A SHORT HISTORY OF THE IRON AND STEEL INDUSTRY IN CENTRAL EUROPE DURING THE ROMAN IRON AGE

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Abstract

Metallurgy includes the oldest branch of technology and science of the humanity. Starting with discovering of the first metals till the actual nanostructures and special alloyed materials, the evolution of the metallurgy is fascinating.

The ferrous metallurgy had a fast evolution during time. The technical processes are in continuous changing, depending on humanity demands. The present article limits only to some milestones regarding the evolution of the thermal aggregates used for iron manufacturing. There are presented some processing technologies of iron ore in Europe, starting with the proto-metallurgy, when the used row material was the meteorite iron. At the beginning, human believed that everything must remain hidden in the basement. Also, the entire equipment was rudimentary, constructed by wood, burned clay or iron and had specific forms, seemingly a cavity. Later, humanity began to understand the iron ore importance, starting to use iron for many activities. Being such a big demand, there has been an evolution of the iron ore processing instruments that has reflected in materials, shape and techniques. The main objective was to ease people's work and to increase their productivity. The article has in view the primary extractive processes and the processing methods as puddling, forging or casting.

In the context of Central European ferrous metallurgy, it is interesting to have a perspective view of the processes evolution, by comparing the rudimentary techniques with the modern ones, to understand better where we come from and where we are heading.

Keywords: Iron, steel, ferrous metallurgy, history, technologies

1. INTRODUCTION

In archaeology, the Iron Age is the period when the iron usage and the technological processes of its obtaining were the most important for society. The Iron Age is the last period from the system of the three ages of classifying the prehistoric societies, preceded by the Bronze Age (**Table 1**).

With the discovery and exploitation of mineral resources, critics and philosophers of the time have launched different assumptions regarding the advantages and disadvantages of mining, realizing a comparison between incomes resulted from agricultural activities or mining, its negative impacts and healthy risks. Generally, the opinions are not favorable, although Timocles [1] said "If iron does not exist, people may have had a horrible existence, together with wild beasts". As time passing and noting the advantages that come from the iron exploitation, by turning it into weapons, tools and instruments, there has been a change in people's thinking, which was reflected in the techniques of ore processing, which have continuously evolved.

The goal of the paper is to analyze chronologically the obtaining processes of steel and cast iron, starting with proto metallurgy, when people were processing the meteorite iron and until the development of the puddling, forging and casting processes, when people were exploiting the ore mines and were building furnaces.

Table 1 Classification ages of the prehistoric societies

AGE	PERIOD	TOOLS	SETTLEMENTS
STONE AGE	**PALAEOLITHIC** *1 000 000 - 10 000 B.C.*	Tools and the usage of some objects found in nature as bones or corns.	Migrations and dwelling in caves, small camps, mostly around the water sources.
	MESOLITHIC *10 000 - 5 500 B.C.*	Tools and the usage of some objects found in nature; arches and arrow are invented; animal domestications begin.	
	NEOLITHIC *5 500 - 3500 B.C.*	Tools and the usage of some objects found in nature (ceramic pots).	Sedentary housing, based on agriculture and animal husbandry.
BRONZE AGE	*3 500 - 2 200 B.C.*	Copper and bronze tools, potter's wheel.	
IRON AGE	**PROTO METALLURGY** *2 200 - 1 500 / 1 200 B.C.*	There were produced the first objects, using meteorite iron.	The cities are appearing.
	HALLSTATT *1 200 - 500 B.C.*	Iron tools and weapons	
	LA TÈNE *200 B.C. - 100 A.D.*	Appears and is used the iron plow coulter; are improved iron tools and weapons.	

2. PROTO METALLURGY

To the mythology of polished stone has followed a metals mythology, the most important being developed around iron. It is already known that primitive, as prehistoric population, have worked the meteoritic iron long time before they have learned to use and exploit the superficial iron ores.

