MOISTURE IN CONCRETE

By Roy Cannon

CONCRETE CONTRACTOR®

Used all over the world as a structural component in commercial and residential buildings, pavements, roads, bridges, etc., concrete's use has stood the test of time with awe-inspiring constructions like the pyramids, ancient Greek and Roman structures, the Great Wall of China and more. These buildings prove concrete's longevity, versatility, strength, durability and resilience. Yet, they're made of the same three key ingredients: cement, aggregate and water.

Modern concrete can take advantage of various additives to aid in the water/cement ratio. It's the addition and the chemical reaction of water that makes it both concrete's best friend — and worst enemy.

Excessive internal moisture sources can cause coating failures, blistering, discoloration, bubbles (or pop outs), cracks, delamination, efflorescence, mildew or mold development — negatively affecting the structure's long-term durability and more.

To protect concrete structures from deterioration and avoid issues due to excessive internal moisture and other harmful chemicals, one must understand the factors involved, be aware of the situation at hand, and know what can be done.

Prevention is better than a cure.

CONTENTS

WHAT IS MOISTURE CONTENT IN CONCRETE & WHY IT MATTERS

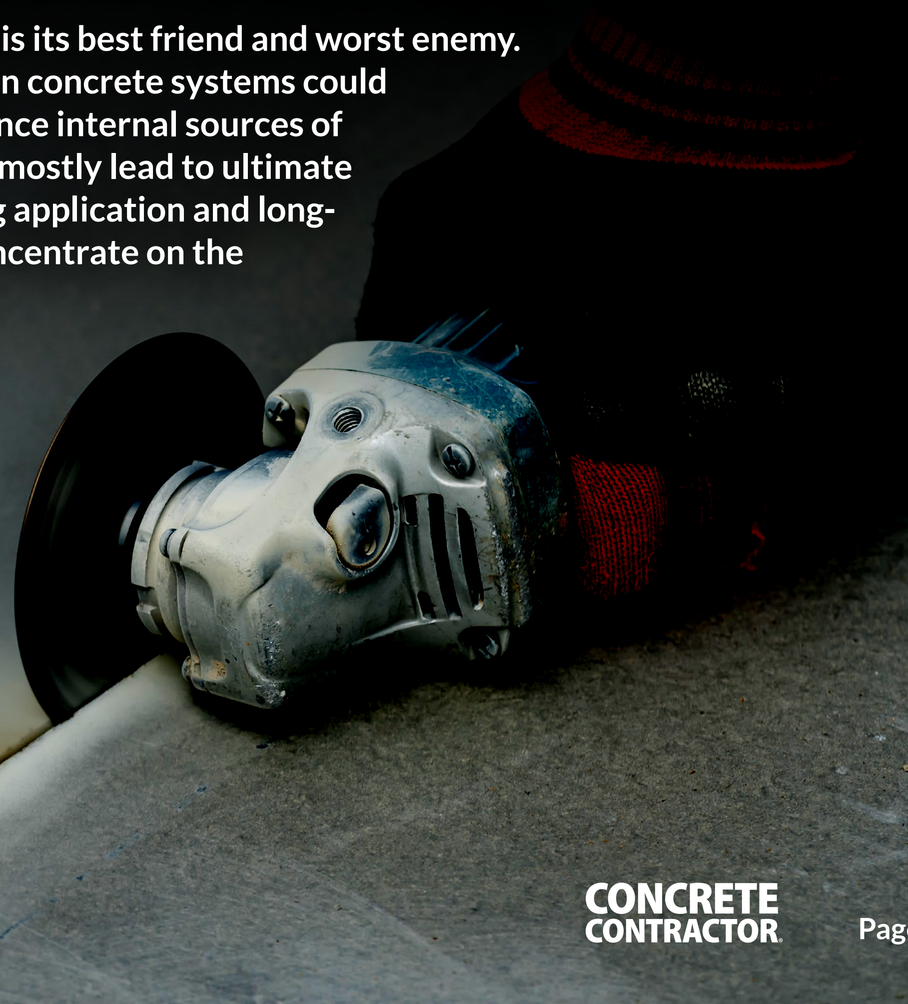
Unless you're working with ideal conditions, moisture content in concrete will likely be an issue. It's helpful to understand what's happening below the surface.

