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Assessment of Stability the Chemical Composition of Slags

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Abstract

Metallurgical slags are an object of the increasing interest in terms of the possibility of their utilization, especially as materials used in the construction and road building industries, in the foundry industry for refining and purifying liquid alloys, the production of abrasives for surface treatment of remanufactured machine parts, as mine backfill materials. Metallurgical slags, in order to be used in foundry processes, should be characterized by the stability of the chemical composition.
This paper presents the results of statistical analysis calculations, in which using a specific group f samples, knowing their chemical composition, the mean value Ā, variance $Ϭ^2$, standard deviation Ϭ and the classical coefficient of variation V were determined. The research and its results report the amount of variation in considered components of the slags.

Keywords: Slag, Chemical composition, Mean, Variance, Standard deviation, Coefficient of variation

1. Introduction

Metallurgical processes of production of metals from ores and the casting of ferrous and non-ferrous alloys contribute to the generation of a range of wastes that can pose a potential threat to the environment, as well as be processed into products useful to the national economy.

The largest group among the total amount of industrial waste is metallurgical waste, and among them, there are slags from the process of smelting pig iron (blast furnace slag), smelting steel (steelmaking-converter slag) and smelting non-ferrous metals (copper slag, nickel slag, etc.).

Metallurgical slags are the object of the increasing interest in terms of their management potential, especially as materials used in construction and road construction [1], foundry industry for refining and purifying liquid alloys [2], production of abrasives for surface treatment remanufactured machine parts [3], and as components of construction cements and concretes [4-6].

The chemical composition of the slags is variable, depending on the type of feedstock and the process itself. Metallurgical slags include several valuable components that can take part in the refining and the modification processes casting alloys, and when introduced into the composition of these alloys can improve their performance properties.

Most often, in various industries, blast furnace slag, converter slag, steelmaking slag and copper slag and steelmaking dust are used. In order to meet expected properties, these slags should be characterized by the stability in mineralogical and chemical composition.

2. The research method

With a view to the use of slags in refining and modification processes some casting alloys, chemical compositions of blast furnace, steelmaking, converter and copper slags were statistically analyzed. The selection of components (elements or chemical compounds) was made with a view to their expected role in refining and modification processes of casting alloys (cast steel, bronze , silumin and IN-713C nickel alloy).

In post-copper granulated slag, the presence of Si, Al, Cu, Mn, Fe, i.e. the main components most metal alloys, well as components with modifying properties, such as Na, Mg, Ca, Ti and P. These components are mostly present in form of oxides and in metallic form. In steelmaking dust, most above-mentioned components are present, plus in greater amounts Zn, Fe and Pb and compounds NaCl, KCl CaF_2, which is important for refining and modifying properties.

Similar components are found in blast furnace and converter slags.

The chemical composition blast-furnace and converter slags for analysis was collected from literature data [7-9], while the results for steelmaking and copper slags came from our own research, conducted in 1998-2002 [10, 11]. Samples for these studies (in cycles of about two weeks), were provided from the Głogów smelter and from EAFD (Electric Arc Furnace Dust process from electric steelmaking furnaces from BOL REC Ltd. (Boleslaw Recycling).

Analyses the chemical composition of slags were performed using classical methods at the Institute of Refractory Materials in Gliwice and AAS (atomic adsorption spectrometry), at Foundry Institute in Kraków.

3. The results of research

The chemical compositions collected from literature and our own research are shown in Tables 1-4.

Table 1.
Chemical composition of EAFD dust from electric steelmaking furnaces

Element	Content in samples, %									
	1	2	3	4	5	6	7	8	9	10
C	2.52	0.81	1.42	1.18	3.12	1.82	1.22	1.26	1.18	1.33
Na	1.72	1.22	2.05	1.12	1.65	1.23	1.79	1.86	1.03	1.35
Mg	0.69	1.20	2.10	1.80	1.40	1.80	1.11	1.48	1.96	1.23
Al	2.11	0.72	1.82	2.72	1.15	2.08	1.82	1.12	0.96	1.18
Si	1.45	2.42	2.28	2.41	2.18	1.96	1.28	2.37	2.73	2.56
K	1.50	0.51	1.80	1.40	1.20	1.50	0.87	1.12	0.95	1.23
Ca	1.32	2.45	2.52	2.84	1.47	1.38	2.71	2.42	2.75	2.67
Mn	1.90	2.80	2.12	1.30	1.31	1.78	1.33	2.73	1.83	1.69
Fe	24.90	31,40	24,24	34,90	27,20	30,30	18,60	36,44	26,47	32,87
Zn	26.12	30.82	35.91	26.72	36.43	25.18	33.48	28.35	33.08	28.15
Cl	6.62	5.32	6.54	4.92	8.12	5.68	4.12	4.44	3.98	4.65
Cr	0.35	0.23	–	0.25	–	0.45	0.36	0.62	0.27	0.48
Pb	2.22	2.72	1.94	2.12	2.56	3.11	2.78	2.61	3.05	3.22

