Conductive concrete – an electrifying idea

*Research led by **Christopher Y Tuan** at the **University of Nebraska-Lincoln** is tackling the issue of de-icing concrete. A conductive concrete innovation adds steel shavings and carbon particles to a standard concrete, which conducts enough electricity to melt ice and snow in the worst winter storms, while remaining safe to the touch.*

Figure 1: Heated deck of the Roca Spur Bridge – 6 February 2008.

There has been remarkable advancement made in cementitious materials research to improve concrete strength and durability. For instance, the compressive strength of concrete has approximately tripled in the past 40 years. Concrete production has become more of a science than an art for various structural applications. Engineers nowadays are very familiar with the terms such as high-performance, ultra-high-performance, self-compacting, pervious, decorative concrete and so on.

So, what is conductive concrete (CC)? Conductive concrete may be defined as a mixture containing a certain amount of electrically conductive components in a regular concrete, designed to enable conduction of electricity. Regular concrete is not electrically conductive. Carbon and steel, in the form of particles and fibres have been used for the conductive components. Geological materials, such as iron ore, may also be used for aggregates in concrete to enhance conductivity. Due to its electrical resistance, CC can generate enough heat to prevent ice formation on a paved surface when connected to a power source.

There are many applications for conductive concrete, roadway de-icing, electrical grounding, radiant heating, steel reinforcement corrosion protection, structural health monitoring, electromagnetic wave shielding, to name a few. Some of these applications are passive, such as electrical grounding and electromagnetic wave shielding, in which the conductive concrete is not energised.

Heated deck

The heated deck of Roca Spur Bridge is the first implementation in the world using conductive concrete for de-icing. The three-span highway bridge over Salt Creek at Roca, Nebraska, USA is 150ft long × 36ft wide (46 × 11m) and located near Highway 77 South. Bridge construction was completed in November 2002 and the heated deck control system was finished in March 2003. The technology provides an environmentally friendly solution to the looming crisis of water supply contamination by road salts, especially from bridge run-off over streams and rivers. It is also beneficial to rural communities and residents that are at a great distance from plough truck dispatch centres.

Table 1 – De-icing performance of Roca Spur Bridge heated deck

Storm date	Snow (in.)	Air temperature (°F)	Wind (mph)	Energy (kWh)	Unit cost (US$/ft^2)	Peak power density (W/ft^2)
8–9 Dec 2003	6.5	20.7	16.2	2023	0.050	40.04
25–26 Jan 2004	10.1	14.9	14.4	2885	0.070	30.74
1–2 Feb 2004	5.7	14.4	11.1	2700	0.066	26.57
4–6 Feb 2004	7.8	19.2	11.5	3797	0.093	35.94
2–5 Jan 2005	8.5	15.6	14.3	3128	0.076	33.01
6–8 Feb 2005	4.6	17.3	12.7	3327	0.081	32.25
18–21 Mar 2006	9.9	32.5	16.2	2786	0.068	29.97
13–14 Jan 2007	3.3	10.9	21.7	2366	0.058	18.86
20–21 Jan 2007	6.0	19.4	17.4	2573	0.063	30.19
12–13 Feb 2007	3.8	17.6	16.2	2653	0.065	33.54
1–3 Mar 2007	7.1	29.8	19.9	2893	0.071	36.79
5–7 Dec 2007	3.5	22.5	20.5	2866	0.070	35.02
15–18 Jan 2008	3.8	18.1	24.8	2445	0.059	34.56
4–7 Feb 2008	4.6	21.9	22.4	3046	0.074	36.98

The de-icing performance of the heated deck was monitored during 2003–2008 by the Nebraska Department of Roads. Powered by a 3-phase, 208V AC source, the de-icing system performed exceedingly well, as evidenced by Figure 1. The corresponding temperature–time histories during the de-icing operation are presented in Figure 2. A summary of the performance data during the five-year study is given in Table 1. On average, the energy cost for the heated deck was about US$85/day (£60) during a major winter storm.

De-icing technology

This de-icing technology can be readily implemented at accident-prone locations such as bridge overpasses, exit ramps, airfield runways, street intersections, parking garages, sidewalks and driveways.

Conductive concrete for pavement de-icing has not been widespread due to regulatory restrictions. The US National Electric Code (NEC) in its current version does not have provisions applicable to conductive concrete, but treats CC as an electrical conductor and presumes electrical shock hazards to a human body. The reason that CC is safe to the touch is simply because the electrical resistance of a human body is higher than that of CC. The safe threshold of electrical current to the human body is 5 milliamps (mA).

It takes time for an emerging technology to be approved by regulatory officials before the technology can be made available to the general public. For instance, it took more than 25 years for microwave ovens to become popular in American households.

