Building With Concrete

Design and Construction Techniques

Shrinkage-compensating concrete was used for the waffle ceiling at this Washington, D.C., Metro station. Most concrete shrinks about 0.04% after 28 days.

By C.C. Sullivan and Barbara Horwitz-Bennett

Concrete demands energy and natural resources, a careful design approach, and ongoing maintenance once it is put in place. In this way it is unlike many other structural and finish materials—yet it maintains a special reputation for strength, durability, flexibility, and sustainability. These associations and a host of other factors have made it one of the most widely used building materials globally in just one century.

"The use of concrete for new construction is an environmentally responsible choice that provides building owners with energy-efficient buildings by combining insulation with high thermal mass and low air infiltration and providing occupants with optimal comfort and health," says Lionel Lemay.[1]

Whether it's cast-in-place, tilt-up, insulated concrete forms, or precast, the use of concrete is a common sight on most construction jobs. As varied as the construction techniques are the different forms of concrete available. The trick to making them all work, however, is correctly proportioning and mixing the

Learning Objectives

After reading this article, you should be able to:

- ✔ Describe the various uses and applications of concrete in commercial building.
- ✔ List the various types of materials and admixtures found in concrete mixes, including supplementary cementitious materials, or SCMs.
- ✔ Understand how concrete specification affects such construction methods as pumping, placing, and forming.
- ✔ Explain the advantages and applications of such methods as tilt-up, ICFs, and precast concrete for building construction and operations.

ingredients in order to achieve optimal strength and workability.

Mixed on-site, a typical ready-mix formula comprises 10-15% cement, 60-75% percent aggregates, and 15-20% water, by volume. Entrained air bubbles sometimes take up an additional 5-8%.[2]

However, when Building Teams wish to account for different on-site variables that can affect the outcome of the mix—factors such as such as temperature, humidity, and level of craftsmanship—controlled manufactured options take on a special appeal. Precast concrete products, for example, are recognized for their high level of material quality and uniformity.[3] With prefabricated units, construction schedules may also be sped up because fewer on-site steps are involved. Similarly, concrete masonry can serve as a building block for such applications as interior and exterior walls, partitions, terrace walls, and other enclosures. Such applications are increasingly appealing in terms of architectural aesthetics and are being offered in a wide variety of sizes, shapes, colors, bond patterns, and surface finishes.[4]

Concrete is also an effective choice for horizontal applications. Gravity works for the project during the pours and concrete's compressive strength benefits the building owner during the structure's operational life. Concrete masonry unit (CMU) options include snug-fitting modular pavers, which are often shown to be stronger and more durable than poured concrete options. These include *soil-cement*, which is most commonly used as a capping layer or low-grade sub-base beneath flexible pavements, and *roller-compacted concrete*, which is more durable and capable of supporting heavier loads, such as heavy-duty parking and storage areas.

Concrete also offers a number of advantages over asphalt. "With asphalt prices up 400% from a decade ago, concrete has become competitive on first cost, and even more so when life cycle costs are compared," says Len Swederski.[5] "Concrete paving also offers many environmental benefits, as well as added LEED points."

Whitetopping, which is the placement of a concrete overlay on top of existing asphalt or concrete pavement, will typically last two or three times longer than an asphalt overlay.

Concrete's light-colored surface also contributes to reducing the *urban heat island effect*, lowering localized ambient temperatures, and downsizing lighting requirements. A Portland Concrete Association study that analyzed the light required to achieve the same luminance levels for a concrete and asphalt parking lot concluded that 41% less energy was required to illuminate the concrete surface than the asphalt one. "With the assumption that an average parking lot lighting system operates up to five hours per day, in one year the asphalt parking lot would consume 60% more energy than the concrete parking lot," notes Lemay.

Another concrete pavement product, *pervious pavement*, is a porous concrete that allows rainwater to flow through it directly into the underlying soils. "This method replenishes our underground aquifers, filters out pollutants, reduces water runoff into our rivers and streams, and can allow more efficient use of a congested building site by eliminating detention and retention ponds and their maintenance," explains Swederski, who has been running his own firm for the past 24 years.

