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Foundry Dust - Alternative Additive for Green Sand Mixtures

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Abstract

Foundry dust is a significant component of the waste produced by the foundry industry worldwide. This waste is generated during mould making, melting, casting and discharging of moulds, where dust particles are released and subsequently captured by filters. Like most foundry waste, foundry dust usually ends up in landfills. However, this method of waste management faces problems related to environmental and economic requirements, especially in view of tightening legislation. It is important to point out that foundry dust contains components that could be reused in the production of foundry mixtures. The aim of this study is to evaluate the possible positive and negative effects of two foundry dust samples on the quality of the green sand mixtures. Basic analyses include the chemical composition of the leachate in aqueous solution and the granulometric composition of the dust particles. Furthermore, the properties of other ingredients for the preparation of green sand mixtures will be characterized. The study serves as a starting point for future research in the reuse of foundry dust in green sand mixtures, thus contributing to the sustainability of industrial processes.

Keywords: Foundry dust, Chemical characteristics, Green sand mixture, Waste material, Alternative additives

1. Introduction

The foundry industry annually generates a substantial amount of waste, the volume of which reaches hundreds of millions of tons. Estimates vary; however, it is generally reported that for every ton of castings, approximately 0.6–1 ton of waste is produced [1]. The global production of castings amounts to approximately 112.7 million tons, corresponding to up to 100 million tons of foundry waste per year [2-3].

The main component of this waste is spent foundry sand. Other waste materials include foundry dust, metal scrap, slags, refractory lining, and additional less voluminous by-products. At present, only a small fraction of this waste is recycled, while the majority is disposed of in landfills [4].

European foundries face challenges arising from the Circular Economy Action Plan [5], which prohibits, as of 2030, the landfilling of materials that can be effectively recycled. This category includes most foundry wastes, such as spent sands or slags [6]. Rising landfill fees are already increasing production costs and reducing the competitiveness of European foundries compared to facilities outside the EU.

For these reasons, foundries are increasingly focusing on reducing waste generation and seeking opportunities for secondary utilization. The greatest potential lies in spent foundry sand, which can be reused with minimal or, in some cases, no significant processing. Numerous studies confirm its applicability, for example, in the construction industry and other industrial sectors [7–10].

Foundry dust also holds significant potential. It consists of fine particles collected in dust filters and separators, generated throughout the entire production process—from the preparation of molding mixtures and mold production to metal melting and casting, mold shakeout, and molding sand reclamation. In

particular, the dust generated during this last stage (sand regeneration dust) is still commonly landfilled, even though it contains recoverable fractions, making it a suitable target for separation-based recycling methods [11]. Additional sources also mention products of mechanical operations such as grinding or shot blasting of castings [12].

The composition of foundry dust can vary considerably depending on specific operating conditions, particularly the type of molding mixture used and the type of metal cast [12]. Consequently, it cannot be classified into a single category and must be evaluated on a case-by-case basis.

Foundry dust often contains considerable proportions of reusable components, such as binders and carbonaceous additives. The study Flotation separation of coal dust from foundry dust enhanced by pre-soaking assisted mechanical stirring reports that dust from green sand mixtures may exhibit more than 40% loss on ignition (LOI), indicating the presence of lustrous carbon carriers [13]. According to the study Influence of foundry dust on moulding mixtures quality, this dust also contains active bentonite, which can be reused in molding mixtures without negatively affecting casting quality [14]. Another study, Assessment of Harmfulness of Green Sand with Additions of Dust from Dry Dedusting, dealing with the harmfulness of dusts from green sand mixtures, confirms the presence of 20–25% montmorillonite and a lustrous carbon content in the range of 0.28–0.42%. The study also states that the addition of dust does not result in deterioration in terms of negative environmental impact [15]. The green sand dust examined in the study Physico-Chemical and Environmental Characterisation of the Dust from Dry Dedusting of the Green Sand contains more than 20% montmorillonite and exhibits a high loss on ignition. On the other hand, the dust shows a low ability to form lustrous carbon. Further analyses in this study indicate that the dust causes an increase in the amount of evolved gas by up to 11% compared to the reference mixture and an increase in emissions of BTEX compounds compared to green sand mixtures without dust addition [16].

