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Production Methods for Improving the Sustainability of Ready Mixed Concrete

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ABSTRACT

Concrete must be batched in one condition at the plant to meet acceptance criteria later at the construction site. This situation can result in unnecessary over-design, material waste, concrete variability, excess fuel use, and time delays. New technology is available to manage the batching and delivery process by determining the slump and temperature of concrete in the truck in real time, ensuring concrete is properly mixed and agitated, and if allowed, making automatic adjustments to the concrete by adding water and admixture. This paper describes this new technology and shows how this technology can contribute to increased concrete sustainability.

Keywords. admixture, variability, production, mixture proportioning, slump

INTRODUCTION

Regardless of how well concrete is batched at the plant, variation is introduced during transit and at the construction site. Historically, many of the sources of this variation were beyond the control of the ready mix concrete producer and were addressed by over-designing concrete and, in some cases, by making manual adjustments during and after batching. Specifications, mixture proportions, and standard operating procedures were developed based on limited measurement and automation during delivery. Concrete deficiencies were costly and time consuming. This inefficiency during delivery has created an opportunity to improve the sustainably of concrete.

New technology is available for automatically measuring, managing, and recording concrete slump, temperature, mixing, load volume, and water and admixture additions on board the ready mixed concrete truck during delivery. Such automated concrete management systems enable concrete producers, engineers, contractors, and owners to completely rethink the concrete delivery process, resulting in increased sustainability, among other benefits. Changes to the delivery process are essential to achieving the full economic and sustainability benefits or this new technology.

This paper lists the challenges during ready mix concrete batching and delivery and describes the use of truck-mounted automated concrete management systems to address these challenges. The paper also lists changes to ready mix batching and delivery processes that are enabled by the use of automated concrete management systems. Finally, the paper describes how the use of such systems can increase concrete sustainability.

CHALLENGES IN READY MIXED CONCRETE PRODUCTION

Ready mix concrete producers face the challenge of ensuring the correct concrete properties at the time of final delivery. Concrete must be batched in one condition at the plant to meet acceptance criteria later at the construction site, taking into account changes that may occur in transit from the plant to the site. Variations in raw materials, changes in aggregate moisture content, traffic delays, unpredictable weather, uncertain construction site conditions, and other unforeseen variability make this a complex task. Manual adjustments to concrete in the truck, if allowed, are difficult and time consuming.

Batching. During batching, variations can occur in both raw material quality and quantity. In particular, water content can vary significantly (Day 2006, Cazacliu et al. 2008, Rigueira et al 2009, Obla and Lobo 2011), mainly due to variations in aggregate moisture content, residual water in the drum from the prior load, and driver added water. Aggregate moisture meters, when used, are of finite precision and require routine calibration. Free water from the aggregates often contributes more than a quarter and sometimes as much as half of the water in a batch. Even though batch water can typically be metered accurately, the batch operator may not know the correct amount of water to add due to variations in other sources of water. The batch ticket may show the amount of water batched, but this number is based on the assumption that aggregate moisture was measured correctly and there was no residual water in the drum.

Because of variations in the water added at batching, batch operators or drivers must subsequently add more water to compensate. Variations in water content have a dramatic effect on slump (Obla and Lobo 2011). Therefore, adjusting to a consistent slump for a given mixture proportion by adding water immediately after initial batching and mixing is an effective way to reduce variation in water content provided other sources of variation in slump are properly managed (Day 2006, Cazacliu et al. 2008, Obla and Lobo 2011). This is true even for self-compacting concrete (ACI 2007). In the case of centrally mixed concrete (“wet batch”), this adjustment in water content is often made by evaluating the power requirement of the central mixer before concrete is discharged into the truck and adjusting the water content accordingly (Cazacliu 2008). For truck mixed concrete (“dry batch”), this adjustment to water content is typically made based on the judgment of the driver. However, this decision of how much water to add is often based on a visual estimate of slump. Drivers often do not have immediate or accurate feedback on how much water they added.

