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Charcoal Blast Furnaces on the Territory of Slovakia

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Beginnings and developments of charcoal blast furnaces on the territory of Slovakia from the end of the 17th century. Description of blast furnace construction and technology is provided. Study of remnants of three charcoal blast furnaces from the 19th century. Analysis of blast furnace construction materials, iron ore, blast furnace slags and analysis of refining slags are presented.

Keywords: charcoal blast furnace, pig iron, slag, refining.

1. INTRODUCTION

Territory of Slovakia, situated in the Central Carpathians region, was well – known for production of metals from Antiquity. This paper deals with history of iron production on the territory, mainly with its final phase, introduction of blast furnace technique.

First traces of iron production on the territory are dated to the 8th – 6th centuries B.C., when the methods spread from antic Greece to the central Europe and also to other parts of the continent.

In Hallstat period iron was smelted in primitive bowl furnaces with very small iron yields and big losses of iron oxides in slag.

In LaTéne period bowl furnaces were replaced by small shaft furnaces. Small shaft furnaces in various forms dominated to iron smelting in the 1st millenium A.D. Though various innovations were introduced, the methods of smelting in small shaft furnaces were extremely inefficient, weight of iron yields was about 10 kg or less, iron contents in slag, waste of the smelting process, were about 40 – 50 wt % [1, 2].

Very important change in technology of iron smelting, connected to use of water power for iron blowing into furnace, started in the territory in the 14th century A.D. High bloomeries, shaft furnaces with increased inner working volume, produced up to 150 kg of iron in one smelting. Special variation of the high bloomeries, that worked on the territory of Slovakia in medieval, was called Slovak furnace.

Bowl furnaces, small shaft furnaces, high bloomeries, were the smelting units that produced in one – step process a hammerable iron, suitable for production of iron objects by blacksmiths methods.

Reduction process in the furnace shaft took place in solid state, temperatures in the shaft were not sufficient to melt solid iron. One – step process was replaced by two – step process consisting of pig iron production in blast furnace and its refining in refining furnace. Cause of the change: increased productivity.

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2. INTRODUCTION OF BLAST FURNACE TECHNIQUE IN SLOVAK TERRITORY

The first charcoal blast furnace in our territory was built in 1692 in Ľubietová, central Slovakia, by Karl Kropf. This two – step process of hammerable iron production (pig iron in blast furnace – hammerable iron in refining furnace) lag behind West European countries about 200 – 250 years. The oldest charcoal blast furnace dated to the half of the 13th century was excavated in site Laphyttan (Norberg) in central Sweden. Full development of charcoal blast furnace technique started in the second half of the 15th century in Normandy and England.

Difference of 200 years is too much. Why? Probably it is not true situation. When we consider the blast furnace individual parts, the shaft can be compared with a shaft furnace – high bloomery. Metallic non – carburized iron produced by reduction reactions in solid state, is formed in form of spongy iron at the bottom of both the high bloomery and blast furnace shafts. The second step in production of pig iron is melting of spongy iron, that contacts charcoal pieces and carburizes when flowing down to the blast furnace hearth. Necessary conditions for such process are temperatures over 1500 °C at the bottom of the blast furnace shaft where solid iron starts to melt. How to reach such temperatures? Probably by: a) changes in construction of the furnace; b) increase of blowed air amount.

There are many villages in Slovakia with name (or part of name) "massa". In contemporary literature "massa" is name of the furnace able to produce either pig iron or hammerable iron. No technical details and work descriptions of the massa furnace exist. Changes and innovations in technique and technology that led to such production ability are still mystery for us. Author of this paper [3] analysed a gun ball from the 16th or 17th century, made of pig iron, but the ball had in one part hammerable iron instead of pig iron.

