

Reference	Material	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O
(Ma, Zhao, and Gong 2018)	Fly Ash	59.33	3.16	22.27	9.07	1.38	0.16	0.79
	Slag	33.51	40.70	13.44	-	8.49	-	-
(Sirajuddin 2018)	GGBS	32.38	31.46	21.06	1.87	8.57	0.36	0.88
	Fly Ash	59.32	1.28	29.95	4.32	0.61	0.16	1.44
(Yazıcı 2017)	Silica Fume	92.26	0.49	0.89	1.97	0.96	0.42	1.31
	GGBFS	39.82	36.61	9.36	0.90	6.38	-	-
	Fly Ash	47.15	20.41	20.42	4.15	1.51	0.59	1.36
(Yoo et al. 2018)	GGBFS	32.20	45.1	14.2	0.42	2.95	-	-

3.2 MATERIAL COMPOSITION

Besides the physical properties of material and environmental conditions, material composition and matrix are also highly relevant in cracking. Since plastic shrinkage occurs in paste, the high content of paste in the material matrix will enhance the plastic shrinkage deformations. The addition of binder material such as fly ash and GGBS with varying proportions also influences the plastic shrinkage cracking. The material composition and details of specimens are shown in Table 2. The table provides the data about the size of the specimen used in several studies and the types of materials added to the concrete. It is noted superplasticizer used as an additive in most of the studies.

Table -2: Details of Material composition and Specimen

Reference	Type	Water/ Binder	Binder Type	Additives
("Concreep 10 1157" 2014)	Concrete (70x70x280)	0.368	OPC MK FA GGBS	SP
(Al-amoudi, Abiola, and Maslehuddin 2006)	Concrete (100x100x0.3cm)	0.50	OPC SF	SP
(Al-amoudi, Maslehuddin, and Abiola 2004)	Concrete (100x100x0.3cm	0.45	OPC SF	SP
(Almusallam, Maslehuddin, and Khan 1998)	Concrete (450x450x20mm)	0.40 0.50 0.65	OPC	SP
(Kai et al. 2017)	Concrete (100x100x500mm)	0.35 0.40	OPC Blended Cement	SP
(Leemann, Nygaard, and Lura 2014)	Concrete (355x560x100mm)	0.44	OPC	SP SRA Accelerators Retarders
(Ma, Zhao, and Gong 2018)	Concrete (600x600x63mm)	0.25 0.30 0.35 0.40	OPC FA GGBS	SP
(Matalkah, Jaradat, and Soroushian 2019)	Concrete (355x560x100mm)	0.45 0.55	OPC Blended Cement	
(Sirajuddin 2018)	Concrete (355x560x100mm)	0.55	OPC GGBS FA	SP
(Yazıcı 2017)	Concrete (25x25x290mm)		OPC GGBS FA SF	sp
(Yoo et al. 2018)	Concrete (400X100X100mm)	0.20 0.23	OPC GGBS	SP

3.3 METHODS

Experimental test Methods for Crack Measurement

Test methods intended for studying the plastic shrinkage cracking in concrete presents various mineral admixtures and the measurement of cracking. Some of the techniques for experimental testing of crack presented in the literature include:

- ASTM C1579 Standard using slab specimen under specified environmental conditions.
- Slab or prism-like specimen under restrained edge condition
- Specially designed device

The above-mentioned methods provide a broad range of crack patterns due to different conditions but results are obtained with a different interpretation. All the test methods are useful for evaluating the crack. Table 3 shows different crack measurement methods.

