DEVICES AVAILABLE TO ASSESS THE MOISTURE CONTENT OF AGGREGATES

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BACKGROUND

The primary factor that controls the quality of a concrete mixture is the water-to-cementitious materials (w/cm) ratio. Variations in the amount of water from batch to batch not only result in variations in strength and durability but also affect the workability of the system, making it challenging for contractors to deliver concrete pavements with uniform smoothness and texture. Paving machine operators often are only able to adjust their operations in response to observations of the surface after it has passed through the machine, meaning that they are unable to adjust for variability in the delivered material in real time. This in turn means that plant operators have to be able to respond to variability in the moisture state of incoming materials to deliver uniform mixtures. At high production rates, response times have to be short if large swings occur, particularly in the fine aggregate.

Water is introduced to a concrete mixture at the batch plant in two ways: through deliberate measurement and dosage, and through adsorption on the particles' surfaces. On the other hand, materials that are very dry may absorb water from the mixture, thereby reducing workability. Since aggregates make up roughly 75% of the volume of a concrete mixture, the control of aggregate moisture is a critical quality control element in concrete production. A 1% variation in the moisture content of the aggregate can change the w/cm ratio by up to 0.03 in a typical concrete paving mixture, which is sufficient to impact the quality and consistency of the mixture.

Typically, the fine aggregate moisture content may vary by up to 5%, having a significant impact on the bulking and workability of the mixture. Suppliers are normally less concerned about the amount of water on the coarse aggregate because the surface area of the particles is lower as a function of volume.

Controlling the aggregate moisture is difficult at busy sites where large quantities of materials are being used within hours of delivery. Additionally, aggregate stockpiles are exposed to the weather, which increases the variability of the aggregates' moisture content.

Therefore, tools are needed to provide batch plant operators with real-time information about the moisture content of the aggregates so that the water content can be adjusted accordingly in the mixture. While devices are available that can be inserted into the stockpile, ideally, moisture content would be measured on the belt or within the bins as the aggregate is being delivered to the mixer.

A range of moisture sensors are currently being used to monitor aggregate moisture, but there are concerns about their performance and cost-effectiveness.

This document reviews the available technologies for aggregate moisture sensing, discusses their strengths and weaknesses, and suggests future work that may help improve these technologies.

TYPES OF DEVICES

The devices used to detect aggregate moisture can be grouped into three categories.

Microwave

Water molecules have a dipolar form that changes the phase of microwaves that pass through them. They also absorb and reflect some of the microwave energy. These changes are measured by comparing the characteristics of transmitted and reflected microwaves waves and can be calibrated to report the amount of water (Hydronix 2023, Nel 2016 Nakayama 1994, Nelson and Trabelsi 2004). This technology can be used to assess moisture contents of a wide range of materials. Microwave sensors have the following characteristics:

- The sensor has to be in contact with the material. The device is normally installed in or underneath a bin or above a conveyor or belt feed, with the faceplate of the sensor at an angle of approximately 60 degrees to the flow of material.
- Measurements are taken ~25 times per second.
- The sensor body is typically stainless steel with a ceramic faceplate but is still prone to wear.
- Accuracy is ±0.3% of the total moisture for aggregates with moisture contents of 0% to 15%.
- Penetration depth into the aggregate flow is approximately 75 to 100 mm depending on the material. This is an advantage as a reasonably representative result can be obtained.
- The device is susceptible to temperature changes.
- The system has to be calibrated for the material being measured.

Radar

Radar-based moisture measurement in aggregates is based on monitoring changes in Time Domain Reflectometry (TDR) in which the speed of high frequency electromagnetic pulses through a probe is correlated with the surrounding material's dielectric constant (K_a). The K_a depends on the permittivity of the individual constituents of the medium, including the absorbed water, which allows assessment of the amount of water based on a calibration of the system. (Hailong et.al., 2021). The device must be in direct contact with the aggregate stream. Radar sensors have the following characteristics:

- The device is typically located 12 in. directly under the gate of the bin to allow direct contact with the material.
- Measurement frequency is 4 readings per second.
- Accuracy is ±0.1% of the moisture content.

Optical or Near Infrared

Optical moisture sensors compare the reflectance of particles over a range of light frequencies. Water absorbs light at about 1.4 and 1.9 µm. Therefore, differences in reflectance at these frequencies indicate the amount of water in the system (Haavasoja 2011, Finna Sensors 2023). Optical sensors have the following characteristics:

- The technology only reports surface moisture and not absorbed moisture.
- The device is installed at a fixed distance, typically about 3 ft above a moving sample behind a dust protection window.
- Response time is 0.2 to 10 seconds.
- The device does not contact the material or contain moving parts, meaning there is no wear.
- Depth of penetration into the sample stream is only ~25 mm (1 in.).
- Accuracy is 0.3% to 0.6% by weight for aggregates with moisture contents of 1% to 20%.