Table 2.
Chemical composition of copper shaft slag

Element	Content in samples, %									
	1	2	3	4	5	6	7	8	9	10
SiO_2	41.80	38.22	42.50	37.34	43.70	40.45	37.65	39.54	41.50	41.19
CaO	20.52	19.63	17.43	16.45	18.42	19,85	15.45	17.22	14.35	14.80
MgO	2.32	5.50	3.23	6.74	5.21	4,32	3.85	2.12	3.16	6.25
Al_2O_3	10.8	12.92	13.35	12.32	9.56	12.34	14.34	13.87	11.22	6.44
Fe_2O_3 + FeO	17.11	22.68	15.67	18.64	24.86	17.32	18.35	24.46	21.36	22.74
K_2O	1.34	2.12	1.67	2.12	1.86	2.15	1.67	3.24	2.35	3.15
Cu	0.51	0.85	0.78	0.56	0.58	0.48	0.81	0.72	0.67	0.78
Zn	0.53	0.72	0.65	0.71	0.58	0.64	0.58	0.74	0.62	0.35
Pb	0.44	0.92	0.54	0.82	0.58	0.67	0.76	0.35	0.44	0.74
Cr	0.051	0.075	0.056	0.064	0.072	0.062	0.048	0.078	0.057	0.034
Co	–	0.060	–	0.042	–	0.048	0.054	0.029	0.033	–

Table3.
Chemical composition of blast furnace slag samples

Element	Content in samples, %								
	1	2	3	4	5	6	7	8	9
SiO_2	39.57	45.03	45.55	39.25	38.12	37.13	41.14	42.67	44.78
Al_2O_3	10.30	7.56	8.22	11.25	11.25	11.54	8.75	7.68	10.12
CaO	19.24	20.58	22.12	17.54	17.54	18.54	23.12	18.55	17.45
Fe_2O_3	17.77	14.64	15.45	18.32	18.32	14.78	17.00	17.43	19.32
P_2O_5	0.09	0.06	–	–	0.04	0.11	0.05	–	0.07
MnO	0.48	0.42	0.31	0.43	0.21	0.38	0,41	0.38	0.29
MgO	5.63	5.33	6.12	4.95	5.12	4.18	3.88	4.16	5.15
Na_2O	0.25	0.28	0.22	0.18	0.31	0.16	0.21	0.28	0.14
K_2O	0.26	0.23	0.23	0.22	0.31	0.15	0.18	0.24	0.17
TiO_2	0.59	0.42	0.36	0.55	0.58	0.34	0.64	0.53	0.49

Table 4.
Chemical composition of converter slag samples

Element	Content in samples, %								
	1	2	3	4	5	6	7	8	9
SiO_2	10.80	14.41	15.46	12.33	14.12	11.60	12.67	14.90	10.20
Al_2O_3	2.99	4.17	3.45	4.45	3.12	2.13	4.56	3.12	4.40
CaO	37.53	35.81	39.22	36.12	37.50	32.45	38.40	36.23	39.60
Fe_2O_3	32.45	26.52	33.14	33.45	26.54	28.32	28.55	29.34	32.12
P_2O_5	1.37	0.99	1.12	1.56	1.65	1.31	1.08	1.27	1.17
MnO	3.34	2.40	3.35	2.54	2.12	3.13	2.87	3.42	2.95
MgO	7.00	7.82	8.12	7.34	6.34	8.88	5.89	7.45	6.88
Na_2O	0.01	0.02	–	–	0.02	0.02	–	0.02	0.01
K_2O	0.01	0.02	0.01	–	0.02	–	0.01	0.02	–
TiO_2	0.55	0.45	0.38	0.49	0.37	0.54	0.55	0.37	0.42

4. Statistical calculations

Statistical analysis calculations were carried out on a specific population samples with a specific chemical composition, determining mean $\bar{A}$, variance σ^2, standard deviation σ and coefficient of variation V [12-15]. The calculations used the MS Excel computer system.

