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Effectiveness of SCADA Systems in Control of Green Sands Properties

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Abstract

The paper undertakes an important topic of evaluation of effectiveness of SCADA (*Supervisory Control and Data Acquisition*) systems, used for monitoring and control of selected processing parameters of classic green sands used in foundry. Main focus was put on process studies of properties of so-called 1st generation molding sands in the respect of their preparation process. Possible methods of control of this processing are presented, with consideration of application of fresh raw materials, return sand (regenerate) and water. The studies conducted in one of European foundries were aimed at pointing out how much application of new, automated plant of sand processing incorporating the SCADA systems allows stabilizing results of measurement of selected sand parameters after its mixing. The studies concerned two comparative periods of time, before an implementation of the automated devices for green sands processing (ASMS - *Automatic Sand Measurement System* and MCM – *Main Control Module*) and after the implementation. Results of measurement of selected sand properties after implementation of the ASMS were also evaluated and compared with testing studies conducted periodically in laboratory.

Keywords: Computer aided foundry production, SCADA systems, Data Acquisition, Green sands, Green sand properties

1. Introduction

There is no doubt that classic green sands (green sands of 1st generation) [1] are the oldest and the most widespread material used for production of expendable molds and cores [2]. Generally, they are divided into synthetic, natural, semi-synthetic and clay bonded sands[1]. The most commonly used synthetic green sands contain a sand matrix, a bonding material of mineral origin, water and refining additives. The matrix is usually composed of quartz sands, rarely of zircon, chromite or magnesite sands [3]. Out of the used bonding materials in the green sands, the most important are bentonites – clays of montmorillonite group, with more than 70% contents of these minerals [1, 4]. The additives, used mostly for improvement of sand properties, can be the following: coal dust, starch additives, wood flour and peat. The last ones are used to prevent certain surface defects, such as sand buckles, rattails or veinings [1].

It is noteworthy that in the year 2013, the size of world casting production was more than 103 million tons, out of which over 80% were iron alloys, cast mostly into sand molds, of which the cast iron share was more than 70% [5, 6]. It should be reminded, that the synthetic green sands are still the most frequently used material for making molds for castings made of iron alloys. For more than 90% of Polish foundries, it is a basic mold material [7], in the world scale approx. 50% of cast iron castings are still made in molds of this type [8]. It creates a necessity of rational control of composition and processing properties of these sands [9, 10].

Quality of castings highly depends on quality of the green sands. Their properties can be modified, depending on their type and composition. However, it needs to be noted that properties of a specific type of green sand are determined mostly by moisture, amount and quality of binder, i.e. the water-clay ratio SW [1, 9, 11, 12]. Other important parameters are also widely used as important criteria of quality control of bentonite sands, such as compactibility and Dietert's index of moldability W_F [13, 14]. This aspect will be described in greater detail in Chapter 2.

Nowadays, most foundries producing small and sometimes medium-sized cast iron products use homogeneous, returnable green sand (reclaim) with addition of raw refreshing materials (even above 95% of the reclaimed sand), with the application of appropriate mixing machine along with automatic measurement and adjustment of sand moisture [15, 16]. That is why all foundries trie to implement innovative solutions and modern devices for regeneration and preparation of green sand in the processing plant. It is related to implementation of automatic systems for measurement, on-line control and data acquisition.

The paper describes important problems regarding repeatability of the selected properties of green sands and possibilities of control of these properties. The research was focused on comparative studies of quality of the green sands, realized periodically in the laboratory mode and in the continuous automatic mode, using an example of production system in one of European foundries.

2. Studies of processing properties of green sand. Measurement conditions

Properties of a green sand can be expressed qualitatively (non-measurably) or quantitatively (measurably). The first group includes such features as: ability to plastic strain or ability to knock-out, often estimated by intuition on the basis of observation of certain processes – the parameters and the laboratory methods of their determination do not have a standardized character. The second group of parameters is defined regarding methodology of their determination and is often assigned to specific design of the measurement apparatus. It limits subjectivity in the quality assessment of the green sands. In case of the synthetic green sands, attention must be paid especially to the following measurable properties [1, 11]: moisture, compactibility, compression strength, permeability, testing temperature. The other properties, such as flowability or falling degree are far less frequently determined.