However, previous research has focused exclusively on dust from green sand mixtures. This study therefore also analyzes dust derived from molds produced with a furan binder system. Although such dust does not contain reusable binders, residual organic resins may act as carbonaceous additives or offer other, as yet undescribed, benefits [17]. Nevertheless, potential risks must be taken into account—these resins are cured with sulfur-based acids, the residues of which can cause casting defects, particularly in ductile iron [18]. An open question remains as to whether potential benefits outweigh the negative impacts on the quality of green sand mixtures.

The objective of this experiment is to characterize the chemical and physical properties of two selected dust samples and, based on the obtained data, to evaluate their potential positive and negative effects. These findings will subsequently be applied in further research aimed at the preparation and testing of experimental molding mixtures incorporating foundry dust.

2. Experimental Part

2.1. Materials and methods

Samples of two waste foundry dusts were collected from two foundries in the Czech Republic.

Sample A (Fig. 1.) originated from a cast iron foundry which occasionally also produces steel castings. This foundry specializes in the production of medium to large castings. Quartz sand in combination with a furan binder system is used as the molding material. Molds and cores are treated with a corundum-based refractory coating to eliminate the formation of surface defects. For occasional steel casting production, a water glass system is employed; however, this system is kept separate from the residues of the other production processes. Mold production is carried out by manual molding. Sample A (furan dust) was collected from the separation line and the shakeout area of the foundry.

Sample B (Fig. 2.) was obtained from a cast iron foundry producing small to medium castings. This foundry employs a green sand molding system with carbonaceous additives, while an organic binder system is used for core production. Mold production is performed by machine molding. Sample B (green sand dust) was collected from the molding line and the shakeout area.

Both foundry dust samples were subsequently subjected to the following tests:

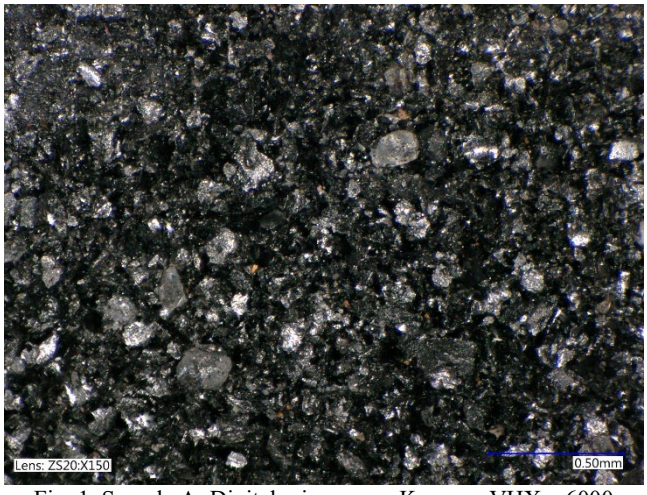

Fig. 1. Sample A; Digital microscope Keyence VHX – 6000

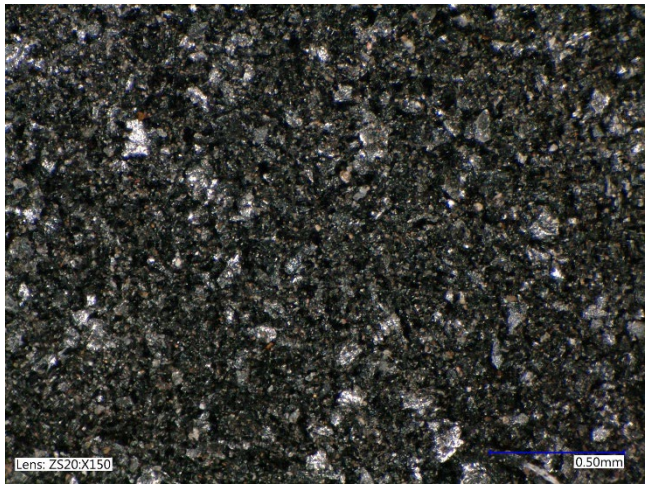

Fig. 2. Sample B; Digital microscope Keyence VHX – 6000

Chemical Composition in Leachates

The determination of elemental concentrations in leachates was conducted in accordance with Decree No. 273/2021 Coll., which corresponds to the standard ČSN EN 12457-4 for waste characterization by leaching – compliance test for leachability of granular waste materials and sludges [19].