A case in point, adds Lemay, a recent study performed at the University of Central Florida analyzing the infiltration rates and the stormwater quality in a pervious concrete reservoir found that the water quality at the bottom of the concrete reservoir was superior to the runoff water quality from the adjacent impervious surface areas.

These before-and-after construction shots show self-consolidating concrete placed in a tall and slender pour with congested reinforcing steel.

MANUFACTURING CONCRETE

Having a clear picture of how concrete is made is a significant advantage for all members of the Building Team. In general,

During the concrete pour for this condominium development with below-grade parking in Southern California, the wall is shown being placed directly against the form. By mixing Shotcrete with an integral waterproofing admixture, the need for a waterproofing membrane was eliminated and construction was sped up.

once the cement and aggregates are combined, the mixture remains in a fluid state for four to six hours, during which time it's transported, placed into forms, compacted, and finished before it begins to harden.[6]

The two basic categories of aggregates are "fine"—made up of natural sand, manufactured sand, or a combination of the two—and "coarse," consisting of either gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, crushed concrete, or various combinations of these ingredients.[8]

Supplementary Cementitious Materials (SCMs)

A brief glossary of common SCMs:[7]

- Fly ash – One of the by-products of burning coal to create electric power.
- Slag – A by-product from production of iron and steel. Because the demand for the product is rising while the supply is falling, new grinding plants are coming on line to process imported slag.
- Silica fume – Once a cheap waste product, high demand has made it a high-cost admixture, used primarily for structures where top weathering performance and high strength are needed.
- Rice hull ash – Still in the laboratory stage, rice hull ash shows promise once a consistent-quality ash becomes available.

Chemical admixtures, such as superplasticizers or accelerants, can also be added to improve the properties of the concrete. For example, admixtures can be used to modify the rate of setting and strength development of concrete, which is very helpful in hot and cold weather conditions. Perhaps the most commonly used admixture is an air-entraining agent, which lends more durability to concrete when exposed to freezing and thawing cycles.[9]

Although concrete is made from many natural and recyclable ingredients, the cement that binds the ingredients in concrete produces a significant carbon footprint during its production. Portland cement emits almost a ton of CO_2 per ton of product, with only half of the greenhouse gas emissions coming from the energy used in the process, explains Michael Chusid.[10] "Consequently, even a more energy-efficient kilning process can never address even half of the CO_2 problem. This constitutes a strong incentive to identify other cementitious materials," he says.

This is where supplementary cementitious materials, or SCMs, come into play. Up to 25% content of slag or fly ash (or a combination of the two) can be added to a concrete mix to help offset raw materials from being extracted and shipped, notes Jay Womack.[11] "The benefit of slag is a whiter concrete color, which will increase the solar reflective index and thus help alleviate urban heat island," he says.

Lemay points out that the slag and fly ash used in concrete would otherwise end up in landfills. Instead, he says, "SCMs can work in combination with Portland cement to improve strength and durability, in addition to reducing the CO_2 embodied in concrete."

PUMPING, POURING, AND PLACING

Once a cement type is chosen and prepared, the action then moves to the job site. "The project's best chances for success occur before arriving on site," says Jeff George.[12] "Pre-planning gives the opportunity to eliminate schedule times, save on general conditions, produce better quality work, and plan safety into the job." In other words, "Build it on paper before showing up with a hammer and nails," says George.

He explains that concrete pumping is of critical importance to the entire Building Team. The nature of the concrete mix, hose size, and distances required are all interrelated:

- Hose size dictates the size of the aggregate required to fit through the space.
- The distance from the mixing plant to the job site dictates which admixtures will be needed in the mix, which can increase costs.
- The further the distance from the plant to the pump point, the less aggregate volume that can be allowed.
- The less aggregate that is allowed, the greater the amount of cementitious materials required to achieve strength.

• The greater the amount of cementitious materials used, the hotter the concrete becomes.
• The hotter the concrete, the more cautious the Building Team needs to be when placing and finishing the concrete.

When dealing with high temperatures , George recommends the use of superplasticizers and retarders along with fly ash or slag, which can reduce friction in the hose. "Other considerations consist of cooling of the aggregates with a sprinkler system at the plant before loading, or early-hour pours to avoid the heat of the day, as well as using ice to cool down the mix," he explains.

