Athens Institute for Education and Research
ATINER

ATINER's Conference Paper Series
CIV2018-2551

Evaluation of Impacts of Crystalline Silica in Concrete on Construction Safety

Kasim A. Korkmaz
Assistant Professor
Eastern Michigan University
USA

Suleiman Ashur
Professor
Eastern Michigan University
USA

An Introduction to ATINER's Conference Paper Series

Conference papers are research/policy papers written and presented by academics at one of ATINER's academic events. ATINER's association started to publish this conference paper series in 2012. All published conference papers go through an initial peer review aiming at disseminating and improving the ideas expressed in each work. Authors welcome comments.

Dr. Gregory T. Papanikos
President
Athens Institute for Education and Research

This paper should be cited as follows:

Korkmaz, K. A. and Ashur, S. (2018). **"Evaluation of Impacts of Crystalline Silica in Concrete on Construction Safety",** Athens: ATINER'S Conference Paper Series, No: **CIV2018-2551.**

Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
URL Conference Papers Series: www.atiner.gr/papers.htm

ISSN: 2241-2891
01/10/2018

Evaluation of Impacts of Crystalline Silica in Concrete on Construction Safety

Kasim A. Korkmaz
Suleiman Ashur

Abstract

Concrete is one of the most common used material in construction industry. Crystalline Silica which has fine particles is used as an additive in concrete construction. Around 2.5 Million people are dealing with concrete in manufacturing concrete blocks, concrete cutting, or other concrete related activities such as trending, drilling, cutting, or sawing concrete. The Occupational Safety and Health Administration (OSHA) has recently stated that, Crystalline Silica in concrete is hazardous to human health. The people at risk are inhaling the silica particles and may develop silicosis, lung cancer, chronic obstructive pulmonary disease, or kidney diseases. To protect people from exposure to crystalline silica, OSHA developed new respirable crystalline silica standards for construction. With this new regulation, Crystalline Silica quantities will be limited. This research work focuses on impacts of crystalline silica in concrete. Paper discusses effects of crystalline silica in the current design on the characteristics of concrete in terms of velocity and compression strength.

Keywords: Crystalline Silica, Concrete Mix Design and Characteristics, Construction Safety, Onsite crystalline silica concentration test.

Introduction

Concrete Industry supplies construction industry in a variety of spectrum for transportation, building and other construction markets. In the construction industry, concrete is one of the most important materials. Concrete as a material is needed at different purposes in construction regardless of the construction type. In Concrete production, cement is the most important ingredient. Besides the cement, a large amount of industrial byproduct material is in use. These byproducts include fly ash from the coal burning power plants, slag from the manufacture of iron and crystalline silica from the silicon/ferro-silicon metal industry (ACI 224, 2007; ACI 301-10, 2010). Crystalline silica is an essential component of materials which have an abundance of uses in industry and are a vital component in many things (OSHA, 2018a).

Occupational exposure to crystalline silica dust occurs is considered hazardous. Toxic chemicals, particulates and other harmful emissions in the workplace can cause significant hazards to workers. Identifying these potential hazards through research is very important to understand the solutions for such a problem. First, it should be understood what the optimum mixture is for concrete production and how we can reduce the effects of crystalline silica on workers. Data collection process is the key part for such investigation.

According to Occupational Safety and Health Administration (OSHA), silica exposure remains a serious threat to nearly 2 million workers, including more than 100,000 workers such as abrasive blasting, foundry work, stonecutting, rock drilling, quarry work and tunneling. The seriousness of the health hazards associated with silica exposure is demonstrated by the fatalities and disabling illnesses that continue to occur (OSHA, 2018b).

With the recent research, crystalline silica has been classified as a human lung carcinogen material. Additionally, breathing crystalline silica dust can cause silicosis, which in severe cases can be disabling, or even fatal. The respirable silica dust enters the lungs and causes various diseases including tuberculosis and silicosis and currently, there is no cure for silicosis. Workers who inhale these very small crystalline silica particles are at increased risk of developing serious silica-related diseases.

