Таблиця 3

Ефективність застосування металодобавки та технологічних заходів щодо збільшення температури дуття, зменшення теплових втрат та збільшення ступеня використання СО та Н2 та вмісту FeO у шихті на викиди діоксиду вуглецю, вихід ВЕР та витрата коксу

	Метало-добавка	**Вміст FeO в шихті**	**Темпера-тура дуття**	**Теплові втрати**	**Ступінь ви-користання СО**	**Ступінь ви-користання H_2**
Діапазон зміни:	0-500 кг/т	0-20%	от 1100°С до 1450°С	від 20 до 5 МВт	від 40% до 50%	від 40% до 70%
Викиди CO_2	-47% (-0,93%)	-9,9% (-0,49%)	-6,4% (-1,82%)	-2,3% (-0,15%)	-13,2% (-1,32%)	-7,2% (-0,24%)
Вихід ВЕР	-108% (-2,16%)	-10,3% (-0,52%)	-26,5% (-7,6%)	-0,4% (-0,03%)	-48,4% (-4,84%)	-29% (-0,97%)
Витрата коксу	-16% (-0,33%)	-12% (-0,6%)	-2% (-0,49%)	-0,6% (-0,04%)	-11,9% (-1,19%)	-6,4% (-0,21%)

** у дужках зазначено зміну впливу збільшення витрати металодобавки на 10 кг/т, температури дуття на 100°С, ступеня використання СО і H_2 та вмісту FeO в шихті на 1% та зменшення теплових втрат на 1 МВт.*

Таким чином, встановлені граничні значення ефективності використання технологій вдування паливних добавок, застосування металодобавки, а також зміни технічних та технологічних параметрів доменної плавки на викиди CO_2 та техніко-економічні показники.

DOI https://doi.org/10.30525/978-9934-26-361-3-16

APPLICATION OF AUTOMATED MINERALOGY IN METALLURGICAL RESEARCH

ВИКОРИСТАННЯ АВТОМАТИЧНОЇ МІНЕРАЛОГІЇ У МЕТАЛУРГІЙНИХ ДОСЛІДЖЕННЯХ

Kostryzhev A.H.
PhD (manufacturing), PhD (materials science), project manager and scientist,
Centre for Microscopy and Microanalysis,
University of Queensland,
Brisbane, Australia

Кострижев А.Г.
к.т.н. (процеси та устаткування),
PhD (матеріалознавство), менеджер проєктів і дослідник,
Центр мікроскопії і мікроаналізу,
Університет Квінсленда,
м. Брісбен, Австралія

Metals play an important role in modern society as they are widely used in various types of construction, machinery, electronic equipment, energy generation, medicine. Transition to the carbon free economy, based on renewable energy generation and storage, requires many metallic elements such as cobalt, lithium, gallium, germanium, hafnium, indium, niobium, platinum group metals, tantalum, titanium, vanadium, tungsten, strontium, and rare earth elements (such as scandium, yttrium, lanthanum, and cerium). Reduction in the quality of ores coupled with an increased demand puts pressure on traditional methods of extractive metallurgy from natural minerals and stimulates development of secondary mining sources (industrial and domestic waste, manufacturing byproducts, mine tailings). Climate change, high energy costs, and lack of clean water raise the price of metal extraction, thus metal recycling technologies become competitive.

Electron microscopy and microanalysis play significant role in metallurgical research providing information about chemical composition of materials and their microstructure. This information facilitates characterisation of chemistry-microstructure-properties relationships and is widely used in industry technology development. Advanced Mineral Identification and Characterisation System (AMICS), discussed here (Figure 1), is based on energy dispersive X-ray spectroscopy utilised in a scanning electron microscope (SEM-EDS). It consists of a (i) Hitachi SEM, (ii) Bruker EDS detector, and (iii) a specially designed software that coordinates the sample positioning inside the microscope chamber, EDS spectra acquisition and analysis, phase identification via matching to the spectra database, and the results visualisation in the form of maps, graphs and tables ready for reporting. The characterisation can be conducted automatically for up to 28 mounted samples, although many options exist for an experience researcher to influence the analysis process. Combination of modern instrumentation with dedicated software allows high resolution studies of fine particles (down to 1 micron). AMICS becomes widely acclaimed in geology, mining, and mineral processing for determination of phase balance and chemical composition of constituents. The principles of data analysis utilized in AMICS can be extended to characterization of various multi-phase materials synthesized in laboratory or produced commercially, such as metal alloys, ceramic composites, and nano-powders.

