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BORAL RESOURCES

# BORAL MICRON³™

## RESISTANCE TO CORROSION, ALKALI SILICA REACTION, AND SULFATE ATTACK

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 waste bound for landfill disposal. Highly refined pozzolans such as Micron³ may be used to dramatically increase concrete durability. This bulletin discusses the ways Micron³ improves concrete durability, particularly with respect to corrosion, alkali silica reaction (ASR) and sulfate attack.

### Corrosion

Exposure to chloride ions is the most common cause of premature deterioration of steel in reinforced concrete. Chlorides, originating from deicing salts and seawater, 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.

Tensile stresses develop within the concrete, ultimately leading to cracking and delamination. The steel cross sectional area is also reduced decreasing the load carrying capacity of the structure. It is widely held that corrosion initiates when the chloride level at the steel reinforcement reaches 1 to 1.5 lb/yd³.

### Chloride Diffusion Coefficient

Micron³ reduces chloride ingress into concrete, due to pozzolanic reaction and improved micro-filler effect, which lowers concrete permeability and disconnects the integral pore network. Pozzolanic reaction products may also contribute to increased chloride binding. Chloride diffusion coefficients were recently measured in concrete using varying dosages of Micron³ (Figure 1). The total cementitious contents and the w/cm were the same for all mixtures, and concrete specimens were moist cured for twenty-eight days. Further testing details are reported elsewhere.[1] When compared to the control concrete without pozzolan, Micron³ reduces chloride diffusion by 2.5

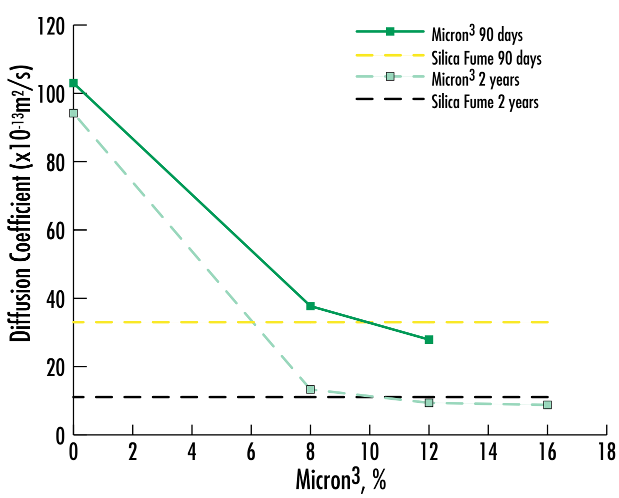


Figure 1. Effect of Micron³ on Chloride Diffusion Coefficient of Concrete

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to 3.5 times when tested after ninety days of chloride ponding and 7 to 11 times when tested after two years of chloride ponding. The ninety-day and two-year test results show that 9.5% Micron³ achieves similar chloride diffusion coefficients as 8% silica fume. This implies that the chloride content located at the steel reinforcement would be the same using these respective dosages. In this test program, concrete slumps were higher in the mixes with Micron³. If the concrete mixtures containing Micron³ had been designed with a lower w/cm (same slump), then parity could have been attained at even lower dosages.

The chloride diffusion coefficient is a controlling parameter for predicting service life of reinforced concrete structures, when using service life modes such as Life-365 (developed by ACI Committee 365-Service Life). Since Micron³ decreases chloride diffusion coefficients, it will increase the service life of reinforced concrete significantly.

**Rapid Chloride Permeability Testing (RCPT)**

RCP testing was conducted in accordance with ASTM C 1202, which measures concrete conductivity. However, RCP may be correlated with chloride diffusion coefficient. ASTM 1202 relates the charge passed (in coulombs) to the chloride ion penetrability as follows: >4000 = High; 2000-4000 = Moderate; 1000-2000 = Low; 100-1000 = Very Low; <100 = Negligible. Some question the validity of this test; however, due to the relative ease of performance, the RCPT is most widely specified. The RCPT values obtained from concrete mixtures tested in different locations with local materials are summarized in Table 1.

