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Kirkland Natural Pozzolan

Enhancing Concrete Strength, Durability, and Corrosion Resistance

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THE KIRKLAND NATURAL POZZOLAN (KNP) is a Pumiceous Tuff that meets the requirements of the Class N category of ASTM C618 as a natural pozzolan. When used in concrete, the material can provide many benefits, especially in terms of durability. Concrete proportioned with KNP develops properties that are not attainable by concrete proportioned with portland cement alone. The typical chemical characteristics and performance of KNP according to ASTM C618 are presented in Table 1.

Table 1: Typical Characteristics of Kirkland Natural Pozzolan

	KNP	ASTM C618 Class N Limit
SiO_2	72 – 75	-
Al_2O_3	13 – 15	-
Fe_2O_3	1 – 3	-
Sum of Oxides (SiO_2+Al_2O_3+Fe_2O_3 %)	88 – 90	50% Min
SO_3 (%)	<1	5% Max
CaO	1 – 3	-
Na_2O	2 – 3	-
MgO	1 – 2	-
K_2O	2 – 4	-
Sodium Oxide Equivalent (Na_2O+0.658K_2O)	4 – 6	-
LOI (%)	3 – 5	10% Max
Fineness (% retained on 45 micron sieve)	<5	34% Max
7-day SAI (% of control)	85 – 95	75% Min
28-day SAI (% of control)	90 – 105	75% Min
Water Requirement (% of control)	102 – 104	115% Max
Specific Gravity	2.3 – 2.5	-

Table 2: Water Requirements for Mortar Mix Designs Containing Varying Levels of Kirkland Natural Pozzolan

Sample	Cement, g	KNP, g	Water, g	w/c ratio	Mortar Flow	Water Demand, % of Control
Control	500	0	242	0.484	120	-
10% KNP	450	50	242	0.484	116	100.00%
15% KNP	425	75	245	0.49	118.5	101.24%
20% KNP	400	100	247	0.494	117	102.07%
25% KNP	375	125	248	0.496	118	102.48%

*Testing performed according to ASTM C109.

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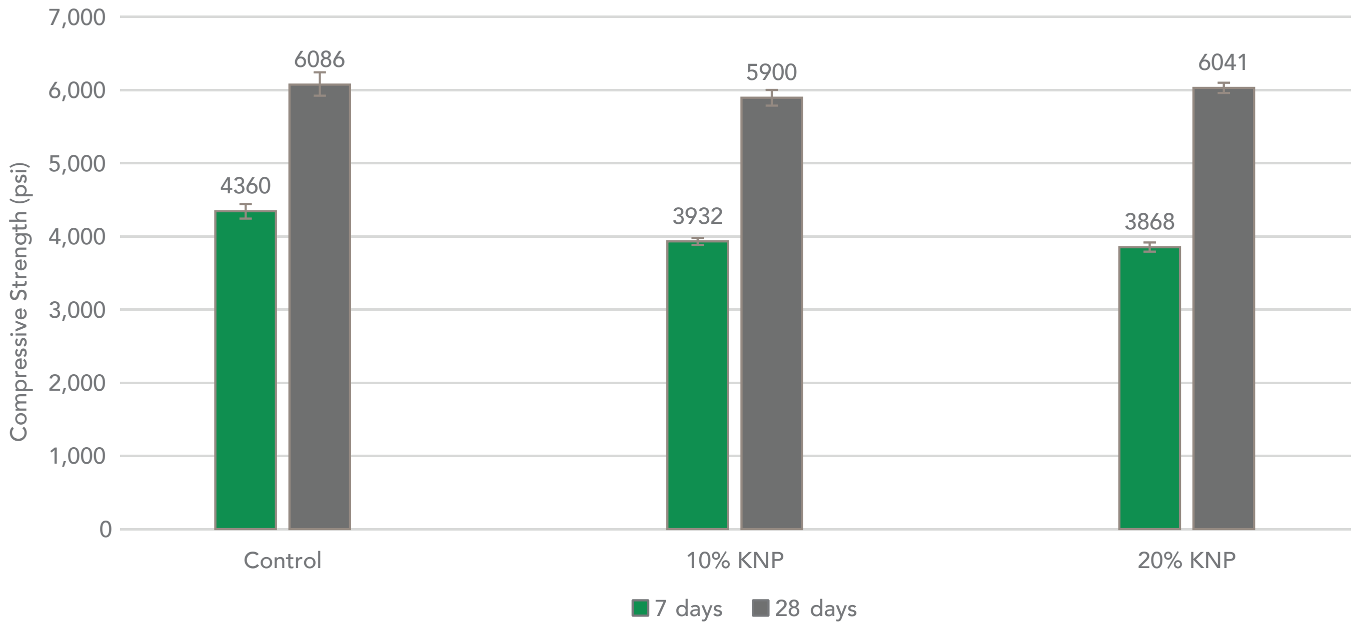
PERFORMANCE IN CONCRETE AND FRESH PROPERTIES

