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Strength Properties of Ceramic Moulds Containing Spent Moulding Sand After Initial Reclamation

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Abstract

The results of testing the strength properties of experimental ceramic materials containing spending moulding sand after initial mechanical reclamation as a material for subsequent layers of the stucco composition were presented.

Tests were carried out on spent moulding sands from various foundry technologies, i.e. sand with furfuryl resin and sand with hydrated sodium silicate. The spent, agglomerated moulding sand has undergone a crushing process. Next, the required granular fractions used for individual layers of the stucco material were separated. Ceramic samples, in which the spent moulding sand was a substitute for fresh silica sand in successive layers of the stucco composition, were prepared. As a reference material, identical ceramic samples were used but with all layers made from the fresh silica sand. Samples prepared in this way were used to determine the bending strength of ceramic materials in the temperature range from 20 to 900ºC. The obtained values of the bending strength have demonstrated that spent moulding sand can be used in investment casting with no adverse effect on the strength of ceramic materials.

Keywords: Ceramic shell moulds, Spending moulding sand, Reclaimed sand, Lost wax process, Strength properties

1. Introduction

Investment casting (lost wax process) allows making castings of complex shapes and diversified wall thickness. Other advantages of this technology include the ability to make castings with high dimensional accuracy and a very smooth surface with no need for coring and splitting of moulds. Machining of finished parts is also effectively eliminated.

The design of modern machines and devices forces the use of cast components of always more complex shapes. This, in turn, demands that these components should be cast by the lost wax process.

Unfortunately, the disadvantage of the lost wax process is the fairly high cost of making castings, since at present only fresh ceramic materials are used for moulds. For this reason, foundries are constantly looking for new ceramic materials that would lower the manufacturing cost of investment moulds without compromising their high strength properties [1- 4].

The foundry industry generates very large amounts of spent materials. In sand mould technology, the waste mainly consists of the used moulding and core sands. The increasing cost of waste storage forces foundries to intensify the search for ways to reduce material consumption, on the one hand, and to effectively re-use the waste generated in the production process, on the other hand [5].

According to the Act on Waste, the basic rule to follow is to prevent the occurrence of the waste, and if this is not possible, to provide a useful recyclable material compatible with environmental protection principles [6-7].

One of the ways to recover sand from the spent moulding mixture is by reclamation, but it is not always possible to completely reclaim the spent sand and re-use it in full in the mould-making process. In practice, about 80% of reclaimed moulding sand is re-used as a base material. The rest is the addition of fresh silica sand. Therefore, even if the foundry reclaims its moulding sand, about 20% of the total sand volume is rejected as a waste and disposed to the landfill [8- 10].

This article discusses the results of studies exploring the possibility of using spent moulding sand as a ceramic material for successive layers of ceramic shell moulds.

2. Purpose of research

The spent moulding sands for disposal in a landfill site were acquired for testing. Moulding sand mixtures were prepared using the following binders: an organic binder - furan resin (Fn) and an inorganic binder - hydrated sodium silicate (Sz). The spent moulding sands were subjected to an mechanical reclamation process carried out in a laboratory reclamation unit installed and operating at the Foundry Research Institute. The initial reclamation process consisted in crushing the agglomerated sand in a mechanical jaw crusher (Fig.1) followed by dust removal. After reclamation, the small metallic parts that remained in the sand were separated by an electromagnetic separator.

Fig.1. Installation for mechanical reclamation of moulding sands

The base sand reclaimed from each batch of the spent moulding mixture was subjected to analysis of the chemical composition and determination of the loss on ignition. The results are compared in Table 1.

Table 1.
Chemical composition and loss on ignition of waste moulding sands

Chemical composition	Sand with furan resin Fn [%]	Sand with hydrated sodium silicate Sz [%]
SiO_2	97.72	96.07
Al_2O_3	0.56	1.74
Fe_2O_3	0.07	0.15
CaO	0.13	0.06
MgO	0.00	0.00
SO_3	0.01	0.00
K_2O	0.09	0.86
Na_2O	0.17	0.45
P_2O_5	0.01	0.01
TiO_2	0.06	0.05
Loss on ignition	2.34	0.68

Both reclaims were characterized by high (over 96%) silica content and low loss on ignition.

The granular composition of the spent moulding sand was determined by laser diffraction on a FRITSCH Analysette 22 NanoTec apparatus. Table 2 summarizes the obtained values of the arithmetic diameter d_a, geometric diameter d_g.