Table -3: Details of the experimental test setups and Crack Measurement Methods

Ref.	Specimen Size	Crack Measuring
(“Concreep 10 1157” 2014)	Concrete (70x70x280)	Using LVDT Sensors
(Al-amoudi, Abiola, and Maslehuddin 2006)	Concrete (100x100x0.3cm)	Measuring movement of embedded aluminium studs
(Al-amoudi, Maslehuddin, and Abiola 2004)	Concrete (100x100x0.3cm)	Visual Inspection by measuring crack length and avg. Crack width
(Almusallam, Maslehuddin, and Khan 1998)	Concrete 450x450x20 mm	Plastic shrinkage cracking was monitored by noting the time to initiation of cracks and the total crack area
(Kai et al. 2017)	Concrete (100x100x500mm)	Crack initiation was determined visually by inspecting specimen surfaces every 30 min. After 6 h, maximum and mean cracking widths were visually measured using a microscope. The length and the average width of cracks recorded and expressed as total cracked area
(Leemann, Nygaard, and Lura 2014)	Concrete (355x560x100mm)	The time of cracking is measured by visual inspection.
(Ma, Zhao, and Gong 2018)	Concrete (600x600x63mm)	the cracking initiation time of each specimen was determined visually by inspecting the specimen and the maximum width was dealt with using a microscope.
(Matalkah, Jaradat, and Soroushian 2019)	Concrete (355x560x100mm)	Visual inspection by capture the pictures of the surface and digital image processing technique.
(Sirajuddin 2018)	Concrete (355x560x100mm)	the crack length was then measured by placing a thin thread along the crack and getting its length with a precision ruler. The crack width was using a hand-held graduated microscope.
(Yazıcı 2017)	Concrete (25x25x290mm)	Cracks are measured using sensors.
(Yoo et al. 2018)	Concrete (400X100X100mm)	Measurement of shrinkage strains is carried out by using sensors.

3.3.1 ASTM C1579

This test method is used to evaluate the plastic shrinkage cracking behaviour of mortar and concrete. In this method, a slab mould is prescribed to use with dimensions560x355x100mm. The restrains are provided by three triangular steel stress risers. The mould can be made from plastic, metal or plywood.

The internal stress riser and restraints shall be bent from one piece of sheet metal having a thickness of 1.2±0.05mm. The central stress riser having a height of 64±2mm serves as an initial point of cracking. There is an environmental chamber used to provide the specified ambient conditions. Advancing sensors also used to measure the temperature, wind velocity and humidity. Figure 1 shows the experimental test setup for the ASTM method.

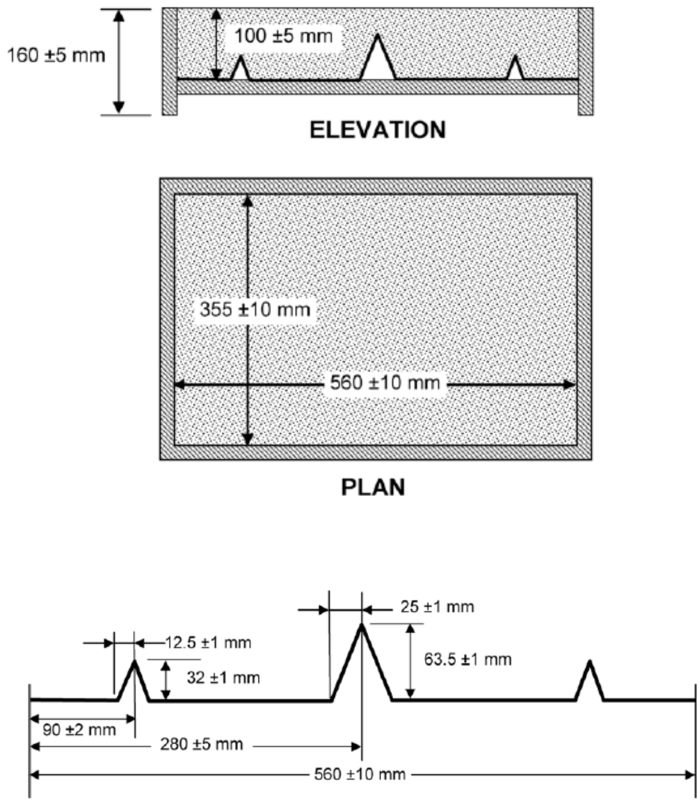
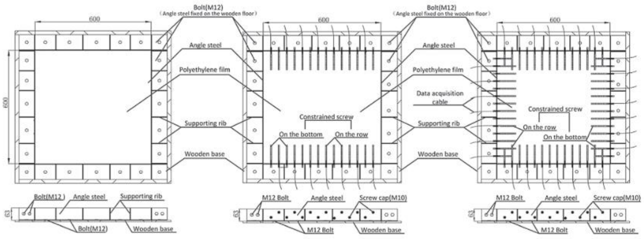


