How Much Fly Ash?

By Don Procter

Are we ready to accept high-volume fly-ash concrete in cold-weather climates? A number of practitioners in Canada's largest city, Toronto, think so. They are betting that a 50/50 fly-ash-to-portland-cement mix for a four-story 120,000-square-foot computer sciences building on the campus of York University will prove their point.

Although fly ash has been used extensively for underground concrete projects—subway tunnels in Toronto are a case in point—high-volume mixes (50% or more) are relatively unheard of in above-ground applications where cold weather slows curing and hampers workability. For concrete purposes, cold weather is defined as 3 consecutive days averaging below 40° F in which the temperature never rises above 50° F for more than half of any 24-hour period.

The university project may be the first-ever successful application for a major structure in a chilly region of Canada, says Lloyd Keller from his office in the research and development department of EllisDon Construction, general contractor for the project. Since the university project got under way late last year, he's received numerous calls from other engineers and building experts requesting data on the mix design. "A lot of people are taking notice and saying, 'Hey, this stuff works.' They are astounded by the performance and the characteristics."

And so they should be. At York, the unusual concrete developed a higher strength than portland-cement-based concrete due to a lower water-cement ratio. At the same time, it cost less than conventional concrete. Keller, who sees the York job as a launching pad for high-volume fly ash in Toronto, had conducted numerous trials before achiev-

Concrete with a high proportion of fly ash to cement has been used successfully in Toronto

Toronto's York University computer sciences building used a mix in which half of the cementitious material was fly ash.

ing the optimum mix. But Keller and a small group of pioneers still face a battle convincing the building community that this product works.

Most engineers and specifiers have dismissed high-volume fly ash in cold-weather applications. A key concern is that a slower curing rate delays concrete finishing, ultimately causing construction scheduling chaos. Keller's overcome that obstacle by modifying the mix and protecting it from the cold.

David Smith, senior project manager of EllisDon, says that at the university project early-age fly-ash concrete strengths were less than those for conventional concrete, but over time the mix actually surpassed portland-cement-based concrete in strength. "It had a kick to it." Keller says that's because the fly-ash concrete relies on the pozzolanic reaction of fly ash to fully cure, which occurs more slowly than the hydration of cement.

The unconventional concrete fit into the university's agenda for the development of an environmentally friendly building. The idea was to minimize the use of portland cement, which was perceived as being "quite hard on the environment" during production, says Walter Bettio, associate of Van Nostrand DiCastri Architects. The Toronto architectural firm was in joint venture with Busby & Associates of Vancouver to design the building.

Fly ash is essentially the soot in the flue gases of burned coal. As a waste product of coal-fired electrical generating stations, it is required, under environmental law, to be collected, stored, and properly disposed of rather than released into the atmosphere. While Toronto's builders pay about $120 a ton for portland cement, fly ash can be as low as $50 (Canadian) a ton. Because a large portion of this cost is transportation, rates in other regions will vary based on availability.

High-volume fly-ash concrete is not without its downside. In cold weather it requires more protection than conventional portland cement mixes to cure at a similar rate. For multistory structures, the concrete slab should be covered with thermal blankets, and supplementary heating might be required

Left: High-volume fly-ash concrete is more difficult to finish because it's stickier, tends to dry out quicker, and has a slower set time. Above: High fly-ash concrete was used throughout for both flatwork and structural members.

in conjunction with a continuous tarp enclosure from the floor below to the one above, suggests Keller.

While the unusual concrete mix may be turning heads as a result of the York University experience, it still faces major hurdles. The industry's unwillingness to embrace new technology is a big one. "The ready-mixed industry is a very insular community," says Keller. "The innovators are very few and far between." As proof, Keller tells how difficult it was to find a ready-mixed company willing to produce his mix. After being rejected by the majors, he turned to a small independent company (not owned by a cement company) called Ontario Redi-Mix Ltd.

Ontario Redi-Mix was no stranger to fly-ash concrete. The company had used a 25% fly-ash-to-cement mix for walls and underground pipes. "But the 50/50 mix was a first for us," says manager Jimmy Sciacca, who, like others, was dubious at first that such a high-content mix would work. "When I saw the results I was amazed to see the strengths it was getting." Seven-day compressive strengths were 30 to 35 MPa (4400 to 5100 psi); after 28 days they were up to 40 to 50 MPa (5800 to 7300 psi). That tops conventional concrete strengths because the fly ash requires about 10% less water than portland cement.

The success at York has made Sciacca a believer, and he is prepared to use fly ash for other buildings. That just might happen soon because the university has its eye on fly ash for a second "green" building in the works for the campus. Toronto's Seneca College is also considering it for a new building.

Sciacca admits it is not just fear of something new that keeps other ready-mix companies from jumping onboard. Not every company has the capacity to dedicate a silo to a material that has yet to gain wide acceptance—as Ontario Redi-Mix had done. Furthermore, fly ash is not readily available everywhere, and not every fly ash will do the job. Toronto builders are lucky. From a 15,000-ton storage facility north of Toronto, Lafarge Canada was able to supply Ontario Redi-Mix with a consistent-quality Class C fly ash. In tests, other fly ashes have not done as well.