Deionized water was used for the preparation of aqueous leachates at a solid-to-liquid ratio of 1:10. The solid phase was separated using membrane filters with a pore size of 0.45 µm. The leachates were subsequently stabilized with concentrated nitric acid and subjected to analytical determination.

The concentrations of fluorides, chlorides, and sulfates were determined by ion chromatography with a conductivity detector (WATERS 431, Waters). Mercury concentrations in the leachates were analyzed by atomic absorption spectrometry (AMA 254, ALTEC). The contents of Ba, Cd, Cr, Cu, Ni, Pb, and Zn were quantified by inductively coupled plasma atomic emission spectrometry (ICP-AES) using a SPECTRO CIROS VISION instrument (Spectro). The concentrations of As, Mo, Sb, and Se were determined by graphite furnace atomic absorption spectrometry (GF-AAS) with a UNICAM 989 QZ instrument (Chromspec).

The phenolic index was determined by UV-VIS spectrophotometry (LAMBDA 11, Perkin-Elmer). Dissolved organic carbon was analyzed using a MULTI N/C 3100 analyzer (Analytik Jena). The pH value of the leachates was measured with a Gryf 158 instrument, with a control measurement performed using an inoLab Level 1 instrument. The concentration of total dissolved solids (TDS) was determined gravimetrically.

Determination of Moisture Content and Loss on Ignition

The moisture content of the dust samples was determined using a moisture analyzer (AND MX-50) at 105 °C until a constant sample weight was achieved. The sample mass used was 10 g ± 1 g.

Subsequently, the loss on ignition (LOI) was determined. The samples were first dried to a constant weight at 105 °C. They were then ignited in a resistance electric furnace (LAC L15S) under oxidizing conditions at 900 °C for two hours.

Elemental Combustion Analysis

The carbon and sulfur contents were determined using an ELTRA CS 2000 analyzer equipped with an induction furnace. Analyses were performed in ceramic combustion crucibles that had been pre-annealed in a furnace at 1000 °C. For calibration of the analyzer, the Automatstal NR 6A standard containing 0.150 % sulfur was used. Approximately 0.1 g of the sample was weighed into the combustion crucible, to which 0.8 g of powdered iron and 1.6 g of tungsten were added as combustion accelerators.

Particle Size Distribution

Granulometric analysis of the dust samples was performed using a particle size analyzer (Anton Paar PSA 990). Prior to measurement, the samples were dried at 105 °C until a constant weight was achieved. The particle size distribution analysis was then carried out, with each measurement performed three times for each dust sample.

X-ray Fluorescence Spectroscopy (XRF)

X-ray fluorescence spectroscopy (XRF) was carried out using a Rigaku Supermini 200 analyzer . Prior to analysis, the samples were prepared in the form of pressed pellets. Approximately 4 g of finely ground sample (grain size < 0.1 mm) was mixed with 1 g of binder (Hoechst wax C). The mixture was homogenized in a mortar, placed into a mold, and subsequently pressed in a hydraulic press to produce an analytical pellet.

The EasyScan method, pre-set and calibrated by the instrument manufacturer, was employed for the measurements. This represents a standardless analytical method.

3. Results and discussion

Chemical Composition of Leachates

The results of the chemical composition of leachates are presented in Table 1, together with the limit values for the concentration of individual elements according to Decree No. 273/2021 Coll. on the management of waste [19]. These values serve as an important criterion for proper waste classification—specifically, whether the waste can be classified as non-hazardous or must be categorized as hazardous waste, which is subject to stricter handling requirements. Components without prescribed limit values are not regulated under this decree and are included only to provide a more comprehensive comparison of the two samples.