Criteria of evaluation of a green sand are a result of manufacturing conditions in a foundry (including the mold compacting methods, the casting cycle, assortment and customer's requirements). It is very important to define a recommended range of working variability of the sand moisture, e.g. by considering criterion of its usability to molding. However, it is a difficult task to perform in industrial conditions, because the green sand is produced also using returnable sand (reclaim) of unstable properties of the sand components and temperature varying in time, which is a result of size of the produced castings and seasons of a year [11, 17, 18].

In the literature, several methods of determination of water amount in the green sands are presented, including direct and indirect methods, where the final result is based on measurement, for instance, of electrical conductivity or capacity. A classification of these methods with consideration of innovative moisture measurement methods can be found in [1, 19-23].

Traditional laboratory tests, also known as accelerated tests, with assumption of using properly calibrated apparatus, usually give repeatable results, verifiable on the same portion of the sand. However, a problem is the practically available frequency of series of these measurements (not more than several per one working shift), speed of reaction (off-line) and correcting parameters of green sand in the preparation system. Thanks to application of an automated measurement system joined in the control system, the number of these measurements can be many times higher [18]. Therefore, the direct methods of moisture measurement are not useful in the automated measurement systems for quality control of green sands in the Regeneration Station (RS) or Processing Stations (PS). Manual picking up of the sand samples from the place located at a certain distance from the laboratory and sum of times needed for determination of parameters on the laboratory workplaces are usually within a range of 15-30 minutes. In such a situation, only indirect methods of moisture measurement (using physical phenomena of permeability, dielectric lossiness, resistance, conductivity) can be taken into account, when the measurement result should be obtained in a relatively short time [1, 24-26]. Quick methods of measurement of other important sand parameters, such as compression strength, compactibility, permeability also require an innovative approach, which is presented in the next chapter of the paper.

3. Process of preparation of green sand

The conducted and analyzed studies concern classic green sands of the 1st generation – where the bonding material consists of multiplied binding bridges of the bentonite paste, creating a network of connections. A factor influencing the quality of bonding of grains of a quartz matrix through the bentonite paste is the amount of water. Keeping this factor in the defined tolerance limits is a basic requirement [1, 11].

From the hypotheses regarding the phenomena accompanying the bonding mechanisms, those based on values of electrical potentials between molecules of bentonite, water and quartz grains are known (polar water presence is suggested) [1]. This hypothesis is related to a typical property of clays from the montmorillonite group – their high potential for swelling in the presence of water. Dipole molecules of water, adsorbed into inter-packet spaces of the clay, help creation of layers of monomolecular water and swelling of the bentonite molecule – water set, which makes a distance between the clay packets to increase more than two times (from 0,94 to 2,1 nm) [11]. A basis for formulation of this hypothesis are observations of sensitivity of mechanical properties of the green sands, as presented in the Figure 1.