For placeability, the 50/50 Class C fly ash mix was comparable to traditional concrete mixes at temperatures of around 70° F, insists Keller. But if the mix requires air entrainment, such as for exterior flatwork, finishers indicate that fly ash tends to be more sticky, resulting in trowel drag. In hot, dry conditions, fog misting or spraying is recommended.

Rocco Dipede of concrete placer Formica Construction says when given the choice he'd rather not use high-volume fly ash because it is troublesome to finish. "In the summer it dries too fast, so you have to constantly sprinkle water on it. In the winter it is very hard to finish because it takes a long time to set."

Sciacca notes that because the fly-ash particulate is so fine, the finished product has a smoother finish than conventional concrete. At the York University project, the void-free basement walls "were so perfect" that the owner didn't bother to have them drywalled. "It is as smooth as a dance floor." He sees a growing market for the product, but how big a piece of the market it gets remains to be seen. "For the big ready-mix companies (owned by large cement companies) fly ash is a waste of time because they can't make money on it."

Don't expect a different response from most engineers. Many of them think fly ash is filler, points out Keller. "They don't understand how it gains strength." Nor do they understand that not all fly ash is created equal. With the right fly ash for the conditions, optimum strengths are achieved; with the wrong fly ash, low strengths might result. "It's a very complex subject."

The Class C fly ash available in Ontario has proven most suitable because it contains a lower carbon content than other fly-ash types, and it is hydraulic (reacts with water to form a hardened paste). "Carbon is a bad thing for concrete because it reduces the air content and increases the water demand," says Keller.

Research into the cementitious properties of fly ash in Canada dates back 20 years to when the federal government agency, the Canadian Centre for Mineral and Energy Technology (CANMET), began evaluating performance characteristics of about 30 fly-ash products in Canada. By the mid-1980s high-volume fly-ash concrete was performing particularly well in thick concrete sections because it didn't generate the high heat that cement does during the setting process. This meant that thermal stress, which can cause cracking, was minimized. This concrete achieved strengths of 35 to 40 MPa (5100 to 5800 psi) after 28 days. But further research indicated that strengths continued to rise for over a year, peaking at 50 to 60 MPa (7300 to 8700 psi), points out Alain Bilodeau, senior research engineer, Materials Technology Laboratory, a division of the federal government's Natural Resources Canada, the replacement entity for the now-defunct CANMET. Fly ash also scored high points on other tests, including durability.

More than a decade ago, trials on high-volume fly ash were conducted on two buildings in Halifax. But unlike York University, tests were limited to a few concrete columns, which continue to perform well, says Bilodeau. He's impressed with initial data he's seen on the concrete at York University. "It shows very promising results. Their main thing is strength development, and they are getting it."

He sees a bright future for fly ash, especially as "green" building technology grows. "Cement is a very energy-intensive material to produce, and in production it gives off a lot of CO_2 (greenhouse gas). Even in a small building, if you are able to replace 50% of the cement with fly ash, you can prevent huge quantities of CO_2 emissions into the environment."

Until more research and fine-tuning are done, Keller doesn't recommend fly-ash concrete for exterior flatwork in regions prone to freeze/thaw cycles because it may result in surface scaling or blistering. Parking structures, driveways, and sidewalks are examples.

Not all experts agree with Keller. Some suggest that poor outdoor performance is based only on lab tests. In the field where a product's performance is often different, fly ash has yet to be tested thoroughly. Bilodeau says that while some high fly-ash mixes exhibited scaling in lab tests conducted by the federal government's MTL, the product seemed to perform well in limited tests in the field. But in cold-weather regions, most fly-ash mixes used to date have been under 20%, a ratio that isn't affected by the lower mercury, explains Keller.

The second-largest general contractor in Canada, EllisDon has conducted research on fly ash since the early 1990s. One of Keller's first experiences with it was when EllisDon bid to build the tallest skyscraper complex in the world in Kuala Lumpur, Malaysia. Although the contractor didn't win the job, Keller learned much about fly-ash concrete, used for the raft foundation, a very thick concrete pad engineered to carry the weight of the towers.

In Toronto, EllisDon has specified high-volume fly ash for 12-foot-thick concrete sections for public transit subway tunnels. Traditionally, sections of concrete that thick have been "excessively reinforced," or cooling pipes had to be installed to prevent the concrete from cracking during the hydration process, explains Keller. Tests proved that in high volumes the coal byproduct would be practical in such applications because it doesn't generate the high heat that conventional portland cement concrete does during the hydration process. "High-volume fly-ash mixes keep the temperatures lower, so the amount of thermal strain on the concrete is significantly less. We can live with getting our strength in 28 days or 56 days."

By the mid-1990s, Keller's tests illustrated that certain types of fly ash performed significantly better than others in massive concrete pours. Much of his data was gained through experiments conducted with slag, an ingredient in concrete for thick sections. Slag, which has properties similar to fly ash for thick concrete sections, is readily available from steel mills, but, because it requires processing, it is more expensive.

It has taken many years to understand the properties of fly ash. It won't take as many for the industry to embrace it, however, Keller suggests. "But we'll need people educated in its use to understand how to optimize it." ■