#24-061
2024 AFS Proceedings ©American Foundry Society

Fast Moisture, VOC, and LOI Testing

R. Makin, Z. Tay, and S. Ramrattan
Western Michigan University, Kalamazoo, Michigan, USA

ABSTRACT

The foundry industry depends upon measurements of moisture content (MC), volatile organic compounds (VOC), and loss-on-ignition (LOI) testing to manage sand systems. At the 2022 AFS Metalcasting Congress an automated LOI test capable of achieving digital data in ten minutes was revealed.

This study identifies the use of magnetron (M) and infrared (IR) heating technologies to achieve rapid MC, VOC, and LOI testing in a single unit. A prototype semi-automated tester has been developed using heating technologies capable of completing all three tests in series.

The new testing technology allows for a short exposure time to heat a foundry sand sample and provides digital data for the three tests. The actual sample test time is comparable to an automated LOI test and is considerably faster than either the muffle furnace or microwave furnace. The standard of 3-hours for the muffle furnace, or 20 minutes for the microwave furnace is time consuming and requires separate samples for individual tests.[1] This study will confirm there is no significant difference between the AFS Standard MC, VOC, and LOI tests and the new semi-automated testing device.

Keywords: Foundry 4.0, infrared heating, loss-on-ignition, magnetron, moisture content, volatile organic compounds

INTRODUCTION

The foundry industry depends upon measurements of moisture content (MC), volatile organic compounds (VOC), and loss-on-ignition (LOI) testing to manage sand systems.[1] Managing either green or chemically bonded sand systems in high production molding lines require fast digital data in an age of Foundry 4.0. The MC is the difference in weight before and after oven drying a foundry sand sample to an AFS-defined temperature.[1] MC is an important component in all green sand castings. Water is generally added at 2-5% of the weight of the green sand mixture, so time to complete thermogravimetric analysis increases with the amount water. Too much MC in foundry sand will lead to gas and penetration defects. Too little MC in foundry sand will lead to friable molds and erosion defects.

In order to determine the VOC and/or LOI, a dried foundry sand sample is required.[1] The gases that are evolved from foundry molding sands may contain VOCs and hazardous air pollutants (HAPs) and have been shown to be major contributors to overall foundry air emissions. The VOC is the difference in weight before and after firing [480C (900F)] of the dried foundry sand sample.[1]

The LOI is the difference in weight before and after firing 982C (1800F) of the dried foundry sand sample. [1] The main method for determining LOI involves heating samples to temperatures at which organic materials decompose and certain inorganic components volatilize. The resulting loss in weight from the sample is the LOI measurement. The LOI measurement indicates the amount of non-active combustibles in raw sand. For green molding sand, these combustibles consume water added to activate the clay. In chemically bonded sand, they absorb binder and reduce its effectiveness. Thus, LOI measurements can provide essential information about the overall quality of a foundry's sand system.[1-5]

By monitoring LOI, the foundry engineer can check on related components of the sand system. The LOI is one measure that displays the effects of new sands, green sand systems, chemically bonded cores and molds, sand additives, and reclaimed sands. Each application has an established control range. The testing procedures defined by the AFS calls for use of either a muffle or microwave furnace.[1] Unfortunately those tests are considerably slow.[2-5] The time lag between testing and results can lead to certain sand-related defects if high levels of organic materials are present in foundry sand systems. Currently, foundries cannot identify the organic materials in real time. The presence of excessive organic materials in foundry sands is problematic, because some of these materials can volatilize at temperatures much lower than that required for the casting process. The outcome is usually gas porosity defects in the castings. This paper addresses those problems.