Table 2.
Granular composition of spent moulding sands

Dust designation	Arithmetic diameter d_a, µm	Geometric diameter d_g, µm
Fresh sand	264.34	230.51
Fn	261.30	221.54
Sz	262.79	224.10

The reclaims of moulding sands with organic resin and sodium silicate were characterized by a homogeneous granular composition.

Figure 2 shows the morphologies of grain surface in fresh sand and spent moulding sand with furan resin (Fn) before and after mechanical reclamation. Photographs were taken with a SCIOS FEG scanning electron microscope.

Analyzing the results presented in Table 2 and surface of sand grains shown on Figure 2a-2c it can be assumed, that the initial reclamation does not cause a degradation of the base sand grains.

a)

b)

c)

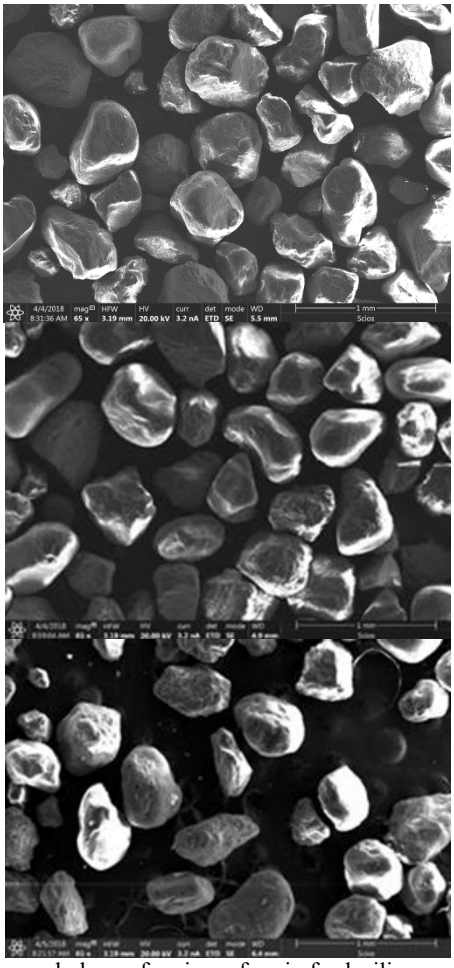


Fig. 2. The morphology of grain surface in fresh silica sand and spent moulding sand: a- fresh sand, b- before reclamation, c - after initial reclamation in jaw crusher. 65x

3. Experimental investigations

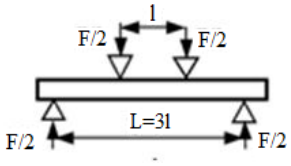
In the next stage of the research, the impact of the spent moulding sand after initial reclamation on the strength of ceramic materials for investment moulds was investigated. For this purpose, a liquid ceramic slurry based on Sobótka MK.100/001 silica powder was prepared. Colloidal silica with the trade name Ludox PX30 was used as a binder. From each tested type of the spent moulding sand, ceramic samples with dimensions of 60 × 20 × 7 mm were prepared. In these samples, for successive layers of the stucco material, the reclaimed sand was used. For the first layer of the stucco material, the reclaims with a particle size of 0.1-0.2 mm were used. The next layers of the stucco material were made from the reclaims in which the particle size was larger than 0.2 mm. Each ceramic sample contained five layers of stucco material. In the same way, standard reference ceramic samples were prepared. In those samples, the subsequent layers of the stucco material were made from the fresh silica sand, the same which had previously been used for the moulding sand mixtures which as a spent material were subjected to testing. Reference samples were made in previously prepared wax patterns (Fig.3).

a)

b)

Fig. 3. Wax pattern (a) to make standard reference ceramic samples (b)

The bending strength of ceramic samples was tested at selected temperatures ranging from 20 to 900°C, using apparatus for the four-point bending test available at the Foundry Research Institute. Ceramic samples were heated in a furnace at a rate of 10 K/min. Then they were held at a given temperature for a minimum of 5 hours and were next subjected to bending in selected temperature. A schematic representation of the four-point bending test carried out on ceramic samples is shown in Figure 4 [11,12].



$$\sigma_f = \frac{3}{2}\frac{F_f(L-l)}{d \cdot h^2}$$

where:
σ_f – the strength of specimen (the rupture stress on bending) [MPa]
F_f – the failure load [N]
L – the support span [mm]
l – the load span [mm]
d – the specimen width [mm]
h – the specimen height [mm]

Fig. 4. Schematic representation of the four-point bending test [11,12]

The values of the bending strength obtained in the ceramic samples containing a reclaim of the spent moulding sand with furan resin are summarized in Table 3 and illustrated in Figures 6 and 7. The numbers next to the Fn and Sz symbols of the reclaim indicate the layers of stucco material made from the reclaim.

