

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Electrically Conductive Concrete

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ABSTRACT: In the construction industry concrete has been a major constituent which has been adopted widely due to its easiness in construction and maintenance. Concrete has been used for many years as a composite material that has excellent strength properties and durability, but it is a poor electrical conductor. Concrete that is excellent in both mechanical and electrical conductivity properties may have important applications in the electrical, electronic and military, hence the conductive concrete has been evolved. Conductive concrete is a cement-based composite that contains electronically conductive components to attain stable and relatively high conductivity. Potential applications include electrical heating for de-icing of parking garages, sidewalks, driveways, highway bridges, and airport runways, as well as electrical grounding.

I. INTRODUCTION

Although concrete has existed in various forms over most of recorded history, it is a material that still has opportunities for exciting developments. Over a number of years, many unsuccessful research efforts were made to develop concrete that could combine good electrical conductivity with the excellent engineering properties of normal concrete mixes. The Institute for Research in Construction (IRC) has succeeded in achieving this challenging goal, with electrically conductive concrete ("conductive concrete" for short), a patented invention that offers future promise for use in a variety of construction applications.

Conductive concrete may be defined as a cementitious composite which contains a certain amount of electronically conductive components to attain stable and relatively high electrical conductivity. It has the potential to address a wide variety of applications, including grounding, heating, cathodic protection of reinforcing steel in concrete structures such as bridges and parking garages, and electromagnetic shielding.

Ongoing IRC research is now focused on optimizing conductive concrete formulations for the best combination of strength, electrical properties, and production methods at the lowest possible cost, leading ultimately to commercial development and widespread use.

II. PRINCIPLE

The principle behind it is the use of cement to bind together electrically conductive materials such as carbon fiber, graphite and 'coke breeze' - a cheap by-product of steel production - to make a continuous network of conducting pathway. The design formulation is based on the 'electrical percolation' principle by which the composite conductivity increases dramatically by several orders of magnitude when the content of the conductive phase reaches a critical 'threshold' value. Further increases in the conductive phase content boost composite conductivity only slightly. The design specifies an amount just over the threshold content, assuring high conductivity and mechanical strength as well as good mixing conditions.

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III. METHOD OF MAKING CONDUCTIVE CONCRETE

Conductive concrete mixture comprised of cement, aggregate, water and conductive materials. Preferably, the conductive materials are both metal fibers and metal particles and make up 1-3% and 5-40% respectively of the total volume of the mixture. More preferably, the metal fibers and metal particles make up 1-3% and 10-30% respectively of the total volume of the mixture [1].

A method of making conductive concrete comprises first mixing all fine materials (i.e., cement, Fly Ash, fine aggregates and Super plasticizer) with water in a container. Subsequently load coarse aggregate and metal particles into the conveyer from their respective containers, placing metal fibers into the conveyer on top of the coarse aggregate and metal particles, emptying all of the contents of the conveyer into the container containing cement and water, and mixing the contents [2]. The mixture is used to manufacture pre-formed concrete slabs that have electrodes embedded therein, although a cast-in-place system is also a viable alternative and may be more cost-effective

IV. PROPERTIES

Conductive concrete is a cement-based composite that contains a certain amount of electronically conductive components to attain stable and relatively high conductivity. In essence, the aggregates normally used in concrete can be largely replaced by a variety of carbon-based materials to achieve electrical conductivity in conductive concrete. This is achieved while retaining the desired engineering properties, as indicated in Table 1 [3]. The conductivity is usually several orders of magnitude higher than that of normal concrete. Normal concrete is effectively an insulator in the dry state, and has unstable and significantly greater resistivity characteristics than conductive concrete, even when wet.

TABLE 1 Conductive Concrete Properties

Electrical Resistivity (ohm - cm)	1 - 40
Compressive Strength (MPa)	30 minimum
Flexural Strength (MPa)	5 - 15
Density (kg/m ³)	1450 - 1850

V. CHARACTERISTICS

While the engineering properties and mixing characteristics of conductive concrete and normal concrete are comparable, conductive concrete does have other distinctive characteristics beyond its ability to conduct electricity [4].

