METAL PROCESS ENGINEERING

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ТЕХНОЛОГИЯ МЕТАЛЛОВ

Под общей редакцией
проф. П. ПОЛУХИНА

СТРОЙИЗДАТ
МОСКВА

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METAL PROCESS ENGINEERING

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The course *Metal Process Engineering* is intended for engineers as a basis for the successful mastery of a number of special subjects.

An acquaintance with the methods employed to produce ferrous and nonferrous metals and their alloys, and a knowledge of their principal properties and processing procedures are of vital importance for expedient selection and proper application of metallic materials. Engineers in all lines of industry must know what effect heat treatment and other processes have on the properties of metals and what can be done to alter these properties in the desired directions.

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1

THE MANUFACTURE OF FERROUS METALS, ALUMINIUM, COPPER AND TITANIUM

Chapter 1

FUELS AND REFRACTORIES OF PROCESS METALLURGY

1-1. Fuels

Metals are extracted from their ores and undergo subsequent refining processes in various types of shaft and flame furnaces in which high temperatures are developed by fuel combustion.

All fuels are of organic origin; their combustible constituents are carbon, hydrogen and various compounds of these elements (hydrocarbons). Fuels also contain a certain amount of oxygen and sulphur. Sulphur is the most harmful constituent of fuel since in the process of smelting some of it may dissolve in the metal thus impairing its properties. Fuels used in metallurgy should contain the least possible amount of inert mineral admixtures (ash) which are incombustible and reduce the calorific value.

Solid, liquid and gaseous fuels are employed in process metallurgy.

Solid fuels. Solid fuels include charcoal, coke and coal (both bituminous and anthracite types).

Charcoal is obtained by the dry distillation of wood (heating without the admission of air) in compartment kilns or stalls. It contains 80 to 90 per cent solid (nonvolatile) carbon, 10 to 18 per cent volatile matter (including moisture), 0.6 to 1.2 per cent ash and a negligible amount of sulphur. The calorific value of charcoal ranges from 6500 to 7500 kcal per kg. Charcoal is highly porous (up to 70 per cent); it burns well but has a low compressive strength (20 to 40 kg per sq cm). Charcoal is used in small-volume blast furnaces for making high grades of cast iron with a low sulphur content.

Charcoal is an expensive fuel; its production is limited because of the shortage of timber.

Coke is the solid carbonised residue formed in the process of heating (dry distillation) of certain grades of coal in retort (coke) ovens at 1000°-1100°C. As a rule, coke contains from 82 to 88 per cent solid (nonvolatile) carbon, 10 to 15 per cent ash and 0.5 to 1.8 per cent sulphur. The chemical composition of coke is determined by the nature of the coal from which it was obtained.

Coke possesses ample porosity (up to 50 per cent) and excellent combustibility; its lumps are grey-black in colour, sometimes they are dull grey and even slightly silvery. It is considerably firmer than charcoal, having a compressive strength as high as 140 kg per sq cm.

Coke is the chief type of metallurgical fuel for blast furnaces and cupolas; very high temperatures may be developed in its combustion. Coke has a calorific value of 6500 to 7500 kcal per kg.

Coal is of vegetable origin; it is a product of the decomposition of wood and plant residues accumulated under a layer of earth in remote geological epochs. Coals from various deposits may differ greatly in their physical and chemical properties; their combustible portion has the following composition: 76 to 90% C, 4 to 5.5% H and the remainder O+N+S. They contain from 12 to 20 per cent ash or even more.

Of the numerous kinds of coal, the best qualities are found in *anthracite*. It has a denser structure and contains little volatile matter. The calorific power of various coals and anthracite ranges from 4500 to 8000 kcal per kg.

Coals, including anthracite, are practically unfit for smelting iron in a blast furnace because of their low gas permeability and because they melt down or splinter at high temperatures.

