Detection and Calculation of water addition by monitoring concrete and water temperature in ready-mix Drum

By Dr Denis Beaupré

Summary

This report presents several records obtained by the IBB Manager and explains how to interpret them. It then presents specific results of water addition detection and how the amount of water can be calculated

Introduction

Water-cement ratio of concrete (W/C) is an important parameter for concrete properties, including, among other, workability, strength and durability. W/C is normally control at the batching plant where amount of water and cement are controlled by several possible means during initial manufacturing of fresh concrete. However, after initial addition of all components into drum the ready-mix truck, the W/C can be altered most commonly by adding water to the concrete to increase its workability. Unfortunately this is left to the good will of the driver as there is little way to be sure nothing has been done to alter this. When it happen, water addition always results in lower mechanical and durability performance unless the addition was made to compensate for batching problems which, with computerize batching system, is a rare occurrence.

Several strategies have been deployed to prevent water addition:

- Flow meter have been installed on truck by concrete producer to monitor the driver
- Consultant have forbade truck to carry any water (Producer do not like this)
- Consultant have required the water tank remain full until the delivery is completed

Adding water to concrete is common in many places. ASTM C- allows such addition if a monitoring system is used. Very often the truck is equipped with is a fixed pipe that can bring water directly into the drum of the ready-mix drum. Most truck have also a flexible hose use for cleaning that can also reach the opening of the drum and therefore can also be used to add water to the fresh concrete.

To monitor the addition of water into a ready-mix drum, it is a common practice to install some sort of water meter (including mechanical, magnetic or electronic flow meter) on the fixed water pipe. Although that kind of apparatus can be very precise, there is always an uncertainty on the total amount of water added because water addition can still be performed with the washing hose or other means (at plant check point for example). As a result, by-passed water is not being monitored by the water meter.

The amount of water recorded by the water flow meter should thus be considered as a minimum. Installing a second flow meter on the flexible hose used for cleaning the truck will not be helpful since there is limited way to determine if and how much of the cleaning water is added into the fresh concrete.

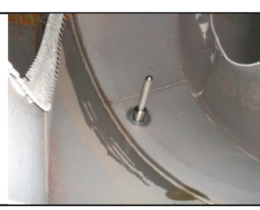
Because water addition is often done after some concrete is discharged, the amount of concrete left into the drum at the time water is added is also an important parameter to calculate the resulting W/C. There are many systems that use the number of turns in reverse direction (as oppose to ready-mix drum mixing direction) to estimate the amount of concrete left in the drum at the time water is added to calculate the W/C. to be precise, this concept need to take into account the priming (number of turns before the concrete start to exit the truck) and concrete workability (which affect the amount of concrete going out every turn).

Monitoring concrete temperature by using a senor installed directly inside or on the intern surface of the ready-mix drum is becoming an common practice in the industry because it can be done automatically (no sampling required) and continuously without operator influence.

IBB Probe System

The IBB Probe has been developed as a component to a more global system that monitors the quality of the ready-mix concrete from production to delivery for both the concrete and the operations. The IBB Probe System has four main components: a workability probe, a solar panel, a receiver/display unit and a Manager System as an option (Figure 1).

System summary



Probe inside drum

Display unit

E-10 unit

Figure 1: Some elements of the IBB Probe system

The IBB Workability Probe is installed in the drum of the ready-mix truck. A solar panel helps to keep the probe's batteries full charged. It is designed to measure fresh concrete properties including workability (yield, viscosity and the more traditional slump or spread test) and temperature in a continuous and automatic way. It also measures the movement characteristics of the ready-mix drum (angle, speed, direction and number of turns) and with proper calibration measures and/or tracks the volume of concrete into the drum. Above figure shows a typical probe installation from the inside of the truck.

The Display unit continuously receives data from the probe via radio signal and displays some of the measured or calculated parameters. The display has internal memory that stores all data. It can also be permanently connected to a communication system (such as Traktronic) to display data in real time.

