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Characterization of Sand and Sand-Binder Systems from the Foundry Industry with Impedance Spectroscopy

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Summary:
It would be very advantageous if the condition of molding materials (sand-binder systems) in regenerator units used in foundries could be monitored in real-time. This work presents the results of investigations in this direction. It is shown that the condition monitoring can possibly be based on impedance spectroscopy because the resulting curves are characteristic of the material used. New and used sands as well as two-component mixtures of sands and binders showed a systematic behavior, which allows the sand or the composition of the mixture to be identified (classified) in the future.

Keywords: Foundry, sand, bentonite, condition monitoring, impedance spectroscopy

Background

The raw material sand is mined more than the natural regeneration of the sand deposits can compensate [1, 2]. One reason for this is that the foundry industry needs the sand to produce so-called lost forms and cores with binders like bentonite. As a consequence, used sand is now routinely recycled to save on raw material and to avoid the expensive disposal of used sand in landfills.

As the type and quality of sand play an important role in foundry applications, the qualification of the raw and regenerated materials is defined by industry regulations. In Germany, e. g., the guidelines are drafted by the Bundesverband der Deutschen Gießerei-Industrie (Federal Association of the German Foundry Industry, BDG). As yet, laboratory tests are the standard method [3].

To achieve optimum results at the lowest possible cost, the sand condition needs to be monitored during the recycling process. Our goal is to base such a condition monitoring on impedance spectroscopy. Known results from the literature indicate that the characteristics of different raw materials such as grain size distribution, crystal structure, and moisture may be distinguishable with this method. For example, [4] shows how the permittivity of bentonite depends on its water content. Ref. [5] describes the complex permittivity of sand-bentonite-water mixtures by a plausible model. We have now extended this approach and have investigated whether the various moulding materials can be characterized by impedance measurements.

Measurement Setup

Our measurement setup comprised a circular cylindrical cell, which could be filled with the material under test (MUT). The cell was equipped with two opposing copper electrodes (diameter 13 cm, plate spacing 4 cm), which were soldered to two coaxial cables. The bottom and top electrodes were respectively glued to a wooden plate and a Makrolon cylinder. The casing of the cell was made of a polymer. The impedance of the MUT-filled cell was measured by an LCR meter E4890A from Agilent in the frequency range from 20 Hz to 1 MHz.

The results presented in this work pertain to the materials listed in Table 1. MUT 1 was a quartz sand suitable for foundries. MUT 2 was a chromite sand that used for molded parts subject to high thermal loads. The average grain diameter was 0.2 mm MUT 1 and 0.3 mm for MUT 2.

Tab. 1: Chemical composition (percentage mass fractions) of the examined materials. B. = Bentonite.

MUT	Mass fraction in %					
	SiO_2	Al_2O_3	Cr_2O_3	Fe_2O_3	MgO	B.
1	99.53	0.01		0.01	0.01	0
1a	(As MUT 1 with heating to 800 °C.)					
2	0.7	14.8	46.4	28.2	9.5	0
3a	98.53	0.01		0.01	0.01	1
3b	96.54	0.01		0.01	0.01	3
3c	94.55	0.01		0.01	0.01	5
3d	91.57	0.01		0.01	0.01	8
3e	89.58	0.01		0.01	0.01	10

A sample of MUT 1 (“MUT 1a” in Table 1) was exposed to 800 °C for more than 88 hours, then cooled and measured again. This simulated the

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casting process and the associated thermal load on the sand. The two differently processed samples of the quartz sand are referred to as "new sand" (MUT 1) and "old sand" (MUT 1a) in the following. The materials termed MUT 3a through 3e in Table 1 were samples of MUT 1 mixed with various amounts of bentonite.

Results

Figure 1 shows the Nyquist plots of measured test-cell impedances for various materials. The results of eleven independent measurements of MUT 2 were plotted to convey an idea of the reproducibility of the measurement. For the quartz sand (MUT 1 and MUT 1a), the reproducibility was even better so that it was justifiable to plot the mean values only (result of nine and five independent measurements in the case of MUT 1 and MUT 1a, respectively). The relative standard deviations in the resistance Re{$\underline{Z}(f)$} and the reactance Im{$\underline{Z}(f)$} were below 1.21 % and 0.07 %, respectively, at all frequencies for MUT 1. The corresponding numbers for MUT 1a were 0.77 % and 0.02 % for MUT 1a.

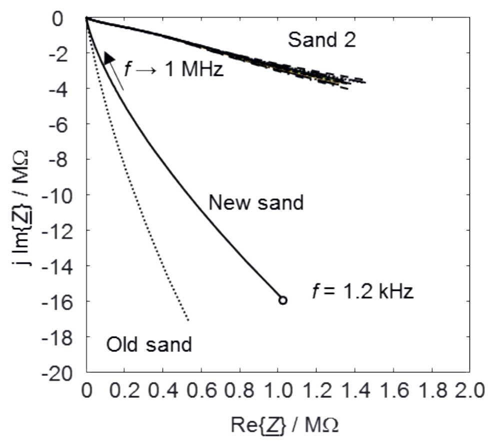

Fig. 1. Measured test-cell impedance with MUT 1, MUT 1a, and MUT 2, respectively.

The measured impedances may be approximately interpreted in terms of parallel RC circuits. The slope of the curve in the Nyquist plot is then equal to –tan(ωRC). At equal frequencies, thermally processed sands (MUT 1a) lead to steeper slopes than the other sands, corresponding to higher values of R, i. e., lower electrical conductivities. This is attributed to the fact that the sand grain surface partly bursts when heated. This leads to an increased porosity and more air in and between the sand grains. SEM images of the grain surface and a decrease in the bulk density corroborate the explanation.

By a similar line of reasoning, MUT 2 is more conductive than the quartz sands. The reason is the higher packing density (more conduction paths) and the different composition (Fe^{2+} ions in the crystal lattice) [3, 6].

The measurement results for sand-bentonite mixtures (MUT 3a through 3e in Table 1) are visualized in Fig. 2. The electrical conductivity obviously increases with the bentonite content. This is plausible as bentonite contains cations and water molecules in its lattice [3].

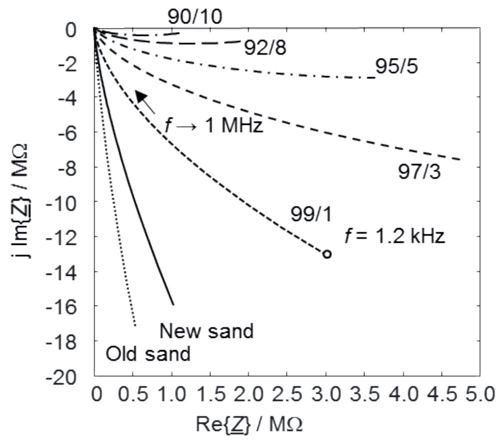

Fig. 2. Measured test-cell impedance with MUT 3a through 3e. The curves for MUT 1 and MUT 1a are given for comparison's sake.

Conclusion

Our study of sand and sand-binder mixtures clearly demonstrates that it is possible to classify the materials based on impedance measurements. The transfer of these results to a measurement system usable for the in-process condition monitoring within sand regenerators in foundries appears highly desirable. This is the subject of ongoing work.

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