The results revealed that in several cases both samples of foundry dust materials exceeded the threshold values stipulated by the decree, particularly in terms of sulfates, fluorides, certain metals, and dissolved solids content. Consequently, the materials do not meet the requirements for classification as non-hazardous waste and must be assigned to the category of hazardous waste.

From a legislative perspective, these dusts may be used as an additive in moulding mixtures despite being classified as hazardous waste. However, they are subject to stricter control and must fulfil a number of criteria, including compliance with the relevant technical requirements for the specific application and ensuring that their use does not result in adverse impacts on the environment or human health [20].

An unusual finding was the sodium concentration in the aqueous leachate of Sample A, which was nearly three times higher than the value typically observed in bentonite dusts. At first glance, no clear explanation for this increase was apparent. One possible factor may be related to the production characteristics of Foundry A, where molding mixtures with water glass are occasionally used for steel casting. Although the foundry reports that this process is kept separate from standard production procedures, contamination of the furan dust by residues from steel casting cannot be ruled out, most likely occurring during the shakeout process.. Separated dust from the shakeout area is collected together with the furan dust. Such contamination could have a secondary positive effect on the quality of green sand mixtures, specifically through Na-activation of bentonite clay.

Table 1.
Chemical composition of extracts with limit values according to Decree No. 273/2021 Coll

Sample		Limits	A	B
Nitrites	[mg/l]	-	<2.00	<2.00
Nitrates	[mg/l]	-	3.27	4.86
Phosphates	[mg/l]	-	6.89	<4.00
Sulphates	[mg/l]	100	675.00	558.00
Fluorides	[mg/l]	1	11.20	2.28
Chlorides	[mg/l]	80	5.42	25.10
Dissolved solids	[mg/l]	400	1900.0	3160.0
Phenol index	[mg/l]	0.1	<0.050	<0.050
Al.	[mg/l]	-	28.4	7.14
As	[µg/l]	50	<6.00	<6.00
Ba	[mg/l]	2	0.035	0.045
Ca	[mg/l]	-	98.0	52.5
Cd	[mg/l]	0.004	0.006	0.006
Cr	[mg/l]	0.05	0.020	0.062
Cu	[mg/l]	0.2	<0.020	<0.020
Hg	[mg/l]	0.001	<0.001	<0.001
K	[mg/l]	-	10.1	10.9
Mg	[mg/l]	-	22.9	86.0
Mo	[mg/l]	0.05	<0.030	<0.030
Na	[mg/l]	-	32.0	10.6
Ni	[mg/l]	0.04	0.424	0.390
Pb	[mg/l]	0.05	<0.050	<0.050
Sb	[µg/l]	6	<3.00	<3.00
Se	[µg/l]	10	<10.0	<10.0
Si	[mg/l]	-	9.01	10.90
Sn	[µg/l]	-	<11.0	<11.0
Zn	[mg/l]	0.4	6.71	8.80

Another method focused on determining the pH of the aqueous leachates, as presented in Table 2. For Sample A, the pH value remained within standard ranges corresponding to this type of waste. The measured value was 3.62, which is consistent with values reported for similar materials in the study The Toxic Compounds and Leaching Characteristics of Spent Foundry Sands (pH for furan/acid sand 3.2 - 4.9) [21].

In the case of bentonite dust (Sample B), the measured pH deviated from typical values (pH for Green Sands 9.5 - 9.8), reaching 5.01 [21]. Due to this anomaly, the test was repeated using an inoLab Level 1 analyzer, which yielded an average pH value of 6.55. Although the two instruments produced different results, even the higher value remained relatively low compared to the expected pH range for this type of waste. A possible explanation for this phenomenon may be the presence of residual organic cores, which could contribute to lowering the pH value.