- Problems & Challenges
- The Science

An approximately 2,000-year-old technology, concrete is used as a structural component in commercial/residential buildings, pavements and driving surfaces of bridges and roads. From earlier use in the Great Pyramids at Giza and the Great Wall of China to modern 3D Printed buildings, concrete is currently being utilized due to its longevity, versatility, strength, durability, in-service energy efficiency, resilience, and economical benefits compared to other masonry composites and/or building materials. However, concrete is not maintenance-free.

Moisture is one of the major concrete system enemies.

Water, the lifeblood of concrete is its best friend and worst enemy. Moisture sources and presence in concrete systems could be both external and internal. Since internal sources of moisture in concrete structures mostly lead to ultimate coating failures, including during application and long-term durability, the goal is to concentrate on the latter (internal) water source.



PROBLEMS & CHALLENGES OF INTERNAL CONCRETE MOISTURE

Modern concrete is a product of a chemical reaction between mixtures of cement binder, water, sand aggregate, and various additives. While water is a necessary and critical component in concrete mix formulas and is needed to ensure strength and durability, inaccurate water concentrations may be the source of poor concrete performance. A higher water-cement ratio (increase in the water content in concrete) tends to make weaker, more permeable, and less durable finished concrete structures.

The second influence of internal concrete moisture is associated with the curing process and the speed of drying at the concrete surface. Excessive water evaporation at the concrete surface can lead to some significant problems in the application of coatings, including adhesive failure, blistering, discoloration, bubbles/ pop-outs, cracks, delamination, efflorescence, mildew/ mold development, etc. These are the results of a water-starved concrete surface reaction leading to weak and substandard surface cures.

The infiltration and absorption of water into concrete coupled with freeze-thaw cycling and associated expansion with internal ice formation will lead to the creation of cracks, corrosion of internal steel, and disintegration in concrete structures. Moisture vapor migrating through the slabs can also cause "efflorescence" or powdery crystalline deposit of salts on unsealed concrete.

Ideal conditions for concrete coating applications would require placing concrete (with 0.45-0.50 water/cement ratio) on a true vapor barrier that cures in 3-7 days using a method that retains original water percentage without adding additional water from external/ internal sources. However, the chance of all these conditions being met is highly unlikely in most construction projects (Craig, 2003).

"Ideal conditions for concrete coating applications would require placing concrete (with 0.45-0.50 water/cement ratio) on a true vapor barrier that cures in 3-7 days using a method that retains original water percentage without adding additional water from external/ internal sources."

UNDER PRESSURE

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Moisture content in concrete is all about water and pressure. The appropriate amount of water is needed to avoid excess pressure that may force any unreacted moisture to the surface of concrete and create a non-conductive substrate condition ultimately leading to coating adhesion failure.

It may take up to several weeks for concrete to cure depending on the thickness and environmental conditions (humidity, ambient temperature, etc.). The concrete continues to dry through moisture vapor transmission over time by drawing moisture up through capillary action to the slab surface (Sicilia, 2014).

A term used to inadvertently describe a very rare concrete moisture problem is “hydrostatic pressure”—a fluid exerted pressure caused due to the force of gravity at equilibrium at a given point within the fluid. Due to the increasing weight of fluid exerting downward force from above or the process of water being pushed through the below-grade concrete slab, hydrostatic pressure increases in proportion to depth measured from the surface. Hydrostatic pressure can result in humidity and water leaks leading to ultimate coating failure (Kater, 2020).

However, hydrostatic pressure and coating moisture tolerance are two separate effects of water on a coating system. Simply put, moisture tolerant products do not rely on atmospheric moisture/ humidity during the application process (do not react poorly to moisture during application).