Variance is defined as average the squares of deviations from mean. The standard deviation is a measure the distribution of results in a distribution and indicates how much, on average, each value in distribution deviates from the mean or center distribution. The standard deviation is calculated from the square root of variance.

By definition, variance and standard deviation are measures of variability and provide information about variation or diversity in population under study. Both variance and standard deviation increase or decrease depending on how closely the results cluster around the mean $\bar{A}$.

An important part of statistical analysis is the coefficient of variation V, as one measures of dispersion, calculated from relationship:

$$V = \sigma / \bar{A} \cdot 100\%$$

The coefficient of variation is a measure expressed as a percentage, which makes it possible to compare variation different statistical characteristics. If the coefficient takes high numerical values, it indicates low homogeneity of statistical community under study. Based on literature, the coefficient of variation V is interpreted as follows [14, 15]:

- A value of less than 20% - the diversity population is low,
- value from 20 to 40% - the diversity population is medium,
- value from 40 to 60% - the diversity population is high,
- value of more than 60% - the diversity population is very high.

Table 5.
Results of statistical analysis of FAFD dust from electric steel furnaces

Component	Mean $\bar{A}$	Variance σ^2	Standard deviation σ	Coefficient of variation V [%]
C	1.486	0.238	0.488	32.81
Na	1.502	0.113	0.336	22.34
Mg	1.477	0.173	0.416	28.14
Al	1.568	0.362	0.602	38.40
Si	2.164	0.199	0.446	20.63
K	1.208	0.123	0.351	29.08
Ca	2.253	0.336	0.579	25.72
Mn	1.879	0.264	0.514	27.34
Fe	28.748	26.773	5.174	18.00
Zn	30.424	15.193	3.898	12.81
Cl	5.439	1.563	1.250	22.98
Cr	0.376	0.016	0.125	33.25
Pb	2.633	0.170	0.412	15.64

Table 6.
Results of statistical analysis for copper shaft slag

Component	Mean $\bar{A}$	Variance σ^2	Standard deviation σ	Coefficient of variation V [%]
SiO_2	39.91	4,145	2.036	5.10
CaO	16.94	3.789	1.947	11.49
MgO	4.27	2.334	1.528	35.78
Al_2O_3	11.24	5.664	2.380	21.17
Fe_2O_3 + FeO	19.84	6.790	2.606	13.13
K_2O	2.17	0.343	0.585	27.02
Cu	0.67	0.016	0.127	18.79
Zn	0.61	0.012	0.108	17.69
Pb	0.63	0.031	0.177	28.21
Cr	0.06	0.000	0.013	21.44
Co	0.04	0.000	0.010	23.08

Table 7.
Results of statistical analysis for blast furnace slag samples

Component	Mean $\bar{A}$	Variance σ^2	Standard deviation σ	Coefficient of variation V [%]
SiO_2	41.47	8.936	2.989	7.21
Al_2O_3	9.25	2.182	1.477	15.96
CaO	19.97	3.840	1.960	9.86
Fe_2O_3	17.00	2.505	1.583	9.31
P_2O_5	0.07	0.000	0.024	34.01
MnO	0.37	0.006	0.079	21.26
MgO	4.95	0.490	0.700	14.15
Na_2O	0.23	0.003	0.055	24.56
K_2O	0.22	0.002	0.046	20.94
TiO_2	0.50	0.010	0.100	19.91

Table 8.
Results of statistical analysis for converter slag samples

Component	Mean $\bar{A}$	Variance σ^2	Standard deviation σ	Coefficient of variation V [%]
SiO_2	12.66	2.337	1.529	12.07
Al_2O_3	3.60	0.625	0.791	21.97
CaO	36.87	3.773	1.942	5.27
Fe_2O_3	29.93	6.242	2.498	8.35
P_2O_5	1.28	0.043	0.207	16.18
MnO	2.90	0.190	0.436	15.02
MgO	7.19	0.656	0.810	11.27
Na_2O	0.02	0.000	0.005	28.28
K_2O	0.02	0.000	0.005	33.33
TiO_2	0.46	0.005	0.073	15.91

5. Discussion of results

Fig. 1 to Fig. 4 summarize a comparison of the values of the coefficient of variation, V, for the components of the various metallurgical slags analyzed. Taking into account the recommendations of statistical analysis for the value of the V coefficient, the ranges of the V area are plotted on the graphs:

- celadon color - the area up to 20%, where the variation in results is low,
- pink color - the area from 20 to 40%, where the variation in results is medium.