The IBB Manager System uses a two ways communication device (referred to as E-10 module) installed in the batching plant and linked with a database. A software, installed on the batching plant computer, controls the information between the user, the E-10 and the database. The Manager improves the system overall performance by allowing the Probe and the batching plant to exchange information and generates report for individual delivery as well as to help control the operation and the probe performance.

The Manager has the following main functions:

- Transmits the ''new load'' information to the receiver that relays it to the probe
- Allows to display the concrete property in the batching room just after loading
- Lists all trucks with last load information, including age of concrete (time from batching)
- Automatically receives the log of the previous delivery from the receiver
- Stores the log into the database and preforms analysis
- Show graph of individual delivery

The main purpose of the Manager is to store the data for all deliveries. This is done automatically when the truck is based at the plant. When the data is stored, it is possible to search the data base using different filters: Time of delivery, Truck numbers, Mixture Name and/or Destination. The data can be represented graphically to show several parameters like in Figure 2 where the drum slump (cm), Volume of concrete, Temperature, Drum speed and Probe pressure are shown.

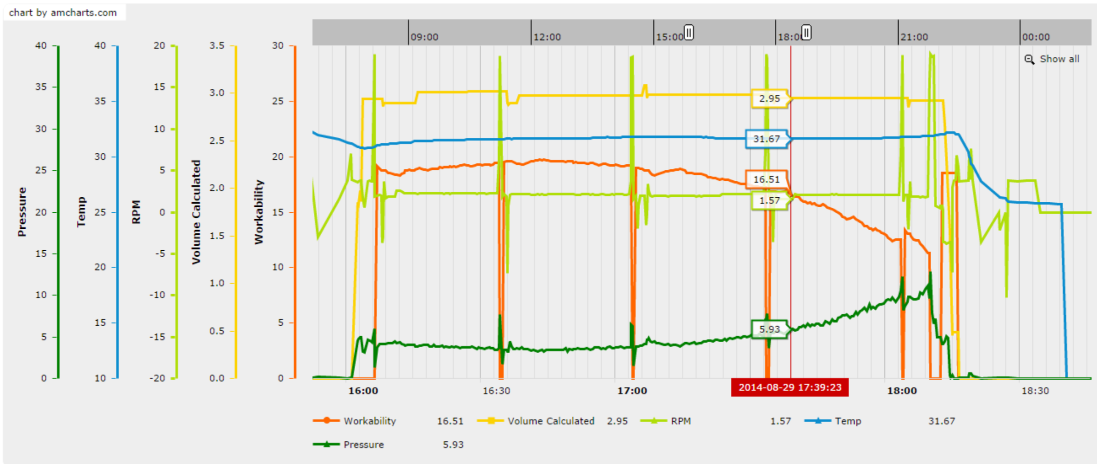


Figure 2: Graphical log of one delivery

Connecting a GPS system to the IBB Probe system is possible and allows tracking the position and other characteristics of the ready-mix truck in real time, as shown in Figure 4.

Figure 3: GPS system linked with IBB Probe system for real time data

Addition of superplasticizer

Figure 4 shows a trial using 3 m3 of concrete with initial slump of 150 mm and initial temperature of 30C. The temperature of concrete measured directly into the drum of the ready mix is quite stable due to the concrete high thermal capacity (2.7 $kJ/m^3/C$). This initial temperature has a natural tendency to slowly adjust to the outside temperature and/or to gradually increase due to slow physical or chemical process: it is rarely constant. This normally smooth temperature evolution can suddenly be modified when water with temperature different than concrete is added in the drum and mixed with the concrete. It does not take too much water with too much temperature difference with the concrete to affect the concrete temperature due to the water high thermal capacity (4.2 kJ/m^3/C).

Change of less than 0.1 degree Fahrenheit can be detected and recorded by the IBB Probe. If the temperature of the added water is known, using the laws of thermodynamics, it is possible to calculate the amount of water that was added without using any flow meter data. Calculation examples will follow.