Meteoritic iron was also available to lithic people; it usually contains about 10 % Ni and is therefore much harder and more difficult to work. The nickel content varies from 4 to 26 % and can be easily detected as there seem to be no ores capable of giving this level of nickel in a homogenous, from direct smelting. It has been calculated that there are at least 250 t of meteoritic material extant, and that 99.4 % of this is malleable [2].

Iron ore processing is radically different from meteoritic iron manufacturing, which requires empirical knowledge, but pragmatic about the reduction of the iron oxides. Technologically, it would have been necessary to possess a reduction furnace and to develop and improve the technology of forging and thermal treatment, to increase the iron hardness.

The possibility of producing and preserving the fire marks an important stage in human evolution, towards discovery and metal working; but terrestrial ore treatment differs from that of meteoritic iron. Only after the discovery of furnaces and especially after the techniques of strengthening the incandescent metals, iron has earned its predominant position. [3] Terrestrial iron metallurgy made this metal apt for everyday use.

3. THE EARLY IRON AGE

It is generally accepted that the Iron Age started in Asia Minor, where iron-using people have occupied the area from about 2000 B.C., but during the period 1500 - 1000 B.C., the knowledge of ironworking was spreading across parts of Europe. The technology of ironworking divides into two sections: smelting and hot forging.

Pure iron has a melting point of 1540 °C and this temperature could not be obtained until the 19th century A.D. So, all early wrought iron was produced in the solid state, by chemical reduction of iron ore to solid, almost pure iron at about 1200 °C, with the aid of charcoal. The reduced iron was removed as bloom, which was a mixture of solid iron, slag and pieces of unburnt charcoal. In some cases, this lump was broken up and the small pieces of iron were separated by hammering; these could be distinguished from the rest because they were ductile and would flatten on hammering. These were then welded up into a larger piece by heating them in a smith's fire followed by hot hammering. In some cases, the bloom consisted of coherent iron and could be smithed in one piece. The product of the bloomer process can be very heterogeneous, with areas of high and low carbon and variable amounts of such elements as S and P. If the ratio of fuel to ore is large and the bellows are efficient, the iron can be made to absorb so much carbon that it forms an alloy of iron and carbon or cast iron, which melts at 1150 °C and forms pools at the bottom of the furnace. [4]