Table 3.
Strength properties of standard reference ceramic samples

Ceramic material	Temperature, °C							Ceramic material	Temperature, °C						
	20	200	400	600	700	800	900		20	200	400	600	700	800	900
	Flexural strength (average), $\times 10^6$ N/m²								Flexural strength (average), $\times 10^6$ N/m²						
Base material	3.98	4.3	4.9	3.71	3.97	5.74	6.4	Base material	4.1	4.3	4.9	3.71	3.97	5.74	6.4
Fn2*	3.19	3.31	3.25	3.2	2.85	4.64	5.37	Sz2*	3.86	4.02	4.39	3.53	4.14	4.16	4.76
Fn3	3.79	3.93	4.38	3.21	4.09	5.58	5.96	Sz3	3.15	3.31	4.46	4.04	4.97	5.09	5.65
Fn4	3.77	3.91	4.16	3.33	3.9	4.71	5.83	Sz4	3.01	3.09	4.52	4.30	3.85	5.06	5.54
Fn5	4.13	4.29	5	4.2	4.08	6.08	6.31	Sz5	3.72	3.91	4.04	3.87	4.46	4.89	5.69
Fn3-4	3.13	3.31	2.85	2.53	3.37	4.41	5.13	Sz3-4	3.93	4.02	3.72	2.87	4.57	4.09	4.09
Fn3-5	3.74	3.93	2.76	2.29	2.95	4.49	5.17	Sz3-5	3.21	3.31	4.09	3.57	5.35	4.57	2.9
Fn4-5	3.79	3.99	3.46	2.79	3.34	5.2	5.72	Sz4-5	3.45	3.8	3.78	2.84	4.73	4.59	3.3
Fn2-3-4-5	3.05	3.25	3.18	2.34	4.01	5.35	5.48	Sz2-3-4-5	3.75	3.91	4.17	5.01	5.46	4.25	3.05

* the number means the layer that was made of spent moulding sand

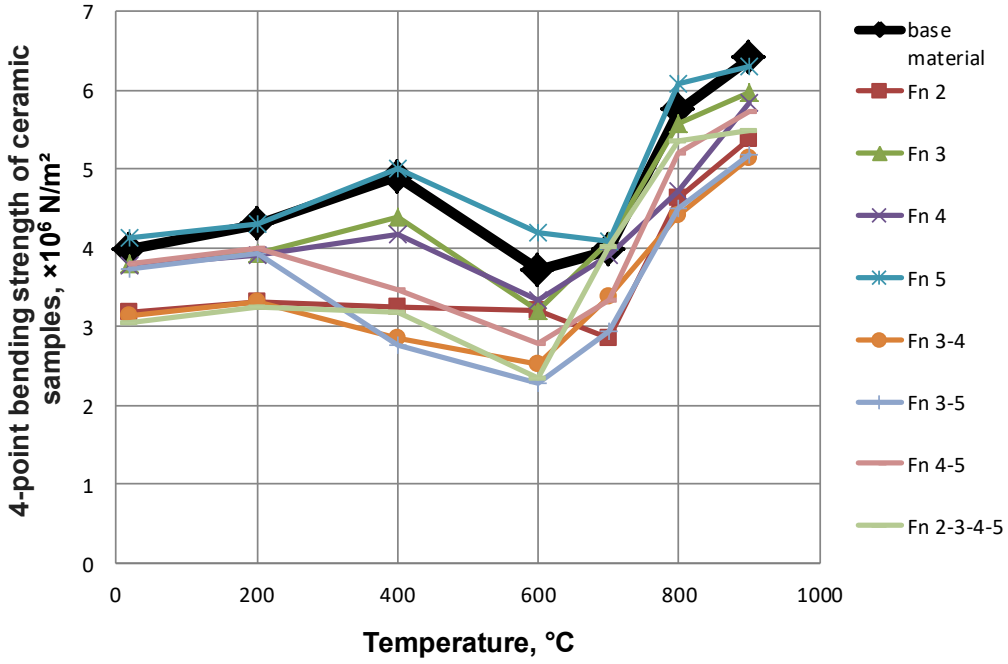


Fig. 5. 4-point bending strength of ceramic samples containing a reclaim of spent moulding sand with furan resin

