Hutnické listy č. 1/2026, roč. LXXIX
ISSN Online: 3029-8350

Optimization of Physico-chemical Properties of Undersize Fractions of Manganese Ores for the Production of Mn Sinter

Optimalizace fyzikálně-chemických vlastností podsítných podílů manganových rud pro výrobu Mn aglomerátu

Ing. Zuzana Miškovičová, PhD.[1]; prof. Ing. Jaroslav Legemza, PhD.[1]; doc. Ing. Róbert Findorák, PhD.[1]; doc. Ing. Branislav Buľko, PhD.[1]; Ing. Patrik Fedorko[1]; doc. Ing. Peter Demeter, PhD.[1]; Ing. Slavomír Hubatka, PhD.[1]; Ing. Lukáš Fogaraš, PhD.[1]; Ing. Jaroslav Demeter, PhD.[1]

[1] TECHNICKÁ UNIVERZITA V KOŠICIACH, Fakulta materiálov metalurgie a recyklácie, Inštitút metalurgických technológií a digitálnej transformácie, Letná 1/9, 042 00 Košice, zuzana.miskovicova@tuke.sk

Abstract

Undersize fractions of manganese ores generated during mining, transportation, and screening represent a significant secondary source of manganese. Despite their relatively high Mn content, these fine fractions cannot be directly charged into electric arc furnaces for ferroalloy production due to reduced charge permeability, increased partial pressure of CO, and the resulting rise in energy consumption of the process.

The aim of the article is to characterize the physicochemical properties of undersize fractions of Mn ores from Bosnia and Herzegovina and Gabon and to propose their optimization for the production of Mn sinters. The results confirmed significant differences in chemical composition, particularly in Mn and SiO_2 contents, which substantially influenced the sintering process and the properties of the produced sinters.

Optimization of the charge by adding dolomite, return sinter, and Gabon Mn ore led to an increase in Mn content, a decrease in SiO_2, an increase in basicity, and improvements in mechanical strength and reducibility. Agglomeration proved to be an effective method for valorizing fine fractions of manganese ores for FeSiMn production.

Key words: *Mn ore; optimization; Mn sinter; reducibility; physico-chemical properties*

Abstrakt

Podsítné podíly manganových rud vznikající při těžbě, transportu a třídění představují významný sekundární zdroj manganu. Navzdory jejich relativně vysokému obsahu Mn není možné tyto jemné frakce přímo vsazovat do elektrických obloukových pecí při výrobě feroslitin z důvodu zhoršení propustnosti vsázky, zvýšení parciálního tlaku CO a následného nárůstu energetické náročnosti procesu.

Cílem článku je charakterizovat fyzikálně-chemické vlastnosti podsítných podílů Mn rud z Bosny a Hercegoviny a Gabonu a navrhnout jejich optimalizaci pro výrobu Mn aglomerátů. Výsledky potvrdily výrazné rozdíly v chemickém složení, zejména v obsahu Mn a SiO_2, které významně ovlivnily průběh spekání a vlastnosti aglomerátů.

Optimalizace vsázky přídavkem dolomitu, vratného aglomerátu a Mn rudy Gabon vedla ke zvýšení obsahu Mn, snížení SiO_2, zvýšení bazicity a zlepšení mechanické pevnosti i redukovatelnosti. Aglomerace se ukázala jako efektivní způsob zhodnocení jemných frakcí manganových rud pro výrobu FeSiMn.

Klíčová slova*: Mn ruda; optimalizace; Mn aglomerát; redukovatelnost; fyzikálně-chemické vlastnosti*

Hutnické listy č. 1/2026, roč. LXXIX
ISSN Online: 3029-8350

1. Introduction

The quality of input raw materials fundamentally affects the course of reduction processes, the energy consumption of smelting, and the overall economics of production. As a result of mechanical degradation of ores during mining and handling, a significant amount of undersized fractions with particle sizes below 5–10 mm is generated, which in industrial practice often accumulates as unused material. However, these fine fractions contain a considerable amount of manganese, and their efficient processing represents both a technological and an economic challenge. Direct charging of fine particles into the furnace leads to reduced burden porosity, restricted gas flow, and increased energy losses. Therefore, these materials must be converted into a suitable granulometric form, with agglomeration being one of the most effective methods [1, 2].