On the other hand, hydrostatic pressure is a strong destructive force related to effects on the coating after application and curing, that can cause coating failure/ delamination through the moisture/ water vapor movement in the slab, typically by a moisture source located in the bottom of the slab. This migration of moisture may cause blow-offs or blisters on low moisture vapor permeable membrane surfaces by being trapped beneath an impermeable film on the surface (Josephsen, 2010).

HOW TO TEST FOR MOISTURE CONTENT IN CONCRETE

Five proven methods on conducting the moisture content test in concrete and what you need to know before coating the surface.

- Methods of Measuring Moisture
- Procedures
- Practice

Concrete is essentially a product of a chemical reaction that occurs after mixing cement powder, water, sand, and aggregate together to form a solid substrate. Internal moisture content in concrete presents a potential threat for concrete coating application processes and also, in long-time durability aspects. It is essential to determine the moisture source and level to avoid any moisture-related coating/waterproofing problems via moisture vapor transmission rating testing.

When measuring concrete moisture content, it is paramount to understand that moisture content (the process of measuring concrete surface moisture at a moment in time) and water vapor transmission rate (tests conducted over time) are two different processes. Water vapor transition rate (WVTR), also known as moisture vapor transition rate (MVTR), is a measure of the passage of water vapor (or gaseous form of water) through a material or barrier over a specific period of time. The most common international standard of measurement for MVTR is g/m²/24 hours. In the USA, the unit g/100-in.²/24 hours (which is approximately 1/15 of the value of an internationally used unit) is also used.

For the installation of resilient concrete floor covering with a coating or sealer, ASTM F1869 recommends an MVTR of 4 lbs./24 hours/1,000ft² or less. For higher than allowable level of MVTR, an appropriate moisture vapor barrier (like Pecora's Pecora Dynapoxy Healer/Sealer or the Pecora Dynapoxy Low-Mod Epoxy) should be applied over the concrete slab to block moisture from below, which could ultimately cause problems for coatings and floor covering materials.

It is not improbable that concrete may pass the former (moisture content) test while failing the latter (moisture vapor transmission rate) test (Raglani, 2018).

The first step in the Rubber Mat Test is to tape and seal a rubber mat or polyethylene sheet to the concrete surface for 16 hours or more.

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5 METHODS IN TESTING MOISTURE CONTENT

Construction and concrete protective coating professionals have used a variety of test methods to determine moisture levels in concrete. There are a few methods employed in measuring cured concrete moisture contents:

Method 1: Rubber Mat Test (Qualitative - Water Vapor Transmission Rate)

This qualitative test is conducted to determine the presence of capillary moisture in concrete per ASTM D4263 qualitative test methods when surface and ambient temperatures are within the recommended application temperature for the coating system.

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The Procedure:

1. Tape and properly seal approximately 12 x 12 in. rubber mat or polyethylene sheet to the concrete surface and allow it to remain in place for >16 hours.

2. After 16 hours, remove the mat and observe the underside of the mat and the concrete surface.

3. While slight amounts of moisture on the mat are normal and are to be expected, actual beads of water indicate the concrete is too wet for moisture-sensitive coatings to be applied.

Method 2: Anhydrous Calcium Chloride Method (Quantitative – Water Vapor Transmission Rate)

This quantitative surface-based moisture test method is used to determine the moisture vapor emission rate (MVER) from a concrete slab per ASTM F1869-11: Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride. The amount of MVTR by the concrete surface is measured in terms of (pounds of water/day/1,000ft.2). According to ASTM F1869, the acceptable MVTR should be <3-4 lbs./day/1,000ft.2 unless otherwise mentioned by coating or flooring manufacturers.

The Procedure:

1. Seal a small dish of calcium chloride on a clean section of concrete under a plastic dome.

2. Allow the salt to absorb moisture in that environment (presumably coming from the concrete slab) for three days.

3. Calculate the MVTR from the weight gain after the three days.

While the method is still used by many adhesive and flooring manufactures, it is easily affected by ambient conditions and can potentially give misleading results (Spangler, 2021).

