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Effect of Silica Fume and Coarse Aggregate type on the Mechanical Properties of Pervious Concrete

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ABSTRACT

Silica fume has long been used as a supplementary cementing material to provide a high-density, high strength, and durable building material. Silica fume has a particle size a fraction of Any conventional cement, which allows it to increase concrete strength by decreasing the Porosity especially near the aggregates surface. Because Portland Cement Pervious Concrete (PCPC) has a smaller bond area between aggregate and paste, silica fume has significant Impacts on the properties of the PCPC. The research in this paper studies the workability of a Cement paste containing silica fume in addition to analyzing the results of testing on Portland Cement Pervious Concrete mixtures that also contained silica fume. In addition to the testing of the cement paste, trials were also conducted on the Pervious concrete samples. Sample groups included mixes with river gravel and chipped Limestone as aggregate, washed and unwashed, and two different void contents. Workability Tests showed that mixtures containing a silica fume dosage rate of 5 percent or less had Comparable or slightly improved workability when compared to control groups. Workability Was found to decrease at a 7 percent dosage rate. Samples were tested for compressive Strength at 7 and 28 days and splitting tensile strength at 28 days. It was found inmost sample Groups, strength increased with dosage rates of 3 to 5 percent but often decreased when the Dosage reached 7 percent. Abrasion testing showed that both samples containing washed Aggregate and samples containing silica fume exhibited a reduced mass.

INTRODUCTION

Concrete, a widely used composite construction material, comprises of aggregates (both fine As well as coarse aggregates mixed with an appropriate binder (mostly cement) in presence of Water that hardens along with time. It is the most commonly used material for construction and is universally proven to have good performance under compression loading. Cement, as is well established by now, is one of the major components of concrete and its use produces Substantial emissions of CO2. An efficient way to lessen the utilization of cement in concrete Making is to add supplementary cementitious materials (SCM‟s) which includes pulverized Fly ash (PFA), silica fume, different types of slags like ground granulated blast furnace slag (GGBS) etc. A significant amount of research has gone into identifying the best alternatives For replacement of cement and their probable percentage replacements. However, majority of these developments have mostly been limited to replacing cement with macro to micro-fines. The use of these materials in-fact, has also led to significant enhancement in the durability and strength properties of resulting concrete, but to improve the packing density, it is Imperative to prefer materials which can fill the voids at a finer level. Nano-Silica (NS) is one of the material which has a high potential as cement replacement material and as an additive to the concrete mixture. However, commercial nano-silica is synthesized in a rather complex Way, leading to the high purity and complex procedures that, at present, does not make them Feasible for use in the construction industry. Additionally, the application of NS and its effect on concrete is not understood completely yet.

HIGH PERFORMANCE CONCRETE (HPC)

High performance concrete (HPC) is concrete that is designed to provide optimal Performance characteristics for the provided set of mixture materials, for specific exposure and usage conditions, unswerving with the cost requirement, durability and service life. The American Concrete Institute (ACI) defines HPC as "concrete meeting special performance and requirements of uniformity that cannot always be attained routinely by adopting only conventional materials and nominal mixing, placing as well as curing practices". In other Words, any concrete satisfying certain criteria for overcoming the limitation of conventional Concretes may be termed as High-Performance Concrete (HPC). The performance Characteristics includes improved workability as well as compaction without any sort of segregation, long term as well as early age strength characteristics or service life in extreme environments. It may also be said that HPC provides substantially increased resistance to the extreme environment or substantially increased capacity of structures while maintaining adequate durability as well as significantly reduced construction time. High performance concrete has only a small share in the whole of concrete production; however, it has many advantages in reasonable applications compared to standard concrete. Manufacture of such type of concretes is more complicated than production of common Concrete.

Advantages of HPC

The advantages of using high performance concretes often balance the increase in its initial Cost. The major advantages of HPC are as given below:

a) Reduces the size of structural member and leads to direct savings in volume of Concrete without the reduction in the strength and durability properties.
b) Reduces the self-weight and super imposed dead load of structural member which ultimately reduces the size of foundation, thus also saves the volume of concrete.
c) Reduces the form work area and cost by reducing the stripping time due to gain of High early strength of concrete.
d) Provides better long-term service performance under static, dynamic loading
e) Reduces the maintenance and repair costs.
f) Provides high resistance to chemical attack, freezing and thawing, and significantly Improves the durability.

