PUMICE IMPROVES CONCRETE PERFORMANCE:

Summary *of* Research on Pumice Pozzolan

by the University of Utah *and the* University of Texas-Austin

Pumice has enjoyed a long (two millennia) relationship with cement—the Romans paired fine-grained pumice with hydrated lime to formulate a concrete that is famous for its astonishing durability. Modern Portland cement needs pumice too—finely-graded pumice (pozzolan) ignites a secondary reaction within curing concrete that amplifies the performance of concrete in every key category.

The following summarizes the research done at the Universities of Utah and Texas-Austin[1] quantifying the improvements pumice pozzolan (from the Hess deposit in southeast Idaho) makes to ordinary Portland cement.

The research done by the University of Utah was done in two phases—the second phase focusing on understanding why pumice was so effective on flatlining the alkali-silica reaction (ASR). The research from the University of Texas-Austin was commissioned by the Texas Department of Transportation to quantify options for supplementary cementing materials (SCMs) as alternatives to problematic fly ash. These extensive tests also used pumice pozz from the Hess deposit.

The University of Utah

Evaluation of Hess Pumice as a Natural Pozzolan for Concrete

The University of Texas at Austin

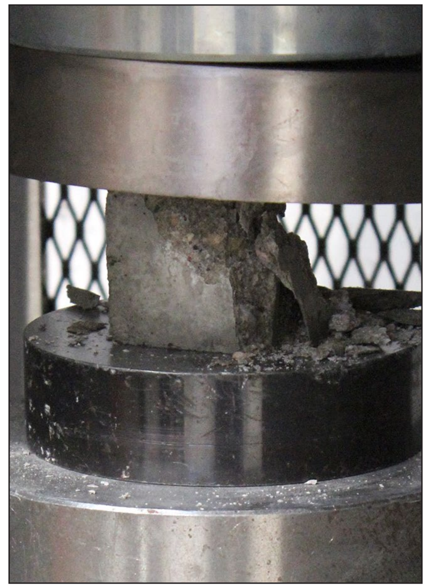
Evaluating the Performance of Alternative Supplementary Cementing Material in Concrete

Why Pozzolan?

According to ASTM C 618, pozzolans are "the siliceous and aluminous material in finely divided form and in the presence of moisture, at ordinary temperature, chemically react with Calcium Hydroxide to form compounds possessing cementitious properties." Calcium Hydroxide (CH) is a deleterious by-product of the reaction between Portland cement and water. Via a secondary reaction, pozzolan repurposes CH into beneficial Calcium Silicate Hydrate (C-S-H), the critical binder that makes concrete what it is. So, not only is more C-S-H made available to densify and strengthen concrete, but the deleterious effects[2] of CH are mitigated. The resulting concrete has a greatly enhanced performance signature.

1 • The research was conducted from 2012 through 2014

2 • The problems instigated by CH include a network of microscopic wormholes left behind as CH escapes to the concrete surface, allowing future ingress of water, often tainted with sulfates, chlorides and other concrete-damaging chemicals; CH will combine and react with sulfates and attack concrete from within; CH has been identified as necessary for the ignition of devastating alkali-silica-reaction (ASR); when CH reaches the surface, it reacts with the Carbon Dioxide in the air to become Calcium Carbonate, staining the surface of the concrete in what is known as efflorescence.



HESS POZZ GRADES

Hess StandardPozz DS-325

PARTICLE SIZE SPECIFICATION

Dx	Micron Size
D50	14-16

Hess UltraPozz NCS-3

PARTICLE SIZE SPECIFICATION

Dx	Micron Size
D50	2 - 4

CHEMICAL COMPOSITION

Common Name: Pumice
Chemical Name: Amorphous Aluminum Silicate
Silicon Dioxide - 87.4%
Aluminum Oxide - 10.52%
Ferric Oxide - 0.194%
Ferrous Oxide - 0.174%
Sodium - 0.128%
Potassium - 0.099%
Calcium - 0.090%
Titanium Dioxide - 0.0074%
Sulfate - 0.0043%
Magnesium Oxide - 0.126%
Water - 1.11%

Hess POZZ
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pozzinfo@hesspumice.com
www.hesspozz.com

Health and Safety

U of Utah: The University of Utah study corroborated previous test data, which indicates that Hess Pumice natural pozzolans are free of Crystalline Silica and other hazardous materials.