Method 3: Internal Humidity (Indirectly Quantitative - Moisture Content)

This procedure is used to determine the moisture level on the internal structure of concrete. The results are expressed in percentage per ASTM F2170: Relative Humidity (RH) Using In Situ Probes.

The Procedure:

1. Drill holes into the concrete to a specified depth and insert liners into the bottoms of the holes.
2. Cap holes for 72 hours to equilibrate, then insert the probes (at 40% depth of the concrete) to take RH readings.
3. Acceptable RH is <80%.

Method 4: ***Surface Moisture Content (Conductivity - Indirectly Quantitative Using Electronic Meters – Surface Probes)***

This test method covers the quantitative determination of percent relative humidity above the surface of concrete floor slabs for field or laboratory tests per ASTEM F2420-05: Determining Relative Humidity on the Surface of Concrete Floor Slabs Using Probe Measurement and Insulated Hood. This method measures relative humidity directly above the porous surfaces of a floor slab. It is employed for moisture/humidity testing of concrete slabs affecting the performance of flooring systems due to moisture permeating from the concrete floor (Tolson).

Method 5: ***Internal Moisture Content (Conductivity - Indirectly Quantitative Using Electronic Meters, Sub-surface Probes)***

This method involves the use of an electrical conductivity (resistance) moisture meter to utilize conductivity to determine moisture content, as described in Appendix X2.4 of ASTM F710, Preparing Concrete Floors to Receive Resilient Flooring (Trimber, 2021).

The Procedure:

1. Push two contact pins on the end of the instrument against the surface.
2. Measure the relative moisture content (on a relative scale of 1 to 100) of the concrete between the pins.

PUTTING IT INTO PRACTICE

Prior to surface preparation for coating, it is essential that all concrete is visually inspected for defects, physical and chemical damage, contamination, and excess moisture. Some surface cleaning methods include vacuum cleaning, air blast cleaning, water cleaning, mechanical surface preparation (shot blast), chemical cleaning, acid etching, etc. per ASTM D4258, Surface Cleaning Concrete for Coating.

Surface moisture can interfere with the initial cure and result in adhesion loss in some coatings. Before applying a coating, the concrete surface should be clean, dry, and free of frost and it must be confirmed that the slab is internally adequately dry (with a moisture meter or plastic mat test) per ICRI Guideline 310.2 and ASTM D4258, Surface Cleaning Concrete for Coating describe the cleaning methods (Trimber, 2021). A moisture test should be performed regardless of concrete's age (new or renovation) because a major moisture problem could be hidden within the concrete's porous composition (Sicilia, 2014). The most effective, practical, and widely utilized method of concrete moisture testing procedure is a qualitative rubber mat/plastic sheet test taped to the concrete deck or floor systems (see Method 1).

The migration of moisture from the concrete may cause bubbling or "fisheyes" (also known as outgassing) in single component moisture-dependent cure polyurethane (PU) coatings. Isocyanates react with water (if present in the reaction mixture) to form a urea linkage and carbon dioxide gas, creating a potential for foaming, blistering, or delamination of the applied coating under certain adverse condition. This carbon dioxide acts as a blowing agent.

CO2 evolution in single-component PU coatings: $RNCO + H_2O \rightarrow RNH_2 + CO2$

The presence of solvents in the coating system may also produce blistering if trapped within a fast-curing moisture-cure polyurethane coating.

Once the coating cure process is complete moisture may become trapped under the coating surface, causing disbandment as moisture migrates to the surface and out of concrete. The strong vapor drives or hydrostatic pressure can exceed the coating adhesion strength and the concrete's tensile strength. To minimize these problems coating manufacturers, use penetrating primers or moisture mitigation primers/penetrating coatings to create a strong barrier to any moisture or moisture vapor drive that could occur during a sharp rise in the concrete slab temperature. This condition is made worse in unvented or otherwise encapsulated concrete slabs, i.e. between slab membranes, unvented metal pans. In addition, to prevent coating failure on concrete where water continues to enter, investigators proposed the following solutions:


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Non-continuous (through environmental factors) sources of water may be removed from concrete through ventilation, heating, and desiccant dehumidification processes. The amount of time needed to remove concrete's moisture content is dependent upon a few factors, including concrete thickness, density, moisture content, surface, ambient and dew point temperatures, etc. (Schnell, 1998).