Transportation. The largest variations during transportation are in transportation time and weather. To ensure concrete arrives at the jobsite at the right slump, ready mix producers typically batch concrete at a high slump in anticipation of slump loss, make adjustments at the jobsite, or both. The choice of which approach to use depends on specification requirements, which can vary in different countries. If adjustments are made at the plant but prohibited at the site, the ready mix producer must correctly anticipate and adjust for changes during transportation and at the site. This can result in a large number of loads rejected for being out of specification and unnecessary overdesign. In cases where adjustments are allowed at the site—either with water or admixture—such adjustments can be imprecise and cause time delays. Adjustments made with water will result in lower strength and increased variability in strength, both of which must be compensated for by increasing the cementitious materials content.

Construction Site. At the construction site, further delays can occur. Slump is not usually measured on every load. When slump is measured, sampling and testing variability occur. This further complicates the challenge of making suitable adjustments to the mixture at the plant, site, or both. The result is greater variability, increased overdesign, and more loads rejected for being out of specification. In addition, contractors and other site personnel may request an increase in slump above the ordered slump to ease placement.

Another option for reducing the variation in slump, water content, or both at the construction site and to prevent loads being rejected for being out of specification is to use admixture in transit to maintain slump. For example, increasing the transit time can increase the amount of water needed to maintain slump, whether this water is added at the plant, site, or both. This water affects concrete quality and must be compensated for by increasing the cementitious materials content. In contrast, adding superplasticizer to maintain slump in transit and at the site avoids increasing the amount of and variability in water content. It is advisable to adjust to a target slump immediately after batching by adding water, and then to adjust to a target slump at delivery by adding admixture. If water is added in the truck to compensate for workability loss, this water should be tracked to ensure the total water content does not exceed the maximum water content allowed by the mixture proportions. Variations in water content affect not just slump, but compressive strength, finishability, setting time, air content, and durability.

AUTOMATED CONCRETE MANAGEMENT SYSTEMS

Multiple systems have been developed for determining the slump and other workability characteristics of concrete in a truck mixer (ACI 2008). Some systems are called slump meters, but only consist of a gauge indicating hydraulic pressure required to rotate the mixing drum. However, modern slump management systems incorporate other factors in determining slump and/or slump flow—such as load volume, mixture proportions, and drum speed—utilize advanced signal processing and algorithms to calculate slump and/or slump flow, and display and record this information electronically (Koehler et al. 2010). In addition to measuring slump or slump flow, some systems can directly or indirectly control the water content.

The automated concrete management system (ACMS) used for the experimental testing in this paper is shown in Figure 1 and was made by Verifi (Koehler et al. 2010). This system continuously measures slump, slump flow, temperature, water use, admixture use, drum speed, load volume, and number of drum revolutions from batching to final discharge. The system can be configured to add water or admixture automatically to reach a target slump or slump flow.

The components of the system are shown in Figure 1. Slump or slump flow is calculated by the processor based on the load volume and readings of hydraulic pressure and drum speed. The system can also take into consideration the mix proportions to calculate slump or slump flow; however, in the vast majority of cases one calibration per truck is sufficient to measure all concrete mixture proportions in a plant. Figure 2 shows the correlation between the calculated slump from the ACMS and the slump measured manually in accordance with ASTM C 143. Measurements were made at 2 plants for 3 trucks. Each plant utilized different materials and mixture proportions, the data for which are provided in Koehler et al. (2010). Figure 3 shows the correlation between the calculated slump flow from the ACMS and the slump flow measured manually in accordance with ASTM C 1611.

Figure 1 also shows the temperature sensor, which is mounted to the drum hatch and includes a small probe that is inserted into a hole in the drum to contact concrete. Admixture is dispensed from a 45-liter (12-gal) tank mounted to the truck and delivered through an admixture nozzle attached to the existing water nozzle to the drum (if present). This nozzle injects admixture under pressure in a narrow stream so that all admixture reaches the concrete in the drum and does not contact the drum walls or mixing fins. Valves and meters are provided to control and measure the dispensing of admixture and water (if present). An external display shows the current slump for the driver, contractors, inspectors, and other personnel on the construction site. The driver has access to further data on the in-cab interface. In addition to showing slump and slump flow, the external display and in-cab interface prompt the driver to mix the concrete at the proper mixing speed for the required number of revolutions after batching and after additions of water and admixture. At other times, the driver is prompted to rotate the drum at agitating speed.