Concrete with RCPT values less than 1000 coulombs, corresponding to ASTM C 1202 "Very Low" chloride penetrability, may be achieved using Micron³. The use of fly ash in conjunction with Micron³ decreases the amount of Micron³ required to attain a given RCPT value. Early age (<28 days) RCPT values tend to be relatively higher for concrete containing Micron³ as opposed to concrete with silica fume at similar replacement levels. However, concrete with 8% Micron³ had a lower RCPT value than 8% silica fume when tested at 90 days or later.[1]

When designing concrete for chloride resistance, some engineers specify RCPT values less than a given value by a set age, such as 1000 coulombs by 28 or 56 days.

This approach, however, does not consider the reduction in chloride permeability at later ages. In order to achieve low permeability at an early age, the concrete producer must use a very low w/cm, high cementitious content, and large amounts of highly reactive pozzolan. This results in excessively over-designed concrete with potential workability and cracking problems in the field. Interestingly, the Virginia Department of Transportation (VDOT) offers an innovative solution. It specifies 28-day RCPT limits, but subjects the concrete specimens to a higher temperature.[2] Such a requirement may be satisfied by a concrete mixture with a lower cementitious content, a reasonable w/cm (0.35-0.40), and a more reasonable amount of highly reactive pozzolans, thus reducing the problems mentioned earlier.

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Table 1. RCPT Results of Micron³ Concrete at Various Locations

| Location | Salt Lake City, UT | | San Antonio, TX | | | | Pascagoula, MS | |
|---|---|---|---|---|---|---|---|---|
| Cement | 700 | 600 | 600 | 600 | 525 | 600 | 564 | 564 |
| Class F Fly Ash | - | 100 | - | - | 125 | 100 | - | - |
| Class C Fly Ash | - | - | - | - | - | - | 141 | 141 |
| Micron³ | 100 | 100 | - | 75 | 50 | 100 | 80 | 120 |
| Silica Fume | - | - | 50 | - | - | - | - | - |
| Water | 251 | 267 | 250 | 225 | 230 | 230 | 250 | 250 |
| w/cm | 0.31 | 0.33 | 0.39 | 0.33 | 0.33 | 0.29 | 0.32 | 0.30 |
| Type A | 3 | 3 | - | - | - | - | - | - |
| Type B | - | - | - | - | - | - | 27 | 29 |
| Type F | 15 | 15 | 19.8 | 11.2 | 7.2 | 9.4 | 73 | 83 |
| AEA | - | - | 0.8 | 0.8 | 0.8 | 0.8 | 4 | 3.5 |
| Slump, in. | 5.25 | 9.25 | 7.25 | 8.0 | 7.25 | 7.25 | 7.5 | 8 |
| Air, % | - | 1.5 | 6.0 | 5.1 | 5.3 | 3.7 | 4.7 | 4.5 |
| U.W., $lb/ft^3$ | - | - | 142.4 | 144.8 | 144.0 | 146.6 | 147.08 | 147.8 |
| Compressive Strength, psi | | | | | | | | |
| 1 day | - | - | - | - | 2434 | 3504 | - | - |
| 3 day | - | - | 6191 | 6451 | 4599 | 6204 | - | - |
| 7 day | 8465 | 7525 | - | - | 5821 | 6833 | - | - |
| 28 day | 11590 | 11385 | 9480 | 9721 | 7458 | 8671 | - | - |
| 56 day | 12425 | 12860 | - | - | - | - | - | - |
| 90 day | - | - | - | - | 9045 | 10420 | - | - |
| Rapid Chloride Permeability, Coulombs | | | | | | | | |
| 28 day | 1425 | 1386 | 958 | 1218 | 1584 | 1128 | 1527 | 1021 |
| 56 day | 596 | 578 | 888 | 932 | 959 | 692 | 777 | 567 |
| 90 day | 348 | 354 | - | - | - | - | 529 | 436 |