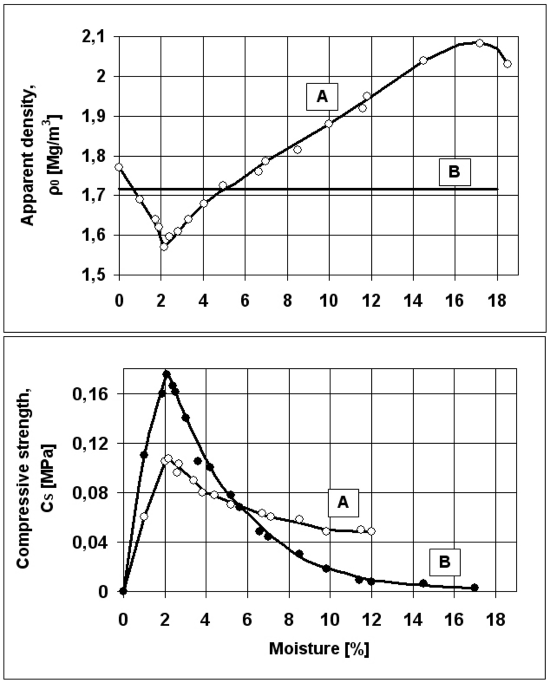

Fig. 1. Influence of moisture on compressive strength of a green sand, A – for continuous work of compacting the sample, B – for constant apparent density, ρ_0=1,715 [Mg/m^3] (prepared on the basis of [1])

Interpretation of Fig. 1 presented in [1] allows to conclude, that green sands during processing are more sensitive to moistening than it would result directly from the standard laboratory testing. Considerations about influence of an appropriate amount of clay of good packaging properties, in dependence of used quartz sands and conditions of contact with water can be found e.g. in [1, 11, 12].

In the bonding mechanism, the water-clay ratio is very important. It should be kept within range of 0,35-0,5 [1, 11]. It is known that the green sand reaches its maximum strength at a specific, rather low value of moisture. However, good processing properties of the sand are also largely determined by other parameters (compactability, permeability). The sand homogeneity aspect is also very significant – it is mostly related to amount of the return sand applied [25-26]. The change of moisture by only 0,5% strongly affects the obtained castings quality in a negative way [16].

Independently on the used components, it is also very important to apply them in specific amounts, to obtain required quality of the sand after mulling [27]. Appropriate control of the water amount in the feedback loop (the converter is a part of a mixer) can be extended. On the basis of the sand parameters obtained from a sample picked from a conveyor, best before the release funnel of the molding machine, the sand properties can be controlled by changing amount of dosage of the fresh components [28]. This aspect is described in greater detail in the Chapter 4.

4. Possibilities of control of green sand properties

To sum up, the manufacturing process of green sands can be realized in the following control systems of the sands properties:

- classic off-line control (could be partially automated in section of actuators),
- fully automated on-line control,
- fully automated on-line control with off-line elements.

The first case (off-line) can be still often found in foundries. In such a case, measurements of properties of the green sands are performed by the laboratory worker. Even if a foundry has a mechanized and automated infrastructure for preparation of the green sands, laboratory tests are still conducted, and on their basis sand refreshing procedures are corrected during mixing. It means that control of the sand parameters is possible only in time of realization of those several pick-ups of samples during a single shift, which is always performed with a significant delay, at least by one release of the processed sand.

Partially automated off-line control takes place, when the selected measurements are carried out using measuring sensors and then transferred to the control station, where manual control (off-line) of appropriate components dosage is conducted (additional use of measuring moisture probe placed in a mixer and/or temperature sensors). A detailed classification and characteristics of the automated systems for the green sand processing can be found in [29].

The second case is fully automated on-line control. In such a case, it is necessary to buy and implement systems for acquisition of the selected sand properties (compactability, compressive strength) data and including them into the system of integrated devices of reclaiming plant and processing, as well as using them for the follow-up control [24, 25]. Such systems, allowing automated, on-line control of processing of the green sand are offered, among others, by Michenfelder (Germany), ATD Engineering & Machine LLC (USA), Green Sand Control LLC (USA), Scoval (France), or Technical (Poland) company.

The third case is periodically applied for the second case, for comparative and calibration purposes.

In practice, it turns out that the on-line control can concern one assortment of the castings or their group. In such situations, the on-line control can be based upon overdrive of the parameters on-line and/or interchangeable off-line control (participation of servicing personnel in acceptance of certain settings may be necessary). As mentioned before, the moisture measurement is an integral part of control of properties of the green sand, that is why the systems controlling the water amount in a mixer are required to have a high accuracy – 0,1% H_20 (0,05±0,1% of the applied value). Automatic installations for the moisture control which fulfill these narrow criteria are, among others, the RMW system produced by the Technical company, the FSE-19S system (by Lipke systems), more advanced system FS-CC6-PLC (Foundry Control) and Micomp UNI G-CH (by Michenfelder) [26]. Process of green sands preparation with use of a reclaimed sand can will be conducted in a plant of type RS or PS. An example of the MSPS (Molding Sand Processing Station) installation with scheme of a system for monitoring and control of the selected sand properties is presented in Figure 2.