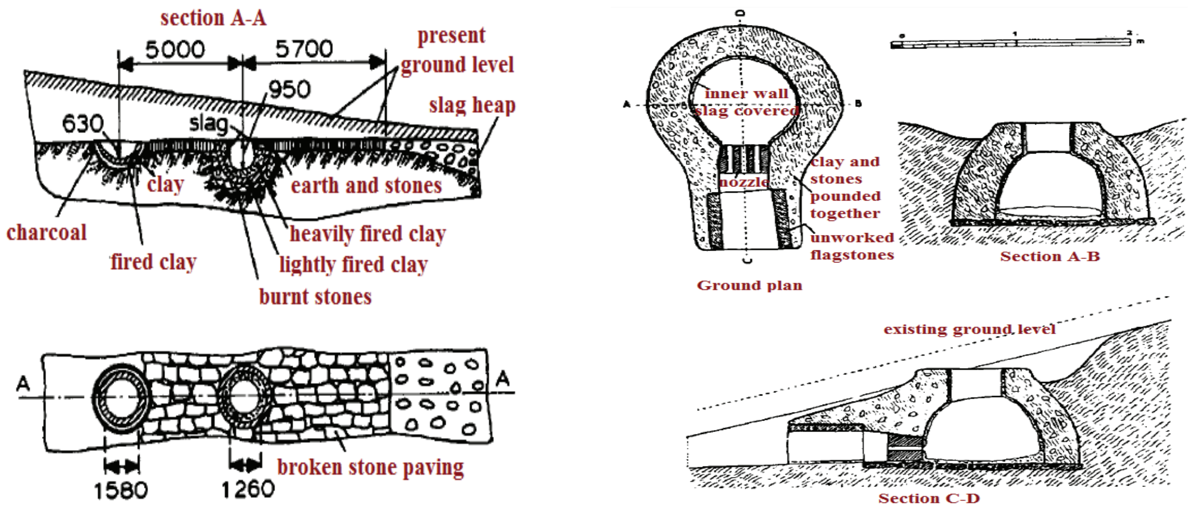
3.1. Furnaces

The main problem in deciding what sort of furnace was used in any period is the fact that, in most cases, only the base of the furnace remains. This has meant that many talk of 'bowl' furnaces in which the diameter is much the same as the height when excavated. We do not often know the original height, but it is clear from experiments that the height / diameter ratio does not exceed 2:1 to get iron smelting conditions and that, with proper manipulation, smelting can be carried out with ratios less than this.

The bowl furnace is usually thought as the simplest type of furnace; this is no more than a hole in the ground or a rock into which air from bellows can be *directed through a tuyere with a short.* The broken ore and the charcoal are mixed together or charged in layers on a hot charcoal fire. The maximum temperature should be at least 1150 °C. The furnace has no outlet for slag and the slag runs down to the bottom (**Figure 1**).

3.2. The spread of ironworking techniques across Europe

Iron was introduced in Europe around 1000 B.C., from Asia Minor, probably on Danube and then, it extended in the next 500 years. In East Europe, the 1st millennia mark the beginning of the Iron Age. At the steppes from the north of the Black Sea and Azov Sea, the Iron Age starts with the evolution of Koban and Novocerkassk cultures. After 800 years, this technology extended to the Hallstatt culture, as a result of Thracian Cimmerians migrations.



a - Bowl furnace from Huttenberg, Austria (mm) **b** - Domed furnace from Engsbachtal, Germany (m)

Figure 1 Early Iron Age furnaces from Central Europe *(after Coghlan, 1951, [6])* In Central Europe, the Iron Age divides in two periods: Hallstatt, in Austria and La Tène, in Switzerland. Austria has provided many examples of early furnaces; these may be classified into three types: the bowl furnace (**Figure 1a**), the shaft furnace and the domed furnace (**Figure 1b**). In Central Europe, the Iron Age ended up after the roman reduction. [6]

In the Mediterranean Area, the iron technology was introduced by Villanova culture, but it also ends up after the roman reduction.

In the British Isles, the Iron Age began in the 5th century B.C. and it lasts until the roman reduction; in some parts, which were unreduced by roman, the Iron Age lasts until the 5th century A.D.

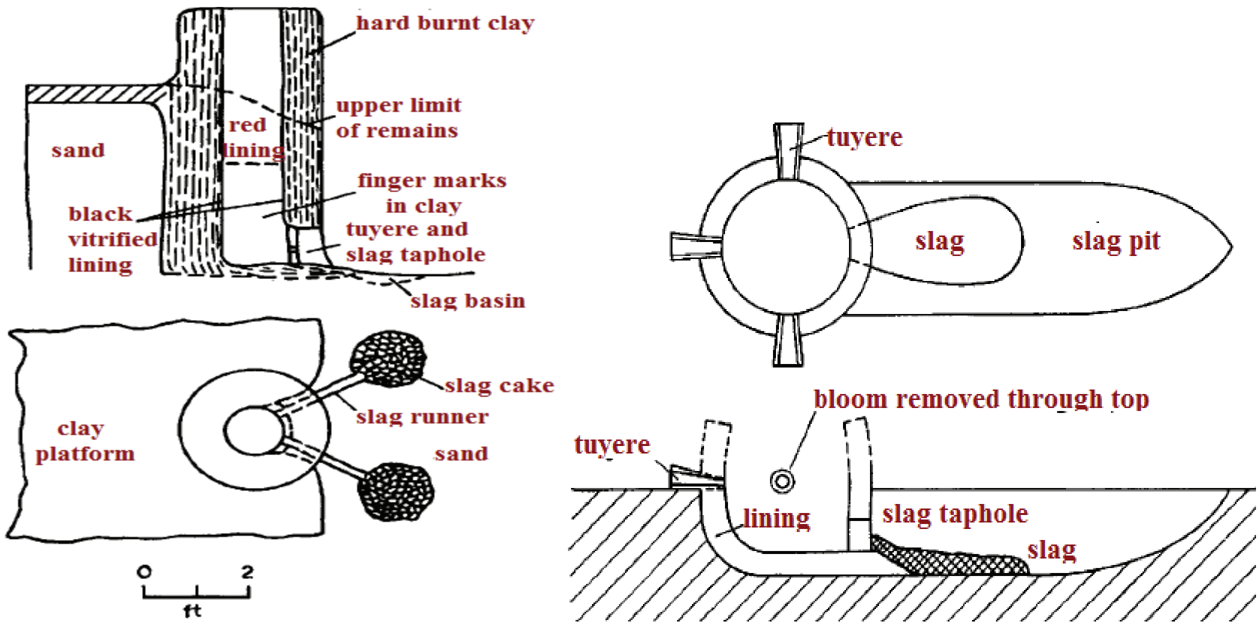
In Germany and Scandinavia, the Iron Age is divided in two periods: the pre-roman Iron Age and the Roman Iron Age. During this period, the North of Germany and Denmark were dominated by Jarstof culture.