Limitations of HPC:

The followings are the limitations of using HPC:

a) Manufacturing and placing of high-performance concrete has to be done carefully in Comparison to normal concrete.
b) A comprehensive quality control requirement. There is increase in cost as additional tests are required to be carried out on concrete Specifically at the delivery site. In ready mix concrete plants, some special components are required which in General may not be available.

USE OF NANO-MATERIALS IN CONCRETE

In comparison to other technologies, nanotechnology is not that well-structured and well-Defined. In general, nano-technology refers to manipulation as well as understanding of matter on nanoscale, say, from 0.1 nm to 100 nm. The importance of controlling matter at the Nanoscale is that at this scale use of different laws of quantum physics come into play. Traditional materials as in, ceramics and metals indicate radically enhanced properties as well as new functionalities. The behavior of surface dominates the bulk material behavior, and completely new realms open up for scientists and engineers alike. Attaining control of structures at the Nano scale also sometimes results in the formation of truly extraordinary materials like Carbon nanotubes, which have a tensile strength measured at100 times that of steel.

Silica Fume

Silica fume or micro-silica is a secondary product of the silicon manufacturing and silicon Alloys process in the electric-arc furnaces. Silica fumes condense from the gas blowing from a Furnace. They contain high proportion of amorphous SiO_2 in the shape of round particles with the size 0.1 – 0.2μm. Silica fume is a very highly reactive pozzolanic material, which reacts with calcium hydroxide in hydrating cement thereby forming the Calcium-Silicate- Hydrate (C-S-H) gel. Untreated micro silica is a form of very fine powder collected from dust collecting filters and it can be applied directly without any modification. However, extreme fineness and Low volume weight cause problems during the transportation process and further handling (dustiness). Content of micro silica is mostly 42 – 60%. Compact micro silica is supplied in the form of agglomerated particles, Wherein, the heavier agglomerated particles are periodically taken away and further processed For specific uses. Micro silica speeds up hydration of cement during initial stages of hydration and also enhances the encapsulation of solid particles; takes up space between cement grains and contributes to formation of denser structure; smaller air pores and also decreases the amount of water in pores in hardened concrete.

Nano silica

This material with very high specific surface and high proportion of very fine particles Consisting of nearly clean SiO_2 (99%) provides an excellent alternative to further alter the Concrete characteristics, especially for higher end uses. Properties of this material are similar to Silica fume; however, they are amplified further primarily due to higher specific surface, hence Higher reactiveness. Nano silica has a very similar effect on cement or to say the resultant Concrete, as silica fume, however, higher specific surface of nano-silica and higher content of Silicon oxide makes them more marked. Nano-silica has been found to increase the strength of Bond between aggregate and cement and forms even denser structure with even smaller pores. It Reacts with crystals of Portlandite Ca(OH)2 and forms CSH gel faster. Nano-silica has also been Found to considerably decrease the size of pores and also lowers the permeability of concrete to Water and corrosives.

Effect of Nano silica and silica fume on fresh concrete: Addition of nano silica and silica fume makes fresh concrete more cohesive thus resulting in lesser segregation. In order to maintain sufficient workability for concretes with lower water-Cement ratios, it is imperative to use hyper plasticizers or super plasticizers. As is well Established, bleeding occurs with concrete of thin consistency, higher dosage of nano silica and Silica fume in the concrete mixtures considerably decreases bleeding, whereas, on the other Hand high watered specific surface also leaves only little water for bleeding.

Effect of Nano silica and silica fume on hardened concrete: Silica fines of nano silica and silica fume are known for their capability to improve the Properties of concrete specially strength and durability due to the chemical composition as well As hydration reaction.

LITERATURE REVIEW

Numerous researchers have worked on the utilization of Silica fume in concrete. They have found that the large surface area and small particle size of these materials improved the Characteristics of the resulting materials. A brief review of the work carried out in the Subject area is presented in this section.

Mohammed et al. (2017) reported that for improving the modulus of elasticity as well as Compressive strength and minimizing the drying shrinkage in self-compacting (SC) ECC Without adversely affecting its ductility, nano-silica (NS) is included in the cementitious Composite.