OSHA has issued two new respirable crystalline silica standards: one for construction, and the other for general industry and maritime. OSHA will begin enforcing most provisions of the standard for construction on September 23, 2017 and will begin enforcing most provisions of the standard for general industry and maritime on June 23, 2018 (OSHA, 2018a). Therefore, it is important to discuss the crystalline silica. This paper discusses the effects of crystalline silica in the current design on the characteristics of concrete. An experimental setup was established for the research. Velocity and compression strength were recorded.

Silica in Construction

In construction industry, silica is used in combination of alkali which is considered as the concentration of concrete. When alkali is in the presence of silica hydroxyl, there is an expansion occurs, that may cause crakes. This is the main reason of that alkali cement in low percentage is used in the presence of silica fume. Silica fume is a pozzolan having cement properties. Silica fume acts as if it were cement because there are small particles, having silicon dioxide. Surface area can make the admixture active pozzolan if the contact area is bigger. If concrete has silica fume and water, the outcome of the concrete becomes resistant to cracks and that may cause penetration by chloride ions (Slicafume, 2018).

When concrete has silica fume the strength is increased. Since silica fume is resistant to corrosion, concrete with silica fume is used in highway constructions specially, bridges and for rehabilitating old structures. Silica fume molecules have the ability to combine with calcium hydroxide, which increases the cement's overall durability. Since silica fume's particle is extremely small that may make it fit to the voids made from the spacing between the cement particles, hence, permeability may get reduced.

About 2.3 million people is facing with respirable crystalline silica in their workplaces, including two million construction workers who drill and cut silica-containing materials such as concrete and stone, and 300,000 workers in operations such as brick manufacturing, foundries and hydraulic fracturing. Most of the employers can limit harmful dust exposure by using equipment that is widely available – even just using water to keep dust from getting into the air would be beneficial and ventilation system to get dust is also very helpful to reduce the risk (OSHA, 2016).

Material

Concrete is a mixture of Portland cement, water, and fine and coarse mineral aggregates, and sometimes various admixtures are also added in most of the cases. When all of the ingredients are mixed in the appropriate proportion, a complex chemical reaction occurs. This reaction is called as 'cement hydration', the process by concrete hardens and cures (Domone and Illston, 2010). All concrete making materials were placed inside the laboratory to prevent any change in water/cement ratio due to external weather conditions. In the present study in testings, Slag cement and fly ash were used.

Slag cement: In the past few decades, the use of slag cement in the concrete industry has rapidly increased since it has been considered an inexpensive material that enhances concrete properties. Before, slag cement was used in concrete industry in Europe. It had been found that the concrete structures made with slag cement show long-term high performance. In addition, using slag cement provides a durable concrete structure, which will reduce life-cycle cost (Slag Cement Association, 2002). Slag cement has been used either as supplementary material added with the concrete mix or as a mineral admixture blended with the Portland cement during its production. Slag cement consists of silicates, aluminosilicates, and calcium-alumina-silicates (FHWA Research and Technology, 2016; Lewis, 1981).

Fly ash: This material is a by-product that resultσ from electrical power generations. Fly ash is the residue, carried by the generated gasses away from the burning zone while the heavier unburned residue settles down in the bottom of the furnace. The lighter residue characterized with cementitious properties is used with concrete. For most of the cases, the fly ash contains varying percentages of calcium and amorphous alumino-silicate (Thomas, 2007).

Methodology

Materials generally contain crystalline silica which is not hazardous unless they are disturbed, generating small-sized particles that can get in people's lungs. For example, in construction industry and in various applications of silica, blasting, cutting, chipping, drilling and grinding materials that contain silica can result in silica dust that is hazardous for construction workers and others to get breath. In Portland cement production, as a result of hydration is thermodynamically stable. Stability comes with high temperature as well. High temperature creates a stable environment and therefore, a formation turn out a chemical reaction with high demand reactive material.

Hydration at high temperatures leads to the formation of highly crystalline silicate hydrates with more Ca/Si ratio in the reactive material (Alp and Akin, 2013; Bouzoubaa and Foo, 2005). Type I portland cements contain less than 0.1% crystalline silica by weight. In concrete, slag cement has been used either as supplementary material added with the concrete mix or as a mineral admixture blended with the Portland cement during its production (ASTM 2003; 2012).