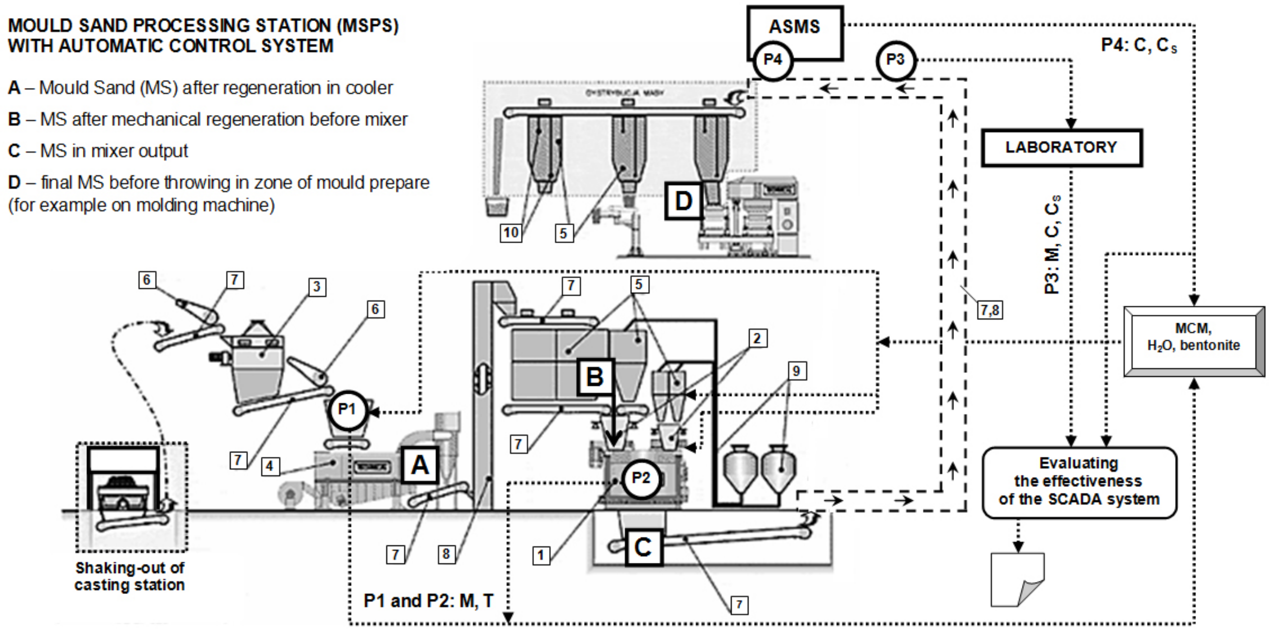

Fig. 2. Sand processing plant with automated quality control system, where: 1. Turbine mixer MTI, 2. Set of extensometric scales, 3. Sand screen, 4. Fluidizing cooler, 5. Containers of sand and additives, 6. Electromagnetic separator, 7. Belt conveyors, 8. Elevator, 9. Pneumatic transport, 10. Probes of upper and lower level, ASMS – Automated Sand Measurement System, MCM – Main Control Module (lot of water and bentonite), P1, P2, P3, P4 – Measuring points, M – Moisture, T – Temperature, C – Compactability, C_S – Compressive strength (own work on the basis of www.technical.com.pl)

In the defined and chronologically scheduled moments of time, with full identification of place and time of picking the samples of the final sand, its selected properties are examined (see P2-P3 in the Fig. 2). It can also concern the return sand independently (sand after regeneration – see P1, Fig. 2 or sand after regeneration in case of e.g. resin sands). Basic properties of the sand materials can be then studied, e.g. characteristics of the sand matrix, which is of high importance for complex evaluation of quality of the sand or reclaim.

