Improving Automated Green Sand Control of Water and Bond Addition Using Optical Moisture Sensors

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ABSTRACT

Optical moisture sensing technology is applied to improve the control of water and bond additions into the muller. The optical moisture sensor measures moisture more accurately than conductivity-based measurements. New control algorithms using optical moisture sensing technology are applied to three different production systems for control of water and/or bond additions. With compactability fixed to a target, the optical moisture measurement correlated to the amount of new bond added to the muller signifying an adjustment in moisture to maintain a water-bond balance. In systems adjusting bond addition based upon control to an available bond target, using optical moisture measurement in place of conductivity-based moisture reduced clay and moisture variability. The optical moisture sensor can be a valuable tool in providing better green sand system control and monitoring.

Keywords: green sand, moisture, compactability, bond, bond control, water control, sand system control, green sand properties

INTRODUCTION

Green sand molding is attractive due to its low cost and its ability to be easily automated for high molding production rates. The clay-water bond is the source of strength of a green sand mold. The compactability and green compressive strength are directly related to the moisture content, the clay content, and their preparation.[1] Because the casting process evaporates much of the water in the green sand mold, water is the component that requires the most replacement in each casting cycle. Water is also the component whose concentration can be adjusted most quickly. Precise and accurate water addition is important to maintain casting quality. The water impacts most properties of the green sand during both molding and casting: compactability, green strength, hot strength, flowability, permeability, expansion and contraction, mold hardness, deformation, toughness, and density.[2] High or low moisture is responsible for 90% of casting defects including blows, scabs, burn-on, metal penetration, pinholes, stickers, and inclusions.[2]

Maintaining the proper water to clay balance is critical to providing consistent, strong molds.[3] The proper moisture amount is also affected by the sand size distribution and the presence of additives such as cereal flour that absorb water. To maintain proper management of water and clay concentrations as well as sand mixing and mulling, researchers[1,3-10] developed controls based upon the concepts of available bond, working bond, and compactability. Available bond and working bond are calculations from the measurements of green compressive strength, moisture, and compactability (Equations 1-3). The term bond instead of clay is employed to account for the other constituents present in the mold (flour, sand fines, etc.) Available bond indicates the amount of moisture absorbing material but does not necessarily relate to a direct clay determination.[5]

$$Working\ Bond = \frac{15.29 \times GCS}{(132.1 - Comp)} \qquad \text{Eqn. 1}$$

$$Available\ Bond = 0.105 \times GCS + 1.316 \times MST \qquad \text{Eqn. 2}$$

$$Mixing\ Effectiveness = \frac{100 \times Working\ Bond}{Available\ Bond} \qquad \text{Eqn. 3}$$

GCS = green compressive strength
MST = percent moisture
Comp= percent compactability

A foundry manages compactability to ensure a water to bond balance, available bond to ensure a consistent clay level, and working/available bond ratio to ensure proper sand mulling.[3-5,7,8] Proper control of these parameters helps ensure a strong mold. However, good molding properties do not ensure good casting properties. For example, if a high moisture is required for proper balance because of the presence of excess sand fines, then the proper moisture balance for molding will result in excess moisture during casting resulting in defects. This tension demonstrates the importance of a foundry maintaining proper and consistent properties of both moisture and compactability.

Based on these concepts, automatic control of moisture to a target compactability is standard practice at almost all foundries,[9,11] and many foundries are automatically controlling bond addition to a target available bond. These control concepts have found favor because compactability, moisture, and green strength are relatively easily automated. Clay measurement and other laboratory tests are less suited to automation but provide important checks on the automated operations. These relationships for fully mulled sand are illustrated in Figure 1 from Heine.[12] In Heine's laboratory mulling tests, he considers a sand fully mulled once additional mulling time no longer changes the sand properties.[9] Note two sets of moisture and clay combinations exist that will achieve a given strength. It is attractive to operate the sand system near the top of this curve because here is where variations in moisture or clay will have the smallest effect on strength.