Manganese is considered a strategic raw material for the global metallurgical industry. More than 90 % of total manganese production is used in steelmaking, where it functions as a deoxidizing, desulfurizing, and alloying element. It is essential for achieving the required mechanical properties of steels, particularly strength, toughness, and wear resistance. The dominant forms of its utilization are manganese ferroalloys, primarily high-carbon ferromanganese (HC FeMn) and silicomanganese (FeSiMn) [2, 3].

The quality of manganese input materials significantly influences the technological parameters of ferroalloy production. The chemical composition, mineralogical structure, granulometry, and physical properties of the ore determine the course of reduction processes in the electric arc furnace, the energy demand of smelting, the amount of slag produced, and the overall production economics. Under global market conditions, ferroalloy production is exposed to strong pressure to reduce costs and increase material efficiency. One of the major issues in current practice is the generation of large quantities of undersized manganese ore fractions during mining, transport, and screening [4, 5].

The share of fine fractions (<10 mm) may reach 10–40 % of the total processed ore. Despite their relatively high manganese content, these fine particles cannot be directly charged into the furnace, as they reduce the gas permeability of the burden, increase the partial pressure of CO, and destabilize reduction reactions. The result is increased electrical energy consumption, higher consumption of reducing agents, and reduced technological stability of the process. From the perspective of sustainable development and the circular economy, it is therefore essential to seek effective methods for valorizing these fine fractions. One of the most technologically promising approaches is agglomeration, which enables the transformation of fine-grained material into mechanically stable lump products suitable for furnace charging [4, 6].

Optimization of the agglomeration process requires detailed knowledge of the properties of the input raw materials. Without comprehensive characterization of the undersized fractions, it is not possible to design a technologically and economically efficient processing method [4, 7].

Furthermore, current trends in metallurgy, including the application of digital twins for process monitoring and optimization, as well as the gradual transition toward hydrogen-assisted processing routes, highlight the need for detailed material characterization as a prerequisite for future low-carbon and data-driven production strategies [8].

Hutnické listy č. 1/2026, roč. LXXIX
ISSN Online: 3029-8350

In light of the above, the aim of this study is to comprehensively analyze the physicochemical properties of undersized manganese ore fractions and experimentally verify the possibilities for their optimization through laboratory-scale agglomeration.

2. Materials and methods

The granulometric composition of Mn ores and Mn agglomerates was determined by sieve analysis using a KVT-U-2 vibratory pendulum sieve shaker. The bulk density was determined experimentally by measuring the mass of the material in a known volume. The chemical composition was analyzed by atomic absorption spectrometry (AAS) and using a portable Niton XL3 Goldd spectrometer. The phase composition was determined by X-ray diffraction (XRD) analysis on PANalytical X'Pert PRO MRD and SEIFERT XRD 3003/PTS instruments. The melting temperature interval was determined using a Leitz WETZLAR high-temperature microscope. Laboratory sintering tests were carried out in a laboratory sintering pan (LSP). The mechanical strength of Mn agglomerates was determined by the drum test in accordance with STN ISO 3271 (44 1570). The reducibility of the agglomerates was evaluated according to ISO 4695:2007, which was used as a comparative methodology due to the lack of a standardized procedure for manganese agglomerates.

