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RADIO WAVE HEATER FOR CONCRETE

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ABSTRACT

In dielectric heating, the specimen is placed in an electromagnetic field that alternates at high frequency. Electrically charged molecules and ions start to vibrate and the temperature of the material rises. The domestic microwave oven is an example of this phenomenon. Microwave radiation penetrated fresh concrete to a depth of about 2 cm only. Penetration with radio frequency was far better. A radio frequency heater was found to be an effective heater for concrete. The following conclusions can be drawn from the results: A whole mass of concrete can be heated simultaneously. With this heater it is possible to raise the concrete temperature to 50–60°C in just a few minutes (3–4 minutes).

General

The aim of the study was to find ways of speeding up the manufacturing process of concrete structures. Of main interest was the manufacture of prefabricated concrete units. One way to achieve a very fast strength development rate is heat treatment. The fastest possible rate needs a very fast temperature rise. Using a wet oven with a circulating blower made it possible to raise the concrete temperature from about 23°C to 50–60°C in 1–1½ h (100 mm cube)/3/. If an even faster temperature rise is needed or the specimen is so much bigger that the temperature rise is slower, other kinds of heating arrangements are necessary. Steam curing, electric wires or direct electrical heating are some alternatives. In this work an even newer method of concrete heating was investigated: radio frequency heating.

Very fast strength development is achieved by using fast binders and high heat treatment temperatures. Figure 1 shows the strength development of a concrete at different heat treatment temperatures. The cement used was very rapid hardening Portland cement (CEM I 52.5 R, 555 kg/m^3, w/c = 0.31, cube 100 mm). Because fast strength development is the target, a fast temperature rise is beneficial. In the tests presented in Figure 1 heat treatment was carried out in a wet oven.

In normal heating, outside heat must traverse the surfaces into the specimen. The thermal conductivity of concrete is not very high, whereas the thermal capacity is, causing the temperature inside the specimen to rise slowly. Heating of the surface can be done by radiation, hot air or conduction. The temperature of the concrete is uneven and overheating of the surface

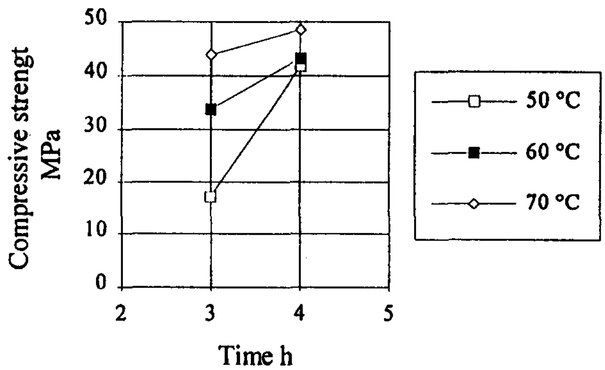

FIG. 1.
Strength development of concrete made with very rapid hardening Portland cement at different heat treatment temperatures.

may occur in some places. If heating could be done evenly throughout the specimen (inside and surfaces alike), no temperature gradient would occur and due to this a fast temperature rise would not cause strength loss.

Dielectric Heating

In dielectric heating, the specimen is placed in an electromagnetic field that alternates at high frequency. Electrically charged molecules and ions start to vibrate and the temperature of the material rises. The domestic microwave oven is an example of this phenomenon. Dielectric heaters are mostly suitable for electrically insulating materials, as conductive materials tend to short-circuit the field. Everyone knows that no metal is allowed in a microwave oven, but water is a sufficiently insulating material. /1, 2/

Two wide frequency bands are used in dielectric heating. Radiowave frequencies are below 300 MHz and microwave frequencies above it. Every material has its own frequency that is best for heating due to the electric properties of that particular material. To minimise interference with the radio, mobile phones, navigation and satellites, specific frequencies are internationally reserved for dielectric heating applications. Normally used frequencies are 13.56 MHz and 27.12 MHz in the radio frequency band and 2 450 MHz in the microwave frequency band /1/.