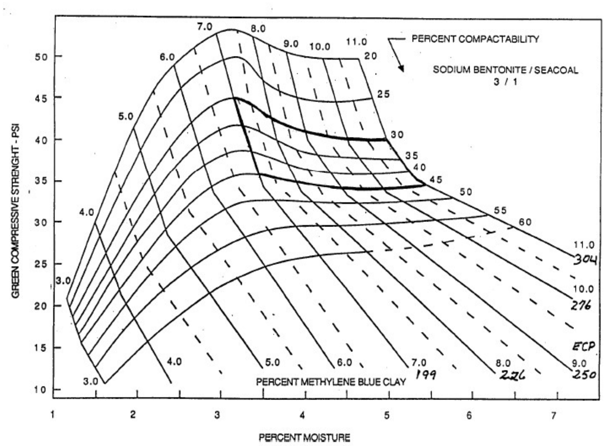

Figure 1. Chart depicting the relationship of moisture, compactability, green strength, and MB clay.[12]

Conductivity is the standard method of automated moisture measurement used in calculating both water and bond additions to the muller. This paper examines the potential benefits of online moisture measurement using an optical sensor based upon absorbance of near infrared light.

METHODS

The methods of moisture measurement discussed in this study are:

- Thermal mass loss—an infrared moisture analyzer heats sand sample at a temperature of 105-110C (221-230F) until the sample weight is constant. (AFS 2216-19-S[13]) This method required sampling and lab measurement.

- Conductivity—the resistance between two probes immersed in the sand is measured and correlated to the moisture level. This measurement is automatically obtained by the muller's sampling and testing system.

- Optical moisture—this method uses the absorbance of near infrared light to determine the moisture levels. This measurement is obtained automatically and continuously with a sensor positioned four to six inches above the green sand.

Comparisons of these measurements are made of the mulled sand with the control system measuring and logging the optical and conductivity-based moisture. The thermal mass loss results are obtained from manual sampling and laboratory testing.

Figure 2 shows an optical moisture sensor (blue device) mounted above a pan feeder filling the muller's weigh hopper. Conductive level probes flank the optical moisture sensor on both sides. Prior to installation, optical moisture sensors were calibrated using a sample of the foundry's green sand with a correlation greater than 0.9995 with laboratory thermal mass loss tests (Figure 3).

Figure 2. Optical moisture sensor and conductivity probes.

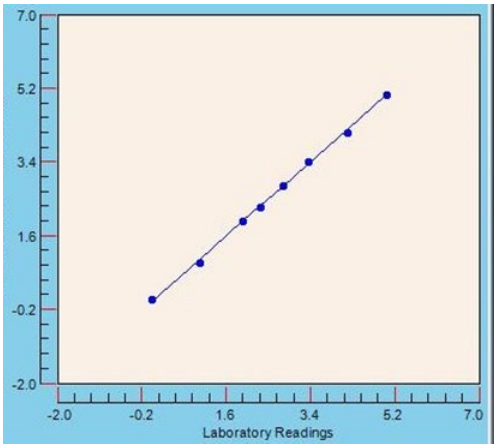

Figure 3. Optical moisture sensor calibration curve.

This case study involves three batch mullers at three different foundries. Foundry A's muller runs 2000-pound batches with a 180 second mull time. Foundry B's muller runs 4500-pound batches with an 80 second mull time. Foundry C's muller runs 4700-pound batches with a 50 second mull time. No changes in mull time or mechanical changes to the muller (i.e., replacement of wheels or ploughs) were made during this study.