Liquid fuels. *Masout* is employed as a liquid fuel for open-hearth and heating furnaces. It is the liquid residue of crude petroleum after driving off the lighter fractions—gasoline, kerosene and gas oil—by distillation. Masout contains 80 to 87% C, 12 to 14%H, 1.2% O+N, and 0.3% ash; it has a calorific value up to 10,000 kcal per kg. Low-sulphur grades of masout (less than 0.4-0.7% S) are used in steelmaking.

Masout is a valuable raw material of the chemical industry, and therefore it should be replaced by gaseous fuels in process metallurgy.

Gaseous fuels. The gaseous fuels are coke-oven, producer, blast-furnace and natural gases.

Coke-oven gas, obtained as a by-product in the manufacture of coke has a calorific power up to 4500 kcal per cu m and contains about 57% H_2, 22% CH_4, 6 to 7% CO and very little N_2 (up to 7-8%). It burns with a colourless flame and enables very high temperatures to be developed in the furnace.

Producer gas is obtained in a producer furnace upon incomplete combustion of solid fuels. Its composition is: 5 to 8% CO_2, up to 30% CO, 2 to 3% CH_4, 10 to 15% H_2, while the remainder is N_2 and water vapour.

Blast-furnace gas is a by-product of the blast-furnace process in pig iron production. After being cleaned of dust it is extensively applied in metallurgical plants both in the pure form (for firing boilers, coke-oven batteries, blast-furnace stoves, etc.) and in a mixture with coke-oven gas (for open-hearth furnaces, soaking pits of rolling mills, etc.). The approximate composition of blast-furnace gas is: 12% CO_2, 28% CO, 0.5% CH_4, 2.5% H_2 and 57% N_2. Its calorific value ranges from 850 to 1000 kcal per cu m.

Natural gas is obtained either from gas fields or from those indigenous to an oil deposit.

Natural gas is a very cheap fuel with a high calorific power and is rich in hydrocarbons, especially methane. Its approximate composition is 93% CH_4, 2% CO_2, 1% N_2, 1% H_2 and 3% C_mH_{2n}. The calorific value is about 8000 kcal per cu m. In recent years metallurgical plants have begun to use natural gas to a great extent.

1-2. Refractories

The internal parts of all metallurgical furnaces, stoves and ovens are lined with refractory materials by laying, ramming or burning-in operations.

Metallurgical furnace refractories must withstand high temperatures; have sufficient mechanical strength and hot resistance against the chemical attack of liquid slags, molten metals and gases; retain a constant volume and possess a definite porosity.

In metallurgical plants refractories are employed in the form of powder, bricks and special shapes—stopper heads, sleeves, etc.

As to their chemical properties, refractories are classified as acid, basic and amphoteric, or neutral, depending upon the chemical nature of their constituent oxides.

Acid refractories include quartzite and quartz sand which are of rock origin and contain from 93 to 100 per cent silica (SiO_2). Ground quartzite containing from 93 to 97 per cent SiO_2 is used to make dinas brick for lining the walls, bottoms and roofs of open-hearth, electric and certain other furnaces. The melting point of dinas brick (also called silica brick) is 1690°-1730°C; its softening temperature is 1550°C. The bottoms of acid open-hearth furnaces are burned in and renewed with ground quartzite and white quartz sand.

Basic refractories include calcined dolomite and calcined or fused magnesite.

The calcined dolomite used in metallurgy is obtained by heating raw dolomite rock $MgCO_3 \cdot CaCO_3$ to a high temperature (1600°C). The CO_2 is driven off in calcinating the raw dolomite and a refractory material is formed which contains 52 to 58% CaO and 35 to 38% MgO. Calcined dolomite can withstand heating up to 1800°-1950°C.

Calcined magnesite is the result of the high-temperature processing of raw magnesite rock $MgCO_3$. Calcining proceeds according to the reaction $MgCO_3 \rightarrow MgO + CO_2$ from which MgO is obtained. The melting point of this magnesium oxide (MgO) is over 2000°C. The highest refractory properties are found in fused magnesite which is obtained from raw magnesite at the fusion temperature (over 2000°C) of the calcined product.