Table 3 summarizes concrete mix designs where 10% and 20% of the cement content was replaced with KNP. The water content was maintained constant throughout the mixes, while a mid-range water reducer was added to adjust the slump and have similar workability for the four concrete mixtures (i.e., a slump of 1.5" – 3"). Figure 1 presents the compressive strength results after 7 and 28 days of curing. These results show that concrete mixtures proportioned with KNP exhibit strength development similar to those of concrete mixtures proportioned with fly ash where strengths are slightly lower than the control mixtures with cement alone at early ages but then catch up at later ages. This represents a textbook example of pozzolanic materials in the strength development of concrete.

Table 3: Concrete Mix Designs

	Control	10% KNP	20% KNP
Cement (lb/yd^3)	550	495	440
KNP (lb/yd^3)	0	55	110
Fine Aggregates (lb/yd^3)	1353	1338	1323
Coarse Aggregates (lb/yd^3)	1809	1809	1809
Water (lb/yd^3)	330	330	330
Mid-Range Water Reducer (oz/cwt)	0	2.8	6.4
Slump (in)	2.5	2.75	2
Air (%)	1.0	0.9	0.9

Figure 1: Strength Development Results



ENHANCING DURABILITY

Durability of concrete is a key consideration in the design of structures and pavements. Longer-lasting concrete structures require fewer repairs over their service life, thus resulting in lower life-cycle costs. Increased service life translates to reduced consumption of natural resources and less demolition waste generation bound for landfill disposal. One of the most important factors to consider when evaluating concrete durability is permeability. Most deleterious reactions that can damage concrete and concrete structures are due in part to the ingress of potentially deleterious agents, such as chlorides, sulfates, and de-icing salts. Denser, less permeable concrete limits the ingress of these potentially deleterious agents. High-quality pozzolans such as KNP may be used to greatly increase concrete durability. This technical sheet discusses the ways KNP improves concrete durability, particularly with respect to reducing the risk of corrosion of embedded reinforcement, alkali silica reaction (ASR), and sulfate attack.

REDUCING THE RISK OF CORROSION

Chloride-induced corrosion is one of the most common causes of premature deterioration of steel in reinforced concrete. Chlorides, originating from deicing salts and sea-water, can migrate throughout the concrete, attacking the passivating oxide layer that coats steel reinforcement. An electrochemical reaction ensues, leading to formation of ferric hydroxides, accompanied by an increase in volume on the perimeter of the rebar. Tensile stresses develop within the concrete, ultimately leading to cracking and delamination as can be seen in the example provided in Figure 2. The functional cross-sectional area of the steel is also reduced, decreasing the load-carrying capacity of the structure.