Fig -1: Experimental Test setup- ASTM C1579 Standard

3.3.2 Edge Restrained Method

In Edge Restrained method, a slab like a specimen with a size of 600x600x63mm is used. For restrained slabs, M10x100mmthreaded rods were placed along the periphery of the specimen(Ma, Zhao, and Gong 2018). Tests are done either restrained on two edges with four edges. Figure 2 shows the specimen with different edge restrained conditions. The strain gauges are bolted at the upper bolts which are connected to a computer to acquire the data.



(a)Unrestrained(b) Two-side Restrained(c)Four-side Restrained

Fig -2: Different Edge Restrained Condition

3.3.3 Specially Designed Device

D. Niknezhad et.al designed a device to measure the plastic shrinkage cracks. The device measures both horizontal deformations and vertical settlement.

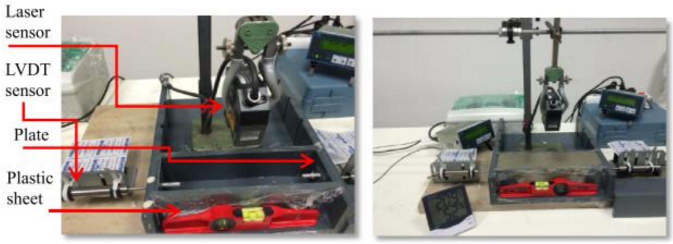


Fig -3: Specially Designed Device

Figure 3 indicates the specially designed device set up in a laboratory. The device consists of a prism-shaped mould made by using PVC with a size of 70x70x280mm. To reduce the friction between the concrete and the mould, a plastic sheet is used to cover the internal sides of the mould. The horizontal displacements are monitored by using LVDT sensors which are placed at the mid-height of the specimen. The accuracy of sensors is 2μm. To monitor the thermal effect of the specimen a thermocouple is placed at the middle region of the sample.

3.4 CRACK MEASURING TECHNIQUES

Plastic shrinkage cracking is highly irregular and varies with different techniques. D. Niknezhad et.al measures the crack by using sensors. The measurement is taken by LVDT sensors and transferred to the computer system. (Al-amoudi, Abiola, and Maslehuddin 2006) et.al measures the crack by embedding aluminium studs. These studs were embedded into the slab specimen at a depth of 10mm. The studs were placed on all four sides of the specimen at the mid-section. The movement of studs was measured by using differential transducers for 24h.

(Al-amoudi, Maslehuddin, and Abiola 2004; Almusallam, Maslehuddin, and Khan 1998) et.al was studied the plastic shrinkage cracking mechanism by visual inspection. They observed the time taken to initiate the cracks and the intensity of cracking. Both the length and average width are measured in their study. Also, the plastic shrinkage strains were observed at regular interval by using a data acquisition system. (Kai et al. 2017) et.al also used the same technique to measure the crack. The visual measurements are done by using a hand-held microscope or by using digital image processing techniques.

4.INFLUENCE OF MINERAL ADMIXTURES ON PLASTIC SHRINKAGE CRACKING

In the following sections, the effect of mineral admixture on plastic shrinkage cracking is illustrated as a function of crack length, average crack width or total crack area are included in this review. Table 2 represent the types of studied mineral admixtures and water to binder ratios.

4.1 Influence Of Ggbs

Most studies in plastic shrinkage cracking have focused on the performance of Ground Granulated Blast Furnace Slag (GGBFS). These are obtained as a by-product from both ferrous and non-ferrous metal industries in finely ground form(Lohtia and Joshi, n.d.). GGBFS is used in concrete due to their glassy nature and chemical composition. These are pozzolanic and cementitious material. The hydraulic reactivity of GGBFS depends on its chemical composition, processing conditions and particle characteristics. As per ASTM C989, GGBFS is classified into three grades namely 120,100 and 80. The particle size of GGBFS should range from 10μm to 45μm. Slag particle less than 10μm in size contribute to the early strength attainment in concrete mortar up to 28days.