Paste & Mortal Studies and Concrete Studies

U of Texas-Austin: The experiments performed in the paste and mortar studies were: isothermal calorimetry, rheological testing, and TGA (paste); compression testing, effect on drying shrinkage, resistance to ASR, and resistance to sulfate attack (mortar). Concrete studies were then conducted because it was "imperative to conduct the tests in concrete as well, since the mortar tests are accelerated in different ways and represent a more simplified system than actual concrete mixtures. In addition, some important durability tests do not have well-established mortar tests." The concrete studies were necessary "to establish how well the SCMs would perform in real-world applications." For the reasons stated above, this summary focuses primarily on the research with concrete prisms.

As for the minimum replacement limit for SCMs, that is dictated by its effect on concrete durability. "In the case of this project, mitigating expansions from ASR was considered to be the most crucial."

The Concrete studies included tests for strength and durability and tests quantifying the effects of the SCMs on the fresh state.

TESTS PERFORMED ON CONCRETE MIXTURES (U of TEXAS-AUSTIN)

STRENGTH AND DURABILITY TESTS	FRESH STATE TESTS
Compressive Strength (ASTM C 39)	Slump (ASTM C 143)
Drying Shrinkage (ASTM C 157)	Air Content (ASTM C 231)
Resistance to ASR (ASTM C 39)	Unit Weight (ASTM C 29)
CoTE (Tex-428-A)	Setting Time (ASTM C 403)
Resistance to Chloride Ion Penetrability (ASTM C 1202)	

Workability & Set Times

U of Utah: Pumice pozzolan based mix designs remain very workable and set times are not significantly longer than the 100% cement control. The various pozzolan mix designs had an extended set time versus the control of anywhere from 44 minutes up to a maximum of 81 minutes. This is directly related to the lowered and extended Heat of Hydration function provided by the pumice pozzolan and higher water-to-cement ratios due to the increased water demand of the pozzolan.

If a quicker set and high early strength are desired, the use of a water reducing agent will offset these properties. Pumice pozzolan based concretes can be 'engineered', with the use of a HRWR, to produce high-performance, high-strength concretes without compromising the amazing chemical resistance properties outlined in the U of U study.

Compressive Strength

U of Utah: In the study, a relatively high water/cement ratio of .485/1 was used for the control and three additional mix designs utilizing the pumice pozzolan. (Note: This is a worst-case scenario…the properties and strength only get better as the w/c ratio goes down.) The pumice pozzolan mix designs ranged from 3300 PSI to 4600 PSI in 7 days and from 4800 PSI to 7000 PSI in 28 days. Pozzolan quantity and particle size accounted for the variation in strengths. These factors are consistent and predictable, pour after pour. All of the pozzolanic qualities can be enhanced and compressive strengths can be boosted generously with the addition of an HRWR to lower the water to cement ratio.

COMPRESSIVE STRENGTH (U of UTAH)

Following ASTM C39, compressive strength of 4x8-inch cylinders were tested with different grades of pumice. **RESULTS**: Mixtures containing pumice reached the compressive strength later than control mixture. However, the minimum strength at age 7 days is greater than 3000 psi and at age 28 days is greater than 4500 psi. *Concrete with slightly slower strength gain qualities is less likely to be subject to early age cracking and has long term strength capability.*

MIXTURE	STRENGTH: 7 DAYS (PSI)	28 DAYS (PSI)	
100C	5636	7400	(Portland Cement)
80C20DS325	3343	4860	(Hess Pozz)
70C30DS325	3398	5359	(Hess Pozz)
80C20Ultra	4648	7083	(Hess UltraPozz)

