Archives of Materials Science and Engineering

Volume 112
Issue 2
December 2021
Pages 70-76

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

DOI: 10.5604/01.3001.0015.6289

Investigation of flowability of the green sand mould by remote control of portable flowability sensor

D. Abdulamer
Energy and Renewable Energies Technology Center, University of Technology, Baghdad, 10066, Iraq
Corresponding e-mail address: Dheya.Abdulamer@daad-alumni.de
ORCID identifier: https://orcid.org/0000-0002-3579-4467

ABSTRACT

Purpose: The useful data and information during the sand compaction process steps should be collected. Direct measurement methods of the sand mould properties during the actual moulding process are not adopted yet.

Design/methodology/approach: In this work, a remote control system [1] have been integrated into a new flowability sensor [2].

Findings: To overcome the complexity of the tools and equipment that existed in laboratory, and in foundry.

Research limitations/implications: In order to investigate, and control behavior of the moulding process of bentonite-bonded green sand process, the sensors have been equipped with the Bluetooth technology for a wireless transmission of the measured data to computers.

Originality/value: This technique contributes to improve of the compaction process based on the non-destructive tests, enhances prediction of the optimum parameter conditions, and reduced the energy, and the compaction time consumed for the green sand moulding process.

Keywords: Green sand mould, Flowability, Moulding process, Foundry, Wireless system

Reference to this paper should be given in the following way:

D. Abdulamer, Investigation of flowability of the green sand mould by remote control of portable flowability sensor, Archives of Materials Science and Engineering 112/2 (2021) 70-76. DOI: https://doi.org/10.5604/01.3001.0015.6289

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Measurements of the sand mould properties during the sand moulding process are not implemented, adopted yet and still require more research. The traditional data acquisition systems are costly, and require high energy. A remote data acquisition unit involves sensors, and remote data transfer capability [3]. Remote sensor systems can collect and communicate information from various hardware sensors such as environmental sensors wirelessly via Bluetooth system [4]. The sensor combined with wireless radio capability are ideal for insertion into the sand moulds to collect data of temperature, pressure, moisture, and gas chemistries of the sand mould [5]. Sama et. al embedded Internet of Things (IoT) sensors to monitor real-time melt flow velocity in the sand moulds during the metal casting [6]. Abdulamer et.al, used the sensor reading for measuring material-dependent flowability [7], distance-dependent mould hardness and distance-dependent mould strength [8]. A flowability sensor have been developed in such a way that it can be fixed on the pattern plate, then sending the sensor signals across a wireless system into the computer [1]. This way ensures preservation of the components of the sensor from failure during inspection process and monitoring of the sand mould, as well as the possibility of transport the sensor to another pattern plates without require into the direct connection of the sensor wires with the computer . Thereby, there is a great ability to exceed the complexity of equipment and devices that exist in foundry.

2. Components of the new portable flowability sensor

The components required for making the sensor work as a portable device by integrating a wireless system into the sensor were listed in a Table 1.

Table 1.
Components of a wireless system

No	Components	Description
1	Strain gauge amplifier	GSV-6BT SD
2	Li-Ion battery	2600 mAh (3.7 V)
3	Charger	Ultramat 14 plus
4	Charging cable and plug	-
5	Bluetooth	USB adapter 4.0
6	GSVMulti software	V. 1.39

The strain gauge amplifier shown in Figure 1, is intended for the wireless transmission of the measured data from the existing compaction sensors to computer. The product GSV-6BT is more modern product as comparison to GSV-4BT. (GSV-6 BT) has higher quality components than GSV-4BT, and the advantages are as follows:

1. Higher sampling rate per channel,
2. Energy-saving, standby mode,
3. Faster data transfer, and
4. System can be used as a data logger (integrated card slot – flash memory).

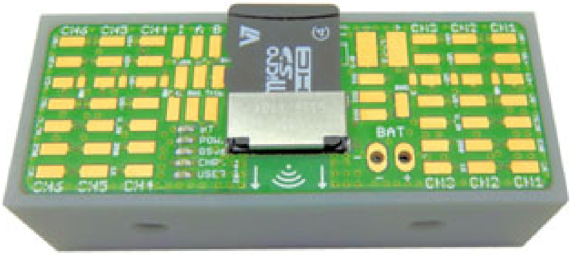

Fig. 1. GSV-6 BT Strain gauge amplifier

The electronics module was installed together with the Li-Ion battery in the black small box as is shown in Figure 2.