3. Results and discussion

The analyzed undersized fractions originated from manganese ores from Bosnia and Herzegovina and Gabon. The undersized fractions of manganese ores from Bosnia and Herzegovina and Gabon differ significantly in both chemical and mineralogical composition (tab. 1). The Gabonese ore is characterized by a substantially higher total manganese content (45.95 wt. %) compared to the ore from Bosnia and Herzegovina, where the Mn content reaches 25.58 wt.%. The iron content is nearly identical in both cases (6.15 wt. % Bosnia; 6.14 wt. % Gabon).

A key difference between the ores lies in their SiO_2 content: the Bosnian ore contains 23.67 wt. % SiO_2, while the Gabonese ore contains only 4.50 wt.%. The higher silicate content in the Bosnian ore increases its gangue character and influences its behavior during thermal processing. Al_2O_3 contents are comparable, while CaO and MgO are slightly higher in the Bosnian ore. Both materials exhibit low basicity (0.09 for Bosnia; 0.02 for Gabon), indicating an overall acidic character. A significant difference was also observed in melting temperature: 1227 °C for the Bosnian ore and above 1550 °C for the Gabonese ore. The lower melting point of the Bosnian ore is related to its high SiO_2 content and formation of low-melting silicate phases, whereas the Gabonese ore, rich in manganese oxides and low in silicates, shows higher thermal stability. Granulometrically, the Bosnian ore is dominated by 1–5 mm fractions, while the Gabonese ore contains more coarse particles. XRD analysis confirmed that the Bosnian ore contains quartz and silicate phases, whereas the Gabonese ore is mainly composed of manganese oxides. Overall, the Gabonese undersized fractions represent a material with higher Mn concentration and greater thermal stability, while the Bosnian ore has higher gangue content and lower melting temperature, which significantly affects its high-temperature behavior.

The processing of undersized Mn ore fractions was carried out under laboratory conditions using a laboratory sintering pan (LSP – **fig. 1**). This equipment is used to simulate operating conditions occurring on the sintering strand during the sintering process. The LSP is characterized by its ability to investigate various factors influencing the sintering process, thereby enabling optimization of the parameters affecting the production of Mn agglomerate.

Hutnické listy č. 1/2026, roč. LXXIX
ISSN Online: 3029-8350

Tab. 1 Physicochemical properties of undersize fractions of Mn ores
Tab. 1 Fyzikálně-chemické vlastnosti podsítných podílů Mn rud

Undersize fractions of Manganese ores			
		Bosna and Hercegovina	**Gabon**
Chemical composition (wt.%)	Mn_{TOT}	25.58	45.95
	Fe_{TOT}	6.15	6.14
	SiO_2	23.67	4.50
	Al_2O_3	5.74	5.93
	CaO	1.14	0.12
	MgO	1.41	0.10
	P	0.08	0.06
	S	0.04	0.06
	Na_2O	0.10	0.10
	K_2O	1.78	0.99
Basicity	B	0.09	0.02
Granulometric composition (%)	< 0.5 mm	2.56	3.05
	0.5-1 mm	3.06	5.13
	1-2 mm	18.12	11.01
	2-3.15 mm	19.16	8.07
	3.15-5 mm	28.54	11.78
	5-6.3 mm	18.21	12.43
	6.3-8 mm	8.95	21.48
	8-10 mm	1.40	27.04
Average grain diameter (mm)	D_{avg}	4.13	6.71
Apparent specific density ($g.cm^{-3}$)	ρ_A	1378.5	1425.2
Melting point (^oC)		1227	> 1550
Mineralogical composition	XRD	quartz pyrochroite braunite jacobsite	pyrochroite hydrated illite pyroluzite magnetite braunite birnessite