Pedro et al. (2017) concluded that the development of the precast industry has given birth to The appearance of waste with great probable for recycling, gave the severe quality control of These companies and the requirement of construction/demolition of structures with growing Strength. An investigation of the mechanical behavior of high-performance concrete (HPC)Having fine as well as coarse recycled aggregates (FRA and CRA) was made. The recycled Aggregates (RA) originated from discarded precast elements having compressive strengths Of 75 Mpa and were used to substitute natural aggregates (NA) in concrete mixes. The Experimental operation also consists of three families of concrete with scope of densified Silica fume (SF) of 0%, 5% and 10%. The results observed in the compressive strength, Splitting tensile strength, modulus of elasticity, ultrasonic pulse velocity and bond strength Tests represented that it is probable to produce high-performance concrete without NA.

Mukharjee and Barai (2014) reported that investigation of the effect of partial replacement Of cement with silica fume (colloidal) on the cement mortar compressive strength. The paper Reports the results of compressive strength of samples of mortar in the mold of 70.6 mm Cube prepared with three different water cement ratios along with altering percentage of Nano- silica and 7 and 28 days of compressive strength is determined. The results of the Current study found that the addition of nano-silica improves the early strength along with Strength at 28 days of cement mortar.

OBJECTIVES OF STUDY

Keeping in mind, the gap of this research area, the objectives of the proposed work areas given below:

1) To investigate the properties of fresh concrete consisting of silica fume as Partial replacement of cement.
2) To study the strength properties of resulting hardened concrete at various curing Ages and conditions.

MATERIALS AND METHODOLOGY

MATERIAL USED AND THEIR PROPERTIES

This chapter discuss various material used for proposed work and also their Properties.

Cement

Cement is fine, grey powder. It is mixed with water and materials such as sand, Crushed stones, fine aggregates, coarse aggregates to make concrete. The cement and water Form a paste that binds the other materials together as the concrete hardens. The ordinary Cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous Materials, clay predominates and in calcareous materials, calcium carbonate predominates. Ordinary Portland cement of grade -43 conforming to Indian standard IS: 8112-1989 has been used in the present study.

The results of the various tests on cement are given in below:

S. No.	Characteristics	Values Obtained	IS :8112:1989
1.	Normal Consistency	30%	30%
2.	Initial Setting Time	1 Hour	Not to be less than 30
3.	Final Setting Time	3 Hours 40 min	Not to be greater than 600
4.	Fineness	2.5%	<10%
5.	Specific Gravity	3.14	3.14
Compressive strength (Mpa)			
1.	3 days	23.75	≥23
2.	7 days	34.10	≥33
3.	28 days	44.15	≥43

Fine Aggregates

The material which passes through BIS test sieve no. 480 is termed as fine aggregates. Usually, natural sand is used as a fine aggregate but, at places where natural sand is not available crushed stone is used as fine aggregates.

Physical Properties of Fine Aggregates

S.No.	Type	Natural Sand
1.	Specific Gravity	2.65
2.	Fineness Modulus	2.74
3.	Grading Zone	II (IS: 383 -1970)
4.	Water Absorption %	2.22
5.	Moisture Content %	0.64

Coarse Aggregates

Locally available crushed stone aggregates of size 20 mm nominal maximum size and having a specific gravity of 2.74 was used as the coarse aggregates. Physical properties of Coarse Aggregates (nominal maximum size = 20mm)

Characteristic	Result
Fineness modulus	6.88
Specific Gravity	2.74
Water Absorption (%)	0.54
Moisture Content (%)	Nil

Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very attentively. Potabale water is generally considered satisfactory. In the present investigation, tap water was used for both mixing and curing process. According to IS: 456-2000, water for concrete should be potable quality (PH – 6.8 to 8.0). Ordinary tap water, which is fit for drinking, has been used in preparing all concrete mixes and curing in this investigation.

Silica Fume

The SF used in testing was grade 920 undensified SF manufactured by Elkem. Undensified SF typically has a bulk density of between 200 and 350 kg/m^3 where densified SF is in the range of 500 to 700 kg/m^3. The SF used in this testing had a bulk density of just less than 300 kg/m^3 (18.11 lbs/ft^3).

Properties of Silica Fume

Property	**Value**
Manufacturer	Elkem
Loss On Ignition	3.41%
pH	7.66
Specific Gravity	2.2
Bulk Density (lbs/ft^3)	18.11

MIXTURE PROPORTIONS

During the phases of testing, concrete mixes were tested. The naming convention used for the PCPC mixtures is aggregate "SF dosage – aggregate type – Design Void Content." Mixtures were evaluated for washed and unwashed aggregate states since the cleanliness of aggregate has been known to affect the aggregate bond strength and workability of concrete. Typically aggregates that are especially dirty are not able to bond as securely with the cement paste and often experience durability issues. The aggregates that are not washed are denoted with a "U" preceding the aggregate name.