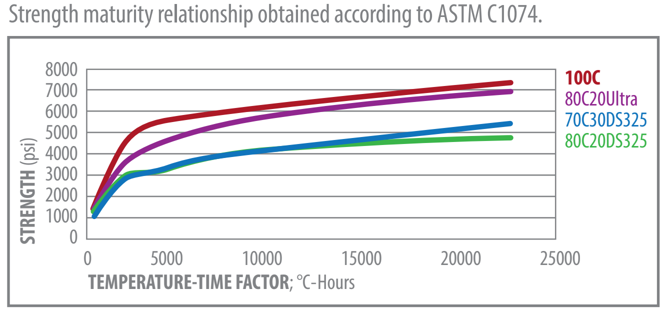
COMPRESSIVE STRENGTH (U of TEXAS-AUSTIN)

Twelve 4-in. x 8-in. cylinders were cast for compressive strength testing at 7, 28, 56, and 90 days. At the appropriate ages, three cylinders were removed from moist storage and tested in a Forney FX-700 compression machine according to ASTM C 39. End caps set per ASTM C 1231. Average compressive strength was calculated from three cylinders. **RESULTS**: The pumice pozzolan concrete mixture gained strength slowly at first, reaching 95% of the control strength at 90 days with a 15% replacement and 99% of the control strength with 25% replacement. This is similar to the trend seen during the mortar studies. It should be noted that although the pumice SCM specimens gained strength slower than the control and the Class F fly ash[3] specimens, at 28 days scored strengths greater than 4500 psi.

	7 DAYS	28 DAYS	56 DAYS	90 DAYS
100C (CONTROL)	5700 (PSI)	6800 (PSI)	7100 (PSI)	7400 (PSI)
SCM @ 15%				
PUMICE	5200 (PSI)	6100 (PSI)	6600 (PSI)	7050 (PSI)
CLASS F FLY ASH	5250 (PSI)	6650 (PSI)	7900 (PSI)	8100 (PSI)
SCM @ 25%				
PUMICE	4500 (PSI)	6200 (PSI)	6800 (PSI)	7400 (PSI)
CLASS F FLY ASH	4600 (PSI)	6300 (PSI)	7300 (PSI)	7700 (PSI)

STRENGTH-MATURITY RELATIONSHIP (U of UTAH)

Strength maturity relationship obtained according to ASTM C1074.



3 • University of Texas-Austin researchers ran class F fly ash specimen tests in conjunction with the tests on the other SCM options to establish a comparative performance baseline and are included here to provide that baseline for those concrete engineers familiar with fly ash performance as a concrete "pozzolan".

Long-term compressive strength tests were not conducted by the University of Utah, however, previous tests indicate that the eventual compressive strength of the pumice pozzolan mixes will exceed the control by 15-40% depending on mix design.

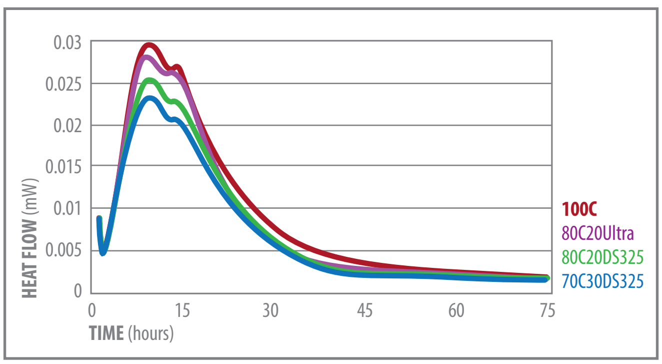
Heat of Hydration

U of Utah: Hess Pumice natural pozzolans reduced the heat of hydration anywhere from 10 - 40% during the first 100 hours, depending on the ultimate mix design, thus lowering the threat of thermal cracking and allowing for a cooler, controlled set.