RESULTS AND DISCUSSION

FOUNDRY A: CONTROLLING MULLER WATER ADDITION WITH OPTICAL MOISTURE SENSOR

Foundry A is a brass and aluminum foundry whose primary green sand components include olivine sand and calcium bentonite (6.0% methylene blue [MB] clay target). Its muller had employed a Dietert moisture control system dating back to 1973. Critical parts for this legacy system were no longer available. The legacy control system samples sand during the mulling cycle onto a vibrating tray with slots. Dry sand falls through these slots to block sensors triggering water valve(s) to open. Water addition stops once the sand has sufficient moisture to clump so that it no longer falls through the slots to block these sensors.
With this prior control system, sand moisture out of the muller was inconsistent and the source of high levels of scrap castings.

The biggest control challenge was the variable return sand moisture usually caused by the switching of the type of metal cast. The foundry installed moisture and temperature sensors above a turntable feeding the muller's charge hopper and a moisture sensor above the transfer belt exiting the muller. A new algorithm determines water addition based upon the measurements from these sensors.

The return sand moisture varied between 0.5% and 2.1% over the month of November 2021 (Figure 4). Return sand moisture change from one batch to the next was as much as 1.4%.

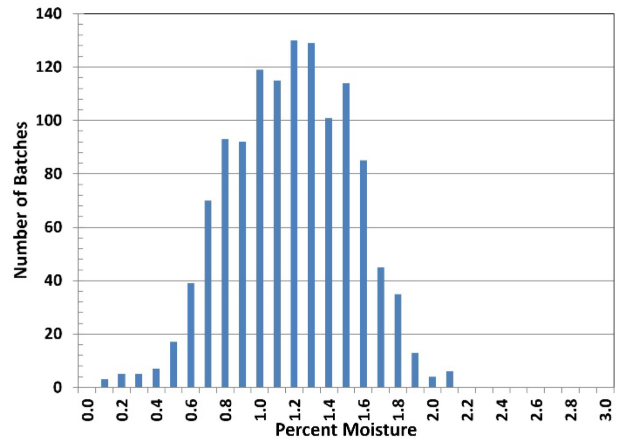

Figure 4. Return sand moisture histogram November 4 to December 2, 2021 for Foundry A.

The optical moisture-based control system performed well in responding to the sudden changes in return sand moisture (Figure 5) and provided consistent sand moisture with an even distribution around its moisture target (Figure 6). The Foundry A operators infrequently adjust moisture target based upon squeeze information from their automated molding equipment. Bond, added prior to the muller, is adjusted based upon lab MB clay tests.

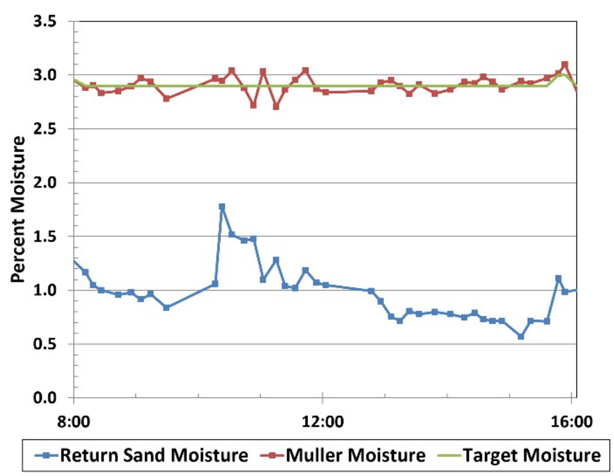

Figure 5. Muller moisture control performance for November 18, 2021 for Foundry A.

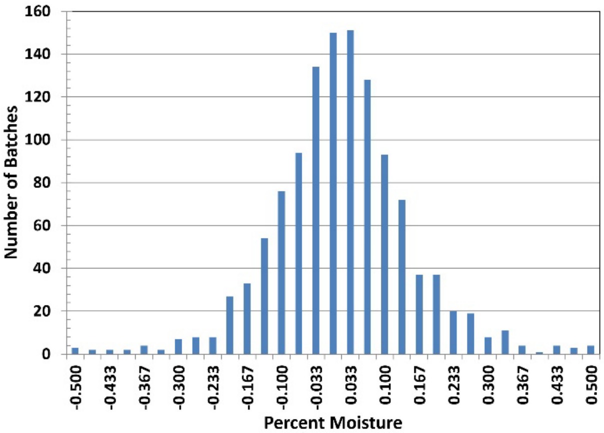

Figure 6. Moisture control histogram November 4 to December 2, 2021 for Foundry A.