Aggregate Naming Convention

Mixture Name	**Mixture**
LS	Washed Limestone
ULS	Unwashed Limestone
RG	Washed River Gravel
URG	Unwashed River Gravel

Pervious Concrete Mixes

While the initial phase of testing was to investigate a PCPC mixture with 25% voids with an OPC replacement rate of 5% by weight, testing results indicated that other mixes be evaluated. Table 3.8 shows the mix design for PCPC utilizing limestone CA with a 5% SF replacement.

Table Pervious Concrete Mixes Designed for 25% Voids with Limestone

Mixture	0 - LS - 25	5 - LS - 25	0 - ULS - 25	5 - ULS - 25
W/C	0.32	0.32	0.32	0.32
PC (lb)	563	535	563	535
SF (lb)	0	28	0	28
CA (lb)	2182	2172	2182	2172
FA (lb)	164	164	164	164
AEA (oz/cwt)	1	1	1	1
HS (oz/cwt)	4	4	4	4
HRWR (oz/cwt)	5	5	5	5

Pervious Concrete Mixes Designed for 20% Voids with Washed Limestone

Mixture	0 - LS - 20	3 - LS - 20	5 - LS - 20	7 - LS - 20
W/C	0.32	0.32	0.32	0.32
PC (lb/yd^3)	601	582	570	559
SF (lb/yd^3)	0	18	30	42
CA (lb/yd^3)	2327	2321	2317	2313
FA (lb/yd^3)	175	175	174	174
AEA (oz/cwt)	1	1	1	1
HS (oz/cwt)	4	4	4	4
HRWR (oz/cwt)	5	5	5	5

Pervious Concrete Mixes Designed for 20% Voids with Unwashed Limestone

Mixture	0 - ULS - 20	3 - ULS - 20	5 - ULS - 20	7 - ULS - 20
W/C	0.32	0.32	0.32	0.32
PC (lb/yd^3)	601	582	570	559
SF (lb/yd^3)	0	18	30	42
CA (lb/yd^3)	2327	2321	2317	2313
FA (lb/yd^3)	175	175	174	174
AEA (oz/cwt)	1	1	1	1
HS (oz/cwt)	4	4	4	4
HRWR (oz/cwt)	5	5	5	5

Pervious Concrete Mixes Designed for 20% Voids with River Gravel

Mixture	0 - RG - 20	3 - RG - 20	5 - RG – 20	7 - RG – 20
W/C	0.32	0.32	0.32	0.32
PC (lb)	601	582	571	559
SF (lb)	0	18	30	42
CA (lb)	2327	2321	2318	2313
FA (lb)	175	175	175	174
AEA (oz/cwt)	1	1	1	1
HS (oz/cwt)	4	4	4	4
HRWR (oz/cwt)	5	5	5	5

Pervious Concrete Mixes Designed for 20% Voids with Unwashed River Gravel

Mixture	0 - URG - 20	3 - URG - 20	5 - URG - 20	7 - URG - 20
W/C	0.32	0.32	0.32	0.32
PC (lb)	601	582	571	559
SF (lb)	0	18	30	42
CA (lb)	2327	2321	2318	2313
FA (lb)	175	175	175	174
AEA (oz/cwt)	1	1	1	1
HS (oz/cwt)	4	4	4	4
HRWR (oz/cwt)	5	5	5	5