Nevertheless, without reducing the w/c ratio, there is sufficient early strength gain to be useful in almost any concrete application, especially if the UltraPozz is used. After 100 hours the cement-water hydration process wanes while the pumice pozzolan mixes continue to hydrate until one of the two remaining hydration agents, Calcium Hydroxide or Pumice Pozzolan, have been consumed. *This slow pozzolanic hydration process can continue for months and even years, bringing the long-term strength of the pumice-based concrete well beyond the Ordinary Portland Cement (OPC) control.*

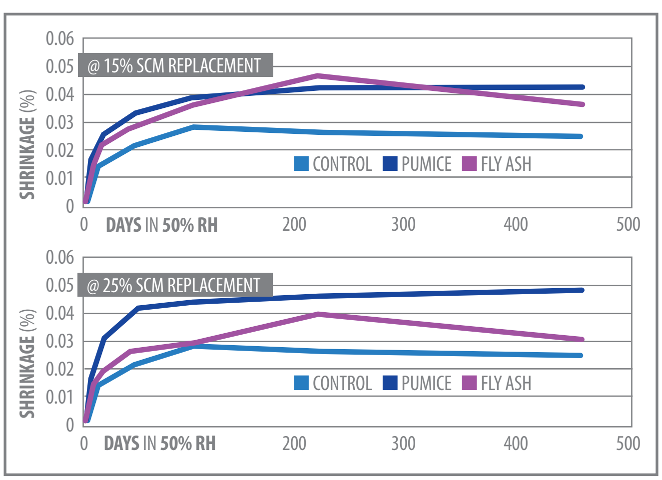
HYDRATION KINETICS: PUMICE BLENDED CEMENTS (U of UTAH)

100% cement mixture produces more heat as compared to the mixtures containing pumice. **RESULTS:** As the pozzolanic content increases, the main peak of heat flow decreases.



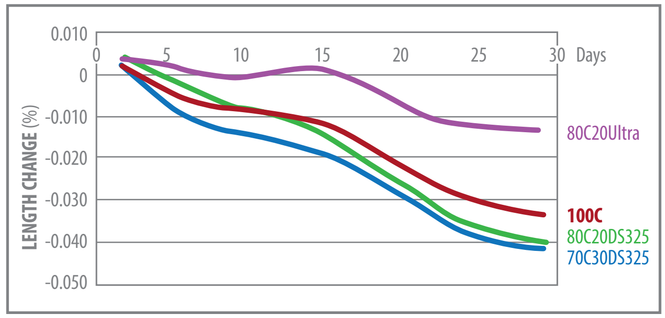
DRYING SHRINKAGE (U of TEXAS-AUSTIN)

The drying shrinkage of the concrete bars was measured according to the procedures of ASTM C 157. **RESULTS:** The pumice SCM concrete mixture had negligible differences in shrinkage compared to the control when used at a replacement dosage of 15%. However, the amount of shrinkage increased to more than 0.010% of the control as the replacement dosage was increased to 25%.



SHRINKAGE (U of UTAH)

Mixture designs were tested for length change in 6"x12"cylinder concrete specimens. The addition of ultrafine pumice reduced the length change (shrinkage) compared to 100% cement.



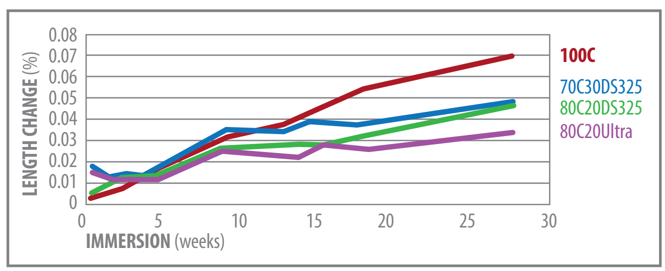
Sulfate Mitigation

U of Utah: Sulfate resistance testing was conducted in accordance with ASTM C1012, which specifies that a cement or cement blend with 'High Resistance' to sulfate attack must remain below .05% expansion over a 6 month period. All three of the Hess pumice pozzolan based blended cements performed exceptionally well and qualified, per ASTM, as 'High Sulfate Resistance Cements.'

