Sixth International Conference on Construction in the 21st Century (CITC-VI)
"Construction Challenges in the New Decade"
July 5-7 2011, Kuala Lumpur, Malaysia

RFID for Concrete Maturity: Impact of RFID Frequency

Julian Kang
Department of Construction Science, Texas A&M University, College Station, TX, USA
juliankang@tamu.edu

Raj Sridharan
Apex Cost Consultants, Dallas, TX, USA
ahmeds@ecu.edu

Abstract
The concrete maturity method, which uses the temperature of concrete, has been utilized to determine the strength development of cast-in-concrete. However, monitoring the concrete temperature using thermocouples brought up a wiring issue, which is not advisable in an equipment and human intensive area like a construction site. One of the ways to get around this wiring issue is to use Radio Frequency Identification (RFID) technology, which is capable of transmitting information wirelessly. Previous research implemented using ultra high frequency RFID tags integrated with a thermocouple found that water could be the impediment for transmitting the temperature data over the RFID signal from within concrete during early stages of curing. Would the frequency of RFID tags then have anything to do with the readability of RFID tags embedded in fresh concrete? This paper presents our experiment with low frequency, high frequency, and ultra high frequency RFID tags to figure out any difference between radio frequencies in terms of transmitting information. The test showed that the readability of the RFID signals was affected by the radio frequency. The paper also presents how the test was implemented and some lesions learned.

Keywords
Concrete Maturity, RFID

1. Introduction

The American Concrete Institute reported that cast-in-plate concrete structures fail most often during the placement of fresh concrete (Hurd 2005). During the construction of a multi story building in Fairfax County, VA, 14 workers were killed and 34 were injured in 1973 when a portion of the building progressively collapsed (Leyendecker and Fattal 1977). In another incident at Willow Island WV, 51 workers were killed, when a cooling tower that was being constructed collapsed (Lew 1982). The National Bureau of Standards diagnosed that the reason for this was the premature removal of formwork (Will Hanson 2006). The construction failure of the Condominium building in Cocoa Beach in Florida (Lew et al. 1982a, Lew et al. 1982b) is another major accident caused by the same reason.

The strength of concrete is determined by the elapsed time given for the hydration process. The longer you keep concrete in the form the stronger concrete you will end up getting. However, most construction professionals, who want to get the succeeding activities started as soon as possible, remove formwork as soon as concrete in the form reaches a minimum strength. Those who want to follow usual practices remove forms for vertical members such as columns in 3 days, and for horizontal members such as beams in 7 to 14 days, assuming that concrete are cured enough and gained a minimum strength. In many cases, this assumption is working. However, sometime it does work as expected and results in structural failures. For those who want to make sure that concrete has gained a minimum strength before removing formwork, concrete cylinders are cast using the same mix of concrete used on the site, transported to a lab, cured, and tested there. It is assumed that the strength of the concrete cylinder reflects the strength of concrete poured on the site. However, considering that the cocoa beach condominium project collapsed after using laboratory cylinders to determine actual strength of concrete slabs (Ghosh 2008), some practitioners doubt the reliability of the concrete cylinder method. In order to determine the strength of fresh concrete in the form, non-destructive in-situ methods have been sought.

2. Concrete Maturity Method

The concrete maturity method is one such method which can be utilized to determine strength in-situ. This technique is based upon the measured temperature history of concrete during the curing period. According to Saul (1951), concrete of the same mix at the same maturity has approximately the same strength. Since the the chemical reactions taking place between cement and water in the hydration process, it is possible to draw a relationship between the temperature change of concrete and its strength during the early stage of the concrete curing process (McIntosh 1949, Saul 1951, McDaniel 1915, Wiley 1929). The relationship between concrete strength and concrete maturity indix presented in Figure 1 supports this theory.

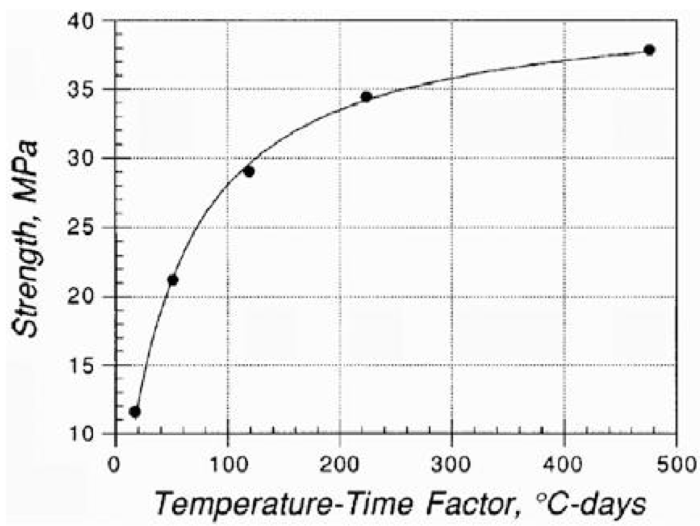

Figure 1. Relationship between Maturity Index and Concrete Strenght gain over time (Source: Paul M. Goodrum 2004)

Concrete maturity method has been successfully applied in practice. The Webbers Falls Bridge, which carries I 40 over the Arkansas River, collapsed on May 26, 2002 after being struck by a barge. The bridge was reconstructed and reopened to traffic on July, 29, just 47 days later. The maturity method was used successfully to expedite the concrete construction process (Bai 2006).