Hutnické listy č. 1/2026, roč. LXXIX
ISSN Online: 3029-8350

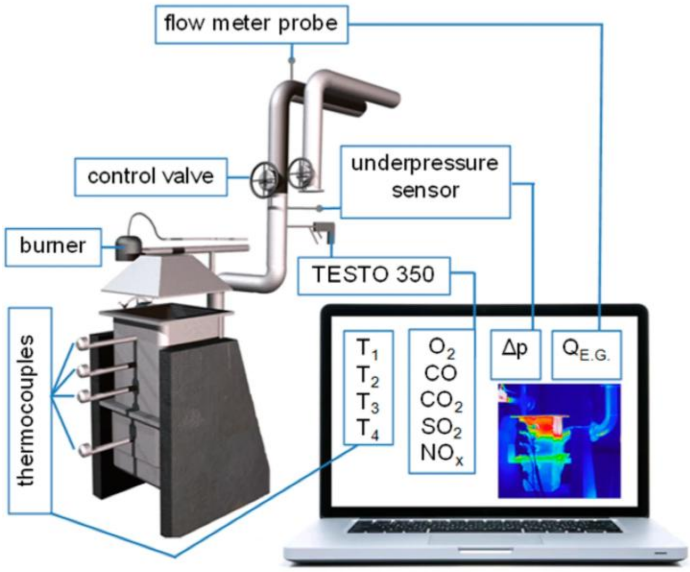


Fig. 1 Laboratory sintering pan
Obr. 1 Laboratorní spékací pánev

The production of Mn agglomerates was divided into a cold and a hot section. The cold section included preparation and weighing of charge components, pre-pelletizing, moisture determination, and permeability measurement by monitoring airflow through the mixture for 120 seconds. The hot section involved preheating the sintering pan, charging it with the pre-pelletized mixture, surface ignition, and sintering. The LSP (300 × 300 × 400 mm) operated under negative pressure provided by an exhaust fan and was equipped with a cyclone for dust capture. Temperatures were monitored by thermocouples (PtRh10–Pt for the sintered layer, NiCr–Ni for flue gas), and flue gas composition was analyzed using a TESTO 350 analyzer, with data recorded via PC software. All experiments were based on BaH manganese ore as the main charge component, with additional materials selected according to optimization requirements for the desired agglomerate properties (**fig. 2**).

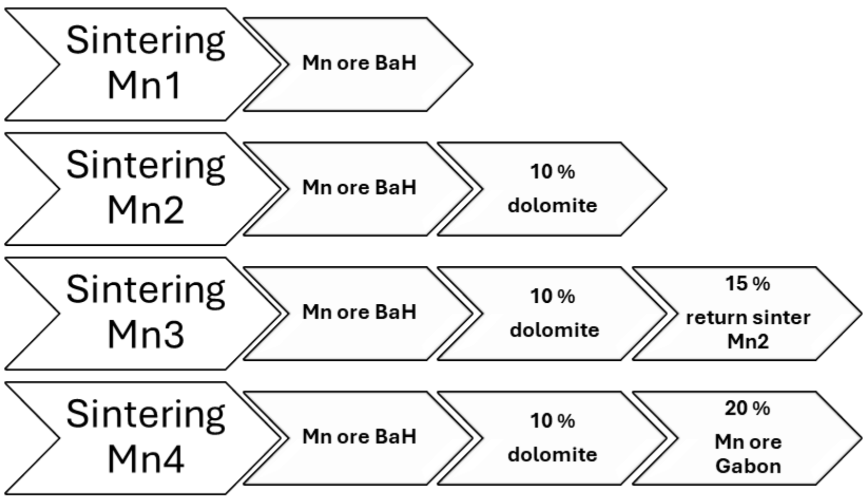


Fig. 2 Schematic diagram of the charge composition for individual sintering experiments
Obr. 2 Schéma složení vsázky pro jednotlivá spékání

 Hutnické listy č. 1/2026, roč. LXXIX
ISSN Online: 3029-8350

The sinter mixture also included coke breeze (**Tab. 2**). The individual sintering tests differed in the composition of the input components.