Samples of the green sand should be taken with consideration of periodical sequences of measurement. The system for data acquisition and use of uniform axis of current time should allow making corrections, for example in relation to standstill of the automatic line and production of the green sand with redirecting it to a buffer container (A&DM author system [28], among others). The best solution is to pick the test sample as close to the green place as it is possible (see D, Fig. 2). Such an approach is used in case of modern measurement-control installations in the sand processing plant [25, 26, 28].

5. Research methodology and data acquisition

The research was carried out in one of European foundries producing cast iron castings for the power, machine and automotive industries, on an automated box-less molding line with the vertical mold partition. The aim of the present study was to prove effectiveness of application of the ASMS (Automated Sand Measurement System) and the MCM (Main Control Module) systems (they can be considered as belonging to the SCADA group [25]) for control of the green sand properties (evaluation of stability of obtained results) through a comparison with results obtained using the traditional laboratory method.

The studies were conducted in 2 stages. In the first stage, evaluation of effectiveness of the automated control systems was performed for the time period, in which the foundry used only partially automated devices for control of the sand processing (the off-line option). In the second stage (after implementation of the ASMS and the MCM), stability of the green sand properties was evaluated by comparing the selected sand parameters, values of which were obtained automatically out of the ASMS and MCM with those obtained by the laboratory method, i.e. with the off-line support (control and calibration). The studies were conducted on a sand of the same raw material composition and for the same casting assortment. Automatic preparation of the consecutive portions of the sand and control of its quality was conducted using a system similar to the one presented in [30].

In both cases, the data was analyzed for the three sand parameters: moisture (M), compactability (C) and compressive strength (C_S). For the measurements carried out automatically, the moisture was measured by a capacitive probe located in the mixer, while the compactibility and compressive strength were measured by a stationary device within ASMS, installed just before the release funnel of the molding machine. The general information and data regarding the data acquisition are presented in Table 1.

Table 1.
Data acquired for evaluation of effectiveness of control of green sand properties

GENERAL INFORMATION REGARDING EXAMINED CLASSIC GREEN SAND		
Sand composition: – Regeneration green sand (95%), Sand (1,5%) – Bentonit Special (0,35%), Coal dust (0,05%) – Water (3,1%)	Tolerance limits for measured parameters: – Moisture M (2,6-3,3%) – Compactability C (34-46%) – Compressive strength C_S (0,16-0,23 MPa)	
DATA ACQUISITION		
Type of measurement	**Laboratory measurement**	**Automatic measurement**
Method of picking the sand samples	Manually (LAB)	Automatically (ASMS)
Measurement frequency	Each 25 minutes	Each 30 seconds
Place of measurement	Manual laboratory	Automatic laboratory
Distance between measurement location and sample pick-up location	30 m	The same place
Method of obtaining measurements for parameters		
Moisture (M)	Weigher-drier	MCM, probe in mixer
Compactability (C)	Hand rammer +GF+	ASMS
Compressive strength (C_S)	Apparatus +GF+	ASMS
GENERAL STATISTICS OF OBTAINED DATA		
Number of collected data records (M, C, C_S)	97	97

In the presented case, the signals from the mixer (measurement of M parameter) and the ASMS device (C and C_S parameter) are transmitted to the main module MCM. On the basis of the measured values, it corrects water amount (by changing the formula controlling the water amount on the basis of the measurements of temperature and moisture of the return sand fed to the mixer) and bentonite dosage during preparation of the next portion of the green sand. In case of the traditional laboratory method, the sand sample was picked up from the conveyor belt just before the automated ASMS device (see P3, Fig. 2).