Slag cement consists of silicates, aluminosilicates, and calcium-alumina-silicates (FHWA Research and Technology, 2016). By using fly ash in the concrete mix; concrete quality has enhanced and performance has increased. Fly ash is the light unburned residue that is carried by the generated gasses away from the burning zone while the heavier unburned residue settles down in the bottom of the furnace. The lighter residue characterized with cementitious properties is used with concrete. Based on the current practices and applications in construction, Fly ash contains various percentage of calcium (Thomas, 2007; Barnett et al., 2006).

In this present paper, through using an experimental design setup, the efficiency of crystalline silica in concrete samples has been investigated. In the experiments, various concrete samples were created and used in the research. As given in Figure 1, samples were created by using different Portland cement percentages and in different mixture proportion as listed in Table 1 and Table 2. In the testing process, UPV and Compression test equipment were used to record different percentages (Qasrawi and Marie, 2003; Yang et al., 2011).

Table 1. *Prepared Sample Sets used in the Tests*

Mix 1 (Sample A)	Control mix without Slag and Fly ash
Mix 2 (Sample B)	Concrete mix with 50% slag
Mix 3 (Sample C)	Concrete mix with 25% fly ash

Figure 1. *Concrete Samples used in the Testing*

Table 2. *Mixture Proportion of the Concrete Mixes*

Mix Number	W/C	Concrete volume ft^3	Mixture proportion lb/ft^3 (kg/m^2)				
			Cement	Slag cement	Fly ash	Fine aggregate	Coarse aggregate
1	0.45	1	21.43 (343)	0	0	42.85 (686)	85.72 (1,373)
2	0.45	1	10.72 (171.71)	10.72 (171.71)	0	42.85 (686)	85.72 (1,373)
3	0.45	1	16.1 (258)	0	5.36 (85.85)	42.85 (686)	85.72 (1,373)

Experimental Testing

To determine the effectiveness of the crystalline silica on concrete samples, created samples were first put in the water for 28 days and 14 days after removed from the water, samples were investigated by using UPV test as seen in Figure 2a. Afterwards, samples were cracked by using compression equipment up to 50K loading as seen in Figure 2b. After cracking the samples, second UPV test was run. Then, the samples were put under the compression load until they got crashed as seen in Figure 2c. Crashed loads were recorded for the final stage of the research and the results were compared with each other in graphs.

Figure 2. *Testing Procedure*

(a) UPV Test (b) Small crack (c) Crash the sample

The Ultrasonic Pulse Velocity (UPV) test is a non-destructive test that is used to evaluate the quality of different materials, such as concrete, steel, or wood. Historically, in 1920, the Russian scientist Sokolov was the first to use the UPV test to determine the defects in metal. In the 1940s, the pulse technique was first used on concrete by American scientists through a mechanically generated pulse. They found that the velocity depends on the elastic properties of the concrete. Later, electro-acoustic transducers were developed by the Canadian and British, which provided more accurate data (Hannachi and Guetteche, 2014; Bungey and Millard, 1996). The UPV test is a cost effective test, which can be employed easily and rapidly (Lawson et al., 2011). Test results will be used in the contentious evaluation of the concrete structures during their service life, which minimizes possibility of deficiencies in the concrete and also understand the effect on the concrete material (Lorenzi et al., 2007).

The UPV test essentially consists of an electrical pulse generator, two transducers (transmitting transducer and receiver transducer), calibration bar, and coupling gel (Hannachi, and Guetteche, 2014; Bungey and Millard, 1996). The gel should be placed between the transducers and the contact surface because “accuracy of transit time measurement can only be assured if good acoustic coupling between the transducer face and concrete surface can be achieved” (Sutan and Meganathan, 2003). The UPV test method is based on measuring the pulse speed and the transit time inside the concrete structures. The speed of waves depends on the elastic properties of the concrete. High-frequency sound waves travel through the concrete by using a transducer, which stays in contact with one of the concrete surface. The longitudinal speed of waves depends on the density of the concrete. A higher density means a faster wave speed.