Tab. 2 Composition of coke breeze
Tab. 2 Složení koksového prachu

Moisture (%)	**Ash (%)**	**Volatile matter (%)**	**Fixed carbon (%)**	**Sulfur (%)**	**Calorific value (MJ/kg)**	
0.8	13.9	2.65	83.45	0.55	28.45	
Chemical composition of ash (%)						
SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**K_2O**	**P_2O_5**
34.7	21.1	27.2	6.8	2.8	1.6	0.6

Sintering test Mn1 represented a pilot verification experiment for the series of experiments carried out on the undersized fractions of the BaH manganese ore. Sintering test Mn2 was conducted with the addition of 10 % dolomite (**tab. 3**).

Tab. 3 Chemical composition of dolomite
Tab. 3 Chemické složení dolomitu

Content (%)									
Fe_{TOT}	**Fe_2O_3**	**SiO_2**	**CaO**	**MgO**	**Al_2O_3**	**Mn_{TOT}**	**S**	**C**	**H_2O**
0.12	0.17	0.93	29.69	21.33	0.33	0.01	0.007	12.974	3

Dolomite was added in order to influence the phase composition and improve the reducibility of the agglomerate. The undersized fractions of the BaH manganese ore have an acidic character, and during sintering, poorly reducible silicate phases are formed.

Therefore, the addition of dolomite was selected as an optimization measure. The 10 % addition was determined with the aim of maintaining the acidic character of the Mn agglomerate intended for FeSiMn production, and this proportion was also used in subsequent sintering tests. Sintering test Mn3 included the addition of 15% return agglomerate Mn2 with a particle size below 8 mm (**tab. 4**).

This addition was implemented from technological, economic, and environmental perspectives. The return agglomerate contains unreacted fuel, thereby contributing to the thermal balance of the process, increasing the Mn content in the charge, and reducing the need for landfilling. At the same time, it improves the granulation of the mixture and reduces the required water addition.

Tab. 4 Chemical composition of return sinter
Tab. 4 Chemické složení vratného aglomerátu

	Content (%)								
Return sinter Mn2	Mn_{TOT}	Fe_{TOT}	SiO_2	Al_2O_3	CaO	MgO	P	K_2O	C
	27.29	5.62	21.84	3.68	4.94	2.37	0.049	1.96	3.83

Sintering test Mn4 was carried out with the addition of 20 % undersized fractions of Gabon manganese ore. The aim was to increase the manganese content of the agglomerate, as the Gabonese ore contains approximately 45.95 % total Mn and represents a high-quality raw material. The 20 % proportion was determined with regard to the material balance, since the fraction below 10 mm accounts for approximately 27 % of the total supply of this ore delivered to the plant. Half of the used Gabon manganese ore was pre-treated by crushing prior to use in order to ensure a high degree of mixture homogeneity (**tab. 5**).

Tab. 5 Granulometric composition of modified Gabon Mn ore
Tab. 5 Granulometrické složení modifikované Mn rudy Gabon

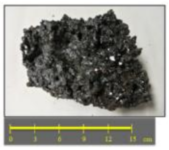
	Particle size classes (mm)									
Percentage share (%)	- 0.5	0.5-1	1-2	2-3.15	3.15-5	5-6.3	6.3-8	8-10	+ 10	D_{str}
	18.25	10.0	21.84	15.29	16.86	7.95	4.99	3.57	1.25	2.82

The individual sintering tests were carried out according to the established methodology, with the charge composition based on the material balance. The components were precisely weighed and homogenized in a pre-pelletizing device. The permeability of the prepared sinter mixtures was approximately 0.4 m^3/min, ensuring suitable conditions for air suction during sintering.