The equipment on the truck connects via a cellular data connection to an online data service. The system communicates with the batch software to obtain information to manage each load of concrete, such as the load volume, target slump, and the amount of water the truck can add without exceeded the maximum water-to-cementitious materials ratio (w/cm). The data service consists of a database of all measurements from the truck equipment. The data is analyzed and sent to reporting and alerting applications.

The system can be set to add water or admixture automatically to reach a target slump or slump flow, subject to limits on the maximum w/cm. A typical delivery cycle is shown in Figure 4. Water additions can be completely disabled if required by specifications or project engineers. The system records all measurements of water and admixture. The amount of water to the drum is reported separately from hose water used externally, such as for washing the chute and exterior of the truck. If an attempt is made to add water or admixture from a source outside the system, such as from a hose external to the truck, the system can record such an addition based on evaluating the change in slump. An alert can be issued to the engineer, inspector, or plant management.

The actual amount of water added to the load, slump or slump flow readings through the delivery cycle, mixing performed, number of revolutions, concrete temperature, load volume, and event times such as batching, leaving the plant, and discharging are reported. This record can be used by ready mix producer personnel and provided to the contractor, inspector, owner, engineer, or other party as part of a quality assurance program.

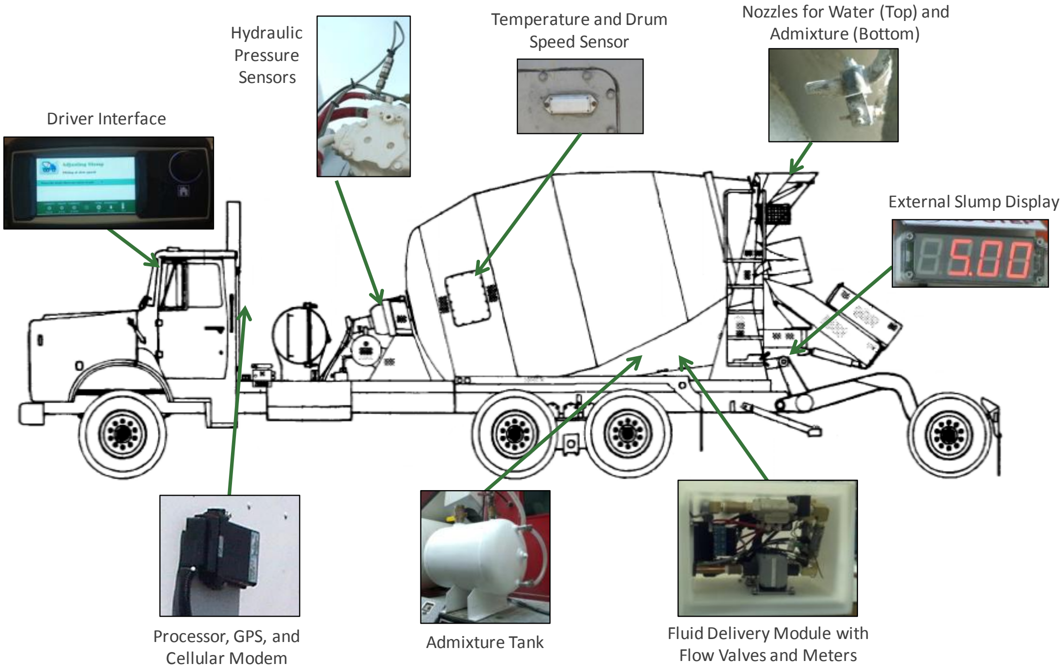

Figure 1. Automated concrete management system

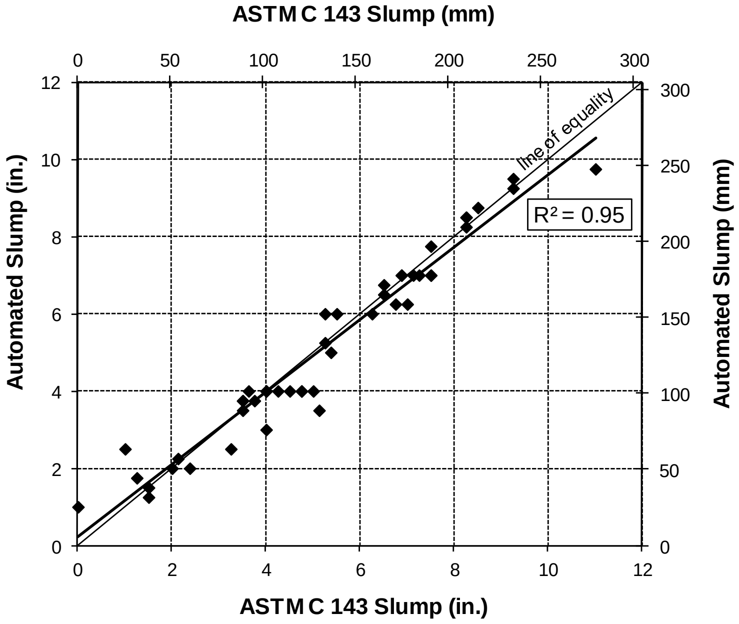

Figure 2. Slump measurement

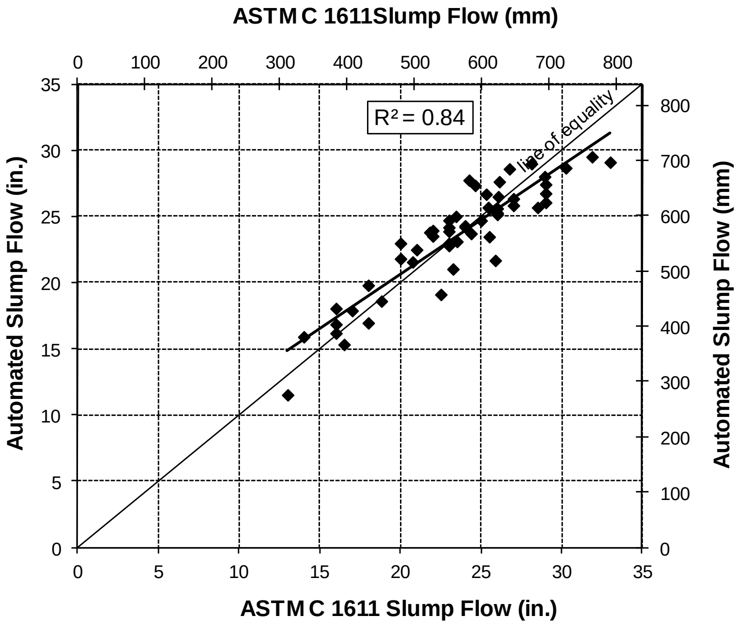

Figure 3. Slump flow measurement

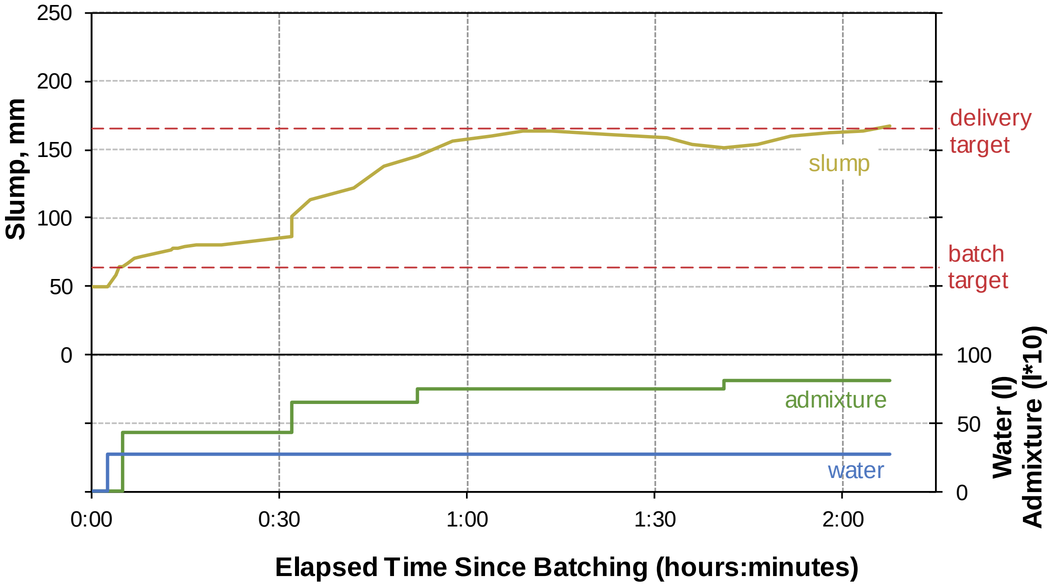

Figure 4. Slump control with water and admixture addition

RETHINKING CONCRETE DELIVERY

To obtain the full benefits of an automated concrete management system, the data generated must be used to implement changes to mix proportions, standard operating procedures, and specifications. These changes are aimed at optimizing materials use and increasing operational efficiency, thereby resulting in improved concrete sustainability.