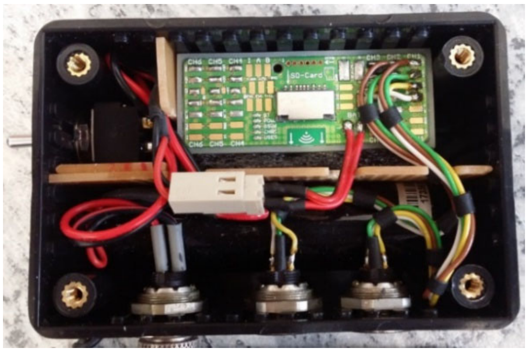

Fig. 2. Integrate GSV-6 BT in the small box

As is shown in Figure 3, the sensor is installed in the upper, and bottom levels of the stepped pattern. The two sensors, as well as the charging cable is connected to the black box via the plug connectors. Furthermore, there is a switch with three options (charge battery <off> measure) to select the respective function.

Fig. 3. Flowability sensor and the wireless system

GSVMulti software of the MEsystem company that shown in Figure 4, in combination with the USB Bluetooth adapter, enables a wireless acquisition of the measured data from the sensor. Figure 5 shows both a sensor and small box were placed in the pressing machine. The principle of the new flowability test, the tube test is placed on the stepped pattern, and filled with the green sand. During the compaction process, the sensors starts to display the changes in the state of stress of moulding sand and generate signals, if the green sand does not move, the sensor motion impossible [9]. The obtained sensor readings are transmitted from the sensors to computer across Bluetooth technique as the ($S_u(mm)$) white curve, movement of the bottom sensor, and the ($S_o(mm)$) red curve, movement of the upper sensor [7] as shown in Figure 6.

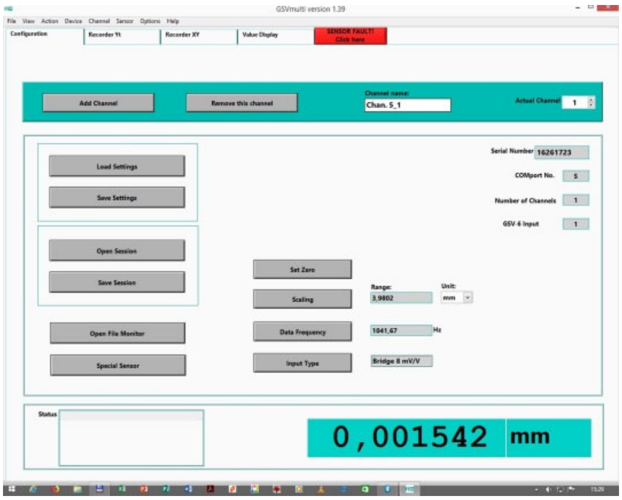

Fig. 4. GSVMulti software

Fig. 5. Pressing machine, sensor and wireless system

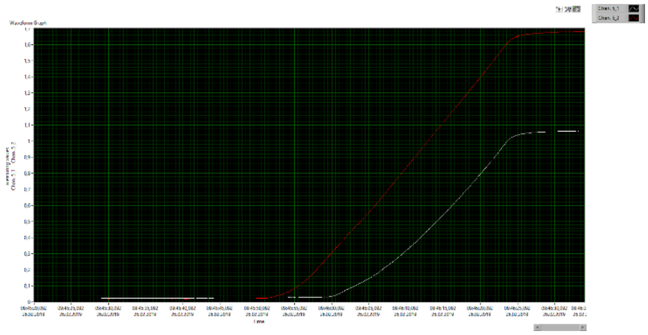

Fig. 6. Signals of the sensor

3. Validation of the portable sensor

Validity of a new portable wireless sensor for measuring of the sand mould properties during the moulding process has been investigated through study effect of Bentonite, Dextrin, Water Content and Pressing Speed on flowability of Specific Foundry Sand *SFS* mixed with additives. Factors and its level, description of these levels were mentioned in Table 2. Table 3 listed response of the sensor signals, and the calculated material-dependent flowability by using multi-levels factorial design of experiments. Equation 1 [7, 10], is used to calculate time-dependent-flowability (*FB(t)*) of the green sand dependent on the sensor signals. This equation is derived based on the spring stiffness of the sensor, the probe movement of the sensor spring into 1 mm generates a force of 0.855 N [9].

$$FB(t)\% = \frac{S_u(t)}{S_o(t)} \times \left[\frac{\sin\left(\cos^{-1}\left(\frac{S_o(t)}{r}\right)\right)}{\sin\left(\cos^{-1}\left(\frac{S_u(t)}{r}\right)\right)}\right]^2 \quad (1)$$

were r is 3 (mm) the radius of the sensor, and t (sec) is the compaction time.