U of Texas-Austin: An SCM qualifies for a Class 1 mild sulfate exposure if it can keep expansions below 0.1% for 6 months, when tested for sulfate attack using ASTM C 1012. Similarly, an SCM qualifies for a Class 2 moderate sulfate exposure at expansions below 0.1% for 12 months. Finally, a Class 3 severe sulfate exposure requires the SCM to keep expansions below 0.1% for 18 months.

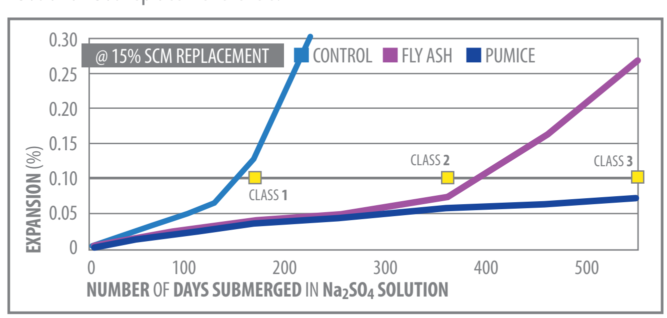
SULFATE MITIGATION (U of UTAH)

Per ASTM C1012, mortar mixtures were tested for sulfate resistance through 6 months. **RESULTS:** Mixtures containing pumice are *classified as HS (High sulfate resistant cement)* as the length change is less than 0.05% after 26 weeks.



RESISTANCE TO SULFATE ATTACK (U of TEXAS-AUSTIN)

The yellow dots in the graph represent the "ACI 201: Guide to Durability" limits of Class 1, Class 2 and Class 3 sulfate exposure. **RESULTS:** The pumice pozzolan concrete qualifies for use in a *Class 3 severe sulfate exposure environment* at both 15% and 25% replacement levels.



Resistivity

U of Utah: Chloride penetration resistance is a key factor in protecting reinforcing steel embedded in the concrete from corrosion and ultimately protecting the concrete from failure caused by expansion of the iron oxide hydrate (rust). The three pumice pozzolan mix designs increased resistivity anywhere from a minimum of 214% of control to nearly 500% for the Hess UltraPozz.

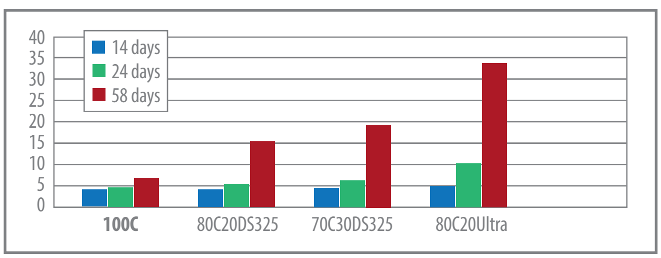
U of Texas-Austin: There are no well-established paste and mortar tests for this measurement, but this durability property is crucial, as the ingress of chloride ions can depassivate the steel in concrete and cause corrosion, without needing a drop in the pH content.

Test results showed that the use of pumice pozzolan increased the resistance of the concrete mixtures to chloride ion penetration. In addition, the pumice-enhanced concrete performed well under sulfate attack, measured according to ASTM C 1012—at a replacement dosage of 15%, pumice was found to be suitable for a Class 3 severe sulfate exposure level (based on "ACI 201: Guide to Durability").

RESISTIVITY AT DIFFERENT TIME INTERVAL IN kΩ-cm (U of UTAH)

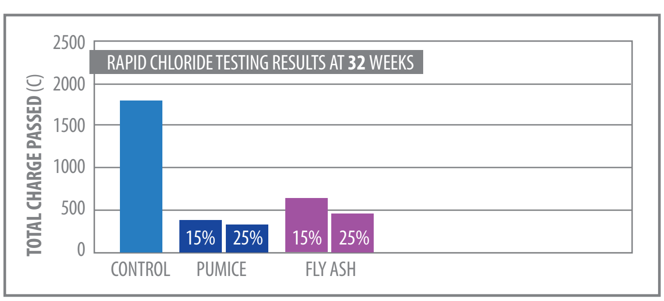
ASTM C192 procedure was followed to make 6"x12" cylinders and moist cured according to ASTM C511. Resistivity increases over time for the mixture with pozzolans whereas it remains relatively constant for the mixture with 100% Portland cement.