To treat the moisture blister problem after it occurs, it is recommended to cut out these blisters and leave the void open to allow the moisture to escape. After the moisture has escaped and the surface has dried, necessary repairs can be made.

- **PENETRATING SEALERS:** These create a vapor barrier on the surface, as result, moisture is not permitted to escape.
- **LATERAL TRANSFER SYSTEMS:** These allow the moisture to travel laterally between the concrete and the finish coating and escape at the perimeters.
- **BREATHABLE COATINGS:** These are used on non-immersed surfaces when considering chemical or abrasion resistance non-factors. (Schnell, 1998)

AVOID MOISTURE CONTENT IN CONCRETE

Understand these four common types of commercial coatings you can use to protect your concrete from moisture content.

- Moisture Mitigation
- Coatings
- Proving Success

In a commercial, residential, and industrial sense, moisture mitigation refers to the process of reducing or eliminating the effects of moisture on concrete slabs. Moisture mitigation can be employed in both concrete wall and floor systems (especially with floor systems due to the fact that concrete floor slabs are more prone to contain an excess amounts of moisture. Designers and contractors can follow two approaches to avoid excessive moisture levels in new and renovated concrete construction projects: topical applications and alternative breathable finishes/admixtures.

Non-cementitious polymeric commercial protective concrete coatings were designed to protect concrete structures from deterioration and prevent damage from moisture and other harmful chemicals.

Topical moisture mitigating products are generally based on low viscosity epoxy-based compounds which fully penetrate and encapsulate at the concrete surface. However, there are multiple factors that can cause failure to moisture mitigating or retarding barriers. For instance, the permeability of the moisture mitigating coating must be less than that of the overlaying traffic coating to avoid entrapment of any moisture vapor passing through the moisture mitigating coating and subsequently becoming trapped beneath the traffic bearing coating system which may ultimately lead to adhesive failures of the traffic bearing coating system.

To reduce moisture vapor emissions and to minimize issues associated with effectively applying moisture mitigating coatings, some manufactures created admixtures for the concrete. According to the American Concrete Institute 212.3 R-10, “Report on Chemical Admixtures”, three categories of admixtures can lead to a reduced concrete permeability: hydrophobic or water repellent admixtures; mineral fillers such as talc, bentonite, and clays; and crystalline admixtures (Ross, 2020). However, some of these admixtures could lead to less porous concrete, leading to adhesive failure in floor finishes.

Since both topical and alternative breathable/ admixture moisture mitigation products are associated with major failures, to help select, review, and install moisture mitigation products, designers and contractors must rely on ASTM F3010, Standard Practice for Two-Component Resin Based Membrane-Forming Moisture Mitigation Systems for Use Under Resilient Floor Coverings, published in July 2013 (Hopps, 2014).

4 TYPES OF COMMERCIAL CONCRETE COATINGS

In commercial applications, coatings protect concrete and internal steel reinforcements from

deterioration by preventing the intrusion of water and soluble contaminants (oil, chemicals, fuel, salts), which can lead to premature degradation. The term “concrete coating” essentially means a liquid or semi-solid membrane or layer applied to concrete for aesthetic purposes or to provide protection against heavy traffic, abrasion, chemicals, moisture exposure, and the effects of water penetration.

The concrete slab must be thoroughly dry prior to coating installation. It is important to consult a moisture meter or perform a plastic mat test to ensure <5% moisture content on concrete over unvented slabs or split slabs with buried membrane and <12% moisture content on “on-grade” or vented slab concrete surfaces to maintain a proper installation. Freshly mixed concrete typically

contains 33 weight percent of water (0.5 lbs. water for every 1 lb. cement). For long-term performance of a commercial coating, most concrete coating applications require less than 5% moisture (Raglani, 2018)**.**

Four commonly used *commercial concrete coatings* fall under the following chemistry classifications: Acrylics, Epoxies, Polyureas, and Polyurethanes.

