Concrete: A hard material engineers hope to make harder

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For thousands of years, people have built civilizations with concrete made from readily available local materials. Just mix and heat, add some sand, stone and water and put it where you want it. Of course, give it time to harden - that is, after you have left your hand print or initials.

So it's no surprise that concrete is the world's most widely used building material. Twice as much concrete has been used to build Pittsburgh - and everything else in the world - than wood and steel combined. So says concrete expert Julie Marie Vandenbossche, a University of Pittsburgh civil engineer.

But, as it turns out, there's far more to concrete than meets the eye, shoe or tire tread. How these materials glue themselves together, harden and maintain their shape over long periods of time involves common materials and complex chemistry. Various factors influence strength and durability, all the way down to the concrete's concentration of air bubbles.

It explains the continuing academic interest in concrete, with Pitt serving as a research mecca, given its team of four notable research scientists devoted to the hard stuff.

That team includes Vandenbossche and her husband, Mark B. Snyder, a concrete consultant still associated with Pitt. Add Lev Khazanovich, who holds an endowed chair in engineering and recently arrived from the University of Minnesota with a reputation for developing design

methods for high-quality, low-cost concrete pavement. Rounding out the team is another recent addition, Steve Sachs, an assistant professor in civil engineering.

Vandenbossche, who holds an engineering Ph.D., said no other university in the nation has as many researchers focused on concrete pavements.

Pitt also has an accelerated loading facility - or ALF - working steadily in Pitt's Pavement Mechanics and Materials Lab in Benedum Hall on the Oakland campus. It applies repeated, high-pressure loads on concrete slabs, simulating the physics of heavy traffic. The specialized equipment tests the strength and durability of dowel bars, which are embedded in highway concrete to transfer the load across joints. The ALF is the only such equipment currently being used nationwide to evaluate new, innovative designs and materials for long-life dowel bars, she said.

The team also continues studying concrete-pavement dynamics on Route 22 in Murrysville, with computerized equipment recording temperature, expansion and contraction, and traffic pressures and strains, all of which affect its stability and longevity. "We've used it extensively over the last 10 years," Vandenbossche said, "to study how climate changes affect the structure."

The university's importance in concrete science was most apparent this past summer when it hosted a U.S. Research Board meeting of its Standing Technical Committee on Design and Rehabilitation of Concrete Pavements in June. That meeting occurred simultaneously with the American Concrete Paving Association's mid-year meeting in Pittsburgh, followed by a meeting of the association's board of directors.

"The key to the team here is that we do impactful research in terms of concrete pavement," said Vandenbossche, whose research includes

developing concrete overlays. They would allow cheaper repair of highways, much the way new layers routinely are added to asphalt pavement.

"The work she's doing on concrete overlays is phenomenal," said Georgene Geary, who headed the standing committee. and currently operates her own consulting firm, GGfGA Engineering. "She's doing research on concrete overlays and better design tools to make sure highways are built right and build to last.

Pitt is active on numerous fronts - and surfaces.

Snyder was key in convincing the state Department of Transportation to develop specifications for long-life concrete, designed to last 40 to 50 years and as long as 60, rather than the current life expectancy of 20 or 25 years. The ultimate goal is formulating concrete to last a lifetime rather than a generation.

Neal Fannin, PennDOT's pavement materials engineer, wrote the state specifications in recent years for long-life concrete that's already being used in building interstate highways.

Time will tell, he said, if the long-life concrete mixture will meet expectations. Gradations of stone (aggregate) is key in allowing the concrete to compact better than stone of one size. Better compaction helps prevent slumping of pavement especially at the edges. Also the new concrete involves less cement, which contributes to concrete shrinkage after it hardens. Less shrinkage means more stability, Fannin said.

The specs were completed about the time the Southern Beltway project was getting underway from Route 22 to Interstate 79 in Washington and Allegheny counties, he said.

But, in fact, the long-life concrete is being used.

The U.S. Department of Transportation reports that 2.74 million miles of paved roads crisscross America, with 83 percent paved with asphalt.

In the United States, there's an estimated 465,800 miles of concrete highways, most of them interstate highways that account for about one-quarter of the total miles driven each year.

The truth is, there are limited financial resources for highway construction and southwestern Pennsylvania's hills and rivers require many more bridges than other states, with Pittsburgh alone having about 460 bridges. That's second nationally to New York City (778).

When talking apple pie, you need a good recipe. The same holds true for concrete. Portland cement, the most common concrete, is made from "a closely controlled chemical combination of calcium, silicon, aluminum, iron and other ingredients," the Portland Cement Association says.

Materials used can include "limestone, shells, and chalk or marl" combined with another large assortment of materials - shale, clay, slate, blast furnace slag, silica sand, and iron ore.

Combinations of ingredients are heated at high temperatures - about 2,700 degrees Fahrenheit - "to form a rock-like substance that is ground into the fine powder that we commonly think of as cement," the association states. When mixed with sand, stone (aggregate) and water, and used as intended, the results include strong walls, roads and sidewalks.

In some ways, concrete research has progressed with an eye on the rear-view mirror.

Ancient Romans were expert concrete makers, having used volcanic ash in its concrete mix. The result is concrete that's lasted 2,000 years, in many cases, with a mix that hardens through time to produce nearly rock-like strength. Flyash, a byproduct of coal combustion in power plants, is Pennsylvania's version of volcanic ash that makes stronger concrete but not nearly as long-lasting as Roman concrete, at least not to date, Khazanovich said.

America's oldest concrete, created experimentally in 1891 to build Court Avenue in Bellefontaine, Ohio, was controversial at the time. George Bartholemew had to post a bond to build his street made of "artificial stone." As it turned out, he accidentally happened upon the perfect recipe that Khazanovich attributes to perfect-sized air bubbles - about 6 percent of air by volume - that accommodates expansion and contraction of water and ice during Ohio's freeze-thaw cycle. People, and pavement gurus, now visit Bellefontaine to see the concrete. Air is now added to most outdoor concrete in northern states.

Khazanovich, who has a doctoral degree in civil engineering, says governments more than ever must develop and use longer-lasting concrete pavements, which can cost 5 percent to 13 percent more. But in the long run, they cost less, improve ride quality, reduce traffic closures, and reduce the number of accidents associated with construction: "We don't have enough money to build cheap roads," he said.

Pitt researchers and Fannin also stress the point that Pennsylvania faces more construction challenges than most states, given a freeze-thaw cycle that's one of the most dramatic in the nation.

But Fannin said the long-life concrete is key to better highways: "We want to build roads as cheaply as we can, but the highest quality that we can, so you are always seeking a balance."