Table 2.
pH values measured on Gryf 158 and inoLab Level 1 devices

Sample		A	B
pH (Gryf 158)	[-]	3.62	5.01
pH (inoLab Level 1)	[-]	3.75	6.55

Loss on Ignition and Elemental Combustion Analyses

The results of the determination of loss on ignition (LOI) and moisture content of the dust samples are presented in Table 3, together with the results of elemental combustion analyses. The moisture content of both samples was nearly identical, averaging around 3 %. The LOI for the furan dust (Sample A) reached 38.21 %, whereas for Sample B it was 62.24 %.

The carbon content determined by elemental combustion analysis was 30.08% for Sample A and 47.7 % for Sample B. Sulfur content was measured at 1.29 % in Sample A and 1.88 % in Sample B.

From these results, it can be concluded that both dust samples exhibit significant LOI values along with high carbon contents, indicating their potential applicability as carbonaceous additives in green sand mixtures. However, these tests alone do not confirm the ability of the dusts to generate lustrous carbon, which is a key characteristic of carbonaceous additives. For this reason, further testing specifically aimed at assessing lustrous carbon formation is required.

Table 3.
Results of analysis of loss on ignition, moisture content, and elemental combustion analysis

Sample	Moisture content [%]	Loss on ignition [%]	C [%]	S [%]
A	3.00	38.21	30.08	1.29
B	3.04	62.24	47.7	1.88

The elevated sulfur concentrations in both samples additionally confirm potential risks associated with the use of dusts as alternative additives. However, the initial assumption that furan dust (Sample A) would show a higher sulfur content than bentonite dust (Sample B) was not confirmed.

Particle Size Distribution

A comparison of the granulometric results of the two samples revealed significant differences, with Sample A exhibiting approximately 50 % higher D_{50} and average grain size values (see Table 4.).

Table 4.
Average particle size distribution

Sample	D_{10}	D_{50}	D_{90}	Mean size	Span
	[µm]	[µm]	[µm]	[µm]	-
A	4.082	43.171	118.690	59.978	2.653
B	2.474	22.869	66.660	31.009	2.807

This finding is also evident from the graphical representation of the results shown in Fig. 3 (particle size distribution).

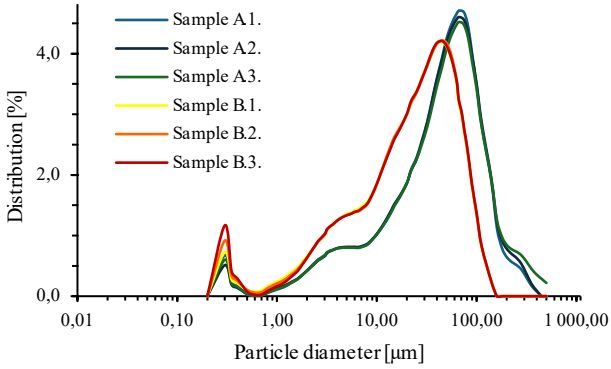

Fig. 3. Graphical representation of particle size distribution

This finding may be attributed to the different characteristics of the molding materials and the operating conditions of the foundry. For green sand mixtures, sands with finer granulometry are generally used (most commonly D50 = 0.21 mm). Foundries employing furan resins typically select coarser sands with D50 values ranging from 0.27 to 0.35 mm. Another contributing factor may be the use of coarser sands for the production of larger castings. The intensity of dust extraction and the performance of the equipment may also play a role.

The differences in granulometry can substantially influence the physical properties of molding mixtures, particularly the specific surface area and bulk density. Smaller particles increase the specific surface area, which in turn leads to higher water demand. At the same time, they contribute to an increase in bulk density, which may negatively affect compactability and permeability of the molding mixtures. These factors can promote the occurrence of casting defects and reduce the overall quality of castings. Based on the granulometric results of the dust samples, it can be concluded that the addition of Sample B is more likely to have a more adverse effect on the quality of the molding mixture than Sample A, and consequently may be associated with a higher risk of surface casting defects.