MIXTURE	14 DAYS	24 DAYS	58 DAYS
100C	4.1	4.6	6.8
80C20DS325	4.3	5.5	15.7
70C30DS325	4.3	6.3	19.2
80C20Ultra	5.1	10.5	33.8



RESISTANCE TO CHLORIDE ION PENETRATION (U of TEXAS-AUSTIN)

The chloride penetrability of concrete cylinders that were cured for 32 weeks was measured according to ASTM C 1202. Although the standard does not require repeat testing, three or more cylinders per concrete mixture were tested for rapid chloride penetrability. The range of the data was checked to see whether it was within the limits prescribed by ASTM C 1202. **RESULTS:** At 32 weeks, all the SCM-concrete samples had less than 1000 coulombs of total charge passing through them when tested, which indicates very low chloride ion penetrability, according to ASTM C 1202. The overall results indicate that increasing the SCM content also increased the resistance to chloride ion penetrability.



Alkali Silica Reaction (ASR)

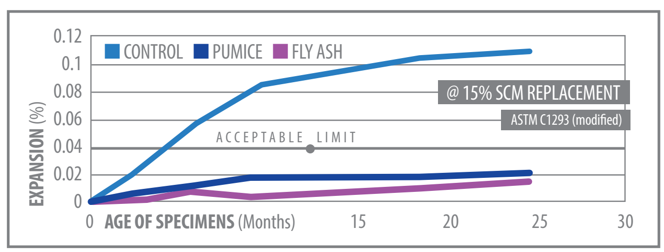
U of Utah: The graph (page 5) tells the story better than words. Using the same expansive aggregate in each mix design, the control with 100% OPC quickly fell into the 'deleterious' category while the three pumice pozzolan-based cements were clearly resistant to the ravages of ASR.

U of Texas-Austin: Results from the concrete mixture studies were crucial in understanding how pumice pozzolans might perform in field applications of concrete. One of the most important concrete results was the validation of the accelerated mortar bar test (ASTM C 1567) for ASR using the longer term, more reliable ASTM C 1293 concrete prism test for ASR. It was found that the pumice pozzolan could keep ASR expansions at 2 years below the 0.04% limit of ASTM C 1293 using replacements dosages of 25% or less.

MITIGATING ALKALI SILICA REACTION (U of TEXAS-AUSTIN)

Resistance to ASR was measured according to the procedures of ASTM C 1293, except for the concrete mixture design used, which is detailed in the MIXTURE DESIGN table below. The average expansion for each mixture was calculated from three or more bars, and the range was checked to see whether it was within the limits stated in ASTM C 1293. **RESULTS:** The pumice SCM concrete mixture performed very well, and kept expansions below the 0.04% limit of ASTM C 1293, validating the results found from the ASTM C 1567 Accelerated Mortar Bar Test for ASR. The table below lists the *average expansion of the concrete prisms at 24 months*, along with the range of the data.

MIXTURE	AVERAGE ASR EXPANSION AT 24 MONTHS (%)
CONTROL	0.109 ± 0.020
PUMICE (15%)	0.022 ± 0.007
FLY ASH (15%)	0.016 ± 0.017
PUMICE (25%)	0.015 ± 0.001
FLY ASH (25%)	0.016 ± 0.005



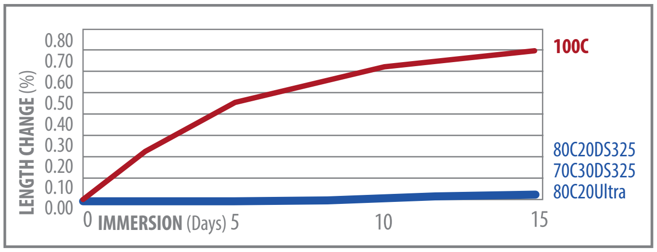
MIXTURE DESIGN FOR ASTM C 1293 ASR TESTING