An explanation why charcoal blast furnaces in Slovakia were introduced so late, is simple. Slovakia is hilly country with rich forests and many water sources. Many local sources of iron ores were utilized in past. Because of very bad transport possibilities in past, high bloomeries smelted iron from local iron ores and realized it in local markets. Hammerable iron, product of high bloomeries (Slovak furnaces) was very suitable for production of agricultural tools. The last high bloomery on the territory of Slovakia was closed in the half of the 19th century.

3. DEVELOPMENTS OF CHARCOAL BLAST FURNACES

Actual developments in charcoal blast furnace technique in our territory started from the beginning of the 18th century. Total 76 charcoal blast furnaces in 51 blast furnace plants worked in the territory, the last of them were closed in the twentieths in the 20th century [4]. Most of the blast furnace plants were owned by three powerful ironworking factories. Two of them were owned by nobility families Coburg and Andrássy, the third iron-working partner was State Ironworks in Hronec. Fig. 1 shows blast furnace Etelka in Nižná Slaná, built by Andrássy, Fig. 2 shows blast furnace in Sirk – Červeňany, owned by Coburg (in reconstructed state), Fig. 3 shows blast furnace in Tri Vody owned by smaller ironworking factory of Daniel Prihradny (in reconstructed state). All three presented blast furnaces worked in the second half of the 19th century.

Fig. 1. Charcoal blast furnace Etelka, Nižná Slaná (Andrassy)

Fig. 2. Charcoal blast furnace in Sirk – Červeňany (Coburg)

Fig. 3. Charcoal blast furnace Tri Vody (Prihradny)

Very few data are in disposition about the oldest blast furnace in Ľubietová. Total height of the furnace was between 5 to 10 m, inner (working) volume was about 10 to 15 m^3, weekly production of pig iron was about 20 to 25 tons. The blast furnaces developed in construction (height, inner volume, shape of hearth, amount of blowed air), productivity, charge composition.

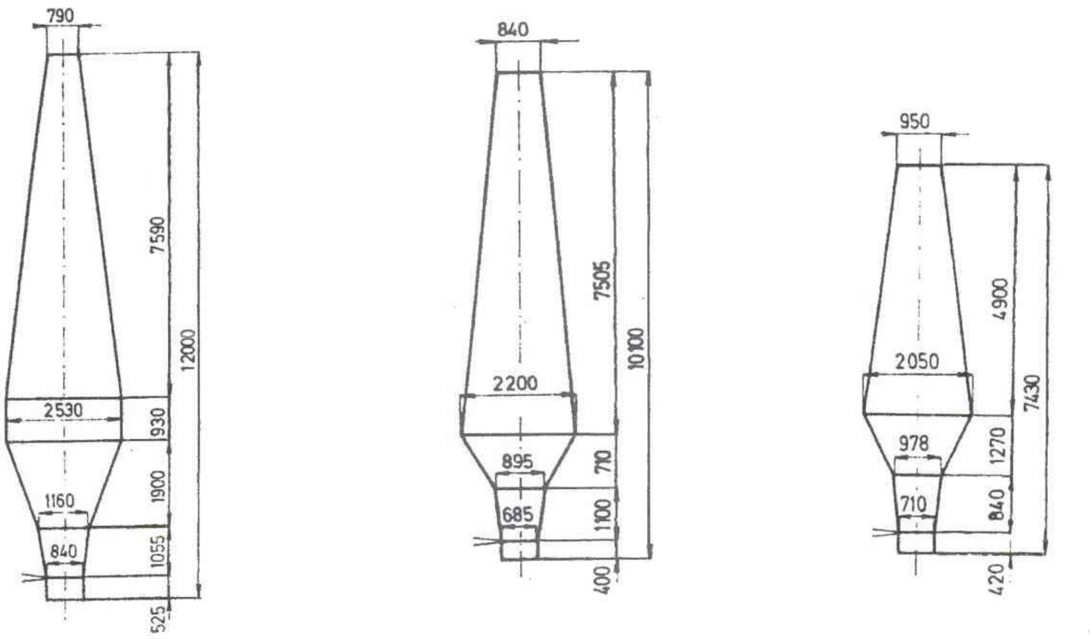
Construction data of three charcoal blast furnaces are presented in Fig. 4. The furnaces with different heights and working volumes were selected. The furnace in Betliar (the biggest one) was owned by the Andrássy family, the furnace in Štítnik (Ujremény) by society Štítnická konkordia, the furnace in Šramková (the smallest one) was part of ironmaking factory in Revúca. All three furnaces worked in the second half of the 19th century.