Figure 4: Addition of superplasticizer (no temperature change)

In Figure 4, although the temperature does not change abruptly, the slump clearly changes from 12 cm to 17 cm after the mixing period: superplasticizer was added. During those trials, manual slump were taken and compared to the displayed value on the Receiver (Table 1). Figure 2 shos how well the slump estimated by the probe match the one measured manually, is some case, (5 min) the probe is right in between to manual mesurments.

Table 1: Slump data before and after addition of superplasticizer

Time (Min)	Slump 1 (mm)	Slump 2 (mm)	IBB Slump (mm)
5	156	134	149
30	129	124	137
60	120	115	125
75 + SP	186	180	167*
105	134	142	131
135	114	113	121

* 175 mm on the graph

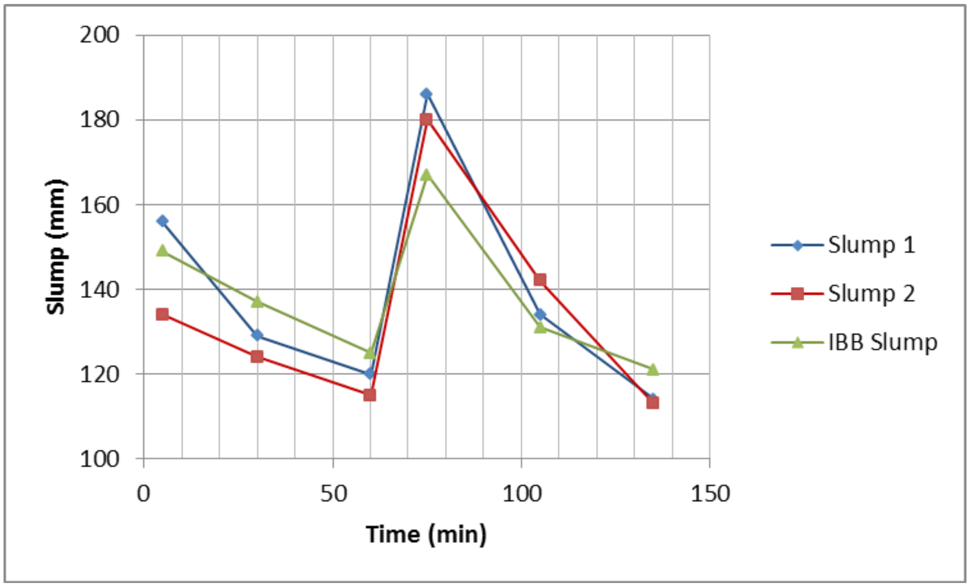


Figure 5: Comparison of slump measurement before and after addition of SP

Detection of water addition (case 1)

Figure 6 shows the record of one concrete delivery which show the following parameters measured by the patented IBB probe system: Drum speed in green (in rpm), Ratio in blue (parameter that estimates volume), Slump in orange (in mm) and Temperature in yellow (C).

This 50 MPa concrete has a cementations content of 320 kg/m^3 and a water content of 140 kg/m^3. From Figure 1, it is possible to make the following observations:

- Initial slump at plant 262.4 mm
- Initial concrete temperature 24.8 mm
- Before discharge started, mixing was performed at high speed
- Slump (before mixing at site) 236.1 mm
- Concrete temperature at site (before mixing at site) 25.54 mm
- Slump at site (after mixing at site) 251.1 mm
- Concrete temperature (after mixing at site) 25.36 mm