Microwave Heating

In these tests, the microwave heater was modified from a household microwave oven. The modification was done at the Laboratory of Radio Engineering of Helsinki University of Technology. The heater was positioned over a concrete slab and microwave radiation focused on the top surface of the slab over an area of 300*300 mm (Figure 2).

The microwave radiation penetrated the fresh concrete to a depth of about 2 cm only. The temperature of the surface (about 1 cm deep) rose to 60°C after 2 minutes of heating. Heating

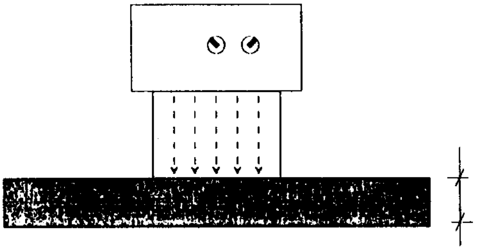

FIG. 2.
Microwave heating test arrangement.

the surface layer of the concrete was easy with the microwave heater, but the inside of the specimen warmed up only by conductivity. Therefore almost the same effect can be achieved with infra-red heaters (IR), which do not pose the health risk associated with microwave radiation.

Radio Frequency Heating

4.1 General. Because microwave radiation did not penetrate fresh concrete sufficiently, the frequency of electromagnetic radiation was lowered to the radio frequency band. In these experiments the frequency was 27.12 MHz. Penetration at this frequency was much better than with microwave radiation.

The aim of the test series was to examine:

- whether a radio frequency heater is appropriate for fresh concrete
- how concrete reinforcements affect heating
- how hollow cores affect heating.

Radio frequency heaters are normally used for heating insulating materials. If the material is electrically conductive, there is a risk of a short-circuit in the electromagnetic field, or the field can discharge through the surfaces of the specimen. In both cases heating would not be successful. Steel is a good conductive and magnetic material, easily drawing high field intensities to itself when placed in an electromagnetic field. The risk of a short-circuit is therefore great. Because the electromagnetic properties of fresh concrete and air are so different, hollow cores will cause large variation in the electromagnetic field. How these variations affect heating is unknown.

4.2 Test Arrangements. In the tests the radio frequency heater was located at Imatran Voima Oy (IVO) (Finnish power company). As the apparatus was not specially tuned for these tests its power is unknown but assumed to be several kilowatts (< 10 kW). The voltage was 3 kV and the frequency was 27.12 MHz.

Two aluminium sheets measuring roughly 0.5*1.5 m were used as aerials, and the test specimens were placed between them. An earthed aluminium box surrounded the aerials and specimens to dampen the radiation.

The concrete was no-slump concrete with a composition of 1:5.5:0.35. In test No. 3, 1.5% of plasticiser was used to ensure proper casting. The concrete was mixed and cast at Helsinki University of Technology. The specimens were transported to IVO for testing. Due to the long transportation time (40 minutes) 2% of a retarder was added.

Three tests were done on specimens measuring 400*400*150 mm. The used plywood moulds had aluminium bottom. In the first test, using a specimen of plain concrete, the validity of the radio frequency heater for concrete heating was examined. In the second test, three 12 mm concrete reinforcements were placed in the specimen. In this test the effect of concrete reinforcements on heat treatment was examined. In the third test, two 100 mm hollow cores and three 12 mm concrete reinforcements were placed in the specimen. The cores were made by leaving two 100 mm plastic (PVC) tubes in the specimen. The effect of hollow cores on heating was then examined. The test specimens and thermocouple locations are shown in Figure 3.

4.3 Test Results.

Test 1. The specimens were heated for 3 min. 15 sec. The temperature before the test was 24°C. After heating, the temperature at the centre of the specimen was 35.5°C and at the edge of the specimen 56°C. It was also very uneven due to the top surface of the specimen not being level, which caused the air gap between the upper aerial and the specimen to vary from 0 to 10 mm.