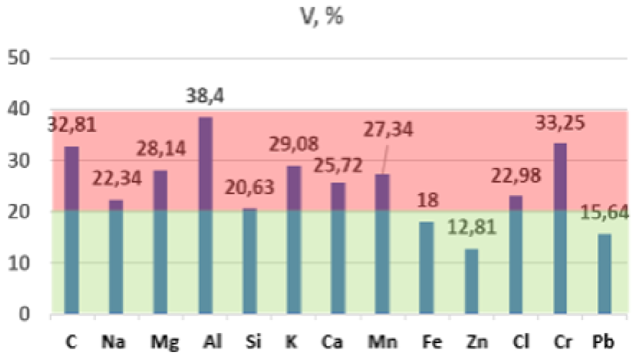

Fig. 1. Value of the coefficient of variation V for FAFD dust components from electric steel furnaces

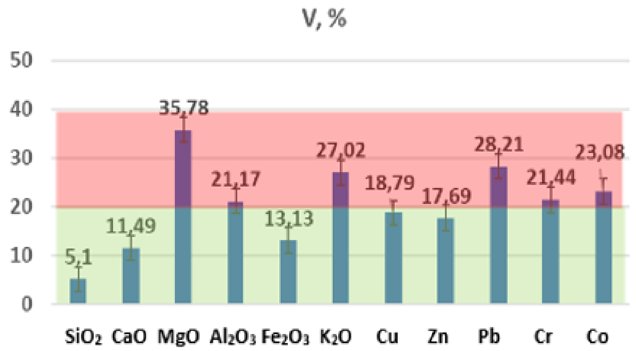

Fig. 2. Value of the coefficient of variation V for copper shaft slag components

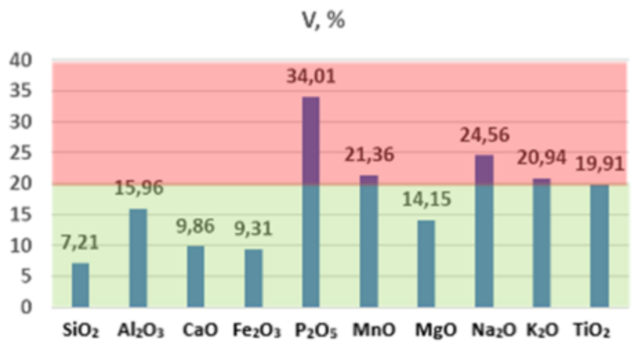

Fig. 3. Value of the coefficient of variation V for components of blast furnace slag

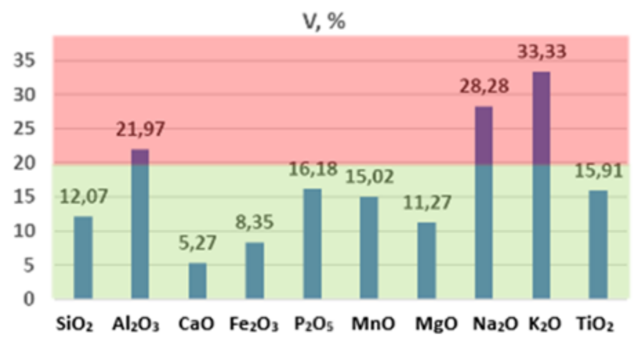

Fig. 4. Value of the coefficient of variation V for components of blast furnace slag

Based on the results of the statistical analysis, it can be concluded the following:

1. In none the analyzed cases does the value of coefficient variation V exceed the 40% range. Therefore, it can be said that the variation of the chemical analysis results is small, at most average!
2. The blast furnace and converter slags show a small scatter of the chemical analysis results (for the samples studied). This may indicate the stability of their chemical composition and their suitability for industrial use, e.g., as materials for road and highway construction, and especially as a substitute for cement in concretes.
3. Copper slag shows stability of components that provide good anti-abrasive properties (Al2O3 and SiO2). Therefore, this confirms its use as an abrasive material.
4. Copper slag and steelmaking slag (FAFD), due to the content of chlorides, sodium and potassium compounds, as well as iron, chromium and copper compounds, which are present in them in a stabilized range (V-factor well below 20%), can be a potential material for the volumetric modification (Al.-Si alloys and bronzes) and the surface modification (nickel and cobalt alloys).

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