Chemical

Another approach uses a calcium carbide reactant that is mixed with a sample of known mass in a pressure vessel. The water in the sample reacts with the carbide, producing gas, so increasing the pressure in the vessel. The change in pressure, measured with a gage, can be calibrated to the moisture content with a reported accuracy of 0.5%. Calibration is relatively easy. Challenges with this approach include the risk of explosion or fire if the carbide is exposed to water outside the vessel, and that a representative sample has to be collected.

DEVICE LOCATIONS AT THE BATCH PLANT

Aggregate moisture sensors can be installed at the following locations at the batch plant.

In the Bin

When a sensor is installed in the bin, the device experiences relatively high wear. Additionally, the device only detects the fraction of material in direct contact with it, which may not be representative of the aggregate overall.

Tuomikko 2018

Microwave Sensor installed in the bottom of a bin

Below a Gate

Installing a sensor below a gate allows direct contact with the aggregate but also leads to high wear for the device. Access to the device for repair or replacement is relatively simple.

MESA Systems Co. 2023

Radar device installed below a gate

Above or at the End of a Belt

When a sensor is installed above or at the end of a belt, access to the device is simple and a representative sample of the material is measured.

Teconer 2020

Optical sensor installed at the end of a belt

Handheld Sensors

A number of handheld devices are available that are based on the technologies described above. These can be inserted into a stockpile to assess moisture content of the pile. One challenge with this approach is that the volume of material measured is small in comparison to the total stockpile, potentially leading to unrepresentative results. An advantage is that sampling can be conducted well before the material is batched, allowing time for water dosages to be adjusted.

HMA Lab Supply

Handheld sensor in use in a stockpile

DISCUSSION

The research team reached out to ready-mix and central batch plant operators to discuss issues related to the use of aggregate moisture sensors. These discussions highlighted the following challenges:

- Periodic recalibration is required for all the systems available, and this activity is often complex. The need for recalibration is particularly challenging when several aggregate sources are in use.
- Variability within a load may not be detected, particularly when data processing takes a significant amount of time. It has been reported that only 60% of each load can be evaluated to allow the operator time to make changes in water content. This may slow the operation of the plant.
- There is a concern that making adjustments solely on the basis of the sensors measurements may result in the plant continually operating one load behind the actual moisture content, resulting in *more* variable production. Some operators reportedly use moisture sensors to monitor moisture states but do not make changes to the operation based on the data provided.
- Sensors are expensive, and the cost of their maintenance and operation is high.
- Devices are most effective in monitoring fine aggregate due to its relatively large specific surface.
- Devices in contact with the aggregate flow may not be sufficiently durable for the aggressive environment of a loading operation.
- Some accuracy requirements for measurement devices are difficult to achieve, such as the Federal Aviation Administration (FAA) tolerance requirement of 0.25% water by mass of sand.
- The volume of material sampled by a sensor may be only a small fraction of the total, increasing the risk of unrepresentative measurements.
- Periodic measurement in the aggregate stockpile, coordinated with the loader operator reportedly yields sufficient control.
- Standardized adjustment protocols would help operators use the data from the sensors more effectively. Some batching systems do provide this capability.
- Operators reported using all the different types.
- Sensors appear to be more useful in association with dry-batch plants because dry-batch plants do not have the ability to adjust water based on the workability of the mixture in the mixer like a central plant, so there is time for analysis of data and adjustment of batch water after the plant.

FUTURE WORK

While moisture sensors are a useful tool in helping batch plant operators control the water content of their concrete mixtures, there are challenges associated with their use. The most significant issues seem to be the need to regularly recalibrate the devices and the time needed to collect and process data in a plant where production volume is high, and adjustments must be made quickly to be most effective.

It appears that manufacturers are working on making their devices more cost-effective and useful, but by their very nature these devices are complex instruments that seek to measure small changes in large volumes of materials in severe environments. In short, there is no simple solution to these challenges. The literature does not appear to have identified any new technologies that would overcome the challenges discussed.

When considering the fundamental need to produce uniform concrete from batch to batch with a controlled water content given variable source materials, there may be value in considering additional control metrics and techniques.

Ideally, the batch plant operator and the paver operator both need in-line, real-time data about the products coming into their equipment and the quality of the product being delivered from that equipment.

Central batch plant operators can use the so-called "slump meter" (i.e., the power demand of the mixer) to assess the workability of the concrete during mixing. Experienced operators are able to adjust the water dosage successfully on-the-fly, but experienced people are difficult to find, and gaining the requisite skill involves making mistakes and learning from them. Development of tools to reliably report the workability of the mixture in the drum, along with guidance on how to adjust the mixture, may be the most cost-effective approach to improve concrete quality.

It also may be possible to rapidly measure the response of concrete to vibration using devices such as the Vibrating Kelly Ball (VKelly) or others that measure the transfer of energy through concrete. These devices could be used to evaluate mixtures on dump trucks, or in front of the paver. The information from these devices could provide the paver operator with near real-time data on what is being delivered and could provide feedback on how operations can be changed to successfully place that material accordingly. These devices can also be used to provide feedback to batch plant operators so that they can better control their processes.