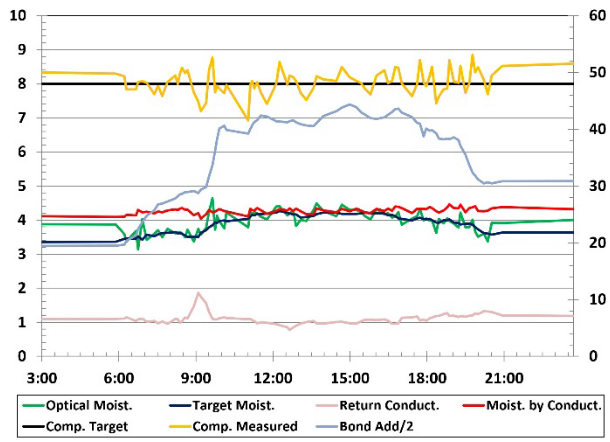

Figure 7. Muller moisture control performance July 5, 2023 for Foundry B.

FOUNDRY B: CONTROLLING MULLER WATER ADDITION WITH COMBINATION OF OPTICAL MOISTURE AND COMPACTABILITY

Foundry B is a foundry casting gray, ductile, and Ni-hard iron castings. This foundry has a fluid bed sand cooler that produces a relatively dry return sand to the muller with moisture typically varying between 0.5% and 1.2%. This foundry had been using a traditional compactability control system for water addition and adjusted bond feed rates with a bond determinator. The foundry installed an optical moisture sensor inside the muller to measure the sand moisture throughout the mulling cycle. The dry sand floated to the top during the mixing process. Thus, the optical sensor only measured a valid moisture result once the mixing had evenly distributed the water throughout the sand. Monitoring the sand moisture and the muller motor's power during the batch determined when the green sand was fully mixed and mulled.

A hybrid water addition control system was implemented that used both the mulled sand moisture and compactability. The control system adjusts the water addition to reach a moisture target and the moisture target is adjusted based upon the compactability target. The operator can adjust how quickly the system responds to changes in each variable. In practice, the system was set to respond to moisture changes more quickly relative to compactability changes.

The moisture control performance over a single operating day is shown in Figure 7. To maintain compactability, the moisture target increased with increased bond addition and decreased with decreased bond addition. The requirement of a fixed compactability drove the moisture to change along with the bond in order to keep a constant water-bond relationship.

Figures 8 and 9 show the compactability distributions for the three months prior and after the water control change. After the water control change, the distribution around the compactability target was more even and narrower. The number of batches within 3% compactability increased by 10% with similar improvements in the number of batches within 1% and 2%.

The next control improvement scheduled for Foundry B is to employ the optical moisture measurement in the available bond calculation used to determine bond additions. To avoid confusing the effects, the control improvements to water and bond addition are done sequentially rather than simultaneously.

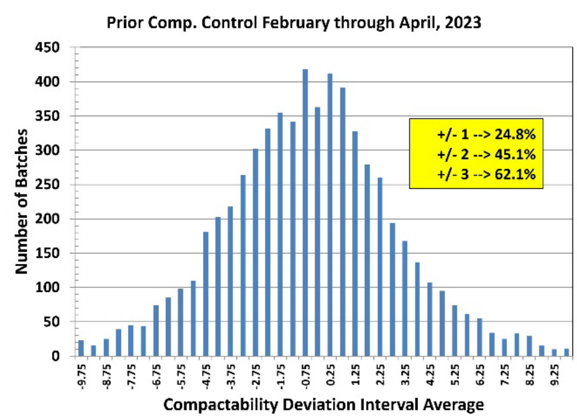

Figure 8. Moisture control histogram prior to water control change for Foundry B.