From Table 1 it's evident that, GGBFS contain (33%-36%) SiO2, (37%-40%) CaO, (7%-9%) Al2O3 are the main chemicals. From the study of (Sirajuddin 2018) et.al, when GGBFS is replaced with OPC, it will result in increased crack width and total crack area. Also, the initiation of crack is 30min earlier than the control mix. The study also points out that the plastic shrinkage crack is more on the addition of GGBFS than other mineral admixture. As the dosage increases the intensity of crack also increases. As per the investigation carried out by (Matalkah, Jaradat, and Soroushian 2019), when GGBFS is used in blended cement, it significantly resist plastic shrinkage cracking as compared to OPC.

In the case of setting time, the addition of GGBFS retards the setting time significantly. (Sirajuddin 2018) states that the initial and final setting time is 40-60min more than the control mix.

4.2 Influence Of Fly Ash

Another most used mineral admixture to study the effect on plastic shrinkage cracking is Fly Ash. These are finely divided, glassy material, which is obtained by separating from flue gases during the combustion of pulverized coal in suspension fired furnace of modern thermal power plant (Lohtia and Joshi, n.d.). These are amorphous and pozzolanic, sometimes self-cementitious. The fly ash particles are spherical and are finer than ordinary Portland cement. Fly ash contains silica, alumina and oxides of calcium and iron as main chemical compounds. As per the ASTM C618 specification, there are mainly two types of fly ash, namely Class C and Class F. High Calcium fly ash is more reactive due to its large surface area.

As per the study of (Sirajuddin 2018) et.al, like GGBFS, fly ash also contributed to the crack development in the specimen. At the same replacement level, fly ash shows lesser crack than GGBFS. Moreover, when the dosage of fly ash increased from 15% to 30%, the total crack area also increases. With the addition of fly ash, the resistance to plastic shrinkage at a very early stage is much lower.

4.3 Influence Of Silica Fume

Silica fume, also called micro silica, is widely used as supplementary cementitious material in the construction industry for decades. These are obtained from the ferrosilicon or silicon metal industries as a waste by-product. SF is a finely material with spherical, glassy particle. These are 100times finer than OPC which enables the SF as a highly reactive and pozzolanic material. Many studies conducted (Al-amoudi, Abiola, and Maslehuddin 2006; Al-amoudi, Maslehuddin, and Abiola 2004; Yoo et al. 2018) to investigate the effect of SF and its dosage on plastic shrinkage cracking. (Al-amoudi, Abiola, and Maslehuddin 2006) et.al studied different types of SF with undensified and densified form and he concluded that undensified SF exhibits more shrinkage strain than the other mix. According to the study of (Al-amoudi, Maslehuddin, and Abiola 2004) et.al, the dosage of SF depends on the plastic shrinkage strain. The plastic shrinkage strain increased with an increase in dosage.

5. CONCLUSIONS

A review covering existing research on plastic shrinkage cracking in concrete was carried out to analyse the effect of the addition of mineral admixture with varying dosage. Several mineral admixtures like GGBFS, fly ash, silica fume and metakaolin are studied with different material composition and properties. Mineral admixture imparts the strength gain and durability of concrete whereas it harms concrete as well. During the first few hours immediately after the mixing process, the addition of mineral admixture results in plastic shrinkage cracking which in turn affect the durability, serviceability and strength of concrete later. Data from previous studies were collected to review the effect of a mineral admixture. Several test methods to measure plastic shrinkage cracking is also reviewed in the literature. From the literature review, it is noted that different crack evaluation techniques were used to monitor the intensity of cracking. The evaluation of plastic shrinkage cracking is done by measuring basic parameters like crack length, average crack width or total crack area. The effect mineral admixtures were studied by using their mineralogical composition and chemical properties. From the literature review the trends observed are as follows:

- From the reviewed data, it is noted that all the mineral admixtures used are finer than OPC and each exhibits almost the same chemical composition in all studies.
- The studied mineral admixtures include GGBFS, fly ash and silica fume. These admixtures have good pozzolanic and cementitious property.
- In most of the studies, it is evident that the addition of mineral admixture by replacing OPC induces plastic shrinkage cracking. Moreover, when mineral admixture added in concrete as the blended form will decrease the cracking impact.