The second transducer converts the longitudinal wave into electrical signals. An electronic timing circuit assists in measuring the transit time. However, in some of the new UPV equipment, time and wave speed are measured directly (Hannachi and Guetteche, 2014; Lorenzi et al., 2007; International Atomic Energy Agency (IAEA), 2002). To perform the UPV test, there are three different methods, depending on the transducer location.

Direct method. In this method, the two transducers are placed opposing each other. It is the most common method of conducting the UPV test. Accurate data can be obtained with the direct method. This method is preferred because maximum pulse energy is transmited, and the transmit path is more clearly defined. The direct method is used when two opposite sides of a concrete structural element are accessible (Hannachi and Guetteche, 2014; Bungey and Millard, 1996).

Semi-direct method. This method is carried out by placing the transducers in a perpendiculars' sides. It is performed when not the all structure sides are visible. The transmit path and the transducers angles should not be very large.

Indirect method. In this method, two transducers are placed on the same side. Usually, this method is carried out when just one side is accessible, and it is last preferable method. Received signal amplitude may be 3% less than the direct method (Hannachi and Guetteche, 2014; Bungey and Millard, 1996). The implication of the UPV in the construction industry has many different advantages, especially, in the concrete structures. It can be used in collecting technical information related to the concrete. Lawson et al. (2011) demonstrated six benefits coming from utilizing this test:

1. Determines the quality of the concrete that had been used in the concrete structure.
2. Detects the cracks inside of the concretes' structural elements.
3. Checks the uniformity of concrete.
4. Determines the depth of surface cracks.
5. Evaluates the condition and concrete deterioration
6. Determines the strength of the concrete.

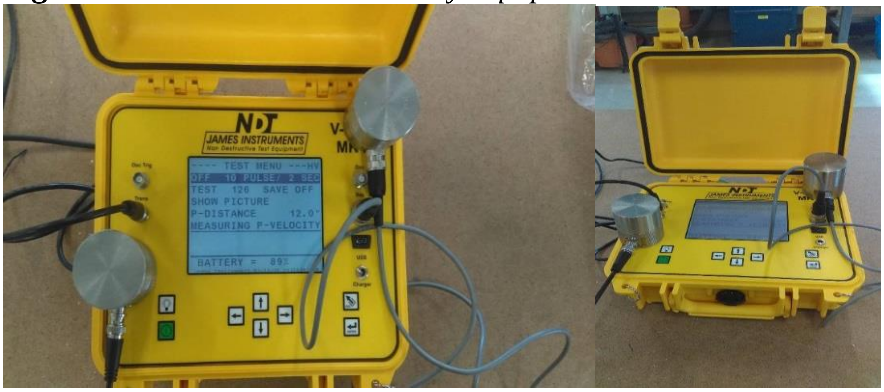
Besides, there are some other benefits of the UPV test. For instance, assessing the progress of rebar corrosion inside the concrete structures in an aggressive environment (Song and Saraswathy, 2007). In Watanabe's (2014) research, the corrosion-induced cracks were evaluated in a concrete beam in different stages by applying ultrasonic measurement. An attenuation of ultrasonic waves due to rebar corrosion was observed in the concrete (Watanabe et al., 2014). In other words, the effectiveness of using ultrasonic tests in evaluating rebar corrosion was confirmed. The pulse velocity equipment that was used in this research is V-Meter MK IV produced by James Instruments, as seen in Figure 3. The unit meets with the ASTM C-597 standard "Standard Test Method for Pulse Velocity through Concrete." This equipment is programmed with a powerful system that provides more efficient handling power to the equipment.

In addition, the UPV equipment has (320 by 240 pixels) display screen, which helps in presenting the measured values without any disruption. A 54 kHZ transducers are supplied with this equipment, which are recommended for testing concrete. The changes in the measured values for each (0.1) microsecond increments can be viewed. Concrete classification based on Ultrasonic Pulse Velocity is given in Table 3.