Dealing with lightweight concrete also demands special care, according to Dennis Ahal.[13] "Because the porous coarse aggregate that contributes to the lower density also results in absorption of water as the concrete passes through the pump line, if steps aren't taken to reduce this absorption, line blockages can cause placing delays," says Ahal.

In the case of concrete containing mid-range water reducers, it falls on both the specifier and concrete producer to ensure that there is still enough unabsorbed mixing water to compensate for movement of water into the pores of the coarse aggregate during pumping. Otherwise, explains Ahal, "slump loss can be excessive and also result in line blockages."

Ahal, who has been working as a concrete contractor and pumper for the past 40 years, stresses the importance of teamwork and collaboration. "A successful pumping experience is usually the result of teamwork among the specifier, concrete producer and lightweight aggregate supplier, the concrete pumper contractor, and the testing agency."

One noteworthy timesaving advance in concrete pumping technology is the use of *self-jacking placing booms*. "Usually we have to pick the placing boom with the tower crane after every pour to set it for the next elevated pour, but with the self-jacking boom, it jacks itself into place without the assistance of the tower crane," says George.

Once the concrete is placed in molds or forms, mechanical vibrators are then used to help the concrete spread to all corners of the mold and release trapped air pockets, according to Chusid. While water will help the concrete to flow, too much water weakens the concrete, so a delicate balance has to be achieved.

Air-entrained concrete. There are times when air is a desirable part of the mix, says Steven P. Osborn.[14] "Air-entrained concrete is important for exterior applications that are exposed to freezing and thawing," he says. "Adding air to the concrete creates microscopic voids that allow moisture to expand during freeze/thaw cycles, which helps avoid damage to the concrete."

However, air-entrained concrete does require special finishing, according to George: "It is preferable to use a rough or broom finish to prevent blistering from the air in the concrete on the surface of the slab. When finishing an air-entrained slab, the surface water must be allowed to dissipate. An air-entrained surface can fool the finishers to get on the slab too early and harm the final finish."

Other technical considerations, according to Steven Osborn[15], include:

• *Structural systems.* Good detailing for proper location of joints is essential to allow for expansion and contraction from shrinkage and thermal change. This helps minimize cracking and improve overall performance.

• *Pre-made openings.* If openings are punched in wrong locations, the problem can only be rectified by core drilling or major excavation, especially in post-tensioned and prestressed concrete. Obviously, this is costly and wasteful, and points out why effective coordination between the trades is a must.

• *Connections, bracing, and reinforcement.* Mechanical connections need to be properly detailed and protected against corrosion.

• *Concrete reinforcing.* Again, good detailing is essential to facilitate proper vibration and avoid congestion of reinforcing steel, so that concrete easily flows between pieces of rebar.

Reinforcement alternatives. When considering such reinforcement options as mesh, fibers, and steel, Osborn suggests fiber micro-reinforcement to control shrinkage and cracking in slabs-on-grade. For hardened structures, he likes to go with steel fibers in combination with reinforcing steel for improved durability. For heavier load applications, structural engineer Osborn finds that steel plate dowels and load plate baskets provide better load transfer than welded wire fabric or traditional round dowels.

The use of wire mesh is common, but Osborn cautions that the placement of rolled welded wire mesh can be hard to control because it has a tendency to curl. He recommends using sheets of wire mesh that are properly spliced. He notes that laborers may have to walk on the mesh before and during concrete placement, which can make it difficult for the mesh to end up exactly where it is needed.

CAST-IN-PLACE METHODS

Cast-in-place concrete is often used for slab-on-ground and foundations, using ready-mixed concrete. Cast-in-place made its debut in Chicago skyscrapers in the late 1950s and early 1960s and has become a popular choice for beams and columns, floors, walls, and even roofs.

In the case of slab-on-ground, the first step is setting up the formwork with the minimal amount of reinforcement. The PCA recommends that the speed of the concrete pour be controlled to allow the concrete to be spread, struck off, and consolidated properly.