The dosage of admixture plays an important role in the plastic shrinkage cracking of concrete. Increasing replacement level results in an increased crack area.

REFERENCES

1. Al-amoudi, Omar S Baghabra, Taofiq O Abiola, and Mohammed Maslehuddin. 2006. "Effect of Superplasticizer on Plastic Shrinkage of Plain and Silica Fume Cement Concretes" 20: 642–47.

https://doi.org/10.1016/j.conbuildmat.2005.02.024.

2. Al-amoudi, Omar S Baghabra, Mohammed Maslehuddin, and Taofiq O Abiola. 2004. "Effect of Type and Dosage of Silica Fume on Plastic Shrinkage in Concrete Exposed to Hot Weather" 18: 737–43. https://doi.org/10.1016/j.conbuildmat.2004.04.031.
3. Almusallam, A A, M Maslehuddin, and M M Khan. 1998. "Effect of Mix Proportions on Plastic Shrinkage Cracking of Concrete in Hot Environments," 353–58.
4. Bertelsen, I M G, L M Ottosen, and G Fischer. 2020. "Influence of Fibre Characteristics on Plastic Shrinkage Cracking in Cement-Based Materials : A Review." *Construction and Building Materials* 230: 116769. https://doi.org/10.1016/j.conbuildmat.2019.116769.
5. Kai, Yang, Zhong Mingquan, Magee Bryan, Yang Changhui, Wang Chong, and Zhu Xiaohong. 2017. "Investigation of Effects of Portland Cement Fineness and Alkali Content on Concrete Plastic Shrinkage Cracking." *Construction and Building Materials* 144: 279–90. https://doi.org/10.1016/j.conbuildmat.2017.03.130.
6. Leemann, Andreas, Peter Nygaard, and Pietro Lura. 2014. "Cement & Concrete Composites Impact of Admixtures on the Plastic Shrinkage Cracking of Self-Compacting Concrete." *Cement and Concrete Composites* 46: 1–7. https://doi.org/10.1016/j.cemconcomp.2013.11.002.
7. Ma, Lina, Yanhua Zhao, and Jinxin Gong. 2018. "Restrained Early-Age Shrinkage Cracking Properties of High-Performance Concrete Containing Fly Ash and Ground Granulated Blast-Furnace Slag." *Construction and Building Materials* 191: 1–12. https://doi.org/10.1016/j.conbuildmat.2018.09.154.
8. Matalkah, Faris, Yaser Jaradat, and Parviz Soroushian. 2019. "Plastic Shrinkage Cracking and Bleeding of Concrete Prepared with Alkali Activated Cement." *Heliyon*, no. December 2018: e01514. https://doi.org/10.1016/j.heliyon.2019.e01514.
9. Sirajuddin, Moghul. 2018. "Plastic Shrinkage Cracking of Concrete Incorporating Mineral Admixtures and Its Mitigation." *Materials and Structures* 51 (2): 1–10. https://doi.org/10.1617/s11527-018-1173-4.
10. Yazıcı, Halit. 2017. "Effects of Ambient Temperature and Relative Humidity on Early-Age Shrinkage of UHPC with High-Volume Mineral Admixtures" 144: 252–59. https://doi.org/10.1016/j.conbuildmat.2017.03.198.
11. Yoo, Doo-yeol, Min-jae Kim, Soonho Kim, Gum-sung Ryu, and Kyung-taek Koh. 2018. "Effects of Mix Proportion and Curing Condition on Shrinkage Behavior of HPFRCCs with Silica Fume and Blast Furnace Slag." *Construction and Building Materials* 166: 241–56. https://doi.org/10.1016/j.conbuildmat.2018.01.126.