Established testing methods include use of a muffle furnace, a magnetron (M), an induction coil, and infrared (IR) to heat the sand sample.[2-9] The muffle furnace method is quite time consuming in order to fully remove all of the organic materials from the sand. It takes approximately three hours of baking the sample. In addition, this method includes at least one step of stirring the sample in the middle of the baking process. While the microwave furnace method reduces the time taken in the muffle furnace method considerably, it still requires twenty minutes to conduct the test of a sample.[4,5] It is further limited to a single test of LOI without the possibility of additional testing during this destructive test. A prototype testing method using an induction coil was developed.[5] This test utilizes an induction coil to quickly bring the sand sample to its critical temperature. This method records more information than simply LOI; it also measures the moisture content and volatile organic compounds of the sand sample in less than ten minutes. However, induction heating technology posed challenges with the control of instrumentation. Ultimately, the researchers successfully switched the heating technology to infrared (IR).[2-5]

Without the ability to monitor real time properties of sand, casting defects such as gas can occur.[2-6] The LOI is an important measure of non-active combustibles within the sand system.[1-6] In 2022, an automated inline technology for LOI testing was developed to move towards Foundry 4.0.[1,2] Until now no AFS testing technology has been shown that would achieve fast MC, VOC, and LOI measures within a single test unit.

PURPOSE

The MC, VOC, and LOI are recognized tests for evaluating foundry granular materials.[1] The LOI is time consuming, requiring up to three hours using a muffle furnace. A modified method, using a microwave furnace, provides results in approximately 20 minutes.[2-9] This represents a significant reduction in time required to run the test. Unfortunately, with cycle times for mold and cores as little as 20 seconds in the foundry industry, 20 minutes can represent a large number of affected castings during high-production molding. In addition, the samples recommended are 50 g for a muffle furnace or 8 g for utilization in a microwave furnace.

The conventional LOI testing technology cannot be used as an inline process control tool because these samples require processing in a sand laboratory.[1] The LOI testing can be an effective quality check of chemical binder additions to sand mixes, and has often been discussed as a control tool for the sand reclamation process.[1] Unfortunately, previous testing methods were too time consuming to be able to be used in such a manner. An automated inline test of MC, VOC, and LOI to provide rapid, accurate, and reliable testing on a working foundry sand system is required. This approach can provide a process monitoring control tool that is commensurate with Foundry 4.0.

OVERVIEW OF THE PROBLEM

This study explores a new semi-automated method for reliably collecting MC, VOC, and LOI from a sample of foundry sand. The required technology was M and IR heater capable of achieving 1832F (1000C). The semi-automated test utilizes M and IR heating of a foundry sand sample together with instrumentation, actuators, data acquisition from temperature and mass sensors which are integrated with a computer to determine the percent MC, VOC, and LOI.

OBJECTIVES

1. Develop a new semi-automated tester as a single unit to rapidly measure MC, VOC, and LOI. The tests are performed in series using M and IR heating technologies.
2. Confirm there is no significant difference between the AFS Standard MC, VOC, and LOI tests and the new semi-automated test.

METHODOLOGY

The standard procedures for MC, VOC, and LOI laboratory testing is provided in the "AFS Mold and Core Test Handbook."[1] For semi-automatic testing, the heating zone is an enclosure containing a M and an IR heater. The foundry sand sample is placed in a crucible and set within the enclosure. This distance is an ideal focal length for the M and IR heater used. The entire heating zone is enclosed with ceramic materials to avoid unnecessary loss of heat within the heating zone.

The instrumentation required for the semi-automated test is a K-type thermocouple lead, which is used to monitor and provide feedback for temperature control of the heating zone during use. The measuring zone consists of a mass sensor that is capable of measurements accurate to ± 0.0001 of a gram. There are ceramic materials at the top of the sensor to protect it from the heating zone just above. Figure 1 shows a schematic of the test setup showing a heating zone and a measurement zone and Fig. 2 shows a picture of the actual semi-automated system.