Component	Batch Weight (lb/yd³)	Weight %	Volume %
COARSE AGGREGATE	1937	48.3	43.4
FINE AGGREGATE	1257	31.3	28.9
CEMENTITIOUS MATERIAL	564	14.1	10.6
WATER	254	6.3	15.1
AIR	—	—	2.0

MITIGATING ALKALI SILICA REACTION (U of UTAH)

Mortar mix designs tested according to a modified ASTM C1567 procedure using Type 1 cement and 25% replacement of fine aggregate with ground cullet glass. The percent length change for "acceptable expansion" is less than 0.10% at fourteen days with reactive aggregates.

MIXTURE	ASR % LENGTH CHANGE	RATING
100C 25%Glass	0.699	Deleterious Expansion
80C20DS325 25%Glass	0.029	Acceptable Expansion
70C30DS325 25%Glass	0.011	Acceptable Expansion
80C20Ultra 25%Glass	0.017	Acceptable Expansion



Fresh State Properties, Setting Time and Water Demand

U of Utah: There is an increase in initial and final setting time for the mixtures containing pumice compared to 100% cement (ASTM Type II/V) when tested at a constant flow without admixtures. The increases are well within the limits of ASTM C5957 specification for blended hydraulic cement, which is likely attributed to the increased water demand. Water demand was more for mixtures containing pumice compared to 100% cement. The increase in water demand can be addressed by addition of common water-reducing admixtures.

FRESH STATE PROPERTIES (U of TEXAS-AUSTIN)

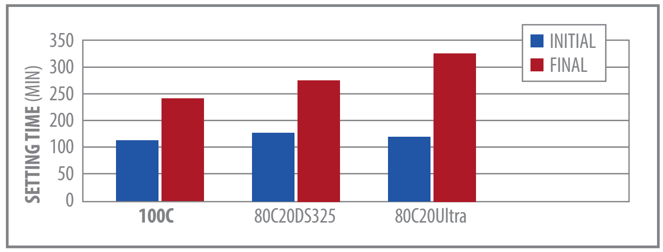
Concrete slump was measured according to ASTM C 143. The air content of the fresh concrete mixtures was measured according to the pressure method described in ASTM C 231. The unit weight of the mixture was found using the procedures described in ASTM C 29. The setting time of concrete mixtures was found using the procedures of ASTM C 403. In addition to the penetration resistance tests, ultrasonic tests were investigated to continuously monitor the setting process on concrete samples and sieved mortar samples. (This study aims to develop a field-applicable nondestructive testing method for in-situ monitoring of the setting and hardening process of concrete.) **RESULTS**: The pumice SCM concrete mixture was able achieve the target slump with the help of a superplasticizer and achieved final set in 3.4 hours, compared to the final set of the control at 4.5 hours.

Concrete Mix Description	Admixture Dosage (% of max)	Slump (inches)	Air (%)	Unit Weight (lb/ft³)	Initial Set (Hrs)	Final Set (Hrs)
CONTROL	12.70	3.25	1.6	150.0	3.4	4.5
PUMICE (15%)	15.48	2.50	1.8	149.6	3.6	5.0
FLY ASH (15%)	2.24	3.75	2.0	148.8	3.5	4.9
PUMICE (25%)	43.73	5.25	2.0	148.8	3.8	5.3
FLY ASH (25%)	0.00	5.50	1.6	148.8	3.9	5.3

EFFECT OF PUMICE: SETTING TIME; WATER DEMAND (U of UTAH)

Setting times were determined by a Vicat Needle test method according to ASTM C19112. Penetration resistance indicates the setting characteristic of cement mixture paste.