Table Error! No text of specified style in document.**.** *Concrete classification based on Ultrasonic Pulse Velocity (Adapted from Jaggerwal and, Bajpai, 2014)*

Ultrasonic Pulse velocity		**Concrete Quality**
m/s	**ft/s**	
> 4500	> 14763.78	Excellent
3500–4500	11482.94–14763.78	Good
3000–3500	9842.52–11482.94	Medium
2000–3000	6561.68–9842.52	Poor
< 2000	< 6561.68	Very Poor

Figure 3. *Ultrasonic Pulse Velocity Equipment*



In the present research work, used concrete compression test equipment is CM-2500 manufactured by Test Mark industries. This equipment has a loading capacity ranging between 2,500-250,000 lbs. (11-1112 kN); it meets with the ASTM C-39 and AASHTO-22 for testing concrete specimens. The machine is controlled by valve and hydraulic pump; the digital reading screen is placed on the right side of the test machine. This equipment has load accuracy ±0.5% and supplied with heavy duty pressure cylinders. The CM-2500 has an auto shutdown when the piston exceeds its maximum stroke. Besides, an electronic safety feature turns the hydraulic pump off at sample failure or when the equipment reaches its maximum capacity. Table 4 gives the details about the equipment as a technical specification.

Table Error! No text of specified style in document.**.** *Ultrasonic Pulse Velocity Equipment Technical Specification (Adapted from James Instruments)*

Frequency range:	54 kHz.
Receiver sensitivity:	250 microvolts, between 30 kHz and 100 kHz.
Receiver input impedance:	approximately 100 k Ohms.
Transit time measurement:	0.1 to 6553.5 microseconds, direct digital display.
Measurement accuracy:	0.1 microseconds.
Transmitter output:	pulse 1000/500V, 2 microseconds.
Transmitter pulse group rate:	selectable 1, 3, or 10.

Gain Selection:	1, 5, 10, 25, 50, 100, 250, 500
Battery:	14 Volt. 4-10 hours continuous use (Lithium Ion).
Display:	320 by 240; backlit for daylight use.
Storage:	1800 plus readings
Software:	Windows XP compatible.
Temperature:	32°- 122° F (0°–50° C)
Instr. Weight:	6 lbs. (2.75 Kg)
Ship Weight:	17 lbs. (7.7 Kg)
Dimensions:	4.5" x 8.5" x 10.5"
	(114.3 mm x 223.5 mm x 267 mm)

In the research, two main experimental set up were established. In these two experiments, samples were tested. Followed experimental steps are given in Table 5. Procedure is followed according to literature review (Bungey and Millard, 1996; Wang et al., 2006; Ye et al., 2001).

Table 5. *Experimental Steps*

Steps	**Action**
1	- Poured concrete into molds
2	- After waiting 48 hours, put in water for 28 days
3	- Removed from water to dry for 14 days
4	- *Run the UPV test for the first time:* calculating the time and velocity (10 test for each sample).
5	- Create small crack inside samples up to 50K loading
6	- *Run the UPV test for the second time*.
7	- Put the sample under the compression load until it crashed.

Research Findings

In the present research, samples were tested by using The Ultrasonic Pulse Velocity (UPV) test and Compression Test equipment to investigate to increase the strength of concrete. As a result, UPV test and compression test results are given in charts. Table 6 gives the UPV test results. Two different sets of UPV tests results are summarized. These results were recorded with the same order of experimental steps as given in Figure 4. Figure 5 gives the comparison of compression test results.

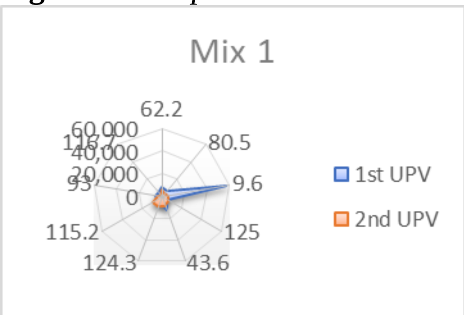
Different mixes were given and time vs velocity values are indicated in this table for two sets of UPV tests. According to the results, mix 2 values are higher comparing to mix 1 and mix 3. Mix 1 and mix 3 values are closed to each other. Mix 2 has slag in the mix. In mix 3, there is fly ash in the mixture. Both of them have similar silica percentages in the mixture. Therefore, it can be seen through this research, strength is not selective parameter for silica fume percentage in the concrete.