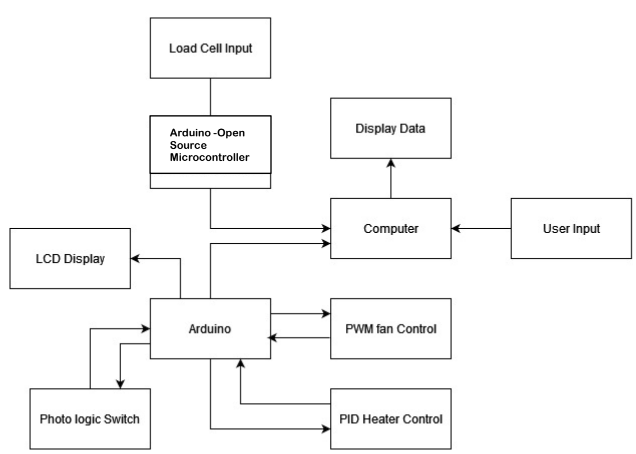

Figure 1. Schematic of the test system.

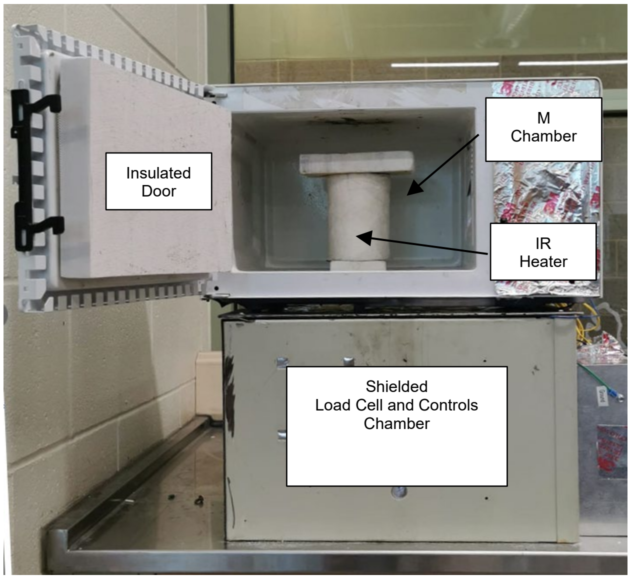

Figure 2. The Fast Moisture, VOC, and LOI tester for this study.

TESTING PROCEDURES

Two chemically bonded sand specimens and a working foundry green sand specimen were employed for this study. A sample was drawn to be used with the AFS Standardized MC, VOC, and LOI tests and simultaneously the new semi-automated test was conducted.

The AFS Standardized MC, VOC, and LOI test procedures are documented in the "AFS Mold and Core Test Handbook."[1] The newly developed semi-automated test procedure is as follows:

1. Crucibles are stored in desiccator and placed into the test enclosure using a pair of tongs.
2. Center the crucible on the sensor within the M and IR heater prior to taring.
3. Load a 4 g (± 0.01 g) sand sample into the crucible,
4. Start the program through the user interface.
5. The program runs MC, VOC and LOI sequentially.
   a. The program monitors the rate of change of mass for each stage and when there is no change in mass at the test temperature it proceeds to the following test until completion.
   b. The program calculates the VOC and LOI for the sand sample using the weight of the dry sample at the end of the MC test.
   c. The data is recorded and displayed to the user in real time.

RESULTS & DISCUSSION

Test results from AFS Standardized MC, VOC, and LOI are compared to the new Semi-Automated test and presented in Tables 1 through 3.

Table 1. Comparing AFS Standardized Results to the New Semi-Automated Test−Chemically Bonded Sand - Sample 1

Test	Sample Mass (g)	Avg. MC (%)	Avg. VOC (%)	Avg. LOI (%)
Standardized AFS Test	50.00	0.01 (0.03)	1.25 (0.03)	2.52 (0.03)
Semi-Automatic Test	4.00	0.07 (0.03)	1.21 (0.03)	2.56 (0.03)

Note: Measurement percent uncertainty in parenthesis

Table 2. Comparing AFS Standardized Results to the New Semi-Automated Test−Chemically Bonded Sand - Sample 2