Because of lack of data, it is very difficult to determine real productivity of charcoal blast furnaces. In most cases only yearly productivity was recorded, but production of blast furnaces was performed in campaigns, not on continuous basis. The data varies from 600 tons per year for small furnaces to 2000 – 2500 tons per year for the biggest ones.

4. RESEARCH OF BLAST FURNACES REMNANTS

Team of archaeometallurgists at the Technical University in Košice, Faculty of Metallurgy, solves the scientific project: research of charcoal blast furnaces on the territory of Slovakia. Nearly all sites where charcoal blast furnaces worked in past, were investigated. Materials related to blast furnaces construction and production were collected, documented and sampled. Collected materials contained pieces of blast furnace slag, iron ore, construction materials of furnaces and, in some cases, also pieces of pig iron. The samples were submitted to chemical, microscopic and physical analysis.

In this paper analysis of materials collected on remnants of above mentioned blast furnace plants, are presented [5]. Chemical analysis of some samples from all three sites is in Table I. The samples 5.3.1; 5.3.3; 5.3.6;



a – Betliar b – Štítnik c – Šramková

Fig. 4. Profiles of three charcoal blast furnaces from the 19th century

Table 1. Chemical analysis of the samples, % wt

Locality	Sample	SiO_2	Fe_{total}	CaO	MgO	Al_2O_3	MnO	P
Betliar	5.2	58.2	2.23	3.36	4.8	4.69	1.66	0.052
Betliar	5.3.1	32.3	2.79	17.36	26.4	0.81	0.53	0.036
Betliar	5.3.3	35.4	2.51	19.60	23.2	0.61	5.97	0.060
Betliar	5.3.6	33.4	4.74	22.40	30.4	1.02	3.16	0.037
Betliar	5.5	30.0	36.02	7.28	21.2	0.81	0.16	0.027
Betliar	5.6	35.8	38.81	10.64	8.0	1.02	0.22	0.005
Štítnik	15.2.1	19.8	6.70	28.00	22.4	0.61	2.80	0.059
Štítnik	15.2.3	46.2	7.26	16.24	11.2	0.61	1.43	0.046
Šramk.	21.2	15.6	58.92	5.60	5.2	0.20	0.11	0.099
Šramk.	21.3.2	34.1	2.51	18.48	19.6	2.56	2.10	0.053

15.2.1; 15.2.3; 21.3.2 represent blast furnace slag, the sample 5.2 represents construction material of the furnace, the sample 21.2 represents iron ore. The samples 5.5 and 5.6 don´t relate to blast furnace process, they represent the process of pig iron refining. Very little sulphur contents were found in the samples. This fact was also confirmed by Baumann prints of the slag samples. Absence of sulphur is typical for slags from charcoal blast furnaces.

A few important facts follow from analysis of slags. Low contents of iron in slags show good reduction conditions in the furnaces. But, when compare the localities, iron contents in slags from the blast furnace in Štítnik are two or three times higher than in slags from the two other furnaces. The level of CaO + MgO, resulting from slag formers additions, is the highest in slags from Betlair site. Very different levels of CaO + MgO can be seen in analysis of two slags from Štítnik. Probably the slags represent two different periods in performance of the furnace with important changes between them. Next important feature of the slags composition is high content of magnesia. Rich sources of magnezite and dolomite ores are typical for this region.