Change 1: Eliminate guesswork by managing slump in transit automatically. Slump at discharge is typically managed by batching concrete at the plant to a slump greater than the target at the construction site. This is to account for expected slump loss during transit, but can result in loads being rejected for being out of specification when slump loss or delivery time is different than expected. In some cases, slump adjustments may also be made at the construction site. However, this requires extra time and can result in increased variability in strength and other properties if adjustments are not made precisely and accurately. An automated concrete management system enables these changes to be made in transit without the need for human involvement. Research has shown that water and admixture additions can be fully mixed, even when the drum is rotated at agitating speed (Koehler et al. 2010). By using an adaptive rather than predictive approach to managing slump, variability in slump and other concrete properties can be reduced.

Change 2: Change standard operating procedures to reduce the time needed to make adjustments. In many concrete plants, drivers are instructed to not leave the plant until the slump is fully adjusted to target. This increases time in the plant and can reduce the number of loads a plant can batch per hour. By batching at or slightly below the target slump and allowing the automated concrete management system to make adjustments during transit, time savings can be achieved and plant productivity increased. The concrete will arrive at the site at the correct slump, eliminating delays on site.

Change 3: Optimize mixture proportions. Concrete mixtures must be overdesigned for strength and other hardened properties to account for the variability due to batching, transportation, sampling, and testing. The use of an automated concrete management system can result in a reduction in variability in strength and hardened properties, thereby enabling mixtures to be optimized. Using admixture rather than water to maintain slump during transit and at the site can result in higher and less variable strength. Mixtures can be optimized by reducing water and cementitious materials.

Change 4: Change specifications to reduce or eliminate minimum cement or cementitious materials contents. Prescriptive specifications often require a minimum cement or cementitious materials content. In other cases, specifications require a maximum w/cm much lower than needed for the design strength and durability properties. This low maximum w/cm results indirectly in a minimum cement or cementitious materials content, as a certain unit amount of water is needed for workability. These specifications were originally written in part to provide a level of overdesign to compensate for the lack of data and potential variation during the batching and delivery process. By documenting and controlling the concrete properties of every load at discharge, such overdesign can be reduced. Concrete producers can be allowed to use lower cementitious materials contents, as long as concrete can be shown to meet performance requirements and/or documentation is provided to confirm concrete properties at discharge.

Change 5: Change specifications to allow adjustments in transit. Many concrete specifications around the world either prohibit all adjustments to concrete after batching, or limit adjustments to the jobsite where an inspector is potentially present. As described earlier, post-batching adjustments are typically needed. These adjustments can be more accurate when made in response to variations, rather than in anticipation of variations. Because full documentation of concrete properties and all water or admixture additions can be provided to the inspector at the site, it is no longer necessary to require that adjustments be made at the site where an inspector may be present. Therefore, specifications can be amended to allow the addition of water and or admixture in transit if an automated concrete management system is provided.

SUSTAINABILITY

The use of automated concrete management systems can potentially result in the following sustainability-related benefits. Potential benefits are considered based on the Sustainable Concrete Plant Guidelines published by the US National Ready Mix Concrete Association (NRMCA).

Cement Use. The amount of cement used can be reduced by reducing the number of loads rejected for being out of specification, such as due to slump, temperature, or water content being out of specification. In addition, an ACMS can reduce the amount of water added by documenting all water additions, reducing the amount of manual water additions, and replacing retempering water with admixture. This reduction in water can result in a reduction in cement content. For example, a 1% reduction in the number of loads rejected for being out of specification would result in a reduction of approximately 500,000 tons of CO_2 emissions in the US.