The NEC also stipulates that if the applied voltage to an electrical device is under 48V, such as the lighting devices commonly used for landscaping, no inspection is necessary. So, for those enthusiastic homeowners who would like to try out the CC technology to heat the driveway and sidewalk, you would

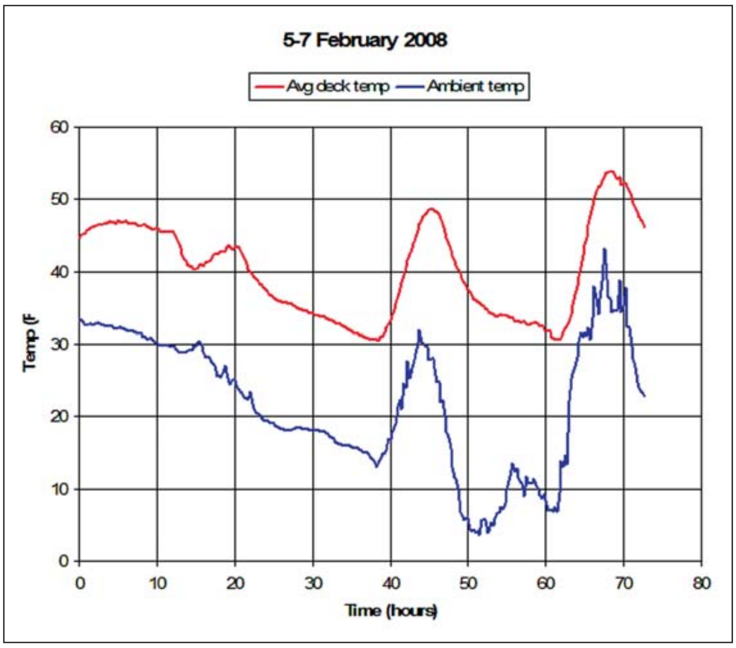

Figure 2: Average deck temperature vs air temperature – 6 February 2008.

Figure 3: Driveway de-icing – December 2010.

need a transformer (from 110 to 48V) and an electrician to complete the electrical work.

Driveway de-icing under 48V

A heated driveway section of 30ft long × 7ft wide (9 × 2m) was constructed in a subdivision in Omaha, Nebraska, in July 2010, using 48V AC. Prior to installation, the entryway was always covered with thick ice in winter, which made for treacherous driving into the garage. The de-icing performance of the heated section has been excellent, as evidenced in Figure 3. The energy cost was about $3 per day (£2) and brought a smile to the owner's face, who preferred flipping a switch to shovelling snow and chopping ice. Unlike the hydronic systems pumping hot water through embedded pipelines that must stay on at all time, you turn the switch off when there is no snowstorm.

Heated airport asphalt

The Federal Aviation Administration (FAA) has been searching for a cost-effective and durable heated pavement technology for large-scale implementation for snow and ice removal at main hubs. The asphalt around the gates at a terminal is always congested due to activities by the ground crew, unloading and loading the passengers, luggage, waste disposal, fuelling, meals and other services. Snow and ice accumulation on the asphalt slows down these operations and causes delay of flights.

> “The heated deck of Roca Spur Bridge is the first implementation in the world using conductive concrete for de-icing.”

A project is being funded by the US Federal Aviation Administration (FAA) to develop a cost-effective conductive concrete that yields the lowest cost, while providing adequate mechanical strength, long-term durability and de-icing performance. The scope of work includes selecting conductive materials, conducting mechanical and accelerated durability tests on CC test specimens, and evaluating the heating characteristics of the various mix designs in a laboratory freezer. The CC developed has met or exceeded the required mechanical strengths for highway and airfield concrete pavements. It has also showed good durability and should provide an anticipated service life of 25–30 years.

A 10 × 20ft (3 × 6m), 6-inch (150mm)

Figure 4: Heated test pad after the snowstorm on 27–28 December 2015.

Table 2 – Summary of performance data of the test pad

Storm date	Snow (in.)	Air temperature (°F)	Wind (mph)	Energy (kWh)	Unit cost* (US$/ft^2)	Peak power density (W/ft^2)
24–25 Dec 2015	7.0	23.4	8.5	45.9	0.021	15.5
27–28 Dec 2015	4.2	13.6	18.6	69.8	0.031	14.4
25 Jan 2016	4.0	25.2	16.5	73.4	0.032	13.0
2–3 Feb 2016	4.9	12.9	12.4	84.9	0.037	11.8

**Utility rate in Omaha, Nebraska: $0.088/kWh*

thick test pad was constructed outdoors using the most cost-effective mix developed and it was energised during the 2015–16 snowstorms. Figure 4 shows the excellent de-icing performance of the test pad. The operating costs range from \$0.02 to \$0.04/ft^2 (see Table 2) and is maintenance free. The conductive concrete de-icing technology is far superior to its peer technologies. The cost of the concrete is approximately \$300/yd^3 (\$400/m^3 (£280)).

This project demonstrates that CC technology is affordable for large-scale implementation. The project will run through September 2016. If the FAA is satisfied with the findings from this study, the Administration would implement a 150 × 40ft (46 × 12m) test asphalt section at its Technical Centre at the Atlantic City International Airport, New Jersey.

Although the cost of CC is about twice that of regular concrete, there is tremendous life-cycle cost savings compared to the use of regular concrete with other de-icing means. The additional cost is justified by its superior strength (about 1.5 times that of regular concrete), its low operating cost and being maintenance free. Conductive concrete also offers intangible benefits such as saving time, saving money and saving lives. ■

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