X-ray Fluorescence Spectroscopy (XRF)

The chemical composition of the two tested samples, determined by X-ray fluorescence spectroscopy (XRF), is presented in Table 5.

Table 5.
Average particle size distribution

Sample		A	B
Na_2O	[%]	0.211	0.088
MgO	[%]	0.561	3.300
Al_2O_3	[%]	5.346	2.574
SiO_2	[%]	44.20	19.85
P_2O_5	[%]	0.109	2.165
Cl	[%]	0.085	0.076
K_2O	[%]	0.646	1.314
CaO	[%]	1.084	0.395
TiO_2	[%]	0.367	0.185
Cr_2O_3	[%]	0.441	0.186
MnO	[%]	0.239	0.198
Fe_2O_3	[%]	11.773	16.142
NiO	[%]	0.030	0.137
CuO	[%]	0.056	0.060
ZnO	[%]	0.118	0.253
ZrO_2	[%]	0.366	0.458

For Sample A, a high SiO_2 content (44.2 %) was observed. This result correlates with the presence of larger particles in the digital microscope images, which likely represent residues of quartz sand. The presence of 5.346 % Al_2O_3 may be related to the use of a corundum-based refractory coating applied for the treatment of molds and cores in the foundry.. A significant proportion of Fe_2O_3 (11.773 %) was also detected, which may have originated from interactions between molten metal and the mold and was subsequently captured during the shakeout and reclamation processes along with other dust particles. The measured Na_2O concentration (0.211 %) supports the assumption of possible contamination by molding mixtures containing water glass.

For Sample B, similarly to Sample A, a high content of SiO_2 (19.85 %) and Fe_2O_3 (16.142 %) was measured, most likely originating from similar processes. The presence of other significant oxides, such as Al_2O_3, MgO, and K_2O, suggests the presence of bentonite clay. However, the exact proportion of bentonite in the dust cannot be unambiguously determined from this analysis, nor can its potential binding properties. To verify these characteristics, further targeted tests focused on determining the active bentonite content will be required. The increased concentration of MgO may also be attributed to the production of ductile iron. During the modification and casting process, magnesium is burned off, and its oxides may subsequently adhere to the mold surfaces, thereby contaminating the waste dust.

4. Conclusions

The objective of this study was to analyze two samples of foundry dust with regard to their potential use as alternative additives in green sand mixtures. Their properties were described, and both the possible benefits and risks associated with their application were evaluated. The tested samples originated from cast iron foundries: Sample A from a foundry using furan–quartz sand, and Sample B from a foundry employing a green sand

mixture with organic cores. Both samples were subjected to the following analyses: determination of chemical composition in leachate, X-ray fluorescence spectroscopy (XRF), elemental combustion analysis, loss on ignition, and particle size distribution.

Based on the results, the following conclusions can be drawn:

- The analysis of chemical composition in aqueous leachates demonstrated that the concentration limits set by Decree No. 273/2021 Coll. were exceeded; therefore, both samples must be classified as hazardous waste. An interesting finding was the elevated sodium concentration in Sample A, most likely caused by contamination from water-glass-based molding mixtures used in steel casting production. This contamination could potentially have a positive effect on the Na-activation of bentonite clay.
- The elemental combustion analysis confirmed high carbon content and significant loss on ignition in both samples, suggesting their potential use as carbonaceous additives. However, the presence of sulfur was also confirmed, which may negatively affect casting quality. The XRF analysis indicated the possible presence of bentonite clay in Sample B, but the exact proportion of active bentonite cannot be determined using this method.
- Granulometric analysis revealed notable differences between the samples: Sample A exhibited approximately 50% higher D50 and average particle size values compared to Sample B, which may influence the physical properties of mixtures and contribute to casting defects.

It can therefore be concluded that the tested dusts display certain favorable characteristics and potential for use as alternative additives in green sand mixtures. Nevertheless, further investigations are required, particularly focused on determining the content of active bentonite, the ability to form lustrous carbon, and the verification of Na-activation, in order to provide a comprehensive characterization of these materials.

Acknowledgements

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