Sintering test Mn1 represented a pilot verification of parameters for the undersized fractions of the BaH manganese ore. The coke breeze content was set at 6.75 %. The maximum temperature reached approximately 1150 °C (T2), and the total sintering time was 21 minutes. In sintering test Mn2 (BaH + 10 % dolomite), the coke breeze content was slightly increased to 6.91 % in order to compensate for the endothermic decomposition of dolomite. The maximum temperature reached approximately 1125 °C, and the sintering time was about 18 minutes. Sintering test Mn3 included the addition of 15 % return agglomerate Mn2 (<8 mm). Due to the residual carbon content in the return agglomerate (3.83 % C), the proportion of coke breeze was reduced to 6.50%. The maximum temperature reached approximately 1191 °C, while the sintering time was extended to 27:50 minutes, which was related to altered gas and heat transfer conditions within the sintered layer. In sintering test Mn4 (BaH + 10 % dolomite + 20% Gabon Mn ore), the coke breeze content was increased to 7.19% due to the coarser-grained nature of the Gabonese ore and the need to ensure a sufficient thermal effect. The maximum temperature reached approximately 1194 °C, and the total sintering time was 21:07 minutes. The temperature profiles were more uniform and the sintering process was more stable compared to the previous variants.

Hutnické listy č. 1/2026, roč. LXXIX
ISSN Online: 3029-8350

Tab. 6 Physicochemical properties of produced Mn sinters / **Tab. 6** Fyzikálně-chemické vlastnosti vyrobených Mn aglomerátů

Mn sinters					
		Mn1	**Mn2**	**Mn3**	**Mn4**
Chemical composition (wt.%)	Mn_{TOT}	33.92	32.66	32.11	38.72
	Fe_{TOT}	7.42	6.09	6.08	6.15
	SiO_2	24.88	21.60	19.11	17.41
	Al_2O_3	4.37	3.63	3.52	4.23
	CaO	1.36	5.56	6.02	4.84
	MgO	1.28	2.74	2.74	1.45
	P	0.06	0.05	0.043	0.046
	S	0.1	0.09	0.111	0.086
	K_2O	1.94	1.85	1.92	1.76
	C	1.13	0.64	0.919	0.409
Basicity	B	0.09	0.33	0.39	0.29
Granulometric composition (%)	< 5 mm	25.14	22.23	15.03	21.50
	5-8 mm	11.68	8.71	5.75	5.59
	8-10 mm	1.95	3.26	1.63	1.54
	10-25 mm	13.58	14.50	16.75	9.88
	25-40 mm	8.64	11.41	9.55	8.14
	> 40 mm	39.01	39.89	51.28	50.34
Average grain diameter (mm)	D_{avg}	26.28	25.89	32.59	30.82
Mechanical strenght (%)	ISO +6.3	47.93	62.91	53.52	57.63
	ISO -0.5	8.87	8.53	10.56	8.75
Melting point (^{o}C)		1225	1220	-	1240
Mineralogical composition (%)	Hausmannite	12.36	13.68	8.75	14.22
	Pyroluzite	0.74	0.68	0.39	0.43
	Manganosite	1.94	1.67	1.45	1.44
	Jacobsite	16.70	19.68	18.88	20.65
	Marokite	8.35	4.77	9.67	12.56
	Quartz	5.38	6.69	6.45	4.84
	Fe-Mn olivine	2.75	3.40	5.79	5.70
	Complex phases	9.04	11.3	14.4	13.1
	Amorphous fraction	42.8	38.1	34.2	27.8

Hutnické listy č. 1/2026, roč. LXXIX
ISSN Online: 3029-8350

The Mn1–Mn4 agglomerates differed in chemical composition, basicity, granulometry, and mechanical strength due to changes in charge composition (**tab. 6**). Mn1 showed low basicity (B = 0.09), high SiO_2 (24.88 wt. %), and the lowest strength (47.93 %). The addition of 10 % dolomite (Mn2) increased basicity (B = 0.33), reduced SiO_2, and resulted in the highest strength (62.91 %). Mn3 (15% return agglomerate) reached the highest basicity (B = 0.39) and the coarsest granulometry, with moderate strength (53.52 %). Mn4 (20% Gabon ore) achieved the highest Mn content (38.72 wt. %) and lowest SiO_2 (17.41 wt. %) while maintaining good strength (57.63 %).