Water Use. An ACMS can reduce the amount of water added to maintain, and is some cases, exceed the target slump. In many countries around the world, it is common for the contractor or other personnel on site, such as the pump operator, to add water to concrete to exceed the target slump. The ACMS can reduce this practice by providing documentation of the actual slump and enabling the use of admixture to achieve the target slump.

Energy Use. Total energy use can be reduced primarily by reducing the amount of cement used. In addition, data on the temperature of the concrete during delivery can be used to optimize the use of heated and chilled water.

Worker Safety. Worker safety can be enhanced because drivers can stay in their trucks longer. Drivers no longer need to get out of the truck to visually assess the slump and make adjustments with water or admixture.

Fuel Use. The amount of fuel used can be reduced by reducing the amount of time the truck spends at the plant and site for adjustments. In addition, over-mixing can be reduced because the ACMS can provide prompts to the driver for when to mix at high speed and when to mix at agitation speed. Data collected on trucks in the US indicated average fuel consumption savings of 2 litres for every 100 revolutions eliminated when the truck is stationary.

Green Building Products. The use of an ACMS can enable increased production of sustainable concrete, such as high durability, high strength, and self-compacting concrete. Such concrete can be difficult to produce consistently without an ACMS.

Excess Concrete Reduction. The amount of excess concrete generated can be reduced by preventing loads being rejected for being outside of specification. In addition, an ACMS can enable the re-use of returned concrete, whether due to the load being rejected or an excess quantity being ordered. The ACMS can determine remaining load volume, concrete temperature, and any additions of water and admixture to the returned concrete. This information can be used to determine the suitability of re-using the concrete. If it is necessary to add more concrete to a returned load, the data from the ACMS can be used to determine the properties of the new concrete that must be top-loaded on the returned concrete.

In addition to the above sustainability benefits, the availability of higher quality, less variable concrete can enable construction projects to be completed faster, at lower cost, and with less repair work. This enables owners of buildings and other structures to do more with the same amount of available resources.

CONCLUSIONS

Automated concrete management systems are available to reduce variation during concrete batching and delivery and to ensure improved concrete quality. In order to take advantage of these systems, changes must be made to mixture proportions, concrete specifications, and standard operating procedures. The use of such systems can result in increased concrete sustainability due to reduced cement use, reduced water use, improved worker safety, reduced fuel use, use of green building products, and reduced excess concrete.

REFERENCES

ACI Committee 237. (2007). *Self Consolidating Concrete*. Report ACI 237R-07. American Concrete Institute, Farmington Hills, MI.

ACI Committee 238. (2008). *Report on Measurements of Workability and Rheology of Fresh Concrete*. Report ACI 238.1R-08. American Concrete Institute, Farmington Hills, MI.

ASTM C143/C143M-08. (2008). *Standard Test Method for Slump of Hydraulic Cement Concrete*, ASTM International, West Conshohocken, PA.

ASTM C1611/C1611M-05. (2005). *Standard Test Method for Slump Flow of Self-Consolidating Concrete*, ASTM International, West Conshohocken, PA.

Cazacliu, B., Le, N.D., and de Larrard, F. (2008). "New method for accurate water dosage in concrete central mix plants", *Materials and Structures*. Vol. 41, No. 10, pp. 1681-1696.

Day, K.W. (2006). *Concrete Mix Design, Quality Control, and Specification*. 3rd Ed., Taylor and Francis, New York, 357 pp.

Koehler, E.P., Sostaric, J., and Durning, T. (2010). "In-Transit Process Control for Improved Ready Mixed Concrete Performance." *Compendium of Papers, Transportation Research Board Meeting*, Washington, DC.

Obla, K., and Lobo, C. (2011). "Mixing Water Control*", Concrete in Focus*. Vol. 10 No. 2, pp. 23-27.

Rigueira, J.W., Garcia-Taengua, E., and Serna-Ros, P. (2009). "Self-Consolidating Concrete Robustness in Continuous Production Regarding Fresh and Hardened State Properties", *ACI Materials Journal*, Vol. 106 No. 3, pp. 301-307.

RMC Research & Education Foundation (2011). *Sustainable Concrete Plant Guidelines*, National Ready Mixed Concrete Association, Silver Spring, MD (USA), 64 pp.