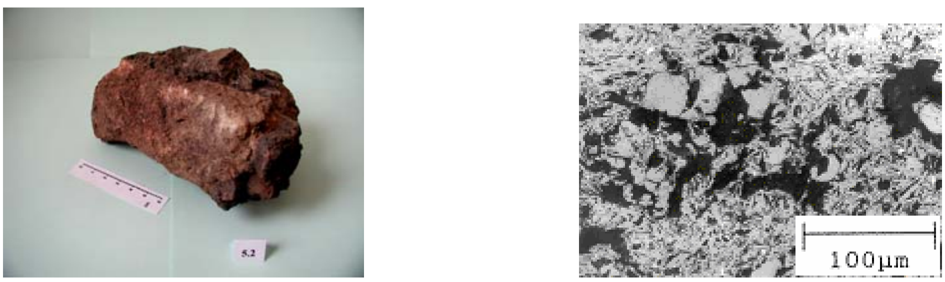


Fig. 5. Microstructure of furnace building material

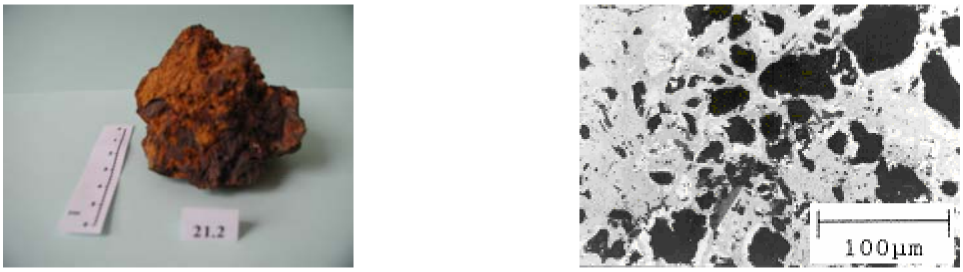


Fig. 6. Microstructure of iron ore

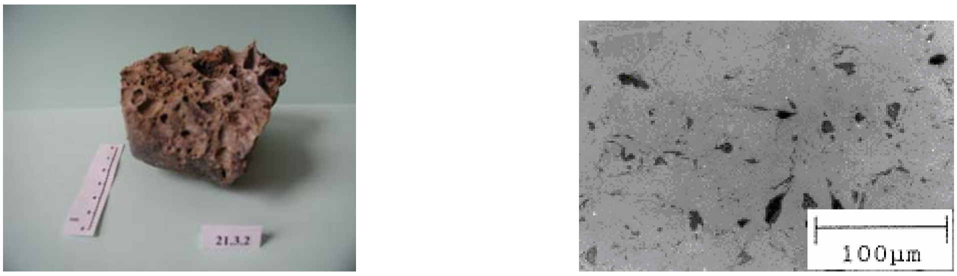


Fig. 7. Microstructure of blast furnace slag, glassy structure

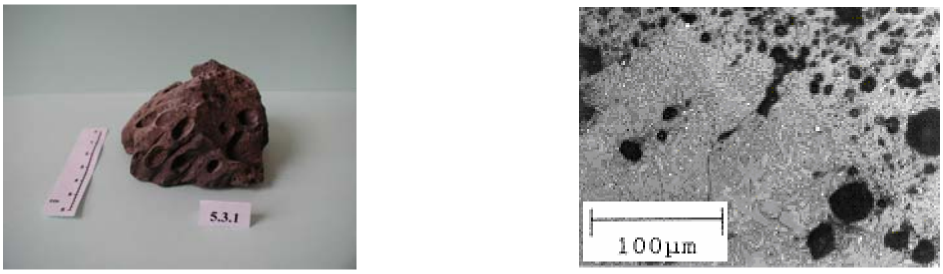


Fig. 8. Microstructure of blast furnace slag, partly crystallized

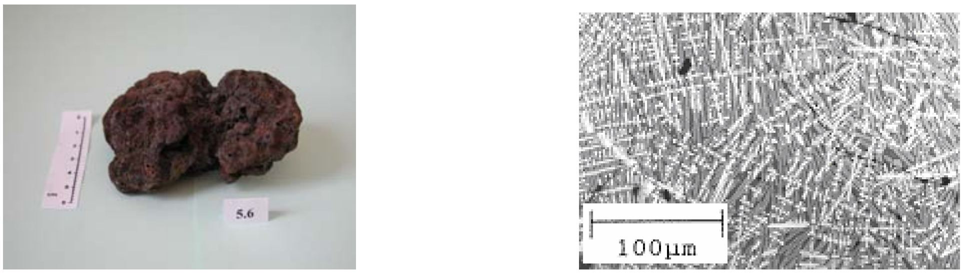


Fig. 9. Microstructure of refining slag

Microscopic analysis revealed typical structural features of blast furnace materials. Fig. 5 shows a piece of furnace building material and its structure composed of bigger silica grains embedded in fine – grained binding material. Fig. 6 shows a piece of iron ore and its structure. Siderite and limonite iron ores in treated state were charged to the blast furnaces. Fig. 7 and Fig. 8 present structure of blast furnace slag. The pieces of blast furnace slag had typical form. They were fragments of bigger slag cakes with big pores on the surface. Broken surfaces had glassy character. Fig. 7 shows glassy structure of slag, typical for most of slags analyzed by the scientific group. Fig. 8 shows partly crystallized structure of blast furnace slag. Fig. 9 presents slag from refining furnace and its structure. The shape of slag piece is different from pieces of blast furnace slag. This slag was skimmed from the refined metal surface. The structure is typical by high amount of iron oxides in form of dendrites, mostly wustite dendrites. They resulted from oxidizing conditions in refining furnace.

Next analysis performed on slag samples was determination of melting points. The slag samples were ground and next small cylinders were made of the powders. The cylinders were positioned in high – temperature chamber of high – temperature microscope Leitz. Melting temperatures were recorded and they are presented in Table II together with some other important data. The highest melting point was recorded in slag 5.3.6 from Betliar, the slag with the highest magnesia content.

Table 2. Some parameters of blast furnaces and blast furnace slags