In general, increasing basicity improved mechanical strength, whereas the addition of Gabon ore enhanced Mn content and reduced SiO_2, making Mn4 the most balanced material in terms of chemical and mechanical properties. Phase analysis confirmed the presence of Mn oxide phases (Mn_3O_4, MnO, MnO_2, jacobsite, marokite) and complex silicates (e.g., $FeMnSiO_4$), along with a significant amorphous fraction in all agglomerates. From Mn1 to Mn4, the amorphous content gradually decreased (42.8 % → 27.8 %), while the proportion of crystalline oxide and silicate phases increased, indicating a higher degree of structural ordering in the optimized agglomerates, particularly Mn4.

The melting temperature of Mn agglomerates was primarily controlled by SiO_2 content, basicity, and phase composition. Higher silicate and amorphous contents lowered melting temperatures due to MnO–SiO_2 eutectic formation, whereas increased basicity and a higher share of Mn oxides enhanced thermal stability. Overall, lower SiO_2 and higher total Mn improved the thermal resistance of the agglomerates.

The reducibility of Mn agglomerates depends mainly on the mineral form of manganese and its bonding in oxide or silicate phases. Mn oxides (MnO_2, Mn_3O_4, MnO) are readily reduced by CO or C, whereas manganese bound in silicate phases such as $(Fe,Mn)_2SiO_4$ is more stable and requires higher temperatures and longer reduction times. Therefore, higher SiO_2 content lowers reducibility by incorporating Mn into less reactive silicate structures. Reduction tests in a controlled reducing atmosphere revealed distinct behavior between Mn1 and Mn4 (**fig. 3**).

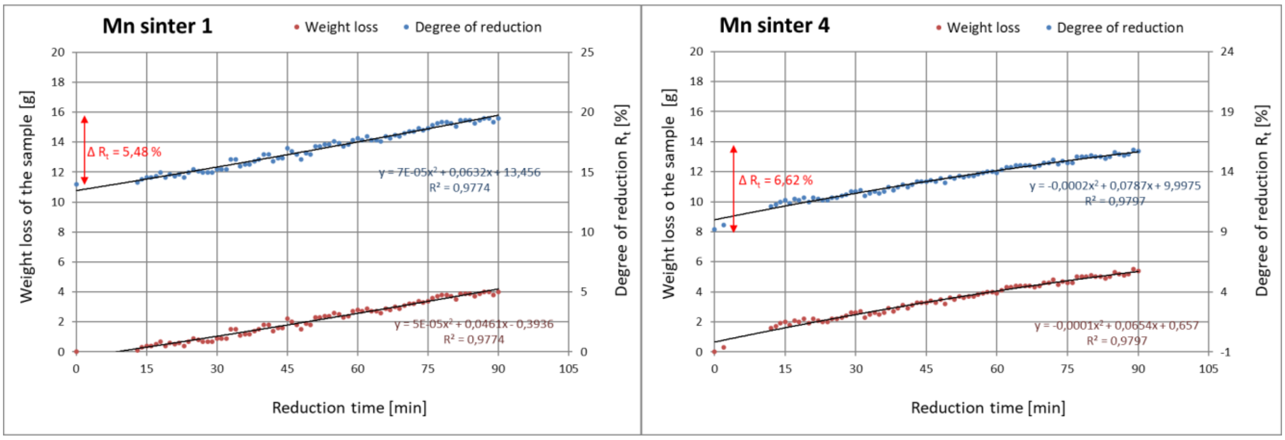


Fig. 3 Evaluation of Mn sinters Mn1 and Mn4 after the reducibility test – 90 min

Obr. 3 Vyhodnocení Mn aglomerátů Mn1 a Mn4 po testu redukovatelnosti – čas 90 min

The more acidic Mn1 showed a slower reduction rate due to its higher SiO_2 content and higher proportion of silicate phases, and part of the manganese remained unreduced even after 90 minutes.