1. **Acrylics are water or solvent-based (in many cases low solid content) sealers applied approximately 2-3 mils per coat. Acrylics' low VOC content, good color, and gloss retention, economical aspect, flexibility, weatherability, low flammability, and reduced odor make them excellent coating solutions. However, downsides of using acrylics include limited durability, poor chemical, solvent, immersion resistance, limited coating thickness, easy crack-formability, etc.**
2. **Epoxies are multi-component materials with a polyamide curing agent applied in approximately 1-3 coats, typically used in concrete floors, such as a traffic-resistive decorative coating in both commercial and residential settings** (Balogh, 2020)**. Low VOC content, good solvent, chemical, and water resistance, rapid curing time make epoxies an excellent choice in concrete protection. However, some**

"The best approach to prevent concrete slab moisture-related failures would be to design and construct concrete slabs where ground moisture or other moisture sources are not a threat."

drawbacks including limited pot life, poor UV resistance/chalking, poor flexibility make them less than ideal choices in concrete waterproofing protection.

3. **Polyureas** (share some characteristics with two-component polyurethanes) can be applied to full-thickness in one coat and are popular in the market because of their super-fast setting time. Some advantages of polyureas include flexibility, chemical, damage and abrasion resistance, UV stability, and fast curing. General limitations of polyurea include non-economical (compared to epoxy) due to the professional installation requirement for maximum performance, strong odor, non-breathable (Sanchez, 2021).
4. **Polyurethane coatings** are usually multilayer coatings, designed to provide specific properties that enhance the quality of the total system and to prevent water from entering the surface to which they are applied while providing a safe (nonslip) surface with pleasing aesthetics. Polyurethanes are generally non-yellowing, elastomeric, UV, chemical, acid, and solvent, scratch, and abrasion-resistant. However, some of their limitations may include, primer requirement, needing proper ventilation and respiratory protection during application, toxic, strong odors, etc. Limitations of polyurethane-based coatings are highly formulation dependent and vary between manufacturers.

PROVING SUCCESS

Selecting appropriate product and contractor are essential in moisture mitigating process to avoid any major coating related issues later on. To employ a proper moisture mitigation process, it is important to follow the steps below:

- Appropriate moisture barriers, such as a moisture mitigating penetrating epoxy-based coating (like Pecora Dynapoxy Healer/Sealer) and/or a low modulus epoxy binding agent (like Pecora Dynapoxy Low-Mod Epoxy) should be used in case of any significant moisture mitigation needs.
- To evaluate the moisture content, select the appropriate concrete moisture testing method.
- Always consult with the coating manufacturer when addressing moisture mitigating processes to ensure appropriate application procedures and materials are being utilized.

PREVENTION IS BETTER THAN CURE

The best approach to prevent concrete slab moisture-related failures would be to design and construct concrete slabs where ground moisture or other moisture sources are not a threat. However, it is highly unlikely to achieve an acceptable level of internal moisture through a natural drying process due to many factors including scheduling, timing, and environmental factors. As a result, moisture control systems (i.e. industrial coatings) are employed to control water-related issues. Manufacturers, owners, contractors, and designers are often faced with serious moisture-related issues when it comes to the application of moisture control coatings over concrete slabs on both new construction and restoration projects. Because of the problems that can occur during coating applications when excessive moisture is present in concrete, it is advisable to take preventive measures before the application of a protective coating system.

Despite concrete's durability and strength, its porosity makes it permeable to fluid and vapor infiltration and migration. Selecting the right product for concrete protection, moisture mitigation, and traffic bearing purposes is key to avoid any future water-related problems associated with concrete coating failures. ■

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ABOUT THE AUTHOR

Roy Cannon is the Director of Construction Materials Technology at Pecora Corporation.
He provides strategic and tactical oversight for overall corporate construction materials technology. Primary construction product lines include waterproofing components related to new construction and restoration of commercial building facades and horizontal concrete applications, i.e., expansion and control joint sealants, elastomeric liquid applied waterproofing membranes, pre-formed extrusions and flashings, and air and vapor barriers. Primary chemistries utilized are Silicone, Urethane, Latex and STPU's.