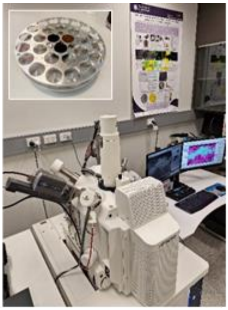
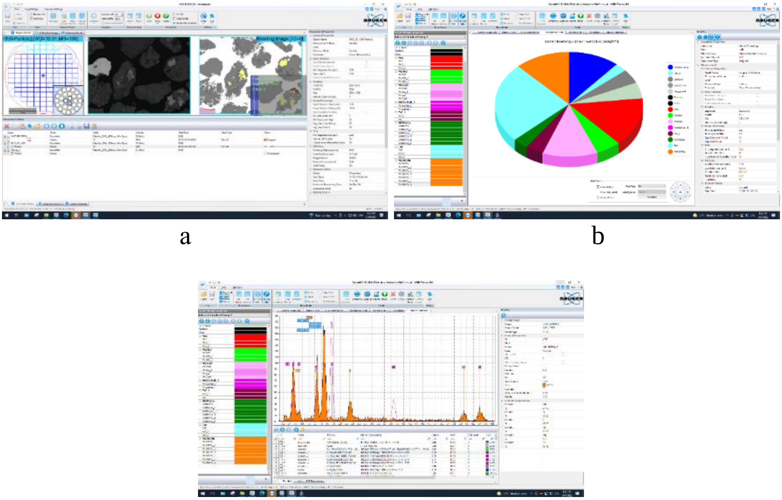


Fig. 1. Hitachi-Bruker automated mineralogy system with a sample holder inserted

AMICS software consists of two programs governing the data acquisition and analysis and allows easy visualisation of the phase balance in a table or graphical form (Figure 2), extraction of geometrical and chemical information for each particle studied, and manually growing the mineral database. In addition to BSE images and mineral maps, there is a possibility to observe distribution of each single phase or a set of phases (Figure 3a-c), this may be useful in analysis of phase interactions and grain boundaries. Pores in a sample surface can also be plotted as a single phase (Figure 3e), this can be used in studies of porosity in cast or 3D printed metal alloys, ceramics, and slags.



a b

c

Fig. 2. AMICS windows for (a) acquisition, (b) phase balance, (c) EDS database

An experienced researcher has options for extensive manual analysis. This is critical for investigation of solutions of metallic elements in mineral phases. In case when an “unusual” element is present in a “standard” mineral, the system will flag it as an “unknown phase” bringing attention to it. The whole population of EDS spectra (hundreds of thousands) acquired from a specified sample area can be divided into groups with respect to a selected parameter, for example, presence of a peak in the energy range characteristic to the element of interest (Figure 4a). Then the system can be given a command to visualise grains containing the element of interest (V in Figure 4b).

Consequently, a detailed chemical analysis can be conducted from these grains using other microanalysis techniques (for example point EDS, WDS or XRF). The chemical analysis can be supported with phase characterisation around the grain of interest (Figure 4c).