In contrast, Mn4, characterized by higher total Mn content and lower SiO_2, exhibited a faster and more intensive reduction process, as the lower silicate matrix content allowed easier access of the reducing gas to oxide phases. Overall, optimization of chemical composition—particularly reduction of SiO_2 and increase of total Mn—enhances agglomerate reducibility and contributes to lower energy consumption in subsequent FeSiMn production.

The experiments were not repeated; therefore, statistical evaluation of repeatability and measurement uncertainty was not performed. The results serve primarily for comparative assessment of the tested charge modifications.

4. Conclusion

The undersized Mn ores from Bosnia and Herzegovina and Gabon differed significantly in chemical composition, which influenced the properties of the produced agglomerates. BaH ore had higher SiO_2 and low basicity, while Gabon ore contained more Mn and fewer silicates. By modifying the charge composition (10 % dolomite, 15% return agglomerate, 20% Gabon ore), total Mn increased from 33.92 wt. % (Mn1) to 38.72 wt. % (Mn4), and SiO_2 decreased from 24.88 wt. % to 17.41 wt. %. Basicity rose from 0.09 to 0.29–0.39, and mechanical strength improved from 47.93 % to a maximum of 62.91 %. The amorphous phase decreased while crystalline phases increased. Lower SiO_2 and higher Mn improved melting and reduction behavior, with Mn4 showing the most balanced overall properties.

Acknowledgements

This research was funded by VEGA project No. 1/0199/24 „Development of mathematical control models and digital twins for individual steel production processes based on machine learning with the aim of increasing the competitiveness of the sector and reducing the carbon footprint“, APVV project APVV-24-0240 „Hydrogen potential in the processing of ferrous materials“ and APVV project APVV-21-0142 „The potential of hydrogen utilization in metallurgical industry of SR aimed on decrease of CO_2 production“.

REFERENCES

[1] TANGSTAD, M., 2013. Chapter 7 – Manganese Ferroalloys Technology. In: GASIK, M., ed. Handbook of Ferroalloys. United Kingdom: Elsevier Ltd., s. 221–266. ISBN 9780080977539.
[2] TANGSTAD, M. et al., [rok neuveden]. Behavior of agglomerates in ferromanganese production. In: The Twelfth International Ferroalloys Congress: Sustainable Future. Helsinki, Finland. ISBN 978-952-92-7340-9.
[3] LEGEMZA, J. et al., 2012. Optimalizace druhů manganových rud pro výrobu manganových ferozliatin v OFZ, a. s., bez použití aglomerátu. Závěrečná zpráva výzkumného úkolu. Košice: Technická univerzita v Košicích.
[4] GUPTA, D. N. a KHANDELWAL, G. P., [rok neuveden]. Utilisation of ore fines by agglomeration with special reference to sintering of manganese ore fines [online]. [cit. 2015-12-01]. Dostupné z: http://eprints.nmlindia.org/6011/1/110-115.PDF
[5] TATHAVADKAR, V. et al., 2010. Effect of manganese ore blends on performance of submerged arc furnace for ferromanganese production. Ironmaking and Steelmaking 37 (2010). ISSN 0301-9233.
[6] MOHAPATRA, B. K. a NAYAK, B., 2005. Petrology of Mn carbonate–silicate rocks from the Gangpur Group, India. Journal of Asian Earth Sciences 25 (2005) 5, 773–780.
[7] SØRENSEN, B. et al., 2010. Phase compositions of manganese ores and their change in the process of calcination. International Journal of Mineral Processing 94 (2010), 101–110. ISSN 0301-7516.
[8] Miškovičová, Z.; Legemza, J.; Demeter, P.; Buľko, B.; Hubatka, S.; Hrubovčáková, M.; Futáš, P.; Findorák, R. An Overview Analysis of Current Research Status in Iron Oxides Reduction by Hydrogen. Metals 2024, 14, 589. https://doi.org/10.3390/met14050589