6. Course of the study and analysis of the results

Samples of the sand in the I stage of the study were picked up in the point P3, while in the II stage – in the points P3 and P4 (see Fig. 2). To evaluate effectiveness of the automated control system, a basic tool of the SPC – a control chart was used. On the basis of authors' positive experience in implementation of the SPC methods for the continuous processes, it was proposed to use the control chart of single observations Xi, where single values of a given parameter are taken into account. For this purpose, the author-made tool A&DM SPC was used [18].

In the second stage of the study, values from the laboratory measurements were compared with values obtained automatically from the ASMS and MCM systems.

The "laboratory" data (LAB: M, C and C_S) were obtained from the standard samples. The measurement results were gathered for more than a dozen of days. It is important to point out, that performing a complete laboratory measurement took 25 minutes on average. That is why obtaining samples for the studies was done each half an hour, which allowed to achieve 16 measurements per working shift. Result of the automated measurement AUT could be obtained after 30 seconds.

The control charts of single observations Xi were prepared for moisture (M). The results are shown in a form of diagrams in the Figures 3 and 4. For the period I, large dispersion and ranges R of the moisture measurement results in comparison with the period II can be observed, where the fully automated plant for processing was used, integrated with the SCADA system.

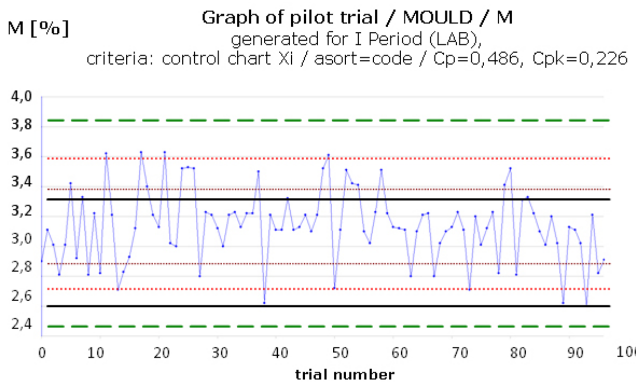

Fig. 3. Control chart for moisture – I period (continuous lines – tolerance limits, dashed and dotted lines – control and warning limits, respectively, on levels 2σ and 1σ)

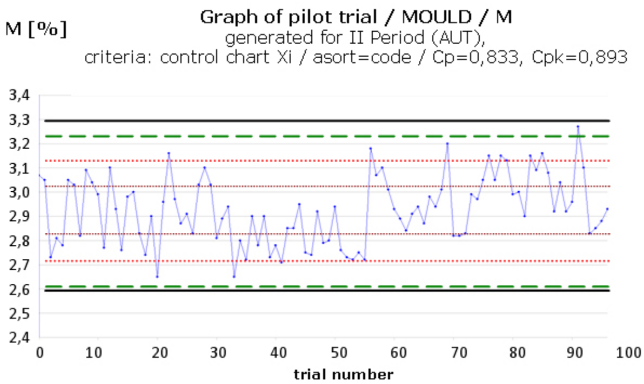

Fig. 4. Control chart for moisture – II period (interpretation of limits as in Fig.3)

In Table 2, basic statistics of the obtained results are shown. These statistics confirm improvement of stability of process of the green sand processing. The comparison contains data obtained by the laboratory method for the I period (LAB) and by the laboratory (LAB) and automatically (AUT) for the II period. In Figure 5, for the M and C_S parameters, a comparison diagram of these statistics is shown. Characteristics of the compactibility parameter changed insignificantly for the two periods, while range, standard deviation, as well as kurtosis for the moisture and compressive strength confirm that the process stability is remarkably improved. It is noteworthy, that in case of the compressive strength, range and standard deviation are on a similar levels, while the kurtosis value is significantly increased in direction of positive values, which shows a strongly leptokurtic distribution in comparison with the normal distribution [31], which means that the results obtained by AUT are less dispersed.