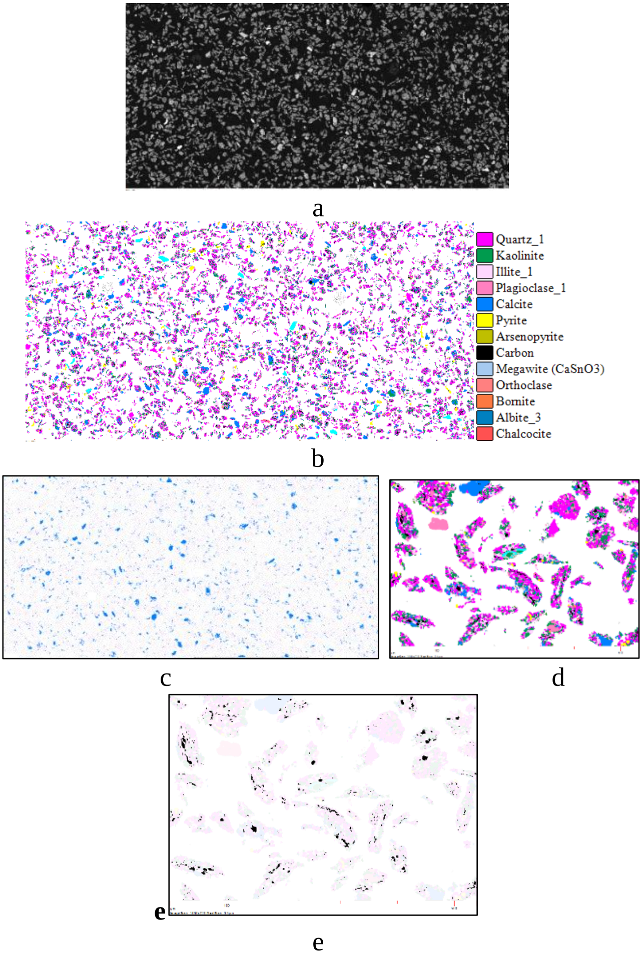
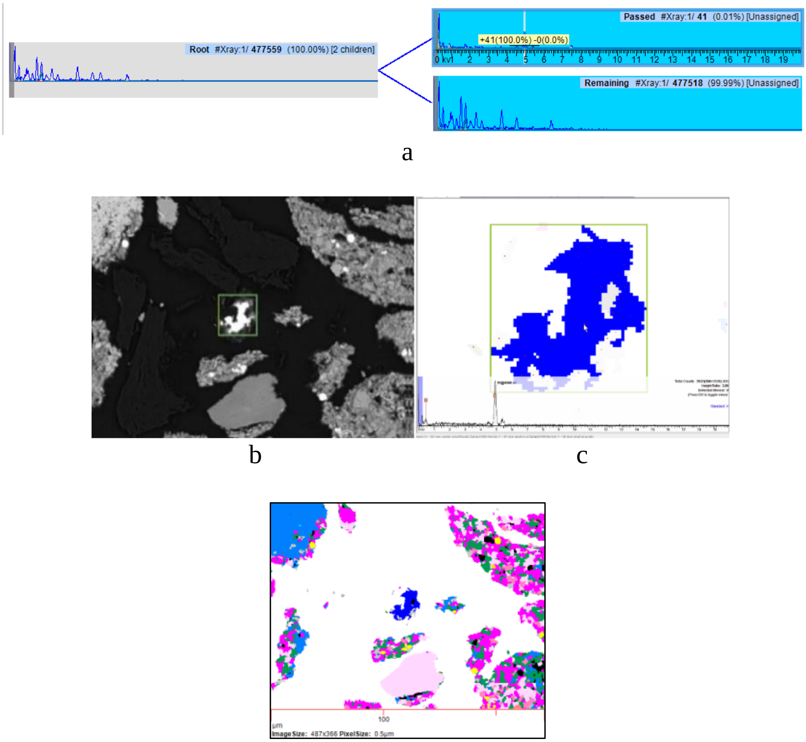


Fig. 3. Phase analysis: (a) BSE image, (b) mineral map with a colour legend showing minerals identified, (c) single phase map, (d) enlarged selected region of the mineral map, (e) pores map for the area presented in (d)



a

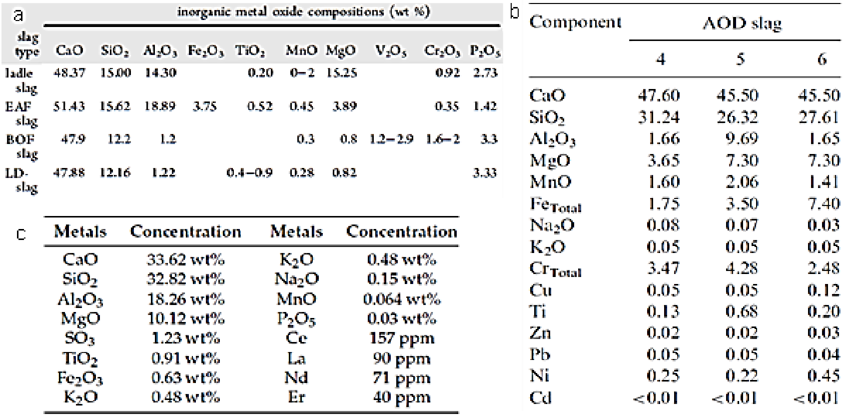
b c

d

Fig. 4. Spectra separation based on presence of the V energy peak followed by the grain identification and phase analysis around those grains