Conclusions

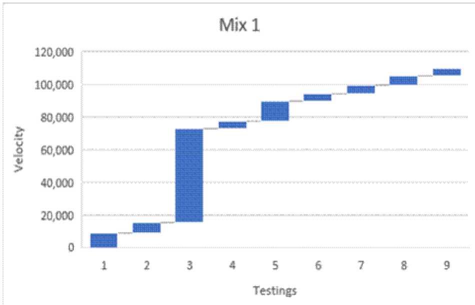
This paper investigates impacts of crystalline silica in concrete by changing concrete mixture proportions through mechanical properties. Effects of crystalline silica on different cementitious and polymeric materials, such as slag cement and fly ash have been investigated and obtained results are given. The research methodology consisted of two different experimental tests as, the ultrasonic pulse velocity (UPV) and compression test. Results were compared in the figures and tables. UPV test results are given in Figure 4. As given in Table 6 and in Figure 4. According to results from UPV and compression tests, Mix 2 has higher values. As seen in Figure 5, resistance of Mix 2 is the highest with 220,000lb ultimate loading.

Mix 3 and Mix 1 are at similar ranges. Based on these results, Mix 2 values are the ones that can be used in the mix design procedure.

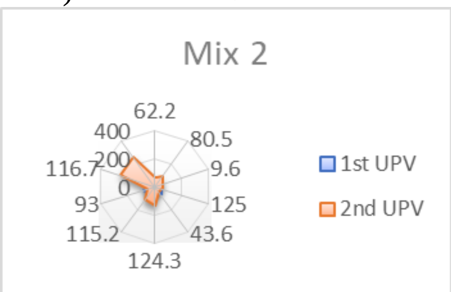
Figure 5. *Compression Test Results*



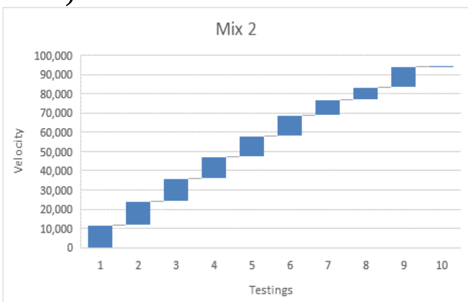
a) Mix 1 UPV Distribution



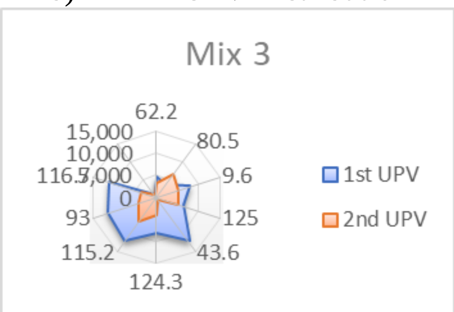
a) Mix 1 UPV Test Results



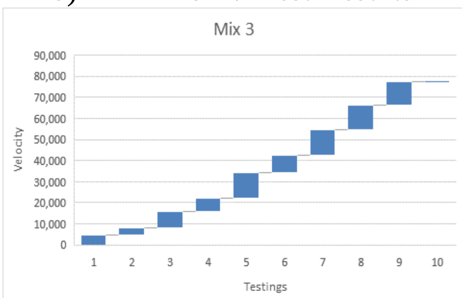
b) Mix 2 UPV Distribution



b) Mix 2 UPV Test Results



c) Mix 3 UPV Distribution



c) Mix 3 UPV Test Results

Figure 4. *UPV Test Results*

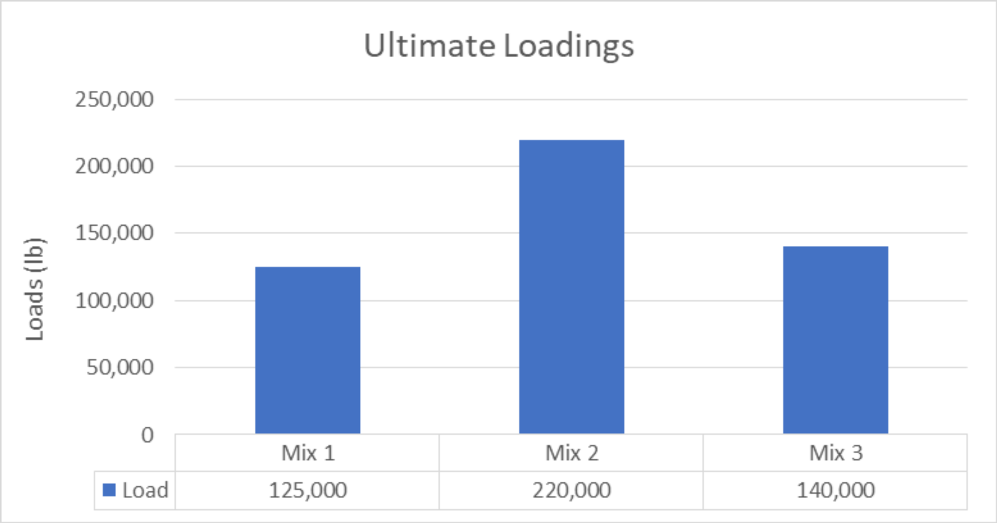


Table 6. *UPV Test Results*

	Mix 1	1st UPV	Mix 1	2nd UPV
	TIME	**VELOCITY**	**TIME**	**VELOCITY**
Mix 1	62	8,842	81	6,740
	80	6,832	137	3,994
	9	57,292	125	4,404
	125	4,416	85	6,433
	43	12,557	82	6,651
	124	4,425	66	8,271
	115	4,774	63	8,648
	93	5,926	154	3,560
	116	4,712	474	1,158
	Mix 2	**1st UPV**	**Mix 2**	**2nd UPV**
	TIME	**VELOCITY**	**TIME**	**VELOCITY**
Mix 2	46	11,752	62	8,748
	45	12,222	83	6,555
	46	11,905	63	8,703
	48	11,364	44	12,443
	52	10,577	52	10,577
	49	11,066	136	4,041
	68	8,076	119	4,591
	87	6,271	51	10,618
	51	10,597	256	2,142
	67	819	256	2,151

	Mix 3	**1st UPV**	**Mix 3**	**2nd UPV**
	TIME	**VELOCITY**	**TIME**	**VELOCITY**
