Mechanical Properties and Durability of High Performance Protecrete Concrete

A summary of the 180-day progress report by the University of Illinois at Chicago

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Introduction

The University of Illinois at Chicago was looking for ways to improve the strength, durability and reliability of concrete. The manufacturer of PROTECRETE was looking for an independent source of impeccable reputation to confirm the field tests which had shown that PROTECRETE Mix Water Conditioner improves the strength, durability and reliability of concrete. Which brings us to this study . . .

The U of I is now conducting an extensive study to evaluate the mechanical properties and long-term corrosion-resisting characteristics of selectable strength high performance concrete (HPC) using PROTECRETE Mix Water Conditioner. Over 40 mix designs were evaluated before the final selection was narrowed to just three high quality mixes (with one of the three being treated with PROTECRETE Densifier for a fourth type of concrete), and over 850 specimens have been cast. The preliminary study will run for one year, and subsequent studies will run for another estimated two to three years.

Objectives

The U of I recognizes that HPC is widely used in the civil infrastructure as a construction and maintenance material, but many aspects of HPC require further studies in order to understand the effects of various environments and loads. Corrosion is a serious problem for reinforced concrete, so finding a way to eliminate corrosion is key. The goal is to create concrete with adequate compressive strength as well as very low porosity and extremely low permeability. This is possible by using low water-cement ratios, superplasticizers, Mix Water Conditioner, Densifier and appropriate aggregates, cements, and mineral admixtures.

Cost is also a factor, however. HPC made using finely divided admixtures is not always reliable and can be complex to use. The U of I reports that Mix Water Conditioner and Densifier enhance the durability of concrete at a fraction of the cost of other pozzolanic materials.

Another objective is to evaluate permeability, which is among the most relevant characteristics of concrete affecting its durability. Concretes with equal compressive strength may have different permeabilities, thus providing different levels of resistance to corrosion.

Mix Water Conditioner is being studied because it yields higher quality concrete at a fraction of the cost, quicker and easier placement which reduces finishing time, less shrinkage and cracking, stronger bond of concrete to steel and increased compressive strength. Densifier requires only a one-time permanent application that makes concrete virtually impermeable, while significantly densifying, improving thermal resistance, increasing strength and lowering creep deformation potential.

RESULTS

The following conclusions have been drawn at the end of 180 days:

1. The addition of Mix Water Conditioner increased the slump through increased lubricity, greatly enhancing the concrete's workability. It also yielded a better surface finish and improved aesthetic appearance.
2. There was a significant increase in strengths and modulus of elasticity for specimens prepared with Mix Water Conditioner.
3. The splitting tensile strength at 7 and 14 days was 6 percent lower than the control for the Mix Water Conditioner specimens which were treated with Densifier; however, this strength increased by 6 percent at 28 and 90 days, and subsequently increased at 180 days.
4. The flexural strengths for the control specimens were the lowest among all four different types of concrete.
5. The flexural strengths for the Mix Water Conditioner specimens in both normal and severe environments showed a continuous increase up to 180 days.
6. The percentage of air voids in the Mix Water Conditioner specimens is the lowest, by about 50 percent compared to the control. Mix Water Conditioner provides greater density and less permeability.
7. The use of Densifier protects the surface from abrasion, scaling, and deterioration and prevents the penetration of aggressive materials. Densifier also provides a better surface appearance.

ABOUT THE TESTING

THE MIXES

After careful evaluation, the 40 different mix designs intially tested were narrowed to the following three:

U.S. Customary

	Mix proportions, pounds per cubic yard					MWC, fluid ounces	Slump, inches	Water/ cement ratio
	Cement	Fly ash	Water	Sand	Coarse aggregate			
Control	597	---	322	1460	1668	---	3.5	.54
MWC	597	---	322	1460	1668	60	5.5	.54
MWC w/ fly ash	509	89	300	1468	1678	60	4.0	.50

Metric

	Mix proportions, kilograms per cubic meter					MWC, liters	Slump, mm	Water/ cement ratio
	Cement	Fly ash	Water	Sand	Coarse aggregate			
Control	354	---	191	866	990	---	87.5	.54
MWC	354	---	191	866	990	2.31	137.5	.54
MWC w/ fly ash	302	53	178	871	996	2.31	100	.50

ENVIRONMENTAL CONDITIONS

The specimens were placed in three environments prior to testing:

1. **NORMAL**: Placed in moisture room with 100% saturation and a constant temperature of 73°F (23°C) within 24 hours from casting until testing.
2. **SEVERE**: Placed in normal environment (above) within 24 hours from casting for 7 days. Then placed in tank with 15% by weight sodium chloride solution until testing. Specimens are fully immersed in the 15% silane solution for 3½ days. Then the water is removed leaving the specimens to dry for another 3½ days. This weekly wetting and drying process will be continuously performed for one year.
3. **LAB**: Placed in room temperature and moisture until testing.