Continous monitoring of the concrete temperature is critical for the successful application of the concrete maturity method. The use of a temperature sensor combined with a temperature recording device would provide a solution for this need. For example, the thermocouples embedded within fresh concrete and connected to a recording system through wires would facilitate to monitor the temperature changes in fresh concrete in real time. However, it would demand a lot of wiring, which is not advisable on a construction site where wires can be easily damaged or broken.

3. Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) tags can be a solution for sending information without depending on wires. Radio Frequency Identification (RFID) is a general term used to define any system that uses radio waves to transmit a unique identification number. The RFID system consists of basically two main components: tag and reader. The memory in the tag contains a unique serial number and this serial number gets transmitted to the reader wirelessly. Unlike the bar codes, RFID tags can be detected without securing a line of sight. RFID tags can be distinguished as active or passive tags. Passive tags depend on the electromagnetic field generated by the RFID reader in order to get activated and emit radio waves with information. Active tags have batteries connected. They can emit stronger radio waves that travel longer distance. RFID tags can be combined with other sensors. For example, it is possible to combine a temperature sensor with an RFID tag. It is therefore reasonable to expect that the RFID tags embedded in fresh concrete can measure the temperature changes in concrete and transmit them to the reader wirelessly, which could the solve the problem of the concrete maturity method caused by extensive wiring for connecting thermocouples and a temperature recording device.

4. Motivation

Previous research found that the RFID readability decreases or stops if the tag is submerged in water (Schneider 2003, Fletcher et al. 2005). The pilot study implemented by Proctor & Gamble reported that the RFID tags attached to liquid products such as liquid detergents were not easily detected while powdered detergents were easier to track (Brewin 2004). These findings suggest that RFID tags located in fresh concrete in the early stage of the curing process may not be well detected by the recoding device because of the high water content in fresh concrete. However, understanding that the hydration process of concrete consumes water, it would be also reasonable to expect that the readability of the RF signals gets better as time elapses. The test carried out at Texas A&M University using Ultra High Frequency (UHF) RFID tags proved this expectation (Kang and Gandhi 2010). In the test, no signal was detected from the RFID tags embedded in fresh concrete for the first 3 hours after concrete was poured. The read range of the RFID tags gradually increased as time went by. The travel distance of the tags embedded in 8 inches was limited to a range of 30 ft. in 4 hours. After 7 days, the range of the tags increased to a distance of 45 ft. The result of this test suggests that the water content in fresh concrete is hindering RFID signals from getting detected. Another research, however, suggests that Low Frequency (LF) radio waves are less affected by water content (Ward 2006, Domdouzis 2007). RFID tags emitting low frequency radio waves therefore may have a better chance to transmit signals through fresh concrete. If it is the case, Low Frequency (LF) RFID tags combined with a temperature sensor can be used to monitor the temperature changes in fresh concrete, without having to worry about the adversarial impact of water on RFID tags.

5. Test

A test was prepared to find if there is a relationship between frequency of a RFID tag and its ability to penetrate fresh concrete. Three wooden formworks were fabricated and placed in a room where the temperature was controlled by the air conditioner. Low Frequency (LF) RFID tags, High Frequency (HF) RFID tags, and Ultra High Frequency (UHF) RFID tags were then placed in a formwork at 4, 8, and 12 inches from the top and one side of the formworks. Distances from any tags to other three sides and to the bottom of the formworks were greater than 12 inches. The RI-TRP-R9TD-30 120 mm cylindrical tags from Texas Instruments were used for the LF range. They emitted radio waves of 134.2 kHz. The RI-TH1-CB1A-00 card transponders from Texas Instruments were used for the HF range. These tags operated at the 13.56 MHz range. The LF and HF tags were passive tags. The UHF i-q8 tags from Identec solutions were used for the UHF range. They were active tags and operated at the frequency of 915 MHz. In total, 9 RFID tags (3 LF RFID tags, 3 HF RFID tags, and 3 UHF RFID tags) were placed in one form, and 3 formworks with these tags placed were used for the test.

Ready mix concrete designed to achieve 3,000 psi at 28 days was brought from a ready mix concrete factory nearby and then poured into all forms. The water cement ratio was kept at 0.595 with the slump of 4 ½ inches.