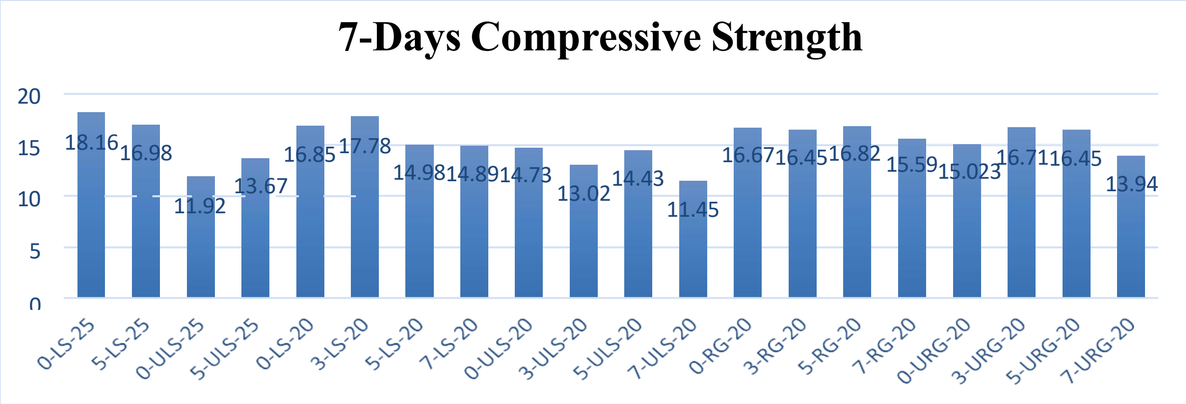
RESULTS AND DISCUSSION

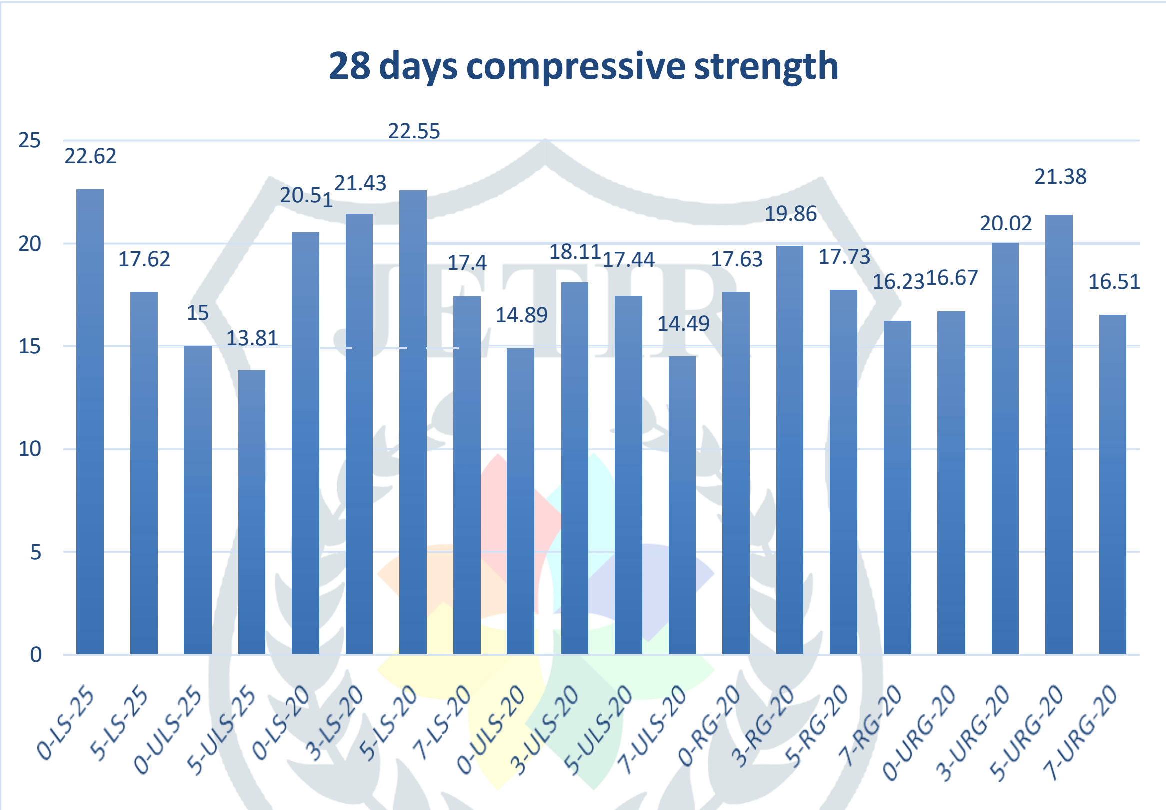
Compressive Strength Test Results

The mixtures described in previous Chapter were designed, mixed, and placed in a methodology attempting to keep a certain void content. Many PCPC studies attempt to study a variety of mixes, while keeping the compaction effort constant. To provide consistent and reliable testing results, a calibration was performed to determine the mass of PCPC that should be batched in each mold. This is done in order to achieve a specific void content and the compaction effort must be adjusted accordingly. The unit weight of the sample was taken separately according to Indian Standard to determine workability. The result of the hardened density test which was conducted in triplicate for all samples is shown in Table.