Dolomite and magnesite brick and other products of these materials are extensively applied in lining smelting and heating furnaces. The bottoms of basic open-hearth furnaces are burned in and renewed with magnesite and dolomite granular products.

Chrome-magnesite refractory bricks possess high resistance to thermal shock. They contain about 65 to 70 per cent calcined magnesite (MgO) and 25 to 28 per cent chromite ($FeO \cdot Cr_2O_3$). This brick is used chiefly to build the hanging arches of open-hearth furnaces.

Calcined fireclay, containing about 30% Al_2O_3, belongs to the group of *neutral refractories*. The main constituent of raw fireclay is the mineral kaolinite $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ from which it obtains its plastic properties. In calcining, the kaolinite loses its combined water while the alumina (Al_2O_3) and silica (SiO_2) go over into the calcined mass called *grog* or chamotte.

Grog withstands heating up to 1610°-1670°C. A mixture with sufficient bonding strength to mould various grog refractory products such as brick, sleeves, stopper heads, etc., is made of ground grog (50 to 60 per cent) and raw fireclay (50 to 40 per cent). The moulded and dried shapes are baked at 1300°-1400°C after which they become suitable for application in the metallurgical industries. Chamotte brick containing 55 to 60% SiO_2, 34 to 38% Al_2O_3 and 1.5 to 3% Fe_2O_3 is employed in both ferrous and nonferrous metallurgy. Ladles for molten metal are lined with this brick; it is used for the lining and checkerwork of blast preheating stoves, blast furnaces, etc. Grog is also used for the refractory parts of ladles employed in pouring steel and for certain other articles (e. g., crucibles).

Recently, high-alumina chamotte refractories ($Al_2O_3 > 40$ per cent) have come into use in process metallurgy. They have a very high chemical stability and refractoriness.

Chapter 2

THE MANUFACTURE OF PIG IRON

The raw materials for the production of pig iron in blast furnaces are: (1) iron and manganese ores, (2) fuel and (3) flux.

2-1. Iron and Manganese Ores

Iron ores. Iron ore comprises the ore body and the dead rock or gangue.

The ore body is the name given to the natural chemical compounds of iron, most frequently its oxides, found in the ore. Practically all of the iron (98 to 99 per cent) is reduced from its chemical compounds in the blast furnace and goes over into the pig iron. The gangue of iron ore may be of various chemical composition. Most frequently it consists of quartzite (SiO_2) or sandstone with an admixture of clayey matter ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and less often of limestone ($CaCO_3$) or dolomite ($CaCO_3 \cdot MgCO_3$). In the blast furnace the gangue is converted into slag thereby separating from the pig iron.

Iron ores are classified as rich or lean according to the amount of gangue they contain. After crushing and sizing, rich ores are charged directly into the furnace while lean ores are subjected to concentration in which the proportion of the ore body (iron oxides) in the ore is increased. As more effective concentration techniques are developed, it becomes possible to use lean ores which were previously dumped or not worked at all.

A certain amount of harmful impurities are always present in iron ores; they include sulphur, arsenic and phosphorus. Deposits mined first on an industrial scale are those in which the iron ore contains a negligible amount of harmful impurities and the optimum amount of gangue for the given conditions.

The metal-bearing components of the charge that are of the greatest commercial importance in pig iron production are hematite, limonite, magnetite and siderite iron ores, composite and manganese ores and metallurgical waste.

Red iron ore, or *hematite*, is an ore in which the iron is in the form of anhydrous ferric oxide Fe_2O_3 (theoretical composition: 70% Fe and 30% O_2). The iron content of this ore is very high—from 55 to 65 per cent—while that of harmful impurities, sulphur and phosphorus, is very low. Hematite may vary in colour, from dark red (cherry red) to dark grey. The gangue in hematite is most often quartzite.

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