Test	Sample Mass (g)	Avg. MC (%)	Avg. VOC (%)	Avg. LOI (%)
Standardized AFS Test	50.00	0.18 (0.03)	3.14 (0.03)	5.37 (0.03)
Semi-Automatic Test	4.00	0.22 (0.03)	3.13 (0.03)	5.40 (0.03)

Note: Measurement percent uncertainty in parenthesis

Table 3. Comparing AFS Standardized Results to the New Semi-Automated Test−Working Green Sand

Test	Sample Mass (g)	Avg. MC (%)	Avg. VOC (%)	Avg. LOI (%)
Standardized AFS Test	50.00	2.59 (0.03)	2.52 (0.03)	5.21 (0.03)
Semi-Automatic Test	4.00	2.60 (0.03)	2.55 (0.03)	5.17 (0.03)

Note: Measurement percent uncertainty in parenthesis

The following three figures show the Virtual Instruments (VI) plots from the user interface. It is important to point out that a test cycle comprises of three testing ranges that are represented graphically. Typical percentage change in mass for foundry sand systems tested are shown in Figs. 3 through 5. The legend of each color demarks a test range as follows; black (MC), blue (VOC), and red (LOI) for chemically bonded sand sample 1 and 2, and green sand sample.

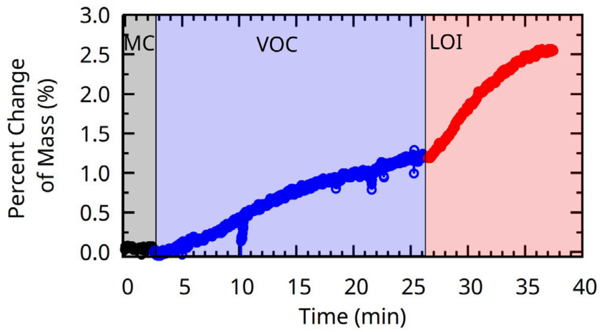

Figure 3. VI screen capture showing the typical %Δ mass−chemically bonded sand−Sample 1.

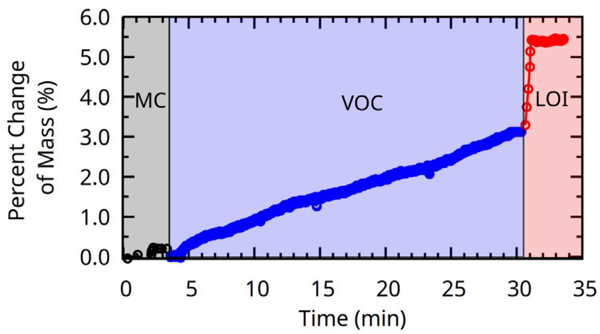

Figure 4. VI screen capture showing the typical %Δ mass−chemically bonded sand−Sample 2.

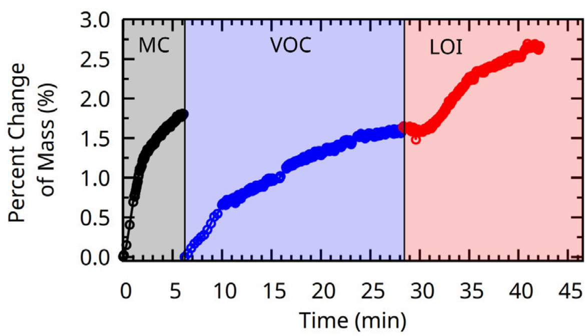

Figure 5. VI screen capture showing the typical %Δ mass−working green sand.

The program that was used to determine the change between MC, VOC and LOI, uses a mathematical algorithm to determine the start and end of each phase of the test, by performing a linear regression to determine the R^2 value. A testing range is deemed complete when the slope and the R^2 value approaches zero. Figure 6 represents the temperature response curve at each stage during testing. The variability of temperature is within ±3.6°F (±2 °C) at the steady state temperature at each stage.