For setting up structural members, "One face of the forms will be set and then reinforcing will be positioned using different ties and spacers. Then the other form will be set prior to casting," explains William D. Palmer, Jr.[16] Once the pour has been completed, the top is screed off to make sure it's level, the surface is smoothed, and then the concrete is left to harden and gain strength. When the concrete has hardened to the point where only a ¼-inch indent can be made by the push of a finger, it's time for trowelling to further smooth the surface for interior locations. For exteriors, a broom finish is applied, says Palmer. This is also the time to apply any decorative techniques, such as stamping or coloring.

The concrete then continues to dry and is set as the moisture more fully hydrates the cement, gaining strength and durability. During the curing process, the concrete must be treated carefully, says Palmer. "It's new and fresh and needs to be taken care of like a baby," he says. "It can't be too hot or too cold, and you don't want it to dry out."

This is especially the case when dealing with severe weather conditions. For example, in cold weather, says Palmer, hydration is very slow, which slows down the rate at which the concrete gains strength. "This is an issue with supporting loads as construction continues, so it's important to keep the concrete warm enough so that it can gain strength," warns Palmer.

At the other end of the temperature scale, hot and dry weather poses the risk that the concrete may dry out before it properly hydrates and strengthens. "Contractors will try to protect it, put up barriers, or cover it with tents to try and prevent the sun from shining on it too much," says Palmer.

TILT-UP CONSTRUCTION AND FINISHING

Introduced in the mid-1940s, tilt-up construction has become a widely accepted building technique, with more than 10,000 such buildings being erected annually.[17]

A tilt-up project begins with a site evaluation and designing and engineering the structure. Next, the footings are installed, taking care to make sure they're as level as possible, followed by double-checking the location, height, and dimensions of the tilt-up panels. When laying out the panels, the construction team commonly lines them up against a chalk line on the floor slab with bordering side forms, typically made from wood. After the panel perimeter is framed, door and window openings are formed. With greater market demand for floor slabs free of holes and patches, technology has been improving, enabling panel formation with minimal penetration of the floor slab, according to James R. Baty II.[18]

Baty says it is important to form the panels side by side, in an arrangement that maximizes the available floor area and creates a reliable panel joint design. If a patterned or textured surface is desired, the contractors will anchor reveal strips to the base slab, just before placing the reinforcement grid. Then, while the grid is being set up, embeds— pre-fabricated steel plates with lugs, which will eventually be used to connect the panel to other panels, the roof, or building accessories—and inserts, which provide attachment points for lifting hardware and braces, are installed.

After the concrete is poured and placed, the panels should be lifted using a carefully coordinated and planned lifting sequence.[19] Then, once a panel has been set but before it is released by the crane, braces must be installed to support the panel and hold it plumb. However, even though the

Mass Concrete: Best Practices

One early fall day, after a construction team from L.L. Geans Construction Company, South Bend, Ind., placed a mass concrete foundation for a project, they discovered a large number of surface cracks in the foundation. After consulting with an expert at the American Society of Concrete Contractors, the team discovered that the problem stemmed from thermal cracking as a result of the thick foundation.

"The ASCC expert told us that many mass concrete foundations built today require careful control of maximum temperatures developed within the concrete, and maximum temperature differences between the core of the foundation and the surface. When cement hydrates, it gives off heat that increases the core temperature," recalls company president Rocky Geans.

According to concrete experts, thermal cracking usually isn't a problem in thin sections because the surface and core cool at about the same rate. In a mass concrete placement, however, the core doesn't cool very rapidly and it takes a long time for the heat to come to the surface.

"The surface cools much more rapidly, especially if the air temperature is low," explains Geans's VP Mike Glenn. "That means the surface contracts due to the cooling, but the slower cooling concrete at the core restrains the contraction. Restrained contraction can cause tensile stresses that exceed the tensile strength of the concrete, and this causes surface thermal cracking."

Based on the information gleaned from the ASCC, the contractors decided to make sure that the maximum temperature difference between the core and the surface did not exceed 50ºF.