Table 2.
Factors and its level

Level	Factors			
	BP-A, %	Dx, %	H_2O, %	Pressing speed (υ), mm/sec
0	8	0.75	1.5	24.5
Varitation	0.5	0.25	0.5	7.5
-1	7.5	0.5	1	17
+1	8.5	1	2	32

Properties of *SFS* sand mixed with additives (Bentonite BP-A and Dextrin (Dx) were listed in Table 4.

Table 3.
Design of Experiments, sensor response and calculated flowability of sand SFS

Ex. No	BP-A, %	Dx, %	H_2O, %	υ, mm/sec	Sensor readings		FB%
					S_u, mm	S_o, mm	
1	-1	-1	-1	-1	0.574	1.186	36.18
2	+1	-1	-1	-1	0.805	1.619	31.32
3	-1	+1	-1	-1	0.582	1.293	31.77
4	+1	+1	-1	-1	0.383	0.860	36.40
5	-1	-1	+1	-1	0.564	1.316	29.62
6	+1	-1	+1	-1	0.561	1.561	21.18
7	-1	+1	+1	-1	0.528	1.413	24.03
8	+1	+1	+1	-1	0.546	1.368	26.53
9	-1	-1	-1	+1	0.541	1.226	31.83
10	+1	-1	-1	+1	0.617	1.233	37.08
11	-1	+1	-1	+1	0.565	1.064	42.16
12	+1	+1	-1	+1	0.613	1.323	32.56
13	-1	-1	+1	+1	0.634	1.505	26.62
14	+1	-1	+1	+1	0.624	1.611	22.61
15	-1	+1	+1	+1	0.679	1.461	30.86
16	+1	+1	+1	+1	0.640	1.413	30.47

Table 4.
Properties of sand SFS

Ex. No	Compactability, %	Compressive strength , N/cm^2	Shear strength, N/cm^2	Tensile strength, N/cm^2
1, 9	44	14.97	4.44	3.225
2, 10	41.55	13.67	3.87	2.623
3, 11	36.22	16.61	4.57	>3.3
4, 12	43	14.82	4.24	2.898
5, 13	55.5	13.34	4.72	2.073
6, 14	60.75	12.27	4.11	1.697
7, 15	59.22	14.12	7.30	2.148
8, 16	59.17	12.50	4.07	1.806

Table 5.
Rearranged final values of Flowability

Ex. No	FB %	Ex. No	FB %
6	21.18	2	31.32
14	22.61	3	31.77
7	24.03	9	31.83
8	26.53	12	32.56
13	26.62	1	36.18
5	29.62	4	36.40
16	30.47	10	37.08
15	30.86	11	42.16

Table 5 rearranged experiments of Table 3 from lowest to highest values of flowability. It is found that experiment number 6 has lowest flowability, while experiment 11 has highest flowability. There is highest flowability 42.16% found at experiment number 11 that has a condition (-1 +1 -1 +1).

Effect of bentonite and dextrin on the final values of the bottom sensor and the supper sensor are shown in the surface plot Figures 7 and 8 respectively. These figures show mainly effect of both additives of bentonite and dextrin on the sensor signals during testing of SFS sand. An addition of the dextrin percentage and Bentonite BP-A percentage show a varied effect on the flowability values of SFS sand. It is found that a 7.5% of Bentonite BP-A, and 1% of dextrain gives flowability of SFS sand higher than flowability of this sand which contain 8.5% of Bentonite BP-A and 0.5% of dextrin. Furthermore, decreases of water content and increases speed of pressing machine contribute to an increase of flowability of sand SFS. The statistical analysis of design of expeiments listed in Table 3, show that the water content, and speed of pressing machine have a slight significant effect on the sensor signals. Thereby, their values in these figures were shifted to the main level of 1.5% of the water content, and 24.5% of the speed of pressing machine.