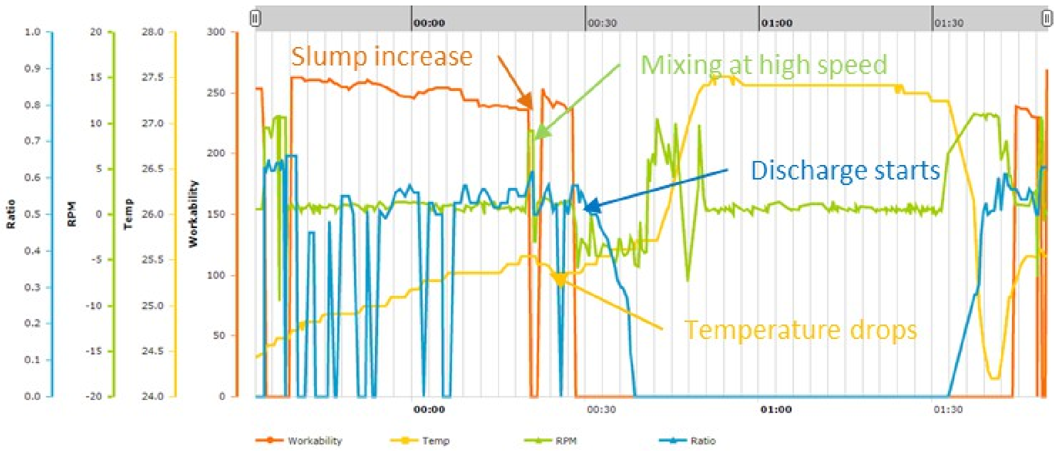


Figure 6: Graphical record of delivery No 1

The main observation is that the concrete slump was higher after mixing. This could have been caused by any of the following possibilities:

- Water was added during mixing
- Admixture was added during mixing
- Structural breakdown has occurred during mixing
- Air was entrained/entrapped during mixing

Looking at the slump alone is not sufficient to distinguish between the above possibilities. However, when considering the temperature record, one can see that the temperature of the concrete drops by 0.18 C after mixing (delay is due to thermal inertia of sensor).

Thermodynamics allows to calculate the amount of water added in to the truck providing that the concrete composition is know so the concrete thermal capacity (CTC) can be calculated. Then by knowing the amount of concrete into the drum and the change in concrete temperature, it is possible to calculate the amount of water if the added water temperature is known. Normally, the amount of water is small compare to the amount of concrete so following simplified equation can be used:

$$DeltaT_{water} \times Q_{water} \times TC_{water} = DeltaT_{conc} \times Q_{conc} \times TC_{conc} \quad (1)$$

Where:

- $DeltaT_{water}$: Temperature variation of added water (C)
- Q_{water} : Quantity of added water (kg)
- TC_{water} : thermal capacity of water (4.2 kJ/kg/C)
- $DeltaT_{conc}$: Temperature variation of concrete in drum (C)
- Q_{conc} : Quantity of concrete in drum (m3)
- TC_{conc} : Concrete thermal capacity in kJ/m3/C calculated as follow:

- TC_{water} = Water (kg/m^3)x 4.200 (kJ/kg/C) + solid (kg/m^3) x 0.92 (kJ/kg/C)
- CTC = 2704 (kJ/m^3/C)
- 0.92 is the solid thermal capacity (STC = 0.92 kJ/kg/C)

For the concrete loaded in the delivery shown in Figure 1, the water content is 162 kg/m^3 (including liquid admixture) and the solid content is 2200 kg/m^3 from which 427 kg/m^3 is cement which give a theoretical W/C of 0.38. The amount of concrete in the drum was 10.5 m^3 and the concrete temperature variation ($DeltaT_{conc}$) after mixing was 0.18 C.

Assuming that the temperature of the water added into the truck was 10 C, then the $DeltaT_{water}$ = 25.36 - 10 = 15.36 C.

By re-arranging equation 1, the amount of water added into the drum can be calculated as follow:

Q_{water} = ($DeltaT_{conc}$ x Q_{conc} x CTC) / ($DeltaT_{water}$ x TC_{water})

Q_{water} = (0.18 x 10. 5 x 2701) / (15.26 x 4.2) = 80 kg (for 10.5 m^3) = 7.6 kg/m^3

One can recalculate the final W/C which will be 169.6/427 = 0.397.

Not a big variation in this case.