4. THE ROMAN IRON AGE

The main contribution of the Roman Empire to the world technology was not one of originality, but one of organization. The effect of the Roman Empire was the widespread dissemination of the best techniques that existed anywhere in the Romanized world. [7] There was an enormous increase of slag found on pre-Roman period are usually measured in kilograms or hundreds of kilograms, the slag heaps of the Roman period are usually measurable in hundreds of tones.

4.1. Furnace types and technique

Furnaces can be divided into two basic types: shaft (**Figure 2a**) and bowl - it grew in height and diameter, until it had to have more than one tuyere (**Figure 2b**).



a - Plain shaft furnace found in Eastern Europe **b** - Developed bowl furnace of the Roman Period

Figure 2 Shaft and bowl furnaces in Roman Period *(after Money J. H. et al, 1979, [8])*

In the Roman Period, there are more discarded pieces of cast iron, because of the greater output rather than a higher accident rate. There were changes in the composition of the slag (**Table 2**); the addition of lime, which when it exceeds about 10 % raises the free-running temperature, was clearly not practiced. Tap slag blocks a British second century site now weighed 18 kg, while the furnace bottoms from Jutland weighed 170 kg [9]. In

France, in the forest of Aillant, there were once 300000 t of slag in mounds, reaching a height of 15-20 m [10]. It is not certain whether the whole of this slag deposits is of Roman date but, even if only a part of it is Roman, it illustrates the scale of operation at this time. Dumps of material of this size containing 30-50 % Fe were in great demand for reworking in later periods, in many European countries.

Table 2 Analyses of iron slag in Roman Period *(after Tylecote R. F., 1992, [2])*

%	France Yonne	Bohemia Prague	Poland Slupia	Austria Lölling	England: Ashwicken	England: Forest of Dean	Denmark Jutland	Germany: Pfalz	Germany: Aachen
FeO	46.9	23.57	52.08	47.7	62.1	40.5	41.2	39.38	65.42
Fe_2O_3	4.8	39.29	7.38	3.36	7.7	13.2	3.6	0.44	5.18
SiO_2	31.8	29.02	25.21	27.3	21.2	27.5	22.7	34.93	17.19
Al_2O_3	9.9	2.38	5.32	6.6	3.2	-	1	9.4	4.95
CaO	2.1	2.30	1.05	2.2	0.4	-	1.4	2.26	2.73
MgO	0.75	-	-	1.08	1.4	-	1.13	1.89	1.68
MnO	2.2	-	1.84	12.1	0.5	-	16.8	7.08	2.17
P_2O_5	0.25	0.35	0.15	0.16	1.72	0.24	2.2	0.25	1
S	0.02	-	0.04	0.03	-	-	-	-	0.22

4.2. Particularities of the Roman Iron Age in Romanian area

The most important metallurgical centers were concentrated in Hunedoara, on the eastern part of Poiana Rusca Mountains. The first confirmation of the iron producing in this area is an iron lump, found in a furnace hearth, from Hallstatt period. The chemical analysis of this iron lump is presented in **Table 3**.