- Cement, fly ash, silica fume, Micron³, water weights are in $lb/yd^3$; 1 $lb/yd^3$=0.593 $kg/m^3$
- Admixture dosages are in oz/100 lb of cementitious; 1 oz/100 lb=65.46 ml/1000 kg

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### Resistivity

Corrosion is an electro-chemical process involving the flow of electrons through concrete. If concrete electrical resistivity is increased, the rate of macrocell corrosion decreases. DC resistivity tests were performed on concrete mixtures containing various levels of Micron³ and silica fume. Further test details are discussed elsewhere.[1] Figure 2 summarizes the test data. After two years, concrete containing Micron³ had 3.1 to 6.6 times higher electrical resistivity than the control concrete containing no pozzolan. The mixtures containing Micron³ had slightly lower resistivities than mixtures with silica fume after 28 days curing, but generally exhibited improved performance after 91 days. At later ages the concrete containing Micron³ had significantly higher resistivities than the concrete with silica fume. Higher resistivity will result in reduced corrosion rate.

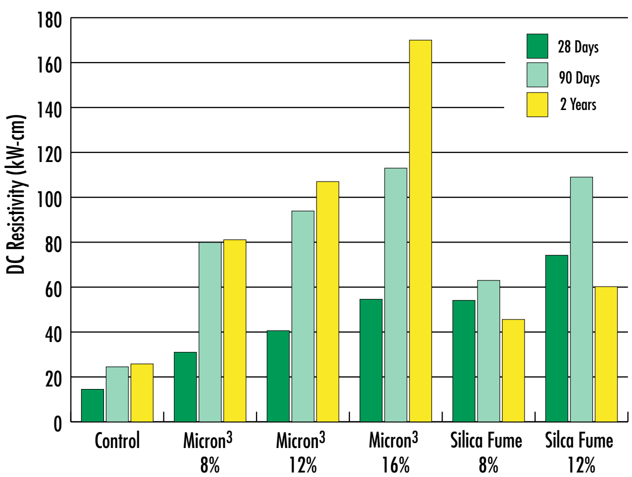


Figure 2. Effect of Micron³ on Electrical Resistivity of Concrete

### Alkali Silica Reaction

When alkalis from cement and other sources contact reactive silica in certain aggregates, while in the presence of moisture, expansive alkali-silica gel may form. The resultant expansive forces may cause concrete cracking and eventual loss of structural integrity. The use of ultra fine fly ash reduces the potential for ASR, primarily by reducing the concrete permeability thus making movement of alkalis and moisture more difficult. It also contributes to binding of alkalis. Accelerated mortar bar tests (ASTM 1260) and concrete prism tests (ASTM 1293) were conducted with various dosages of Micron³ with a highly reactive aggregate. The test results showed that 10% Micron³ was adequate to reduce expansions to acceptable levels. A similar dosage of silica fume was required for controlling expansions. Results from a recent test program, conducted by the Texas Department of Transportation (TxDOT), are summarized in Figure 3. The TxDOT program investigates combinations of Micron³ with Class C fly

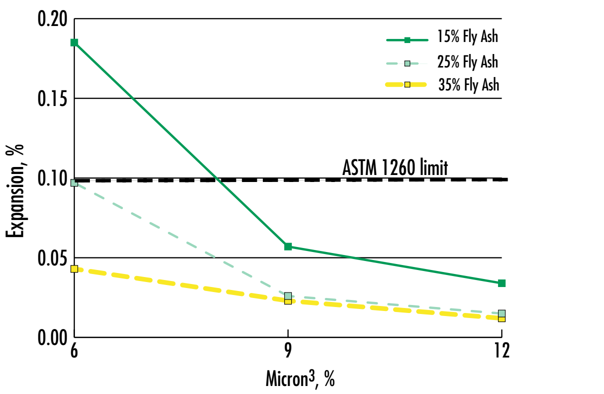


Figure 3. Use of Micron³ to Achieve ASR Resistant Class C Fly Ash Concrete (ASTM 1260)

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ash for efficiently controlling ASR. It can be observed that about 6-8% Micron³ is required to achieve ASR resistant concrete, depending on the dosage of Class C fly ash.