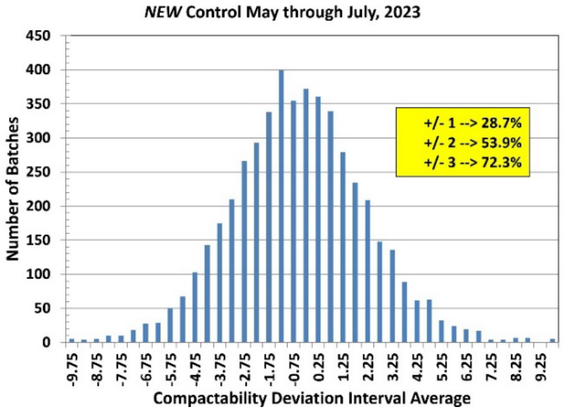

Figure 9. Moisture control histogram after water control change for Foundry B.

FOUNDRY C: CONTROLLING MULLER BOND ADDITION USING OPTICAL MOISTURE MEASUREMENT

Foundry C casts gray and ductile iron into horizontally parted molds. The sand cooler adds enough water to provide moisture between 1.6% and 2.1% to the muller measured as the sand enters the muller's charge hopper. This foundry had been using a traditional compactability control system for water addition and adjusted bond feed rates with a bond determinator. Mulled sand moisture and compactability control was helped by the relatively high incoming sand moisture. The optical moisture measurements were employed to improve the bond control first before adjusting the water control.

The control system calculates the available bond per Equation 2 from automatic measurements of sand moisture and strength and adjusts the bond added to the next muller batch to target an available bond setpoint. To improve the bond addition control, the conductivity-based moisture measurement was replaced with the optical moisture measurement on July 20, 2023. Figures 10-12 depict these values for three consecutive weeks with the compactability, strength, and bond addition charted on the secondary y-axis. The data in these charts represent 25 batch averages (~ one hour operation) to filter out batch-to-batch signal noise. Both strength and conductive-based moisture were relatively insensitive to changes in water and bond, making control of bond addition challenging. Over this three-week period the strength ranged from 27 to 32 psi and the conductive-based moisture ranged from 2.8% to 3.2%. By contrast, the optical moisture ranged from 2.6% to 4.0%. After the change to using optical moisture to calculate available bond on July 20th, the moisture range experienced an immediate reduction. Figure 13 illustrates this tighter moisture control through better bond control. The gap between the minimum and maximum moisture is reduced by more than half. Better control of bond addition resulted in tighter control of both bond and moisture.

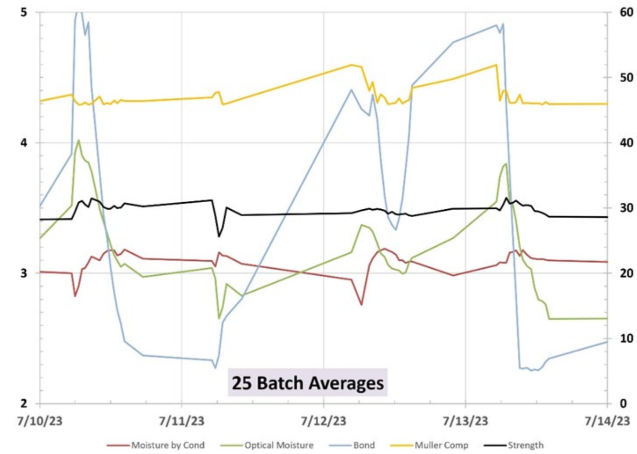

Figure 10. Green sand control in the week prior to available bond calculation change for Foundry C.