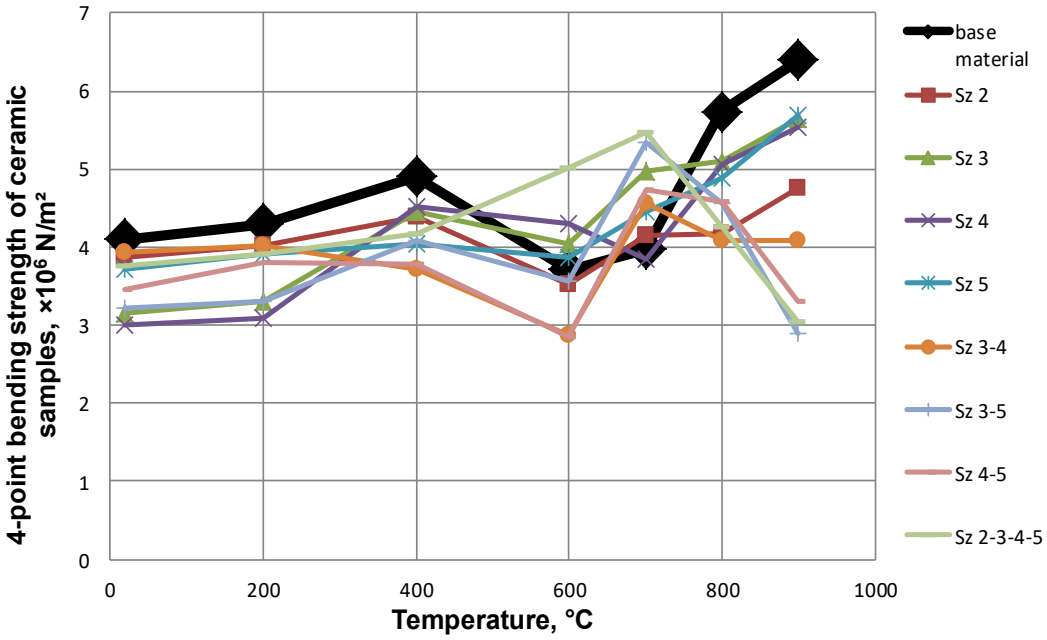


Fig. 6. 4-point bending strength of ceramic samples containing a reclaim of spent moulding sand with hydrated sodium silicate

High strength properties over $5{,}4\times10^6$ N/m² were obtained in the ceramic samples which had all layers of the stucco material made from the reclaimed furan sand, which means that the entire ceramic shell mould can be made from this type of reclaimed material. The value $5{,}4\times10^6$ N/m² is 85% of the maximum 4-point bending strength value of the base samples. This value was taken as the critical limit value. The ceramic samples with lower bending strength were considered as a ceramic material unsuitable for making ceramic moulds.

Ceramic samples made from the reclaimed spent sand with hydrated sodium silicate were much more sensitive to the drop in strength. Satisfactory strength properties over $5{,}4\times10^6$ N/m² were achieved only in those ceramic samples which had one layer of the stucco material based on reclaim, i.e. the third (Sz 3), fourth (Sz 4) or fifth layer (Sz 5). Therefore, in investment moulds, reclaims of the sand with hydrated sodium silicate are suitable for at most one layer of the stucco material.

4. Conclusion

The conducted research allows drawing the following conclusions:

1. The initial mechanical reclamation of the tested spent moulding sands enables the recovery of base sand grains. The obtained reclaims are characterized by a relatively low loss on ignition and contain at least 96% SiO2, which allows their re-use in moulding process.
2. Reclaims of spent moulding sands with either furan resin or hydrated sodium silicate are applicable in the investment moulding technology as a stucco material for subsequent layers of ceramic shell moulds.
3. Using reclaims as a stucco material on subsequent layers of the liquid ceramic slurry in ceramic shell moulds reduces the strength properties of these moulds. Compared to reference samples, the best strength properties were obtained in the ceramic samples in which the reclaim was used for the 3rd, 4th or 5th layer of the stucco. This proves that the effect of reclaim on strength properties is less pronounced if it is used for layers more distant from the surface of the wax pattern. Differences in bending strength are noticeable, but do not exceed 1×10^6 N/m². The obtained strength of 5×10^6 N/m² confirms that it is possible to use reclaims as a stucco material for ceramic investment moulds.

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