Table 2.
Statistics of data for two periods of study (I period – before, II period – after implementation of automated system for sand processing). Automated measurements obtained using devices of a new installation – AUT = MCM + ASMS

Results obtained automatically (AUTOM) and manually (LAB)	I PERIOD			II PERIOD					
	$M_{(LAB)}$	$C_{(LAB)}$	$S_{C(LAB)}$	$M_{(LAB)}$	$C_{(LAB)}$	$S_{C(LAB)}$	$H_{(AUT)}$	$C_{(AUT)}$	$S_{C(AUT)}$
MAX value	3,63	55,00	0,25	3,27	60,00	0,20	3,27	50,00	0,19
MIN value	2,60	32,00	0,14	2,65	29,00	0,11	2,65	37,00	0,14
Average value	3,14	40,59	0,20	2,94	42,31	0,17	2,93	42,73	0,18
Standard deviation	0,24	5,70	0,03	0,16	4,79	0,01	0,14	3,13	0,01
Range R	1,03	23,00	0,11	0,62	31,00	0,09	0,62	13,00	0,06
Kurtosis	-0,21	-0,64	-0,94	-0,84	3,05	3,35	-0,73	-0,57	8,16
Median	3,13	39,00	0,22	2,92	41,00	0,17	2,92	42,00	0,18

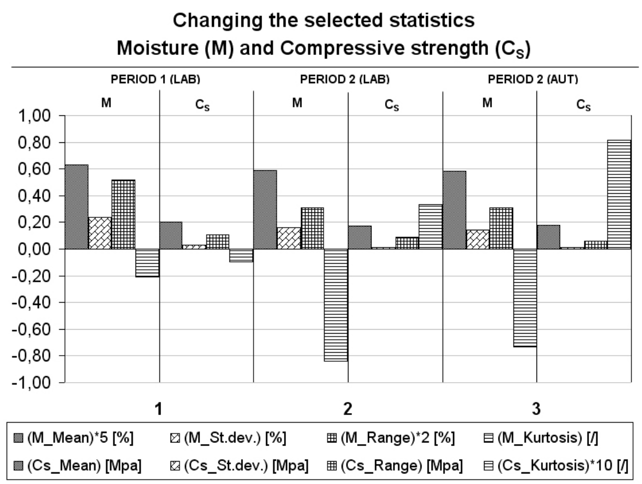

Fig. 5. Selected quantitative descriptive statistics for the two compared periods of work of the sand processing station

The II stage of studies concerned evaluation of effectiveness of the automated system for preparation and control of processing of the green sand. Range of the conducted work was related to comparative diagrams of correlation of moisture measurement, obtained by the laboratory method and automatically (see Fig. 6).

Moreover, influence of moisture on compactibility was verified on the basis of measurements obtained in the laboratory (see Fig. 7) and automatically (see Fig. 8). The estimated values of the correlation index for these parameters are shown in the Table 3. It turns out, that the correlation index for the M=f(C) relation is much higher for the results obtained in the laboratory.

Table 3.
Calculated values of correlation index for different configuration of M, C and C_S parameters

Matched results (M, C i C_S parameters)					Correlation index r_{xy}
Parameter	Method of data acquisition		Parameter	Method of data acquisition	
M	LAB	+	M	AUT	0,2517 (low)
C_S	LAB	+	C_S	AUT	0,1557 (low)
C	LAB	+	C	AUT	0,2745 (low)
M	LAB	+	C	LAB	0,4048 (average)
M	AUT	+	C	AUT	0,0454 (weak)

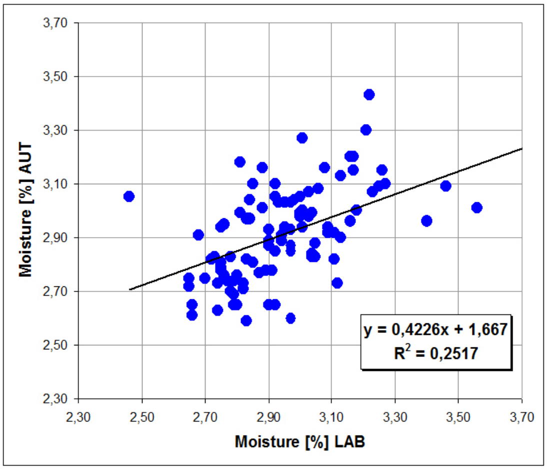

Fig. 6. Matching of results of moisture measurements obtained in the laboratory and automatically