Detection of water addition (case 2)

Figure 7 shows the record of another concrete delivery with two important parameters are:

- Temperature at site (before water addition) 28.06 C
- Temperature at site (after water addition) 26.66 C

Then the drop in temperature is 1.40 C and the amount of water added if the concrete temperature is 10C equal to 569 liters which represents 54 liter/m3 which cause the W/C to increase from 0.38 to 0.505 which will definitively produce low quality concrete.

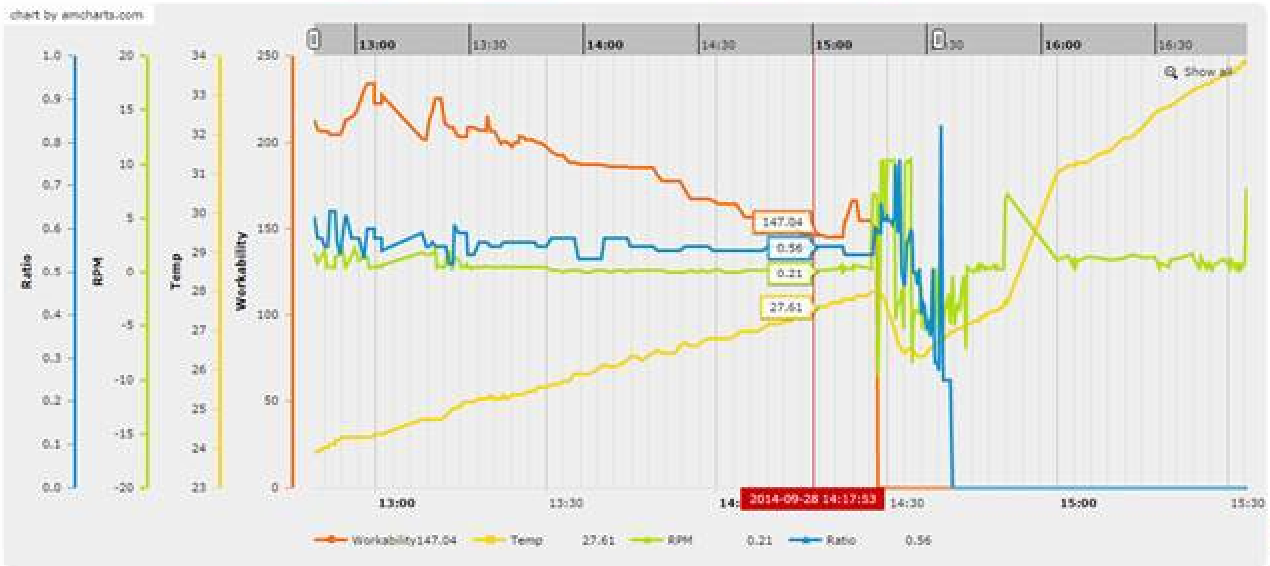


Figure 7: Graphical record of delivery no 2

Detection of water addition (case 3)

Figure 8 shows a trial performed in Japan. Two and half hours after loafing, 43 liter of cold water at 6.2 C was added to the load. The created an increase of slump from 16 cm to 21 cm and a small drop in temperature. The temperature scale of figure 8 does not allowed to evaluate the drop in temperature. However, by using the log of that load, Figure 9 can be draw and from this figure, the drop of temperature is estimated at 0.27 degree Celsius.