MECHANICAL PROPERTIES—

US CUSTOMARY

	No. of Days	Environmental Conditions								
		Normal				**Severe**				**Lab**
		Control	MWC	MWC w/ CDS	MWC w/ fly ash	Control	MWC	MWC w/ CDS	MWC w/ fly ash	MWC w/ CDS
Compressive strength (psi)	7	4354	4833	4514	4702	4354	4833	4514	4702	3817
	14	5486	5747	5283	5544	5327	5617	5065	5298	4427
	28	6183	6604	6401	6372	5951	6372	5907	6212	5109
	90	7141	7286	7257	7388	6851	6909	6488	6923	5472
	180	7221	7415	7290	8061	6932	7301	7027	7061	5409
Splitting tensile strength (psi)	7	436	442	404	420	436	442	404	420	432
	14	470	482	444	490	450	476	476	436	474
	28	532	534	548	540	516	546	546	526	480
	90	580	626	612	642	542	572	558	572	508
	180	610	634	640	691	607	623	555	637	---
Flexural strength (psi)	7	527	533	496	626	508	533	496	626	563
	14	650	649	559	763	716	705	775	849	575
	28	747	774	604	837	765	775	887	970	617
	90	785	829	803	843	866	929	951	1145	781
	180	858	905	884	935	952	1001	1049	1236	794
Modulus of elasticity (ksi)	28	4238	4702	4470	4644	3396	4107	4049	4064	3353

MECHANICAL PROPERTIES—

METRIC

	No. of Days	Environmental Conditions								
		Normal				**Severe**				**Lab**
		Control	MWC	MWC w/ CDS	MWC w/ fly ash	Control	MWC	MWC w/ CDS	MWC w/ fly ash	MWC w/ CDS
Compressive strength (MPa)	7	30.0	33.3	31.1	32.4	30.0	33.3	31.1	32.4	26.3
	14	37.8	39.6	36.4	38.2	36.7	38.7	34.9	36.5	30.5
	28	42.6	45.5	44.1	43.9	41.0	43.9	40.7	42.8	35.2
	90	49.2	50.2	500	50.9	47.2	47.6	44.7	47.7	37.7
	180	49.8	51.1	50.3	55.6	47.8	50.3	48.4	48.7	37.3
Splitting tensile strength (MPa)	7	3.00	3.04	2.78	2.90	3.00	3.04	2.78	2.90	2.98
	14	3.24	3.32	3.06	3.38	3.10	3.28	3.28	3.00	3.26
	28	3.66	3.68	3.78	3.72	3.56	3.76	3.76	3.62	3.32
	90	4.00	4.32	4.22	4.42	3.74	3.94	3.84	3.94	3.50
	180	4.20	4.37	4.41	4.76	4.19	4.29	3.83	4.39	---
Flexural strength (MPa)	7	3.63	3.67	3.42	4.31	3.50	3.67	3.42	4.31	3.88
	14	4.48	4.47	3.85	5.26	4.93	4.86	5.34	5.85	3.96
	28	5.15	5.33	4.16	4.77	5.27	5.34	6.11	6.68	4.25
	90	5.41	5.71	5.53	5.81	5.97	6.40	6.55	7.89	5.38
	180	5.92	6.24	6.10	6.45	6.56	6.90	7.23	8.52	5.47
Modulus of elasticity (GPa)	28	29.2	32.4	30.8	32.0	23.4	28.3	27.9	28.0	23.1

PERMEABILITY

The Mix Water Conditioner mix is five times less permeable than the control mix at the preliminary stage.

	Hydraulic Conductivity, inches/second (cm/second)
Control	13×10^{-9} (5.1×10^{-9})
Mix Water Conditioner	2.5×10^{-9} (1×10^{-9})

CHLORIDE CONTENT

Overall, the specimens with Mix Water Conditioner showed the lowest penetration.

DEFINITIONS AND RELEVANCE

Durability: The most important property of a concrete installation because it is essential that it be capable of withstanding conditions for which it had been designed. Impermeability, or lack thereof, is one of the most important factors (and there are many) affecting durability.

Workability: The amount of useful internal work necessary to produce full compaction; a physical property of concrete; the work or energy required to overcome the surface friction between the individual particles of a concrete mix.

Compressive strength: The measured maximum resistance of a concrete or mortar specimen to axial loading; expressed as force per unit cross-sectional area; or the specified resistance used in design calculations. In US terminology, this is expressed in pounds per square inch (psi).

Splitting tensile strength: To determine this strength, a cylinder specimen of concrete—of the type used for compression tests—is placed with its axis horizontal between the platens of the testing machine, while the load is progressively increased to cylinder failure by indirect tension in the form of splitting along the vertical diameter takes place.

Flexural strength: A property of a solid which indicates its ability to withstand bending.

Modulus of elasticity: The ratio of normal stress to corresponding strain for tensile or compressive stresses below the proportional limit of the material. Also referred to as *elastic modulus*, *Young's modulus*, and *Young's modulus of elasticity*.

Permeability to water, coefficient of: The rate of discharge of water under laminar flow conditions through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions, usually 20° C.

Chloride content: A compound of chlorine with some other substance, i.e., sodium chloride (salt). Chlorides can enter into concrete from many sources. Standards prescribe strict limits on free chloride content of steel-reinforced concrete due to its ability to initiate and maintain corrosion activity. Chlorides are primarily transported to the steel by water/liquids; therefore, impermeability becomes an important factor in the prevention or retardation of chloride-induced corrosion.

Petrographic analysis: An examination of concrete's air void system to determine permeability.

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A copy of the full 53-page report may be obtained by contacting your authorized PROTECRETE distributor or the manufacturer:

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