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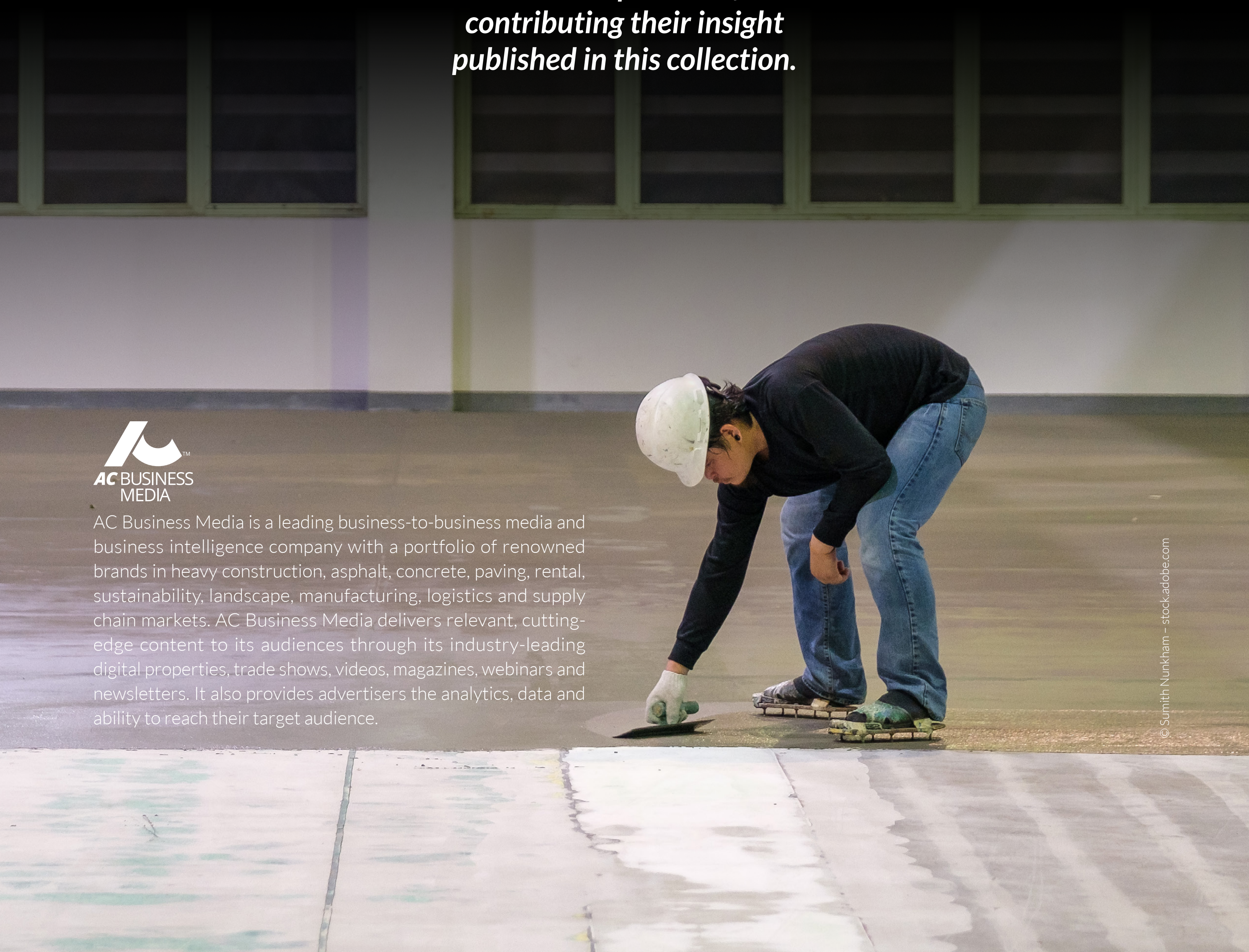

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