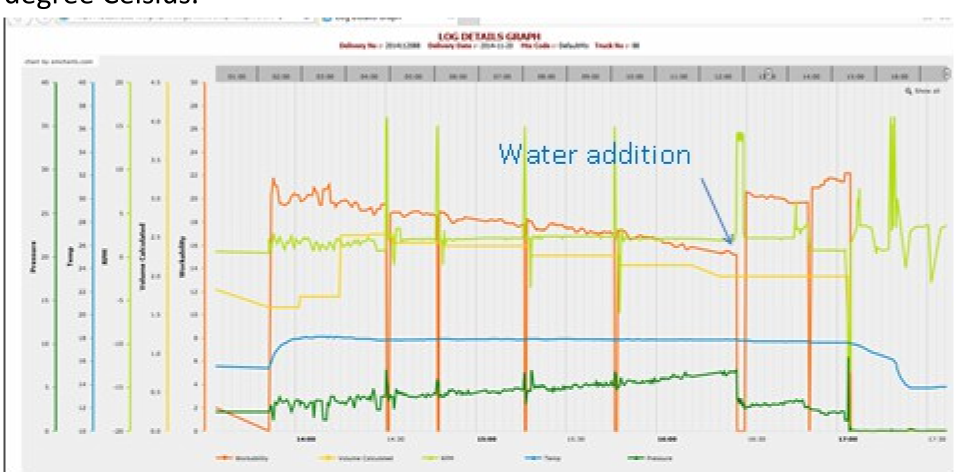
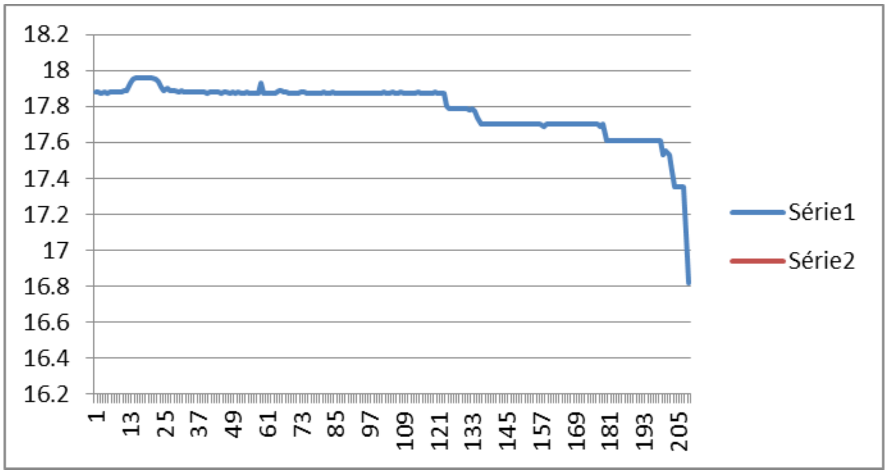


Figure 7: Graphical record of delivery no 3



The equation used to calculate water quantity is from:

$DeltaT_{water}$ x Q_{water} x TC $_{water}$ = $DeltaT_{conc}$ x Q_{conc} x TC_{conc} (1)

Where

- $DeltaT_{water}$: Temperature variation of added water (C)
- Q_{water} : Quantity of added water (kg)
- TC_{water} : thermal capacity of water (4.2 kJ/kg/C)
- $DeltaT_{conc}$: Temperature variation of concrete in drum (C)
- Q_{conc} : Quantity of concrete in drum (m3)
- TC_{conc} : Concrete thermal capacity in kJ/m3/C calculated as follow:
    - TC_{water} = Water (kg/m^3)x 4.200 (kJ/kg/C) + solid (kg/m^3) x 0.92 (kJ/kg/C)

    - CTC = 2704 (kJ/m^3/C)
    - 0.92 is the solid thermal capacity (STC = 0.92 kJ/kg/C)

With

- $DeltaT_{water}$: 17.61 – 6.2 = 11.4 (change in water temperature)
- Q_{water} : Quantity of added water (kg)
- TC_{water} : thermal capacity of water (4.2 kJ/kg/C)
- $DeltaT_{conc}$: 0.27
- Q_{conc} : 2.8 m3
- TC_{conc} : 2750

The amount of added water = (0.27 x 2.8 x 2750) / (11.4 x 4.2)

Amount of added water = 40.1 (the real quantity of added water was 43 liters)

Conclusion

Quality control of concrete was always problematic because there was a blackout between the production at the factory and the arrival at site. Now, with the IBB probe system, it is possible to track the quality of concrete continuously and to detect the worst possible outcome, water addition.