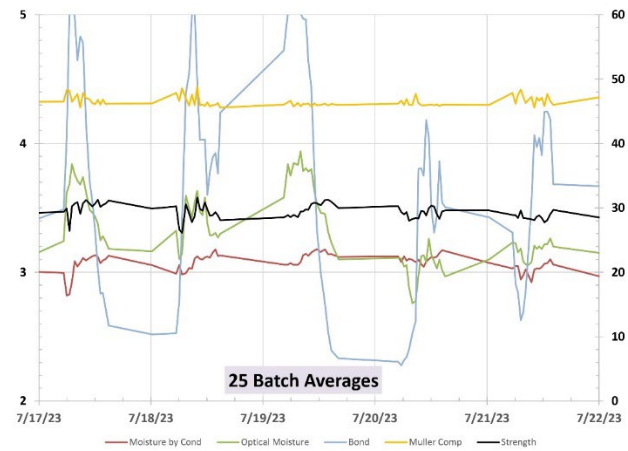

Figure 11. Green sand control in the week with available bond calculation change for Foundry C.

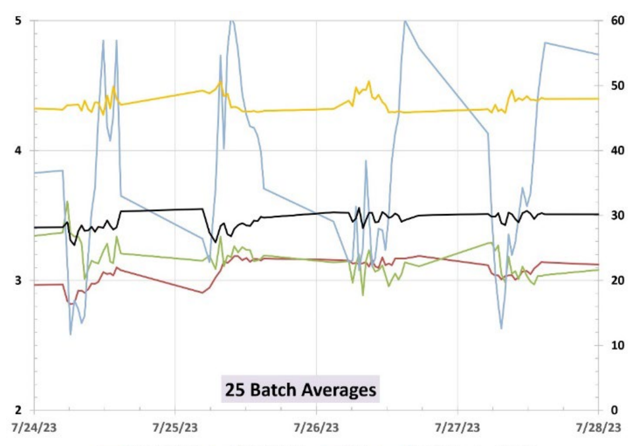

Figure 12. Green sand control after available bond calculation change for Foundry C.

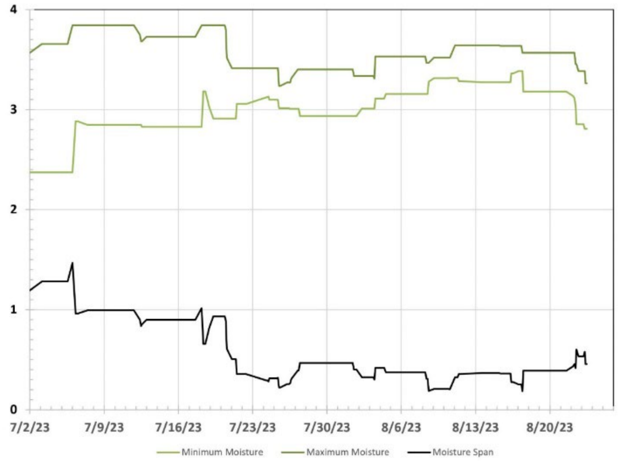

Figure 13. Moisture variation at Foundry C.

COMPARISON OF MOISTURE MEASUREMENT METHODS

At Foundry C as part of the case study, laboratory tests of moisture using thermal mass loss per AFS 2216-19-S and 3-ram compactability were taken on sand sampled from the transfer belt exiting the muller at the same location as an optical moisture sensor. These lab results are compared with the optical moisture, conductivity, and compactability measurements recorded at the same time as sampling (Figure 14).

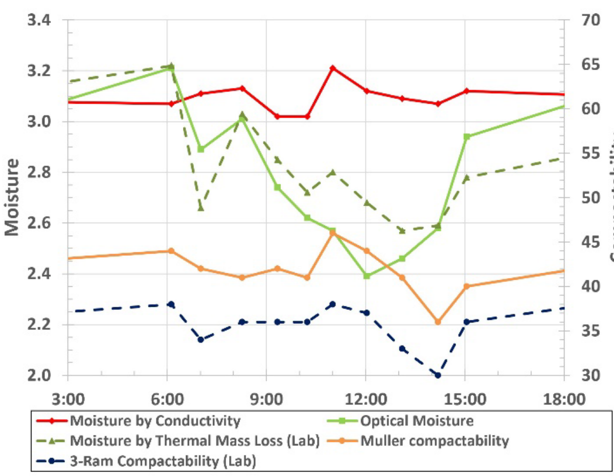

Figure 14. Moisture method comparison during production June 7, 2023 for Foundry C.