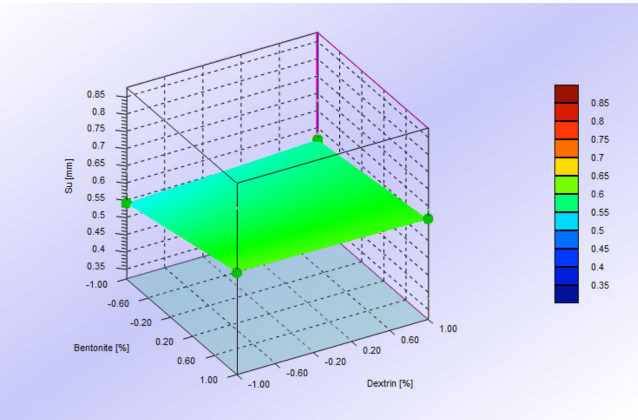

Fig. 7. Correlation of effect of BP-A and Dx on $S_{u\ end}$

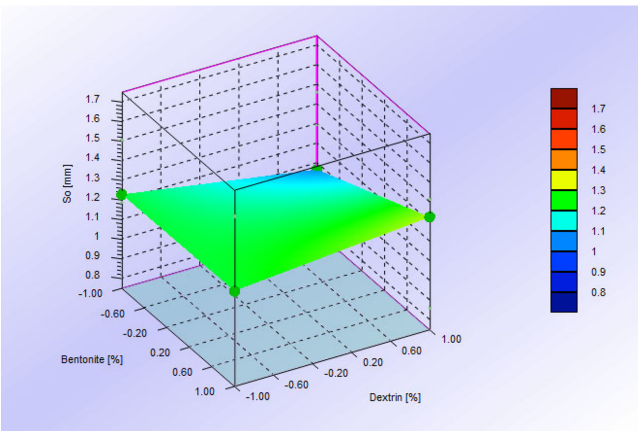

Fig. 8. Correlation of effect of BP-A and Dx on $S_{o\ end}$

4. Effect of water content and pressing speed on flowability of original SFS sand

Effects of water content and pressing machine speed on the flowability of original Specific Foundry Sand *SFS* without additives were investigated. Response of the sensor signals and the calculated flowability were arranged in Table 6. Properties of original sand sand without additives was shown in Table 7. Water content is the main effective factor has an influence on the sand properties. Reduction of this factor enhance mechanical properties of the green sand. It is found 1% of the water content gives 15.99 N/cm^2, 3.77 N/cm^2, 2.64 N/cm^2 of compressive strength, shear strength, and tensile strength respectively. These values of the mechanical properties decrease when increase of the water content into 2%. An increase of the mechanical properties especially tensile strength of the green sand contributes in obtaining sand mould has good profile of the pattern without failure during seperation process of the compacted sand moud from the pattern. Comparison of the final values of flowability between the original *SFS* sand without additives and the same *SFS* sand with additives of bentonite and dextrin is shown in Table 8. At the same conditions of the water content and speed of pressing machine, it is found the additives of bentonite and dextrin improves flowability of *SFS* sand as compared with *SFS* sand without additives. Bentonite is common additive, it smooth, very plastic, and feels like soap [11], dextrin is a specific additive which is a modification of wheat starch.

Table 6.
Sensor response and calculated flowability of original *SFS* sand

Ex. No	H_2O, %	υ, mm/sec	Response,		FB%
			S_u, mm	S_o, mm	
1	-1	-1	0.433	1.272	22.91
2	-1	+1	0.529	1.379	25.16
3	+1	-1	0.197	1.535	6.71
4	+1	+1	0.343	1.783	8.81

Table 7.
Properties of the original sand SFS without additives

Ex. No	Compactability, %	Compressive strength N/cm^2	Shear strength N/cm^2	Tensile strength N/cm^2
1	60.65	15.99	3.77	2.642
2	60.65	15.99	3.77	2.642
3	67.55	12.81	3.4	2.355
4	67.55	12.81	3.4	2.355

Table. 8: Comparison of flowability of sand *SFS* with and without additives

Ex. No	Sand with additives FB%	Ex. No	Original sand without additives FB%
1	36.18	1	22.91
2	31.32		
3	31.77		
4	36.40		
5	29.62	2	25.16
6	21.18		
7	24.03		
8	26.53		
9	31.83	3	6.71
10	37.08		
11	42.16		
12	32.56		
13	26.62	4	8.81
14	22.61		
15	30.86		
16	30.47		

Existing of such additives of bentonite and dextrin contributes in reduce friction between the sand particles, and enhance flowability of the green sand. Regarding flowability of *SFS* sand without additives, experiment number 2 gives 25.16% highest flowability, while experiment number 3 gives 6.71% lowest flowability. This behavior of decrement flowability of the green sand is related into increment of the water content. It is found an increase of the water content make the sand more viscous as compared with the sand has low amount of the water. Increase flowability of the green sand require overcome of cohesive and adhesive forces through increase of the pressing speed. The cohesive forces usually developed by the binder, as well as the adhesive forces between moulding sand, and the tube test. These forces have an influence on flowability of the moulding sand into the pattern [12].