MIXTURE	SETTING TIME (min) INITIAL	SETTING TIME (min) FINAL	WATER USED g (lb)	% INCREASE in WATER
100C	117	242	173 (0.381)	
80C20DS325	148	271	195 (0.430)	12.7
80C20Ultra	129	323	199 (0.439)	15



Optimum SCM Replacement Dosage

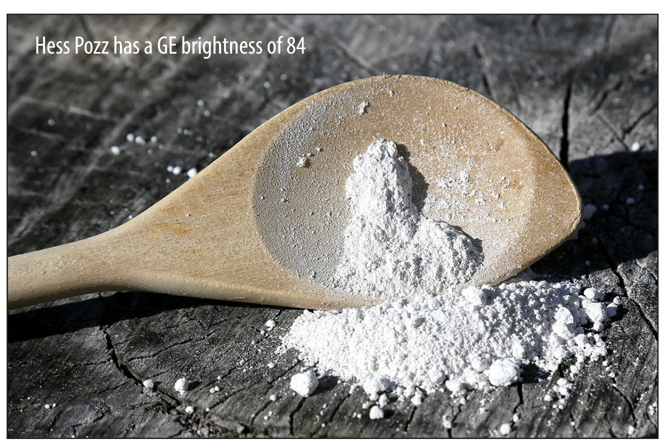
U of Texas-Austin: The minimum replacement limit for a given SCM is dictated by its effect on concrete durability—specifically, mitigating expansions from ASR, especially important in regions where ASR is a common source of durability problems. The minimum replacement level for SCMs in this project was determined through the accelerated mortar bar test for ASR (ASTM C 1567). Long-term measurements of concrete specimens using ASTM C 1293 confirmed these minimum replacement dosages to be effective in mitigating ASR. The maximum dosage was determined by the cost of the SCM and its effect on mixture workability. Strength was also an important factor in determining maximum dosage, as the higher the replacement amount, the lower the early age strength of mixtures, due to the dilution effect of replacing hydraulic cement with a slower reacting, pozzolanic material.

The pumice SCM was able to keep ASR expansion below the limit at a replacement dosage of only 15%.

PUMICE REPLACEMENT DOSAGES (U of TEXAS-AUSTIN)

(BY WEIGHT OF CEMENT IN CONCRETE MIXTURES)

	MINIMUM	MAXIMUM
PUMICE	15%	25%



Hess Pozz has a GE brightness of 84

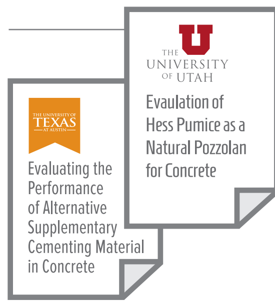
Conclusions

U of Utah: Pumice tested in this research was determined to be pozzolanic and potentially complementary in its reactions in Portland cement concrete. The various grades of pumice behave differently in the hydration characteristic even with the same chemical composition, which may be due to varying particle size distribution. Ultrafine pumice (Hess UltraPozz) showed improved performance over other grades of pumice in hydration, strength and in durability characteristics such as sulfate resistance and alkali silica reaction (ASR). The greater hydration characteristics of ultrafine pumice are also supported by the compressive strength and the penetration resistance results of the same. Although the water demand may be slightly higher for mixtures containing pumice, the use of a water reducing admixture will effectively offset this demand, resulting in comparable set times to 100% cement mixtures.

DS-325 pumice (Hess Pozz) showed improved performance over cement in durability characteristics. If the application requires primarily durability characteristics, i.e. high sulfate resistance and high ASR resistance, then DS-325 pumice can be used as a part of cementitious material. If the requirement is both strength and durability, then ultrafine pumice can be used. The heat produced from mixtures containing pumice is less than that of mixtures with 100% cement which makes it advantageous in mass concrete placements. To maintain higher strength, improve durability characteristics, and reduce the potential for thermal cracking, ultrafine pumice can be used as a portion of the total cementitious material content.

U of Texas-Austin: The concrete results showed that drying shrinkage and CoTE would not be a problem if pumice pozzolan was used in concrete mixtures. In terms of strength, the pumice SCM performed very well with strengths similar to or higher than the control at 90 days. Nor did the measurement of the fresh state properties of the concrete mixtures reveal any problems.

Pumice-blended cement will perform well to increase the durability of concrete and is recommended in applications where high early strength is not a requirement.



Hess Pumice Products' Wright Creek Area pumice mine in Southeast Idaho, USA