All of the control metrics and techniques described above are needed in order to provide a reliable and consistent concrete mixture for a paving project.

NEXT STEPS

The following actions are suggested to help provide reliable and consistent concrete mixtures:

- Fund additional research to create a best practices guide for the use of "slump meters."

- Use tools such as the VKelly and other emerging technologies to measure the consistency of concrete mixtures being produced by different paving contractors to see whether these devices can make meaningful measurements that indicate changes in a concrete mixture.
- Promote the use of all types of moisture sensors during batching, as they do provide a means of monitoring large swings in aggregate moisture.

REFERENCES

BFT International. 2011. Radar moisture probes. *BFT Magazine*, No. 06/2011. https://www.bft-international.com/en/artikel/artikel_en_1207790.html.

Finna Sensors. 2023. SMART III NIR Moisture Sensor. https://finnasensors.com/product/smart-iii-nir-moisture-sensor/.

Haavasoja, T. 2011. Optical moisture measurement in concrete aggregates. Nordic Concrete Research. Publication No. 44 2/2011. pp. 45–53. https://www.teconer.fi/wp-content/uploads/NCR-F48-Haavasoja.pdf.

Hailong He, Kailin Aogu, Min Li, Jinghui Xu, Wenyi Sheng, Scott B. Jones, Juan D. González-Teruel, David A. Robinson, Robert Horton, Keith Bristow, Miles Dyck, Vilim Filipović, Kosuke Noborio, Qingbai Wu, Huijun Jin, Hao Feng, Bingcheng Si, Jialong Lv, Chapter Three - A review of time domain reflectometry (TDR) applications in porous media, Editor(s): Donald L. Sparks, Advances in Agronomy, Academic Press, Volume 168, 2021, Pages 83-155, https://doi.org/10.1016/bs.agron.2021.02.003.

Hydronix. 2023. Why Measure Moisture Using Microwaves? https://www.hydronix.com/why_hydronix/microwave_technology.php.

Nakayama, S. Microwave Measurements of Moisture Content of Aggregate, Japan Journal of Applied Physics, Vol. 33, pp. 2809 – 2810, 1994.

Nelson, S.O. and Trabelsi, S., Principles for Microwave Moisture and Density Measurement in Grain and Seed, Journal of Microwave Power and Electromagnetic Energy, February 2004, DOI: 10.1080/08327823.2004.11688512

MESA Systems Co. 2023. SONO-VARIO Xtrem (Carbide). http://mesasystemsco.com/products/construction-industry-products/aggregates/sono-vario-xtrem-carbide/#more-148.

Nel, S. 2016. Microwave Technology Can Be Used to Measure Moisture Content of Ores, Coal, and Other Minerals. April 5, 2016. ThermoFisher Scientific. https://www.thermofisher.com/blog/mining/microwave-technology-can-be-used-to-measure-moisture-content-of-ores-coal-and-other-minerals/.

Teconer. 2020. Moisture in Materials. https://www.teconer.fi/en/moisture-in-materials/.

Tuomikko, J. 2018. How to Measure Aggregate Moisture in a Concrete Mixing Plant? October 12, 2018. Tecwill. https://www.tecwill.com/eng/blog/how-to-measure-aggregate-moisture-in-a-concrete-mixing-plant.

APPENDIX A – SUMMARY OF TECHNOLOGIES

Technology	Principle	Contact with sample	Location in plant	Strengths	Weaknesses	Brand names
Microwave	Change in wave form in reflected microwaves	Yes	In aggregate flow	Sample size	Wear, Calibration	Hydronix, Command Alkon
Radar	Change in dielectric properties	Yes	In aggregate flow	Less influence of the environment	Calibration	MESA Systems Co., BFT International, Tecwill
Optical	Change in wave form in reflected light	No	Above the belt	No contact with sample	Surface water only	Teconer, Finna Sensors, Polarmatic, Moistech
Chemical	Gas produced with a reactive reagent	-	Laboratory or field	Calibration is simple	Response time, Sample size	Speedy
Other	All	-	In stockpile	Stockpile measurement	Sample size	Aggrameter, Microlance, , Trident…

APPENDIX B – SURVEY RESPONES FROM IA AND AR READY-MIX ASSOCIATION MEETINGS

What system do you use to monitor aggregate moisture?	**How happy are you with it**
Alkon probes	Fair
Mesa	Good
Slump meter in mixer truck	Great
Command moisture probes.	Okay
Mesa probe for fine aggregates	Great
-	Okay
Probes in the sand bins at our batch plants. We use command Alkon batch controls and moisture probes	Good
Sand probe	Good

APPENDIX C – ORGANIZATIONS CONTACTED

- Astec Industries
- Bard Materials
- Concrete Technologies Inc.
- Hahn Ready-mix
- Hawkeye Ready-mix
- IHC Scott
- Manatt’s Inc.
- Milestone Contractors
- Ozinga
- Razorback Concrete
- Smith Ready Mix
- Zachary Construction