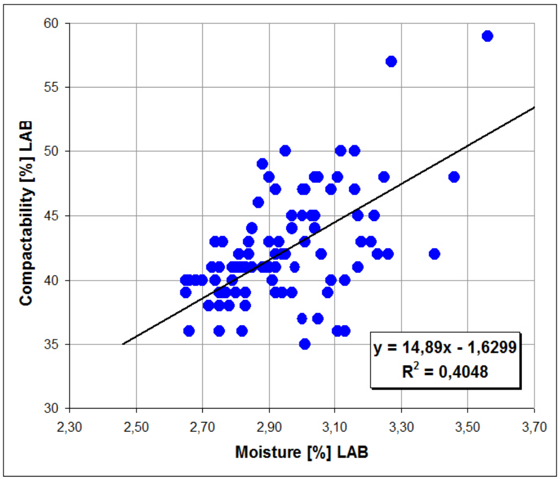

Fig. 7. Matching of results of moisture and compactibility measurements obtained in the laboratory

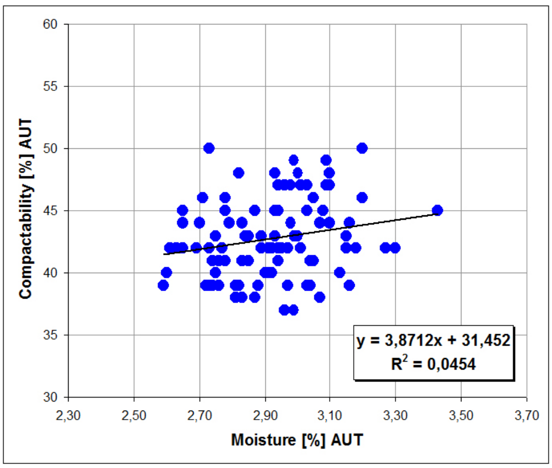

Fig. 8. Matching of results of moisture and compactibility measurements obtained automatically

Despite that the green sand process supervised and controlled automatically has a relatively good stability (see Fig. 4), the information about values of C and C_S parameters (measured automatically before the release funnel of the molding machine by the ASMS) does not give a direct transfer to control of the sand moisture in the mixer. The authors suggest that in such cases it would be better to switch to the manual control and use the laboratory results as a support until the installation elements are calibrated.

7. Summary

The authors have undertaken the topic of green sands of I generation mostly because of their lasting popularity in the manufacturing of castings. The green sand or its matrix, to be more exact, as well as the bonding material, can be reused if the processing is appropriately controlled.

The paper presents results of studies of processing properties of the green sands, from the viewpoint of their stability, in conditions of the same foundry. Two periods of work in the foundry were compared: before and after implementation of devices for automatic measurement (ASMS) and on-line control (MCS) of the mixing parameters (dosage of fresh raw materials and water).

It was found, that the automated control and measurement systems that beneficially affect obtaining results of the green sand properties in the tolerance limits are much useful. As the current literature shows, it is a promising direction. In the presented paper, one of such systems was subjected to evaluation. The AUT system used three important parameters for control of the green sand properties: moisture, compactability and compressive strength. The first parameter (M) measured in a mixer using a capacitive probe indicates its greatest significance in the sand processing. The two other parameters (C and C_S) can be treated as auxiliary, their task is to supply the automated system (MCM) with the additional information about the sand properties. During the comparative verifying-calibrating studies (on-line interchangeably with off-line), the installation must be adjusted to the given foundry infrastructure as well as possible.

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