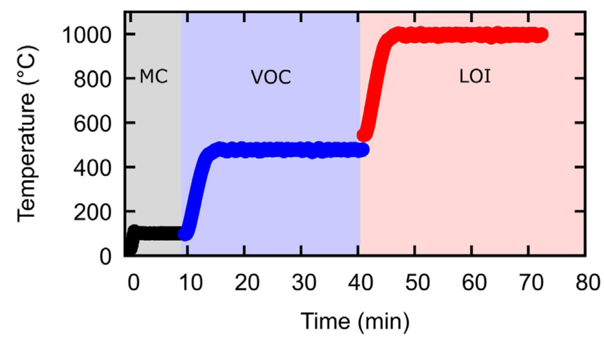

Figure 6. VI screen capture showing the typical temperature response of the heating system.

LIMITATIONS

The work within this paper represents two chemically bonded silica sand systems and a working green sand. There are many more foundry sand systems including specialty sand, alternative molding media, and reclaimed sands that were not considered in this study.

The authors understand that there is limited data at the current stage of the research to validate the methodology identified in this paper. Moreover, the Ramrattan & Kishi *AFS Transactions* Paper #22-069 reveals that fast LOI measurement is achievable.[3] Ultimately, the importance of this project was to show that there is promise for fast sequential measurement of MC, VOC and LOI.

CONCLUSIONS AND RECOMMENDATIONS

The new semi-automatic method for rapid MC, VOC, and LOI can process a sand sample in 45 minutes including ramp time needed to reach each test temperature. The standard AFS tests were more stable but the new semi-automatic method can be used to monitor foundry sand systems at a faster rate.

It is recommended that the new semi-automatic test be employed with working foundry green, chemically bonded, and reclamation sand systems since the speed of testing and digital data output offers opportunities for faster foundry sand system process control and Foundry 4.0 analytics.

The authors plan to continue this research and will consider more efficient M and IR heaters; as well as heating technologies that are not currently employed in this paper. The aim would be to achieve a more agile test cycle. Furthermore, an automated inline test of MC, VOC, and LOI to provide rapid, accurate, and reliable testing on a working foundry sand system is required. This approach can provide a process monitoring control tool that is commensurate with Foundry 4.0.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Sintokogio, Ltd., Aichi, Japan for research support. The authors gratefully acknowledge Shantanu Phalke and Pete Thannhauser from Western Michigan University, for their technical support.

REFERENCES

1. “Mold and Core Test Handbook,” 5th Edition, AFS (2020).
2. Ramrattan, S., & Kishi, N., “Automated LOI Testing,” *Modern Casting*, pp. 37-39 (January 2023).
3. Ramrattan, S., & Kishi, N., “Automated LOI Testing,” *AFS Transactions*, Paper 22-069 (2022).
4. Binoniemi, B.J., & Ramrattan, S.N., “Loss on Ignition Using IR,” *AFS Transactions*, Paper 15-092 (2015).
5. Ramrattan, S.N., & Ikonomov, P.G., “Five Minutes LOI Test,” *AFS Transactions,* Paper 06-124 (2006).
6. Schleg, F.P., “Technology of Metalcasting,” AFS, pp. 49-76 (2003).
7. Laitar, R.A., & Cavanaugh, J.E., “Rapid method for loss-on-ignition,” *Transactions of the American Foundrymen’s Society*, 103 (Paper 95-101), 693 (1995).
8. Laitar, R.A., & Cavanaugh, J.E., “Microwave technology brings LOI testing up to speed,” (Loss on ignition), *Modern Casting*, 86(2), 40 (1996).
9. Love, G.A., & Ramrattan, S.N., “Fast Determination of Moisture, Volatile Organic Compounds, and Loss on Ignition from a Shell Sand Samples,” *AFS Transactions*, Paper 11-060 (2011).