Placing a 5 mm polypropylene sheet between the specimen and the aerial levelled the gap to 5–10 mm. Once the temperature of the specimen had levelled at 40°C, heating was continued for 3 minutes up to 61°C. The temperature was fairly even throughout the specimen.

Test 2. In this test a polypropylene sheet was placed between the upper aerial and the specimen. The starting temperature of the specimen was 23°C and heating lasted for 3 minutes. The concrete temperature close to the reinforcement was 62.5°C and at the centre of the specimen 49°C.

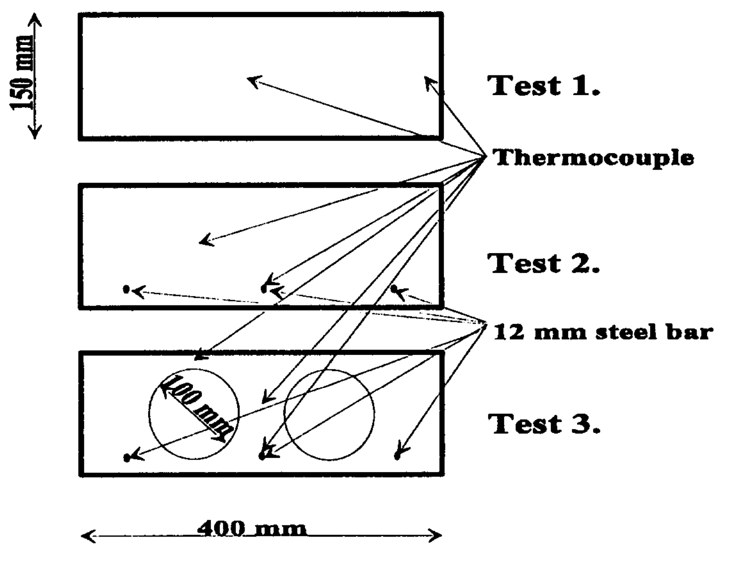

FIG 3.
Test specimens in radio frequency heater tests.

Test 3. In this test a polypropylene sheet was again placed between the upper aerial and the specimen. The starting temperature of the specimen was 15.5°C and heating lasted for 2 min. 20 sec. The concrete temperature close to the reinforcement was 53°C, between the cores at the centre of the specimen 86°C, and at the top of the core 39°C. The temperature at the edges of the specimen was 40–50°C.

The following conclusions can be drawn from the results:

- A radio frequency heater is an effective heater for concrete. A whole mass of concrete can be heated simultaneously.
- The electrical conductivity of concrete is small enough for the electromagnetic field not to short-circuit.
- Reinforcement perpendicular to the field in the concrete drew a high field intensity to itself. No short-circuit took place but heating was more intense in the vicinity of the reinforcement.
- Hollow cores and reinforcement affect the electromagnetic field, making it uneven and creating temperature differences.
- Shaping the aerial might make it possible to reduce field intensity variations.

Conclusions

The benefits of a radio frequency heater over conventional heating methods are good efficiency, adjustability and high power. The largest heaters used in industry have a power of about 500 kW.

The disadvantages are high investment costs and the inconvenient effect of reinforcement, especially parallel to the field.

A radio frequency heater was found to be suitable for some applications in the concrete industry. The easiest would be a concrete product that is not reinforced, especially in the direction of the heating field. Also, the first applications could be small units so that treatment can be done in closed chambers. Pavement blocks, concrete roofing tiles and similar products appeal to be suitable products for radio frequency heaters. With this heater it is possible to raise the concrete temperature to 50–60°C in just a few of minutes (3–4 minutes). With this heating method and fast binder/admixture combination, super fast strength development rates would be possible. Strengths of 30–40 MPa at 2–2½ h seem to be obtainable. However, such utilisation still needs some research and development.

Acknowledgement

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