"To do this we embedded thermocouples at the center of the foundation and near the surface so we could monitor temperature differences," says Geans, who conducts technical seminars at the World of Concrete. "We then used several layers of our insulating blankets to control the rate at which the concrete surface cooled." The approach proved successful as "no surface cracks were visible when we removed the blankets, and none appeared later," according to Glenn.

braces will offer some support, "the walls must be designed to withstand temporary load conditions during construction, even before they are in their final upright position," cautions Michael Knopoff.[20]

It is important, therefore, to wait until the roof and decking are installed before removing the braces, at which point the holes can be patched up along with other finishing work. Although painting, sandblasting, and exposed aggregate finishes are all common tilt-up finishing methods, Chusid claims that they all have their shortcomings. For example, sand-and-cement sacking will only get the surface so smooth, and epoxy has workability issues. As an alternative, Chusid recommends a trowel-applied patching compound made from high-performance, rapid-setting cement. These products cure rapidly and have very low pH levels, so patching and painting can be done on the same day.

Another finishing technique is to leave the "accoutrements" of the tilt-up process in place, says Knopoff, pointing to Seattle University's Chapel of St. Ignatius, designed by architect Steven Holl, as a prime example. Knopoff says he is not alone in admiring the way Holl left the panel lifting attachment points in place and highlighted them with a decorative boss, thus "expressing the tilt-up process."

INSULATING CONCRETE FORMS

Yet another concrete construction approach, insulating concrete forms (ICFs), is commonly used for residential construction. However, these sandwiches of expanded polystyrene insulation and cast concrete also offer good project economics and energy efficiency for multifamily and nonresidential projects, notably hospitality and retail facilities. ICF construction has generally been limited to one- and two-story construction, but there have been successfully engineered freestanding, load-bearing structures as high as 48 feet.

On the job site, explains Palmer, the construction team sets the concrete forms in place, places the plastic or metal rebar within, and sets up the window and door bucks. Then it's time to fill the forms. Placement usually begins through the opening in windowsill plates. As the concrete rises, the remaining pour comes through the top of the form, in lifts of approximately four feet.[21]

However, when pumping, cautions Palmer, "The real concern is being aware how fast the concrete is being poured so that the forms aren't blown out." Don't place concrete too close to corners, openings, or thin columns, in order to not put too much stress on the forms.

In terms of cladding options, exterior finish systems such as synthetic stucco are most common, but brick can be used as well. For the interior, drywall is a popular choice, as it easily connects to attachment inserts in the ICF foam blocks.

The primary draw of insulating concrete forms, as their name implies, is the high their insulating value. "The stay-in-place concrete forms are made from an insulating material and are never removed, so they are very energy efficient and create a completely airtight wall," says Palmer.

An example of a post-tensioned slab at edge beam condition.

PRECAST CONCRETE

Unlike the ICF and tilt-up field techniques, precast concrete forms are prefabricated in an indoor, controlled environment, even though the largest structural pieces are sometimes cast outdoors. Ultimately, the quality of precast or prestressed depends on the rigor of the supplier's operations. Osborn warns that "there should be effective quality control at the plant and consistency in fabrication of the pieces so that the precast stays within industry construction tolerances for fit-up and finish."

Another advantage of precast systems is that the foundations can be backfilled as soon as the slab and first floor are braced.[22] This is because the concrete is pre-cured in the factory. Pre-curing also eliminates many problems associated with adverse weather concerns. In addition, some precast units are cast against foam insulation inside the form, much like ICFs, offering higher R-values for the structure.

There are two basic types of precast products: *standard products*, such as beams, decks, and panels that can be reused, and *specialty products*, which are customized for a particular project.[23] An important point with regard to precast construction is the fact that most of the work is done with self-consolidating concrete (SCC), which is a very workable and flowable type of concrete that can leave a smooth finished surface. With *self-consolidating concrete*, "You don't have to worry about consolidating the concrete into the forms, as vibrating can actually segregate the coarse aggregate out of the concrete," says Palmer.

Osborn also stresses the importance of careful coordination among the trades when working with precast concrete: "In addition to coordination of premade openings, the team should strive for efficiency in the use of mechanical connections, as well as proper detailing to protect against corrosion."