Summary of Compressive Strength

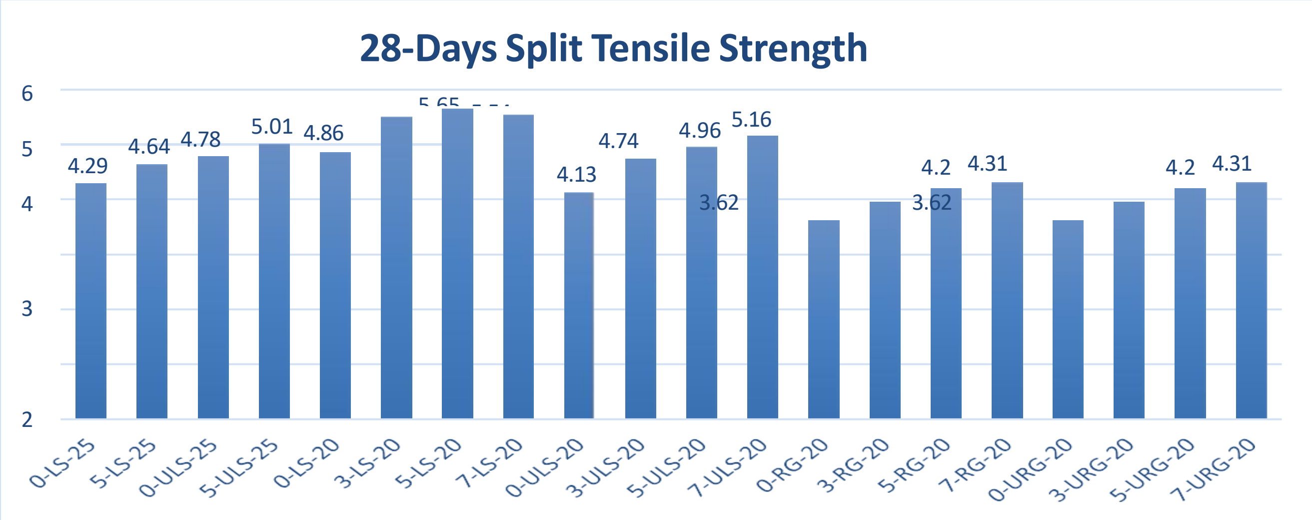
Mix Design	7-Day Compressive Strength		28-Day Compressive Strength	
	Compressive Strength (N/mm^2)	COV (%)	Compressive Strength (N/mm^2)	COV (%)
0-LS-25	18.16	3.07	22.62	1.88
5-LS-25	16.98	7.92	17.62	9.08
0-ULS-25	11.92	3.72	15.00	10.89
5-ULS-25	13.67	7.08	13.81	8.13
0-LS-20	16.85	15.38	20.51	5.44
3-LS-20	17.78	7.51	21.43	5.16
5-LS-20	14.98	6.60	22.55	0.81
7-LS-20	14.89	3.93	17.40	3.60
0-ULS-20	14.73	1.68	14.89	2.64
3-ULS-20	13.02	11.15	18.11	10.32
5-ULS-20	14.43	6.38	17.44	5.14
7-ULS-20	11.45	9.82	14.49	3.73
0-RG-20	16.67	10.12	17.63	7.97
3-RG-20	16.45	12.35	19.86	4.03
5-RG-20	16.82	6.32	17.73	1.61
7-RG-20	15.59	9.07	16.23	12.62
0-URG-20	15.02	3.39	16.67	12.92
3-URG-20	16.71	3.85	20.02	12.01
5-URG-20	16.45	6.40	21.38	2.80
7-URG-20	13.9	9.84	16.51	2.01