### Sulfate Attack

Sulfates from ground water and other sources may react with calcium aluminate hydrate and calcium hydroxide, formed during the hydration of cement, to form ettringite and gypsum, respectively. Ettringite may cause expansion and cracking while gypsum can lead to softening of the cement paste, reducing concrete strength. The use of Micron³ mitigates sulfate attack by reducing permeability and inhibiting the ingress of sulfate ions. Calcium hydroxide is also consumed during the pozzolanic reaction. ASTM C 1012 tests were conducted with various dosages of Micron³ using a high C3A cement. Eight percent Micron³ achieved "high sulfate resistance" (<0.10% expansion at 1 year) whereas 12% Micron³ resulted in "very high sulfate resistance" (<0.05% expansion at 1 year). Testing was also conducted using a Type I high alkali (HA) cement. These results are plotted in Figure 4.

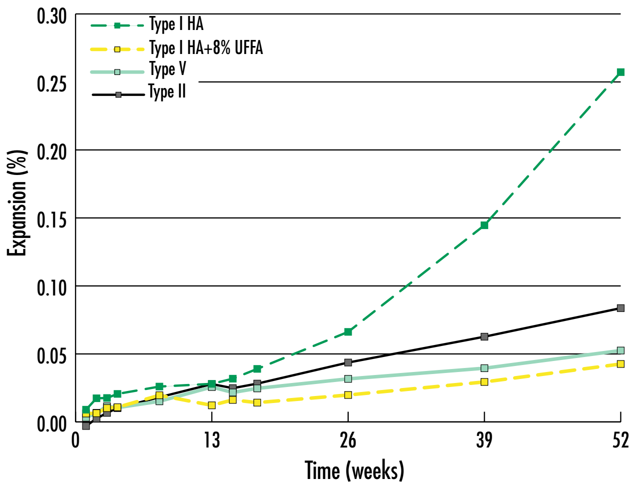


Figure 4. Use of Micron³ to Improve Sulfate Resistance (ASTM 1012 test results)

Figure 4 demonstrates that 8% Micron³ with Type I HA mix outperformed the Type V cement mix. Micron³ gave a "very high sulfate resistance" whereas Type II and Type V mixtures only gave "high sulfate resistance." Type I HA cement by itself gave only "moderate sulfate resistance" (<0.10% at 6 months). Thus, Micron³ may be used with a Type I cement to achieve similar sulfate resistance as Type V cement.

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### Summary

1. The use of small amounts of Micron³, as a cement replacement, significantly reduces chloride ingress in concrete, thereby increasing the time to corrosion initiation of reinforced concrete structures. 9.5% Micron³ achieves similar chloride diffusion coefficients as 8% silica fume in concrete mixture at the same w/cm. If the water reducing properties of Micron³ are taken advantage of, then parity would be attained at similar dosages as silica fume.
2. Micron³ increases the concrete resistivity significantly, thus reducing the rate of macrocell corrosion.
3. Due to the increase in time to corrosion initiation, and the reduction in corrosion rate (after initiation), the use of Micron³ will significantly increases the service life of reinforced concrete structures.
4. Micron³ may be used to effectively increase concrete's resistance to ASR.
5. Micron³, along with a Type I cement attains better sulfate resistance than Type V cement alone.

### References

1. Obla, K.H., Hill, R., Thomas, M.D.A., and Hooton, R.D., "Durability of Concrete Containing Fine Pozzolan," PCI/FHWA/FIB International Symposium on High Performance Concrete, Orlando, FL, September 25-27, 2000.
2. Ozyildirim, Celik, "Effects of Temperature on the Development of Low Permeability in Concrete," Virginia Transportation Research Council, VTRC 98-R14, Charlottesville, Feb. 1998.