No matter which concrete technology you use, Osborn advises selecting a skilled, experienced concrete contractor, due to the unique construction variables inherent in the technology. For complex concrete structures, he recommends holding preconstruction meetings with the contractor, concrete supplier, quality control/testing firm, structural engineer, architect, shoring/formwork subcontractor, and pump supplier, to address potential issues early on, thus creating "a more seamless project process." Further, he calls for implementation of an effective quality-assurance plan that includes frequent jobsite visits by the structural engineer of record.

INNOVATIVE CONCRETE PRODUCTS

As noted above, self-consolidating concrete enables users to reach spots where a concrete vibrator cannot reach. "SCC does this without losing strength as other concretes do when they are runny. The aggregate is smaller as well, allowing it to reach the hard-to-reach places usually found between large amounts of rebar," notes George.

Chusid adds: "The key to SCC is the use of high-range water-reducing admixtures, also known as superplasticizers, plus other viscosity-modifying admixtures to create a concrete mixture that has high flowability without potential for segregation or the strength loss associated with adding water."

Even though the product is still considered too expensive for many typical projects applications, some concrete contractors anticipate that this will change. "I have a feeling the cost will come down and the efficiency recognition will go up, making this a real option in the future," says George.

Shrinkage-compensating concrete. Not to be confused with self-consolidating concrete, shrinkage-compensating concrete mixes expand to cancel out the shrinkage that commonly occurs during curing and which can result in cracking.

Concrete naturally shrinks an average of 0.04% after 28 days as a result of water evaporation; left unchecked, this can cause defects. "The cracks create channels through which liquids and gases can enter the concrete, leading to corrosion, freeze-thaw damage, or other deterioration," warns Chusid. "Moreover, these small cracks become points of stress concentration and propagate larger cracks, and can be aesthetically undesirable."

Shrinkage-compensating concrete is an alternative to cutting joints into the slabs to control cracking, as it expands to cancel out the shrinkage. What enables the product to expand is a

Integral Waterproofing for Thirsty Concrete

Although concrete is a very durable and widely used building material, its Achilles heel is water absorption. Applying external membranes to foundations and slabs has been the traditional approach to this problem, but the development of integral waterproofing technology at the admixture level is now seen as a viable alternative.

According to concrete consultant Steve Crawford[24], integral waterproofing offers a number of benefits:

- Reduced construction cost – Integral waterproofing is typically up to 50% less expensive than other approaches in first-cost terms.
- Speed of construction – Integral waterproofing eliminates the need for a membrane, allowing the Building Team to avoid this time-consuming step. The "pour-and-you're-done" approach can shave weeks off a construction schedule, which translates to faster building occupation, lower risk, and money saved.
- Safer working conditions – No hot rubber and less on-site labor is required. This means a lower risk of injury.
- More durable structures – Integrals, which are physically embedded in the concrete, are inherently protected from damage. Some admixtures have also shown a double benefit of reducing corrosion.

Yet another potential benefit to integral waterproofing is environmental. "Some membranes contain VOCs [volatile organic compounds], have high embedded-carbon footprints, and are often petroleum-based," says Crawford. "At the end of a building's life, those membranes are tightly adhered to the concrete, and at demolition, recycling concrete can be simply impractical." As a result, many tons of concrete head to the landfills.

On the other hand, "Newer admixtures are deemed safe for the environment, make recycling much easier, and can contribute to LEED credits on a building," says Crawford. "Buildings can literally have a green foundation."

special expansive cement, called Type K concrete, which replaces the 15% cement component in a standard concrete mix.

Ductile concrete. The defining property of this innovative concrete product is its high degree of flexibility, enabling it to bend without breaking. By manipulating its ingredients on a micro-level, performance and strength are maximized, allowing it to be used in very thin sections with less structural weight and fewer joints required, according to Chusid. Made from Portland cement, silica fume, fine aggregate, and superplasticizers, the mix is blended with either metallic or polyvinyl alcohol fibers to create a fluid, self-placing, high-performance concrete product.

Rapid-setting cements. Addressing the issue of protecting the concrete during the delicate curing process, rapid-setting cements speed up the process to ensure the concrete more quickly gains strength. In addition, its fast-drying properties make it a desired product for repairs and patchwork.