Moisture measured by optical sensor and thermal mass loss both show a moisture drop between 9 am and 12 pm on June 7, 2023. While these two methods correlate, the conductivity measurement does not react to this sand property change. Figures 15 and 16 show how the moisture in the sand system is changing with clay addition and measurements.

The laboratory tests in Figures 15 and 16 are from samples obtained at the molding equipment per the foundry's standard sand quality testing which is a different location than the results of Figure 14 performed to specifically evaluate the optical moisture sensor.

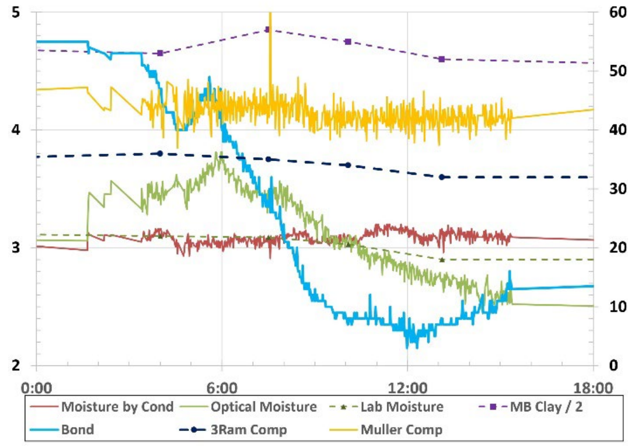

Figure 15. Green sand control automated and laboratory sand properties on May 24, 2023 for Foundry C.

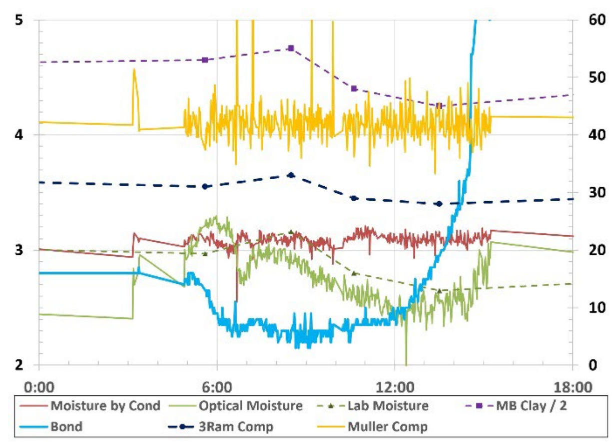

Figure 16. Green sand control automated and laboratory sand properties on June 7, 2023 for Foundry C.

Optical and thermal mass loss moisture measurements correlate to changes in bond additions and the MB clay content of the green sand. To maintain constant compactability, the water addition control system must adjust the moisture to keep a consistent moisture-bond balance. The conductive-based measurement did not recognize these moisture changes that the lab thermal moss loss and optical moisture measurements identified. The optical moisture measurement provided automatic and frequent moisture measurement that the lab thermal mass loss measurement did not.

CONCLUSIONS

The water-clay bond is the basis for green sand molding. Moisture affects most of the important green sand properties and a foundry's ability to make quality castings. Optical moisture sensing can improve accuracy and reliability and does not require sampling equipment making it attractive for automated measurement. Greater sensitivity and accuracy create the opportunity for tighter green sand control. One foundry implemented an effective water addition control system using only optical moisture measurement. Another foundry improved its existing compactability control by adding optical moisture measurement. A third foundry reduced its bond and moisture variation using optical moisture sensing paired with other automated tests of compactability and strength. These improved controls resulted in a more stable molding sand.

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