Figure 2. RFID tags placed in the form

Once all forms were filled with fresh concrete, they were immediately checked for RFID signals. Signals emitted from all tags were detected except for the HF tags at the 8-inch and 12-inch levels and one HF tag at the 4-in level. The Low frequency tags were detected immediately after the concrete was poured at all depths. They were detected immediately till a distance of 20 inches from the tag, which also happens to be the maximum read range of the LF tag in free air. The HF tags were not detected immediately and took around 4 hours in average to be detected at the 4-inch level. Only two of the tags at the 4-inch level could be detected. None of the other tags could be detected till the end of the experiment. The UHF tags placed at the 4-inch level could be detected 15 minutes after concrete was poured. For this purpose the reader had to be kept close to the formwork around 15 inches from the formwork. The tags at the 8-inch level could be detected after 30 minutes when the readers were placed close to the formwork. The tags at the 12-inch level took on an average 2 hours to be detected from the vicinity of the formwork.

6. Concluding Remarks

The test showed that low frequency tags have a better capability to penetrate fresh concrete than higher frequency tags. The low frequency RFID tags were detected at all depths as soon as the concrete was poured. The high frequency tags could be detected only at the 4-inch level. It might be because the high frequency tags used for this test were passive tags and had a limited read range. The burial depth of tag did not have any effect on the readability of the LF tag. However, the performance of the UHF tags was affected by the burial depth and water content of concrete. Comparing readability of LF and UHF tags embedded at various depths in fresh concrete, LF tags appear to perform better than UHF tags.

Since the number of test cases was limited to three, findings from the test cannot be generalized for the entire construction industry. Further research is needed to generalize these conclusions. It was found that LF tags used in the experiment did a good job of transmitting information from within fresh concrete. Further research is necessary to determine its reliability. A pilot study may be needed to ensure that it can be used in onsite conditions too. The read range of LF is another issue. The read range is not as high as it can be used on a construction site. The read range of the LF tag may be increased by using active tags. Factors that affect the read range of LF tag need to be studied. LF tags integrated with sensors are not commercially available on the market yet. Such a device may need to be fabricated and its reliability in predicting the concrete strength needs to be proven.

7. References

Bai,Y., Burkett.W.R., (2006). "Rapid Bridge replacement: Processes, Techniques, and Needs for Improvement". Journal of Construction Engineering and Management, ASCE, Vol. 132, No. 11, November 2006, pp. 1139-1147.

Brewin, B. (2004). "Consumer packaged goods firms: No quick ROI from RFID." Computerworld.

Domdouzis, K., Kumar, B., Anumba, C. (2007) Radio-Frequency Identification (RFID) applications: A brief introduction - Advanced Engineering Informatics.

Fletcher, R., Marti, U.P., and Redemske, R. (2005). "Study of UHF RFID Signal Propagation through Complex Media", IEEE Antennas and Propagations Society International Symposium, Washington, D.C.

Ghosh, S.K.. (2008) "Construction Loading in High-Rise Buildings", Concrete Construction Engineering Handbook", Editor: Edward G. Nawy, Chapter 8, CRC Press. Publisher: CRC Press

Hansen, W. and Surlaker, S. (2006). Embedded Wireless Temperature Monitoring Systems For Concrete Quality Control, University of Michigan, Ann Arbor.

Hurd M.K. (2005) Formwork for Concrete, ACI Committee 347, Special Publication Number 4, Seventh Edition, American Concrete Institute (ACI), Farmington Hills, Michigan

Kang, J. and Gandhi, J. (2010). "Readability Test of RFID Temperature Sensor Embedded in Fresh Concrete", Journal of Civil Engineering and Management, 16(3), 412-417.

Lew, H.S. (1982) Investigation of construction failure of reinforced concrete cooling tower at Willow Island, WV, NBS Building Science Series No. 148. National Bureau of Standards (NBS), Washington, D.C.

Lew, H.S., Carino, N.J., Fattal, S.G., and Batts, M.E. (1982a). Investigation of the Construction Failure of Harbour Cay Condominium in Cocoa Beach, FL. NBS Building Science Series No. 145. National Bureau of Standards, Washington, D.C.

Lew, H.S., Carino, M.J., and Fattal, S.G. (1982b). Cause of the condominium collapse in Cocoa Beach, FL. Concrete Int., 4(8), 64-73.

Leyendecker, E.V. and Fattal, S.G. (1977). Investigation of the Skyline Plaza Collapse in Fairfax County, Virginia, Building Science Series No. 94, 88 pp. National Bureau of Standards, Washington, D.C.

McDaniel, A.B. (1915). "Influences of Temperature on the Strength", University of Illinois Engineers Experiment Station Bulletin, No. 81.

McIntosh, J.D. (1949). "Electrical Curing of Concrete", Magazine of Concrete Research, Vol. 1, No. 1, pp. 21-28.

Saul, A.G.A. (1951). "Principles Underlying the Steam Curing of Concrete at Atmospheric Pressure", Magazine of Concrete Research, Vol. 2, No. 6, pp. 127-140.

Schneider, M. (2003). "Radio Frequency Identification (RFID) Technology and its Applications in the Commercial Construction Industry," Masters, University of Kentucky.

Ward, M. and van Kranenburg, R. (2006). "RFID: Frequency, standards, adoption and innovation", JISC Technology and Standards Watch.

Wiley, C.C. (1929). "Effect of Temperature on the Strength of Concrete", Engineering News Record, Vol. 102, No. 5, pp. 179-181.