5. Conclusions

The wireless control unti was introduced to enhance movement of the sensor, the pattern plate and the sand mould together for a long distance almost up to 14 meters from PC. Live surveillance of the green sand compaction process contributes to facilitate the inspection process without any obstacles and damage of the sensor parts during the moulding process. The profitable assessment of usability of the moulding parameters with the flowability sensor for getting the intended impacts are as follows:

- A gap between the signal curves of the upper sensor and the bottom sensor decrease by increases of the speed of pressing machine, and the water content.
- A small gap between the signal curves of the upper sensor and the bottom sensor gives an indicate to increas of flowability and vice versa.
- Additives of Bentonite BP-A and dextrin improves flowability of sand SFS as compared with sand SFS without additives at the same conditions.
- It was found that an experiment which have conditions (+1 -1 +1 -1) of (BP-A, dextrin, water content and pressing speed) gives 21.18% lowest flowability of sand SFS. While an experiment which have conditions (-1 +1 -1 +1) gives 42.16% highest flowability.

References

[1] J. Bast, D. Abdulamer, A. Kadauw, B. Hentschel, New Investigation of Material-Dependent Control of Flowability in Green Sand Process, Proceedings of the 73rd World Foundry Congress "Creative Foundry", Cracow, Poland, 2018.

[2] J. Bast, A new method for the measurement of flowability of green moulding sand, Archives of Metallurgy and Materials 58/3 (2013) 945-952. DOI: https://doi.org/10.2478/amm-2013-0107

[3] E.S. Aw, Low Cost Monitoring System to Diagnose Problematic Rail Bed: Case Study at a Mud Pumping Site, PhD Thesis, Massachusetts Institute of Technology, USA, 2007.

[4] Dialog Semiconductor, SmartBond: DA14583 IoT Sensor Development Kit. Available online: https://www.dialog-semiconductor.com/iotsensor

[5] J. Walker, E. Harris, C. Lynagh, A. Beck, R. Lonardo, B. Vuksanovich, J. Thiel, K. Rogers, B. Conner, E. MacDonald, 3D Printed Smart Molds for Sand Casting, International Journal of Metalcasting 12 (2018) 785-796. DOI: https://doi.org/10.1007/s40962-018-0211-x

[6] S.R. Sama, E. MacDonald, R. Voigt, G. Manogharan, Measurement of Metal Velocity in Sand Casting during Mold Filling, Metals 9/10 (2019) 1079. DOI: https://doi.org/10.3390/met9101079

[7] D. Abdulamer, A. Kadauw, Development of mathematical relationships for calculating material-dependent flowability of green molding sand, Journal of Materials Engineering and Performance 28/7 (2019) 3394-4001. DOI: https://doi.org/10.1007/s11665-019-04089-w

[8] D. Abdulamer, A. Kadauw, J. Bast, Utilising flowability sensor for green sand mould characterisation, Ziggurat Journal of Materials Technology (ZJMT) 1/1 (2020) 13-22. DOI: https://doi.org/10.36533/zjmt.v1i1.30
[9] A. Malaschkin, Development of a method for continuous quality control in the wet molding process with automatic molding systems, PhD Thesis, Technical University Bergakademie, Freiberg, 2002 (in German).
[10] D. Abdulamer, Developemnt of Mathematical Relationships for Calculating of Material-dependent-Flowability of Green Moulding Sand, Proceedings of the 73rd World Foundry Congress "Creative Foundry", Cracow, Poland, 2018.
[11] S. Hurst, Metal Casting: Appropriate Technology in the Small Foundry, Practical Action, London, 1996, 57.
[12] A. Kadauw, J. Bast, D. Fiedler, I. Betchvaia, H.C. Saewert, Computer simulation of squeeze moulding and validation of results using Industrial Computed Tomography (iTC), Archives of Metallurgy and Materials 52/3 (2007) 447-451.