Mix 3	122	4,508	176	3,125
	159	3,448	86	6,373
	69	7,902	117	4,677
	88	6,201	102	5,345
	45	12,222	922	596
	68	8,088	135	4,065
	45	12,141	83	6,611
	47	11,579	130	4,211
	48	11,247	148	3,699
	768	715	909	605

References

ACI 224 American Concrete Institute 2007. Cracking, and American Concrete Institute. Causes, evaluation, and repair of cracks in concrete structures. Farmington Hills, MI.: American Concrete Institute.

ACI 301-10 American Concrete Institute 2010. Specifications for Structural Concrete. https://www.concrete.org/store/productdetail.aspx?ItemID=30110.

ASTM 2003. American Society for Testing and Materials Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens. C 39/C 39M - 03. West Conshohocken, PA.

ASTM 2012. American Society for Testing and Materials, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. C192/C192M-12a. West Conshohocken, Pa.

Alp B. and Akin S., 2013. Utilization of Supplementary Cementitious Materials in Geothermal Well Cementing, Thirty-Eighth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 11-13, 2013.

Barnett, S. J., Soutsos, M. N., Millard, S. G., and Bungey, J. H. 2006. Strength development of mortars containing ground granulated blast-furnace slag: Effect of curing temperature and determination of apparent activation energies. Cement and Concrete Research, 36(3), 434-440.

Bouzoubaâ, N., and Foo, S. 2005. Use of Fly Ash and Slag in Concrete: A Best Practice Guide. Government of Canada Action Plan 2000 on Climate Change.

Bungey, J. H., and Millard, S. G. 1996. Testing of concrete in structures: Third Edition (3rd ed.). London; New York: Blackie Academic and Professional.

Domone P., Illston J. (2010) Construction Materials: Their Nature and Behavior 4th edition.

FHWA (Federal Highway Administration Research and Technology), 2016. User guidelines for waste and byproduct materials in pavement construction. http://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/bfs1.cfm.

FHWA (Federal Highway Administration Research and Technology), 2016 https://www.fhwa.dot.gov/.