Given that a certain amount of chloride ions (known as the chloride threshold) must permeate from the surface of the concrete to induce corrosion, less-permeable concrete reduces the risk of steel corrosion by restricting the ingress of these chlorides. One of the most common ways of measuring concrete permeability, and thus its susceptibility to steel corrosion, is through the determination of its resistivity. Measuring the resistivity of a concrete sample involves using an electrical probe to determine how much the concrete interferes with the transmission of an electrical field. A higher measured resistance implies the concrete has a denser microstructure and thus lower permeability. Figure 3 presents resistivity results of concrete proportioned with 650 lbs/yd^3 of cement and 0.5 water-to-cement ratio compared to a concrete mixture where 20% of the cement was replaced by KNP. The results show how the resistivity of concrete proportioned with KNP continues to increase, surpassing by far that of the cement control at the age of 90 days. This is an indication that concrete proportioned with KNP is less permeable and less likely to experience steel corrosion than concrete proportioned with cement alone. Additionally, concrete with low permeability not only restricts the ingress of chloride ions, it also restricts the ingress of water, sulfur, and other aggressive ions that can compromise the durability of concrete. Therefore, increased resistivity demonstrates not only the ability for KNP to enhance concrete's resistance to chloride-induced corrosion, but also how it makes concrete more resilient against many other deleterious reactions.

Figure 2: Concrete Cracking and Delamination Caused by Corrosion of Steel Reinforcement

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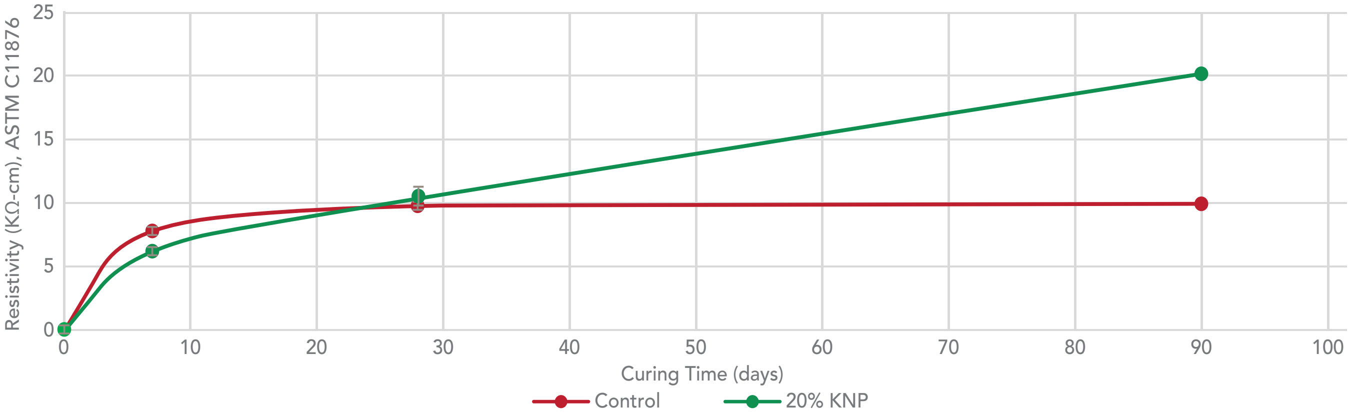
Figure 3: Resistivity Results Measured According to ASTM C1897 of Concretes with 650 lbs/Yd³ of Cement and 0.5 Water-to-Cement Ratio vs. Concrete with 20% of the Cement Replaced by KNP



REDUCING THE RISK OF ALKALI-SILICA REACTION (ASR)

Most concrete contains aggregates that are relatively inert, that is, they do not react with the rest of the components of concrete. However, some aggregates that contain reactive silica are prone to react with alkali hydroxides dissolved in the pore solution of concrete. This reaction produces a gel that forms at the aggregate/paste interface and swells as it adsorbs water. Once the stresses caused by the swelling gel surpass the tensile strength of the concrete, widespread cracking ensues. Premature failures of concrete structures caused by ASR have been reported in nearly every state of the U.S.