Aerated concrete. Although aerated concrete has been used in Europe since the early part of the 1900s, the blocks have only been manufactured in the United States since the mid-1990s. Offering thermal mass and acoustic insulation properties, the unique nature of aerated concrete stems from its ability to expand to five times its original volume. By adding aluminum powder or paste to the mix and then pouring it into a mold, a chemical reaction between the concrete and aluminum creates microscopic hydrogen bubbles, which cause the mixture to expand.

Concrete brick. Made from sand, crushed rock, water, and Portland cement, concrete brick is a popular alternative to fired clay brick, offering the same strength and density, according to Chusid. The concrete brick can also be made in a variety of colors through the use of pigmenting via mineral oxides.

Polished concrete. As a more sustainable and durable alternative to other floor coverings, polished concrete is becoming a popular choice for schools, retail, warehouses, and car dealerships. Offering abrasion resistance and a trendy sheen, the slab itself is used as the finished floor, eliminating the need for an added layer over the floor.

Photocatalytic cement. An environmentally geared product that protects exterior surfaces, photocatalytic cement actually "eats smog," according to Womack. Through a chemical reaction with sunlight, the cement, which can either be added to the mix or applied as a thin layer on the surface, effectively neutralizes toxic particulates.

Translucent concrete with optical fibers. This class of materials is essentially a fine concrete embedded with bundled optical glass fibers. The resulting concrete blocks and panels transmit light and allow visibility through the structural mass. Because the optical fibers only account for 4% of the total product volume, they essentially become a structural component and do not compromise the concrete's load-bearing properties.

Glass-fiber-reinforced concrete. Made from cement, sand, and special alkali-resistant glass fibers, glass-fiber-reinforced concrete or GFRC is a thin, high-strength product. Primarily for exterior use, GFRC is ideal for building façade panels, domes, columns, and other architectural details traditionally made from precast concrete, carved stone, or plaster. GFRC's main benefits include[25]:

- A higher strength-to-weight ratio than unreinforced precast concrete.
- Resistance to environmental degradation and corrosion.
- Easy workability, allowing flexibility in design. BD+C

1 Lionel Lemay, PE, SE, LEED AP, is SVP of technical resources with the National Ready Mixed Concrete Association, Silver Spring, Md.
2 According to the National Ready Mixed Concrete Association, Herndon, Va.
3 According to the National Precast Concrete Association, Indianapolis
4 According to the National Concrete Masonry Association
5 Len Swederski is president of Swederski Concrete Construction, Spring Grove, Ill.
6 According to the National Ready Mixed Concrete Association
7 From the National Association of Home Builders' online construction resource, http://toolbase.org
8 According to the Portland Cement Association, Skokie, Ill.
9 According to the National Concrete Masonry Association
10 Michael Chusid, RA, FCSI, is principal and founder of Chusid Associates, a consultant to building product manufacturers, based in Tarzana, Calif.
11 Jay Womack is director of sustainable design with Wight & Company, Darien, Ill.
12 Jeff George is VP of the commercial construction unit at Balfour Beatty Construction, Atlanta
13 Dennis Ahal is chair and CEO of Ahal Contracting Company, St. Louis
14 Steven P. Osborn, PE, SE, is president of CE Solutions, Carmel, Ind.
15 Steven Osborn is an active member of the American Council of Engineering Companies, ACI, and the American Society of Civil Engineers
16 William D. Palmer, Jr., PE, is president of Complete Construction Consultants, Lyons, Colo.
17 According to the Tilt-Up Concrete Association, Mt. Vernon, Iowa.
18 James R. Baty II is technical director of the Tilt-Up Concrete Association
19 Recommends Ed Sauter, executive director of the Tilt-Up Concrete Association
20 Michael Knopoff, AIA, is with Montalba Architects, Santa Monica, Calif.
21 According to the Insulating Concrete Form Association, Glenview, Ill.
22 According to the National Association of Home Builders' online construction resource, http://toolbase.org
23 According to the Precast Concrete Association
24 Steve Crawford is a concrete consultant based in Las Vegas
25 According to Glass Fibre Reinforced Concrete International