Locality	Sample	Productivity t per week	Melting point,°C	Working volume, m^3	Fe_{mean} % wt	CaO_{mean} % wt	CaO + MgO % wt
Betliar	5.3.6	45	1246	32.5	3.35	19.78	46.45
Štítnik	15.2.1	39	1157	18.6	6.98	22.12	38.92
Šramk.	21.3.2	42	1175	13.1	2.51	18.48	38.08

From above mentioned followed the furnace in Betliar had the highest productivity, its good production parameters resulted from the fact the furnace was built in 1851 under supervision of famous metallurgical specialist Joseph Volny, who utilized modern concepts in construction design. It was the second blast furnace that worked in Betliar ironworks. On the other side ownership of the blast furnace in Štítnik valley (Ujremény) many times changed: Benedikty society – Štítnik konkordia – Štítnik-Pécs ironworks – Konkordia (Karl Sarkány). Such situation did not support introduction of new, modernized techniques and technologies in production of the furnace.

5. CONCLUSIONS

The paper presents brief information about production of pig iron in charcoal blast furnaces on the territory of Slovakia. Beginnings of charcoals blast furnace technique and its developments are described. As an example three charcoal blast furnaces that worked in the 19th century at different sites in Gemer region (Betliar, Štítnik, Šramková) were selected. On the basis of analysis of the remnants found in sites where the furnaces worked, following conclusions were prepared.

1. Inner volumes, heights and productivities of the furnaces were different. The best one, when considering productivity and process parameters, was the blast furnace in Betliar.
2. Different additions of slag formers were used into charge of the blast furnaces. Dolomitic slag formers were used together with limestone.
3. Macroscopic shape and structure of blast furnace slag were defined. Glassy structure resulted from quick cooling of slag after its tapping from the blast furnace.
4. Structure of slag from refining process was also described. It consisted of iron oxides dendrites in ferrous silicate matrix.

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