- The conductivity value is stable. The effects of moisture content, hydration time and temperature on conductivity are insignificant.
- It is lightweight: conventionally mixed, conductive concrete has a density of about 70 percent that of normal concrete.
- Conductive concrete is chemically compatible with normal concrete, bonding well with it if used as an overlay.
- Thermal stability is comparable to that of normal concrete.
- The colour of conductive concrete is a darker grey, reflecting its carbon content.

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VI. BENEFITS

Conductive concrete has excellent mechanical and electrical conductivity properties.

- It is much lighter in weight than conventional concrete.
- It can be produced easily, without special equipment.
- It will reduce the need of salts and save millions in dollars in snow removal costs.
- It warms by power taken off-line, it uses an AC current. It is also safe for a person crossing a charged concrete pathway.
- It can also be used for protecting structures against static electricity and lightning, and preventing steel structures and reinforcing layer of steel in concrete structures from corroding.
- It absorbs over 90% of the electromagnetic energy and it is cheaper and more convenient than the existing ways of blocking out electromagnetic energy.

A. Applications

Conductive concrete has several important engineering applications:

- * Cathodic protection of reinforcement in concrete structures
- * Electrical heating or de-icing of roads and bridges
- * Electrical grounding
- * Electromagnetic shielding

1. Cathodic protection of reinforcement

Corrosion of the reinforcement is a major problem for most concrete structures, such as highway bridges and parking garages. Laboratory experiments have shown that the electrical energy needed for the operation of a cathodic protection system can be reduced by over 50 percent if a conductive concrete overlay is used [5].

Electrical heating using conductive concrete has great potential for domestic and outdoor use. It can be deployed for de-icing of parking garages, sidewalks, driveways, highway bridges and airport runways. This approach would eliminate the need to use de-icing salts. According to laboratory-scale experiment, the surface temperature of a 5- (y) 24- (y) 30-cm. concrete slab could be maintained above the freezing point even at an air temperature of -30 degrees C. It is estimated that over 8 ft [6]. of accumulated snow was melted off this test pad last winter. (It is appropriate that this work is being carried out in Ottawa, the world's coldest capital city.)

B. ELECTRICAL GROUNDING

Grounding is required for almost every electrical installation. ECC is an economical and durable electrical grounding system. Researchers note that ECC can simply be cast around the grounding electrode.

C. ELECTROMAGNETIC SHIELDING

For electro-magnetic shielding, the use of ECC provides an economical alternative to the installation of a welded steel liner or a layer of carbon fiber sheet on walls.

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Potential applications of ECC will likely grow significantly, suggest the researchers. They also surmise that care and attention to the production and use of ECC will have cost and engineering benefits for the industry at large. Certainly a driveway that would never have to be shoveled holds promise [7].

Roca Spur Bridge is a 46-m (150-ft) long and 11-m (36-ft) wide, three-span highway bridge over the Salt Creek at Roca, located on Nebraska Highway 77 South about 24 km (15 miles) south of Lincoln. A railroad crossing is located immediately following the end of the bridge, making it a prime candidate for electrical deicing application. The Roca Bridge project began in December 2001, and construction was completed in November 2002. The bridge deck has a 36-m (117-ft) by 8.5-m (28-ft) by 100-mm (4-in.) conductive concrete inlay, which is instrumented with thermocouples to provide data for deicing monitoring during winter storms.

VII. MIX DESIGN

The mix design used in this project contained steel fibers and carbon products for conductive materials. Steel fibers of variable lengths amounted to 1.5% and the carbon products of different particle sizes amounted to 25% per volume of the conductive concrete. Crushed limestone of 13-mm (0.5-in.) maximum size and Nebraska 47B fine aggregate were also used in the mix.