Steel slags, for example, may contain precious metallic elements, such as zinc (Zn), chromium (Cr), iron (Fe), nickel (Ni), manganese (Mn), silicon (Si), aluminium (Al), vanadium (V), titanium (Ti), magnesium (Mg), and rare earth elements (REE) (Figure 5), and, therefore, may become secondary sources for many metals. The metallurgical slag produced globally is equal to 50–100 % of the rolled steel tonnage [4], such a large amount of slag justifies the economic benefit of extraction of metallic elements from slag. Metals can be recovered from slags using several mineral processing techniques like crushing, grinding, magnetic separation, eddy current separation, flotation, leaching, and/or roasting [1, 5–7]. Metal extraction from steelmaking slag would not only support metal supplies but also protect the environment.

Currently the slag is utilised in construction, cement manufacturing, and road fill. However, there is a potential of application in water filtration, neutralisation of acidic liquids, CO_2 absorption, and extraction of economically valuable metallic elements. Phase characterisation of steel slags for presence of valuable metallic elements can be conducted, in particular, with AMICS system presented above.



slag type	inorganic metal oxide compositions (wt %)									
	CaO	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	MgO	V_2O_5	Cr_2O_3	P_2O_5
ladle slag	48.37	15.00	14.30		0.20	0−2	15.25		0.92	2.73
EAF slag	51.43	15.62	18.89	3.75	0.52	0.45	3.89		0.35	1.42
BOF slag	47.9	12.2	1.2			0.3	0.8	1.2−2.9	1.6−2	3.3
LD-slag	47.88	12.16	1.22		0.4−0.9	0.28	0.82			3.33

Component	AOD slag		
	4	5	6
CaO	47.60	45.50	45.50
SiO_2	31.24	26.32	27.61
Al_2O_3	1.66	9.69	1.65
MgO	3.65	7.30	7.30
MnO	1.60	2.06	1.41
Fe_{Total}	1.75	3.50	7.40
Na_2O	0.08	0.07	0.03
K_2O	0.05	0.05	0.05
Cr_{Total}	3.47	4.28	2.48
Cu	0.05	0.05	0.12
Ti	0.13	0.68	0.20
Zn	0.02	0.02	0.03
Pb	0.05	0.05	0.04
Ni	0.25	0.22	0.45
Cd	<0.01	<0.01	<0.01

Metals	Concentration	Metals	Concentration
CaO	33.62 wt%	K_2O	0.48 wt%
SiO_2	32.82 wt%	Na_2O	0.15 wt%
Al_2O_3	18.26 wt%	MnO	0.064 wt%
MgO	10.12 wt%	P_2O_5	0.03 wt%
SO_3	1.23 wt%	Ce	157 ppm
TiO_2	0.91 wt%	La	90 ppm
Fe_2O_3	0.63 wt%	Nd	71 ppm
K_2O	0.48 wt%	Er	40 ppm

Fig. 5. Chemical composition of (a) various slags [1], (b) stainless steel slag [2], and (c) blast furnace slag [3]

Bibliography

1. N. S. Samanta, P. P. Das, S. Dhara, M. K. Purkait, Industrial and Engineering Chemistry Research 62 (23) (2023) 9006-9031.
2. H. Shen, E. Forssberg, Waste Management 23 (2003) 933–949.
3. Abhilash, S. Hedrich, P. Meshram, A. Schippers, A. Gupta, S. Sen, Minerals 12 (2022) 701.
4. X. Zhang . J. Chen . J. Jiang . J. Li . R. D. Tyagi, R. Y. Surampalli, Environmental Geochemistry and Health 42 (2020) 1321–1334.
5. J. F. P. Gomes, C. G. Pinto, Revista de Metalurgia, 42(6) (2006) 409-416.
6. Abhilash, P. Meshram, S. Sarkar, T. Venugopalan, Minerals and Metallurgical Processing, 34 (2017) 178-182.
7. Z.-Z. Bian, Y.-L. Feng, H.-R. Li, Transactions of Nonferrous Metals Society of China 30 (2020) 2836−2847.