Table 3 Chemical analysis of the iron lump discovered in Hunedoara, [%] *(Source: Ioan R. V., 2000, [11])*

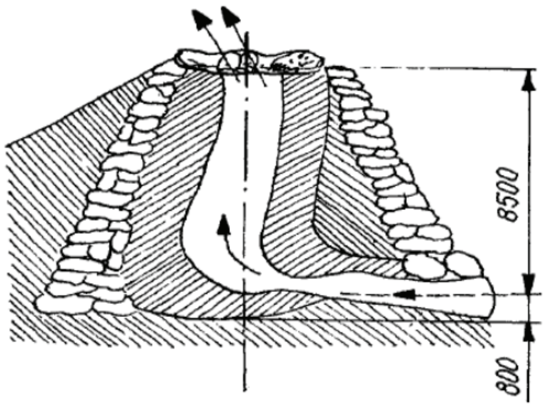
C	Mn	Si	Cr	Ni	Mo	Al
0.08	0.30	0.010	0.022	0.029	0.015	0.012

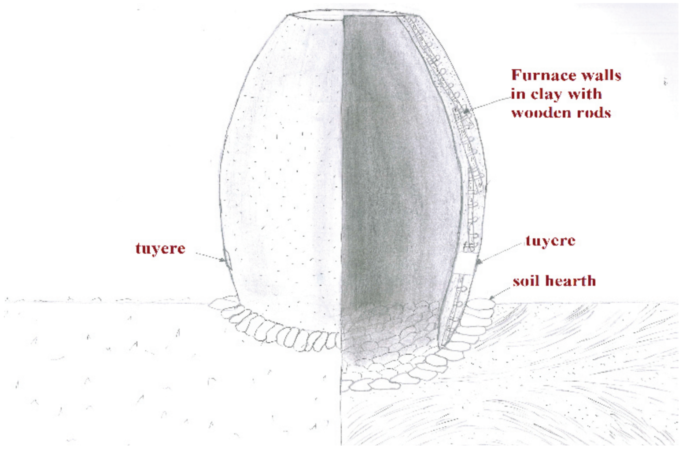
The iron slag were also analyzed in laboratory (**Table 4**) and the results shows that they are specific to a process for obtaining iron using ore; the furnaces works by reduction of the iron oxide, on a low yield.

Table 4 Chemical analysis of slag samples discovered in Hunedoara, [%] *(Source: Ioan R. V., 2000, [11])*

Sample number	SiO_2	Al_2O_3	MgO	CaO	MnO	Fe
1	17.16	4.73	8.44	3.60	5.28	49.07
2	43.80	74.93	6.59	3.22	1.21	12.13
3	21.54	5.37	3.95	2.0	5.96	41.90

In the Roman Iron Age, in furnaces (**Figure 3**) was produced: ***the iron lump*** (on the furnace hearth); ***carburized iron*** (the iron was reduced with a carburized substance, T > 1200 °C); ***cast iron granules*** (mixed with pasty phases); ***pre-reduced iron ore*** (which will be processed in a final form). [12]





a - Furnace which works on up-current principle; b - Furnace placed on a level place *(by Garbacianu G.)*

Figure 3 Iron obtaining furnaces discovered in Hunedoara, Romania [mm] *(after Ioan R. V., 2000, [13])*

5. CONCLUSION

Starting with the proto-metallurgy, where the raw material was the meteorite iron and until the Roman Iron Age, when techniques were improved, depending on human demands, there has been a considerable increase in the mining of ferruginous minerals. Discovering and learning how to control the metallurgical techniques, it was a huge step in people's way of living, by building modern settlements and grouping them in cities. It is fascinating to analyze this evolution, with the changes in aggregates design during historical ages, having as main tool the 'metallurgical glasses', to may anticipate the future humanity perspectives.

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