A. Project Significance

It is expected that this project will demonstrate that conductive concrete technology has national and international importance. Statistics indicate that 10% to 15% of all roadway accidents are directly related to weather conditions. This percentage alone represents thousands of human injuries and deaths and millions of dollars in property damage annually. Ice accumulation on paved surfaces is not merely a concern for motorists; ice on pedestrian walkways accounts for numerous slip and fall injuries. The payoff potential for this project is tremendous: it could eliminate icy bridge roadways and save lives.

B. Construction Sequence

A 100-mm (4-in.) thick inlay of conductive concrete was cast on top of a 256-mm (10.5-in.) thick regular reinforced concrete deck. The inlay consists of 52 individual 1.2-m x 4.1-m (4-ft x 14-ft) conductive concrete slabs. In each slab, two angle irons were embedded for electrodes (Figure 1).



Fig.1

Coupling nuts were welded to one end of the angle irons for making an electrical connection. A thermocouple was installed at the center of each slab at about 13 mm (0.5 in.) below the surface to measure the slab temperature. The power cords and Thermocouple wiring for each slab were secured in two PVC conduits and are accessible from junction boxes along the centerline of the bridge deck.

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The conductive concrete inlay was cast after the regular bridge deck had been cured for 30 days. The westbound lane was placed first. After hardening, the conductive concrete inlay was saw cut to a 100-mm (4-in.) depth along the perimeters of the individual slabs, and the gaps were filled with polyurethane sealant. There was a 150-mm (6-in.) gap along the centerline of the bridge to allow power cord connections with the coupling nuts of the angle irons. The gap was then filled with a non-shrink, high-strength grout.

C. Integration of Power Supply, Sensors, and Control Circuit

A three-phase, 600 A and 220 V AC power source is available from a power line nearby. In a control room a microprocessor monitors and controls the deicing operation of the 52 slabs. The system includes four main elements: (1) a temperature-sensing unit, (2) a power-switching unit, (3) a current-monitoring unit, and (4) an operator-interface unit. The temperature-sensing unit takes and records the thermocouple readings of the slabs every 15 minutes. A slab's power will be turned on by the controller if the temperature of the slab is below 4.5°C (40°F) and turned off if the temperature is above 12.8°C (55°F). The power-switching unit controls power relays to perform the desired on/off function. To ensure safety, a current-monitoring unit limits the current going through a slab to a user-specified amount. The operator-interface unit allows a user to connect to the controller with a PC or laptop via a phone modem. The operator interface displays all temperature and electrical current readings of every slab in real time. A user also has the option of using a PC or laptop to download controller-stored data into a spreadsheet.



Fig.2. Deicing Operation

The deicing controller system was completed in March 2003 and was tested successfully under snow storms in January and February 2004 (Figure 2). The system was activated in 2003 for an early April storm with less than 6 mm (1/4 in.) of sleet. The slush on the bridge deck was melted during the storm period. Temperature distribution was uniform across the bridge. The controller system kept the slab temperature about 9°C (16°F) above the ambient temperature.

The 52 slabs were energized in an alternating fashion to avoid a power surge. Groups of two slabs were started up in turn at 3-minute intervals and energized at 208 V for 30 minutes. This alternating form of energizing the slabs was followed throughout the storm. The maximum current recorded varied between 7 and 10 amps, with an average of 8. Peak power density delivered to the slabs varied between 360 and 560 W/m² (33 to 52 W/ft²) with an average of 452 W/m² (42 W/ft²). Energy consumed by the conductive slabs during the three-day period varied from 47 to 70 kW-hr, with an average of 58 kW-hr per slab. Total energy consumption was about 3,000 kW-hr.

The conductive concrete bridge deck will continue to be studied for the next several winters to evaluate the effect of electrical deicing and compare it to alternatives. This promising new technology should prove to be a valuable tool in the fight against icy conditions on roadways.

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VIII.CONCLUSION

Conductive concrete due to its effectiveness in deicing and also advancements made towards implementing conductive concrete for electromagnetic shielding and electrical grounding it is proving to be a valuable invention. Further researches are on in improving mechanical strength of conductive concrete so that it can be effectively used as a sole member in withstanding load and not as an overlay.

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