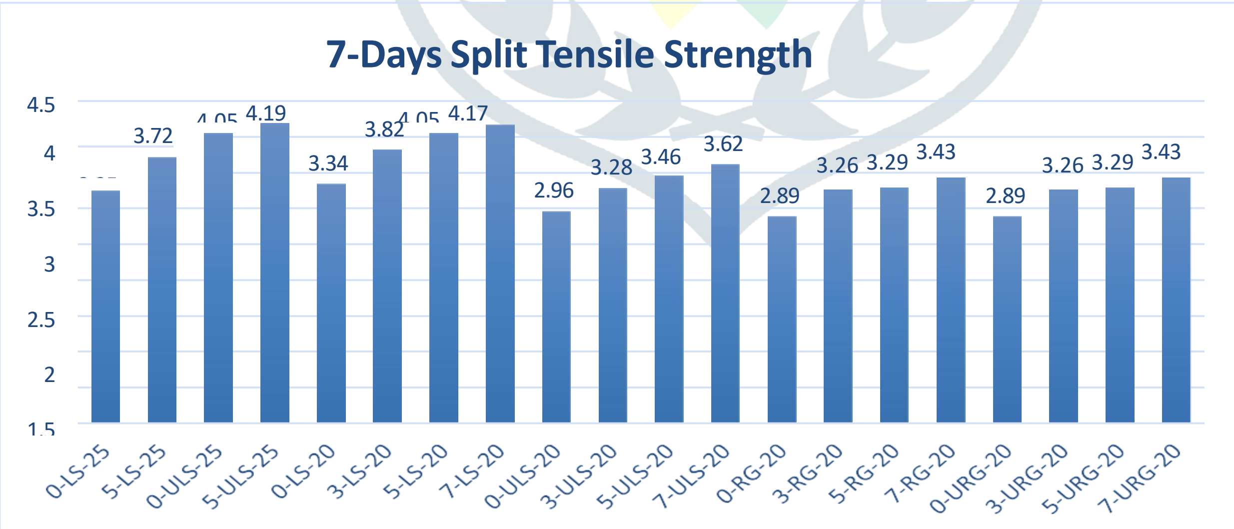


Split Tensile Strength test Results

Mix Design	7-Day Split Tensile Strength		28-Day Split Tensile Strength	
	Split Tensile Strength (N/mm^2)	COV (%)	Split Tensile Strength (N/mm^2)	COV (%)
0-LS-25	3.25	3.07	4.29	1.88
5-LS-25	3.72	7.92	4.64	9.08
0-ULS-25	4.05	3.72	4.78	10.89
5-ULS-25	4.19	7.08	5.01	8.13
0-LS-20	3.34	15.38	4.86	5.44
3-LS-20	3.82	7.51	5.50	5.16
5-LS-20	4.05	6.60	5.65	0.81
7-LS-20	4.17	3.93	5.54	3.60
	2.96	1.68	4.13	2.64



0-ULS-20				
3-ULS-20	3.28	11.15	4.74	10.32
5-ULS-20	3.46	6.38	4.96	5.14
7-ULS-20	3.62	9.82	5.16	3.73
0-RG-20	2.89	10.12	3.62	7.97
3-RG-20	3.26	12.35	3.95	4.03
5-RG-20	3.29	6.32	4.20	1.61
7-RG-20	3.43	9.07	4.31	12.62
0-URG-20	2.89	3.39	3.62	12.92
3-URG-20	3.26	3.85	3.95	12.01
5-URG-20	3.29	6.40	4.20	2.80
7-URG-20	3.43	9.84	4.31	2.01



CONCLUSION

After conducting these tests and analyzing the results, several conclusions can be made regarding the use of silica fume as a supplementary cementing material for use in Portland cement pervious concrete:

1. Cement paste containing silica fume does have a non-linear relationship between stress and strain, and exhibits shear thinning tendencies. This would tend to indicate that silica fume would mix better at a higher shear rate, and could mean that in real world applications a faster mixing speed would result in a better mix for mixes containing silica fume.
2. PCPC mixes containing silica fume at the 3 to 5 percent range tended to have a higher compressive and splitting tensile strength than the control samples. Most mixes with silica fume dosage rates of 7 percent exhibited a decrease in compressive strength.
3. The mixes containing silica fume appeared to exhibit a stronger bond to the aggregate than the control mixes. This was confirmed visually in the apparent reduction of aggregate pull out, especially in the river gravel samples, and in the strength exhibited in the samples containing silica fume.
4. Since mixes were batched by density, permeability and void content was not affected by the addition of silica fume. PCPC mixes containing silica fume should be placed in such a way that the mass of the concrete is known for the given volume being filled, and the compaction effort adjusted accordingly. Since silica fume affects the workability of concrete, if the same compaction effort is not calibrated to the mix being used, higher or lower voids and permeability than designed could result.
5. The addition of silica fume had a greater effect on unwashed limestone than it did on washed limestone. As a result, silica fume reduced the importance of washing the limestone aggregate.
6. Applying ultrasound to a mortar mixture with while hand mixing did not have an effect on compressive strength of the samples. More testing may be warranted on mixes with differing levels of workability and mixing techniques to determine if ultrasound may still be useful during the mixing phase.

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