Hannachi, S., and Guetteche, M. N. (2014) Review of the ultrasonic pulse velocity evaluating concrete compressive strength on site. http://eng-scoop.org/papers2014/IWCEA/16.SamiaHannachi.pdf.

International Atomic Energy Agency (IAEA). (2002) Guidebook on non-destructive testing of concrete structures. Vienna, Austria: Industrial Applications and Chemistry Section. http://www-pub.iaea.org/mtcd/publications/pdf/tcs-17_web.pdf.

Jaggerwal, H., and Bajpai, Y. (2014) Estimating the quality of concrete bridge girder using ultrasonic pulse velocity test. International Journal of Computational Engineering Research, 4(4), 63-69.

Lawson, I., Danso, K. A., Odoi, H. C., Adjei, C. A., Quashie, F. K., Mumuni, I. I., and Ibrahim, I. S. (2011) Non-Destructive evaluation of concrete using ultrasonic pulse velocity. Research Journal of Applied Sciences, Engineering and Technology, 3(6), 499-504.

Lewis, D. W. (1981) History of Slag Cements (pp. 1-9). National Slag Association. http://www.nationalslag.org/sites/nationalslag/files/documents/nsa_181-6_history_of_slag_cements.pdf.

Lorenzi, A., Tisbierek, F. T., and Silva, L. C. P. (2007) Ultrasonic pulse velocity análysis in concrete specimens. In IV Conferencia Panamericana de End, Buenos Aires. https://bit.ly/2NSFLX0.

OSHA 2018a. Occupational Safety and Health Administration Crystalline silica Exposure Health Hazard Information. https://bit.ly/1kCJRb8.

OSHA 2018b. Occupational Safety and Health Administration https://www.osha.gov/dsg/topics/silicacrystalline/.

OSHA, 2006. 29 CFR Parts 1910, 1915, and 1926 Assigned Protection Factors; Final Rule. https://www.osha.gov/FedReg_osha_pdf/FED20060824.pdf.

OSHA 2016. US Labor Department announces final rule to improve U.S. workers' protection from the dangers of 'respirable' silica dust. https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=news_releases&p_id=30534.

Qasrawi, H. Y., and Marie, I. A. 2003. The use of USPV to anticipate failure in concrete under compression. Cement and Concrete Research, 33 (12), 2017–2021.

Silicafume, 2018. http://www.silicafume.org/general-silicafume.html.

Slag Cement Association. (2002) Slag Cement in Concrete. http://www.slagcement.org/pdf/no1%20slag%20cement.pdf.

Song, H.-W., and Saraswathy, V. (2007) Corrosion monitoring of reinforced concrete structures - A review. International Journal of Electrochemical Science, 1-28.

Sutan, N. M., and Meganathan, M. (2003) A comparison between direct and indirect method of ultrasonic pulse velocity in detecting concrete defects, 8(5). Retrieved from http://www.ndt.net/article/v08n05/sutan/sutan.htm.

Thomas M. (2007) Optimizing the Use of Fly Ash in Concrete, Cement. https://www.cement.org/docs/default-source/fc_concrete_technology/is548-optimizing-the-use-of-fly-ash-concrete.pdf.

Wang, K., Schaefer, V. R., Kevern, J. T., and Suleiman, M. T. 2006. Development of mix proportion for functional and durable pervious concrete. In Proceedings of the 2006 NRMCA Concrete Technology Forum, Focus on Pervious Concrete.

Watanabe, T., Trang, H. T. H., Harada, K., and Hashimoto, C. (2014). Evaluation of corrosion-induced crack and rebar corrosion by ultrasonic testing. Construction and Building Materials, 67, 197-201. https://bit.ly/2xOHBxI.

Yang, Z., Hollar, J., He, X., and Shi, X. 2011, A self-healing cementitious composite using oil core/silica gel shell microcapsules. Cement and Concrete Composites, 33(4), 506-512. http://doi.org/10.1016/j.cemconcomp.2011.01.010.

Ye, G., Van Breugel, K., and Fraaij, A. L. A. 2001. Experimental study on ultrasonic pulse velocity evaluation of the microstructure: TU Delft Institutional Repository, Delft Uni. of Technology.