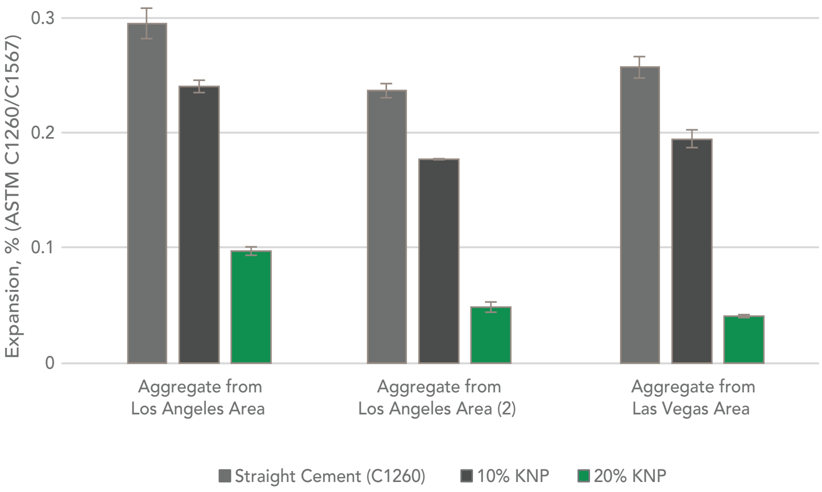
Understanding that moisture, reactive aggregates, and a sufficient concentration of alkalis in the pore solution are all necessary for ASR to occur provides insight into how the risk of premature failures due to ASR can be reduced. The use of KNP reduces the potential for ASR by two mechanisms: (1) by reducing the concrete permeability, thus limiting the movement of alkalis and moisture to the reactive interface, and (2) by contributing to the binding of alkalis through the pozzolanic reaction.

The ability for KNP to mitigate expansion caused by ASR was tested according to ASTM C1567 Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method). In this test, the aggregate in question is crushed and graded to specific size fractions and then used to produce 2″x 2″ mortar bars proportioned with the desired combination of cementitious materials to measure expansion caused by ASR. The bars are first submerged in water for 24 hours at 80°C, then placed in a 1N NaOH solution for 14 days at 80°C. The difference between the length of the bars measured initially and after the 14-day period is considered to be the expansion caused by ASR. If the combination of aggregate and cementitious materials generates expansion of less than 0.1%, it is generally deemed acceptable for use in concrete. The results presented in Figure 4 show the expansion of mortars made with three highly reactive aggregates from the Los Angeles and Las Vegas areas. These results show that concrete made with these aggregates would be expected to be at high risk of causing ASR damage if proportioned with portland cement alone. However, the graph also shows that replacing 20% of the cement by KNP would reduce ASR expansion to less than 0.1%, which is generally deemed acceptable according to ASTM C1778 Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete.

SULFATE ATTACK

Another deleterious reaction that needs to be considered when designing durable concrete is sulfate attack. Sulfates from sources such as ground water or soil can penetrate concrete and react with residual products formed during cement hydration. This results in the formation of sulfur phases such as ettringite that can lead to expansion and cracking. It is known that pozzolans reduce the risk of expansion caused by sulfate attack by reducing permeability and inhibiting the ingress of sulfate ions. The effectiveness of KNP in reducing the risk of sulfate attack was tested according to ASTM C1012 Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution. In this test, a standard mortar is made and cast into 2"x 2" bars. After reaching a certain strength, the bars are measured and placed in a solution containing 50g/L of sodium sulfate at room temperature and then measured at various time intervals. The difference between the length of the bars measured initially and after a certain period of time is considered to be the expansion caused by sulfate attack. According to ASTM C618, if the expansion values are less than 0.10% and 0.05%, then the cementitious material or combination of cementitious materials are considered to have moderate or high sulfate resistance, respectively.

Figure 4: Expansion Caused by ASR Measured According to ASTM C1567 Using Aggregates from the Los Angeles and Las Vegas Areas and Proportioned with Increasing Amounts of KPN



SUMMARY

1. Partially replacing cement with KNP results in concrete with the quintessential strength development of concrete containing pozzolans.
2. KNP can help to greatly reduce concrete permeability.
3. KNP can reduce the risk of deleterious expansion caused by ASR in concrete.
4. KNP can help reduce the risk of expansion due to sulfate attack.

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Servicing 135 locations in 45 states, **Eco Material Technologies** is the nation's leading marketer of fly ash products and natural pozzolans. The company operates an extensive distribution network for fly ash and related products and provides site services to power plants.

A family-owned Arizona corporation, **Kirkland Mining Company** completed the stringent process for obtaining all necessary approvals to mine the high-quality natural pozzolan deposit near Kirkland, Arizona. In late 2019, the company joined forces with Boral Resources to proceed with mining and marketing of this unique deposit.

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